AOE POE Integrated Curriculum Unit: Bridge Builder

Lesson 2.1

POE or Physics

Science of Bridge Structure

This lesson covers the physics and mathematics associated with calculating the forces on a truss bridge. This lesson is almost identical to the PLTW Principles of Engineering Lesson 5.1 and is provided here as reference. Parts of this lesson (originally intended for instruction within the POE class) could be taught by a Physics or Geometry teacher, if those classes are being offered concurrently.

This lesson is expected to take seven class periods.

Lesson Framework

Learning Objectives

Each student will:

- Define, describe, and analyze the stresses and forces acting on an object.
- Mathematically analyze a simple truss to determine types and magnitude of forces supported in the truss.

Academic Standards

- Represent and analyze mathematical situations and structures using algebraic symbols. (NCTM Standards for School Mathematics, Algebra)
- Analyze characteristics and properties of two- and three-dimensional geometric shapes and develop mathematical arguments about geometric relationships. (NCTM Standards for School Mathematics, Geometry)
- Specify locations and describe spatial relationships using coordinate geometry and other representational systems. (NCTM Standards for School Mathematics, Geometry)
- Use visualization, spatial reasoning, and geometric modeling to solve problems. (NCTM Standards for School Mathematics, Geometry)
- Understand measurable attributes of objects and the units, systems, and processes of measurement. (NCTM Standards for School Mathematics, Measurement)
- Create and use representations to organize, record, and communicate mathematical ideas. (NCTM Standards for School Mathematics, Representation)

Assessment

Assessment Product	Assessment Criteria
Student Resource 2.1.1—Working with X and Y Components of Vectors worksheet	Teacher Resource 2.1.2—Answer Key: Working with X and Y Components of Vectors
Student Resource 2.1.2—Free-Body Diagrams worksheet	Teacher Resource 2.1.4—Answer Key: Free-Body Diagrams
Student Resource 2.1.3—Reaction Forces Using Spring Scales lab	None provided
Student Resource 2.1.4—Truss Calculations worksheet	Teacher Resource 2.1.6—Presentation: Truss Calculations Answers
West Point Bridge Design Problem	None provided

Prerequisites

- Working knowledge of how to solve single-variable equations

Instructional Materials

Teacher Resources

- Teacher Resource 2.1.1—Presentation: Shapes, Forces, and Equilibrium
- Teacher Resource 2.1.2—Answer Key: Working with X and Y Components of Vectors
- Teacher Resource 2.1.3—Presentation: Free-Body Diagrams
- Teacher Resource 2.1.4—Answer Key: Free-Body Diagrams
- Teacher Resource 2.1.5—Presentation: Truss Bridge Math
- Teacher Resource 2.1.6—Presentation: Truss Calculations Answers
- Teacher Resource 2.1.7—Presentation: Vector Calculations

Student Resources

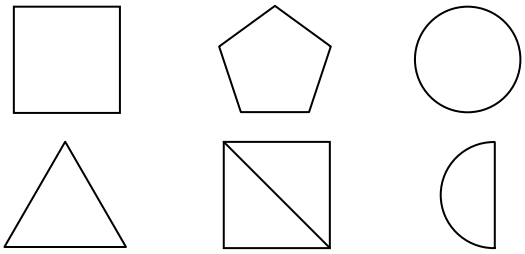
- Student Resource 2.1.1—Worksheet: Working with X and Y Components of Vectors
- Student Resource 2.1.2—Worksheet: Free-Body Diagrams
- Student Resource 2.1.3—Lab: Reaction Forces Using Spring Scales

- Student Resource 2.1.4—Worksheet: Truss Calculations
- Student Resource 2.1.5—Worksheet: West Point Bridge Builder Designer Introduction
- Student Resource 2.1.6—Worksheet: West Point Bridge Designer Problem

Equipment and Supplies

- Computer lab with MDSolids and West Point Bridge Designer software
- Pipe cleaners
- Plastic straws
- Items commonly found in the technology lab: hammer, wrench, saw, or other tools
- String
- Paper clips
- Spring scales
- 3/8" diameter flat washers
- Nuts or bolts to use as plumb bobs
- Protractors

Lesson Steps

Step	Min.	Activity
		CLASS PERIOD 1: PRINCIPLES OF ENGINEERING (OR PHYSICS)
1	**15**	**Demonstration: Squishy Shapes** Construct the shapes shown here with plastic straws that have pipe cleaners threaded inside. Show students the shapes and ask them to guess which shapes are the strongest. Which shapes will deform when pulled? Which shapes will deform when squished? Which shapes will deform when twisted? After students have made their predictions, test the shapes which predictions were correct. Students should observe that the triangle and the reinforced square are the strongest. 
2	**35**	**Direct Instruction: Shapes, Forces, and Equilibrium** Present a lesson on strength and shape of forces using Teacher Resource 2.1.1—Presentation: Shapes, Forces, and Equilibrium, as a guide.

Step	Min.	Activity
		CLASS PERIOD 2: PRINCIPLES OF ENGINEERING, PHYSICS, OR GEOMETRY
3	**30**	**Direct Instruction: Vectors** Introduce vectors using the Vector Calculations presentation as a guide.
4	**20**	**Partner Problem-solving: Vectors** Have students work together in pairs to complete Student Resource 2.1.1—Worksheet: Working with X and Y Components of Vectors. Assign any unfinished problems for homework.
		CLASS PERIOD 3: PRINCIPLES OF ENGINEERING OR PHYSICS
5	**10**	**Homework Review: Vectors** Go over the worksheet using Teacher Resource 2.1.2—Answer Key: Working with X and Y Components of Vectors.
6	**30**	**Direct Instruction: Free-Body Diagrams** Introduce free-body diagrams using Teacher Resource 2.1.3—Presentation: Free-Body Diagrams as a guide. If this activity is being taught in Physics class, substitute your traditional instruction on free-body diagrams, but be sure to include the Bridge Truss example from the presentation (Example 5, slide 17).
7	**10**	**Partner Problem-solving: Free-Body Diagrams** Pair students up to work on Student Resource 2.1.2—Worksheet: Free-Body Diagrams. Assign any unfinished problems for homework.
		CLASS PERIOD 4: PRINCIPLES OF ENGINEERING OR PHYSICS
8	**10**	**Homework Review: Free-Body Diagrams** Go over the worksheet using Teacher Resource 2.1.4—Answer Key: Free-Body Diagrams.
9	**40**	**Lab: Reaction Forces Using Spring Scales** Pass out Student Resource 2.1.3—Lab: Reaction Forces Using Spring Scales. Have students pair up, and pass out their lab materials. Read the procedures together as a class, and have students complete the lab independently. After students are finished, review their findings as a class.

Step	Min.	Activity
		CLASS PERIOD 5: PRINCIPLES OF ENGINEERING
10	**40**	**Direct Instruction: Truss Forces and MDSolids** Remind students of the Truss Bridge Free-Body Diagram example from the Free-Body Diagrams lecture. Introduce the calculation of forces at work on a truss bridge using Teacher Resource 2.1.5—Presentation: Truss Bridge Math, as a guide. After students are familiar with doing truss calculations by hand, introduce the use of the MDSolids software.
11	**10**	**Partner Problem-solving: Truss Calculations** Pair students up to work on Student Resource 2.1.4—Worksheet: Truss Calculations. Assign any unfinished problems for homework.
		CLASS PERIOD 6: PRINCIPLES OF ENGINEERING OR PHYSICS
12	**10**	**Homework Review: Truss Calculations** Go over the previous worksheet using Teacher Resource 2.1.6—Presentation: Truss Calculations Answers.
13	**40**	**Computer Software: West Point Bridge Designer** Provide students time to familiarize themselves with the West Point Bridge Designer software using Student Resource 2.1.5—Worksheet: West Point Bridge Designer Introduction.
		CLASS PERIOD 7: PRINCIPLES OF ENGINEERING
14	**50**	**Computer Software: West Point Bridge Designer continued** Give students time to finish the West Point Bridge Designer Introduction if they were unable to finish in the previous class. Once they are familiar with the software, have them work on the assignment in Student Resource 2.1.6—Worksheet: West Point Bridge Designer Problem.

AOE POE Integrated Curriculum Unit: Bridge Builder

Lesson 2.1

Science of Bridge Structure

Student Resources

Resource	Description
Student Resource 2.1.1	Worksheet: Working with X and Y Components of Vectors
Student Resource 2.1.2	Worksheet: Free-Body Diagrams
Student Resource 2.1.3	Lab: Reaction Forces Using Spring Scales
Student Resource 2.1.4	Worksheet: Truss Calculations
Student Resource 2.1.5	Worksheet: West Point Bridge Designer Introduction
Student Resource 2.1.6	Worksheet: West Point Bridge Designer Problem

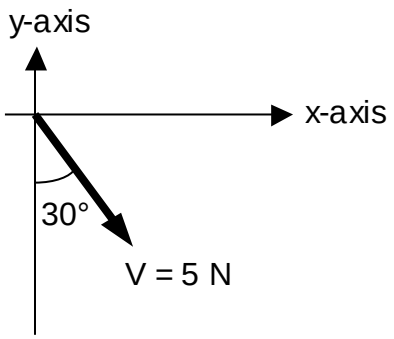
Student Resource 2.1.1

Worksheet: Working with X and Y Components of Vectors

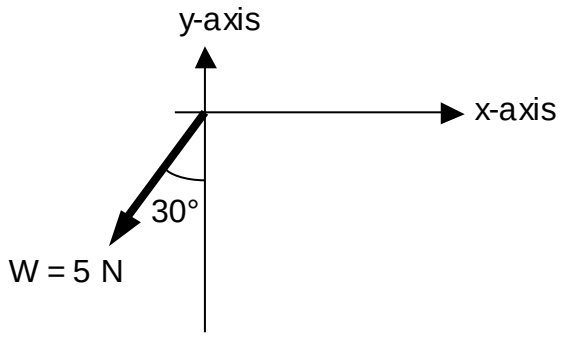
Directions

In order to be effective in design work, it is necessary to be able to mathematically discover answers to questions. This exercise is designed to help you discover forces and what effect the angle that force is exerted from has on your design. Solve the following problems. Show your work in the space provided.

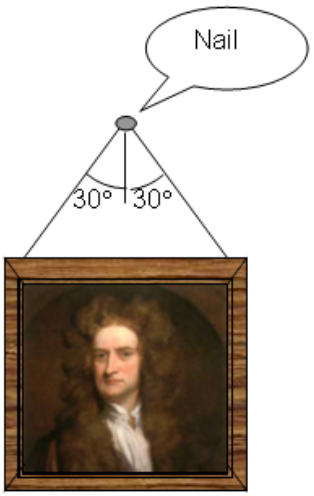
1. Find the x and y components of vector V. Solution hint: Think of the vector as pointing southeast. You will need to split it up into its y component (pointing south) and its x component (pointing east).

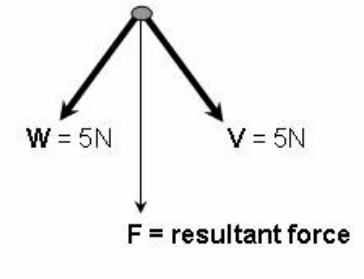


2. Find the x and y components of vector W. Can you predict the solution based on problem 1? Solution hint: Think of the vector as pointing southwest. You need to split it up into its y component (pointing south) and its x component (pointing west).

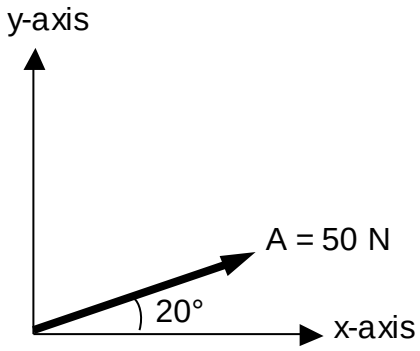


3. This picture is hung from a nail with wire. The nail supports two forces V = 5N and W = 5N. If the resultant of these forces acts vertically downward, find its x and y components (using your solutions from problems 1 and 2).

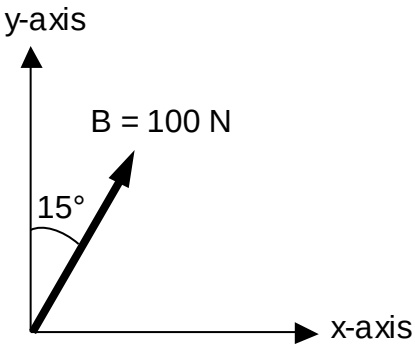




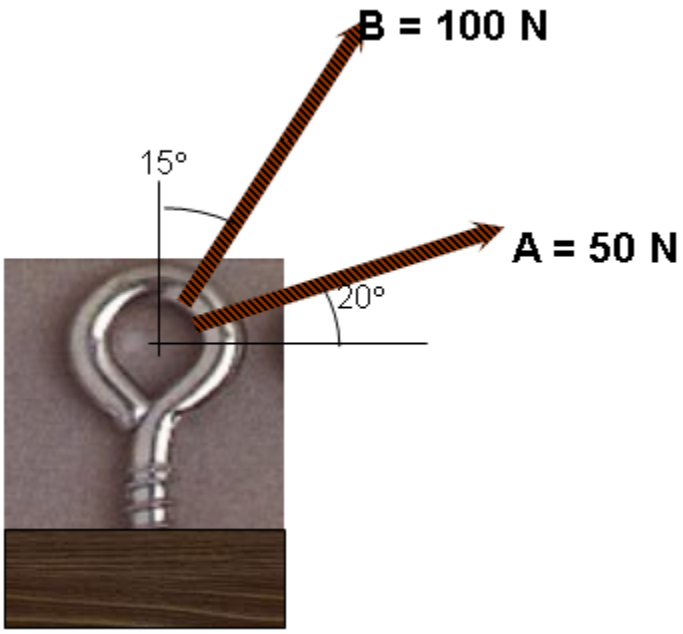
4. Find the x and y components of vector A. Solution hint: Think of the vector as pointing northeast. You need to split it up into the y component (pointing north) and the x component (pointing east).



5. Find the x and y components of vector B. Solution hint: Think of the vector as pointing northeast. You need to split it up into the y component (pointing north) and the x component (pointing east).



6. Two ropes are attached to the screw eye hook in this picture. Rope B is being pulled with a force of 100 N at an angle of 15 degrees to the y-axis. Rope A is being pulled with a force of 50 N at an angle of 20 degrees to the x-axis. Use your solutions from problems 4 and 5 to find the x and y components of the resultant force, F.



Conclusions

1. When you are opening a classroom door, what are the forces acting on it, and how are they balanced out so the door does not slam shut when released?

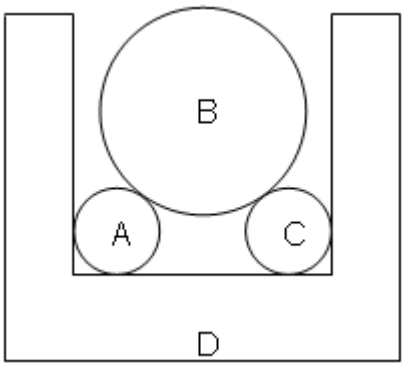
2. You have been asked to hang a mirror ball in the center of the gym, 10 feet from the ceiling. There are beams that run across the gym, but they are not centered. One beam is 10 feet off-center and the other is 7 feet from the center. The mirror ball weighs 67 pounds. How long should each cable be, and how much force should each one be able to hold?

Student Resource 2.1.2

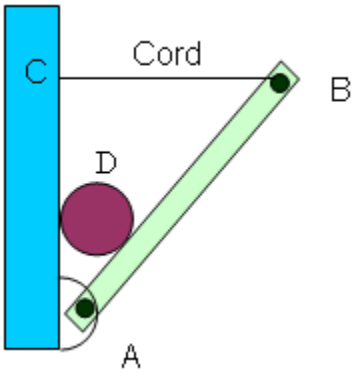
Worksheet: Free-Body Diagrams

Directions: Free-body diagrams are drawings used to show the relative magnitude and direction of all forces acting upon an object in a given situation. A free-body diagram is a special example of a vector diagram. Draw free-body diagrams (force diagrams) for each of the following.

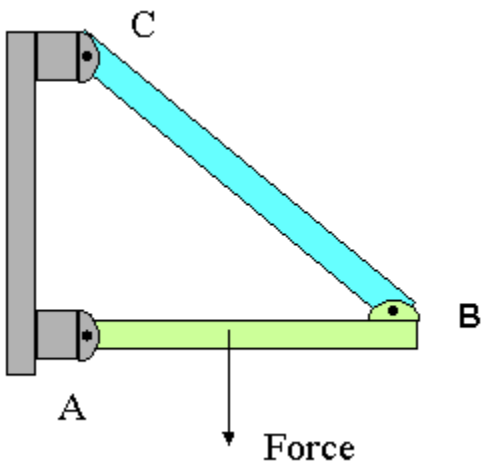
1. Draw a free-body diagram for items A, B, C, and D.



2. Draw a free-body diagram for member AB and cylinder D.



3. Draw a free-body diagram for member AB, which is pin-connected at A and supported by member BC.



Conclusions

1. What is the point behind creating a free-body diagram of an object?

2. Sketch a free-body diagram of a person sitting in the seat of a car. Which force arrows do you think would be the largest? Why?

Student Resource 2.1.3

Lab: Reaction Forces Using Spring Scales

Directions: Use the formulas for reaction forces that you learned in the previous lesson to calculate the weight of objects that are suspended from string attached to spring scales.

Materials

- Items commonly found in the technology lab: hammer, wrench, saw, or other tools
- String
- Paper clips
- Two spring scales
- 3/8" diameter flat washer
- Nut or bolt to use as plumb bob
- Protractor

Procedure

1.

   1. Cut two lengths of string and attach one end to the washer and the other end to a spring scale as shown in figure 1.

   2. Suspend the object with paper clips attached to the washer.

      Note: Use only two strings to suspend the object; this will ensure you have a two-dimensional problem. A third string might not be in the same plane as the first two strings, so the 2-D equations you learned in class would not be valid.

   3. Suspend a nut or bolt from another string to establish a vertical line, and use a protractor to measure the angles θ_A and θ_B as shown in figure 2.

   4. Measure the reaction force on each scale, F_A and F_B.

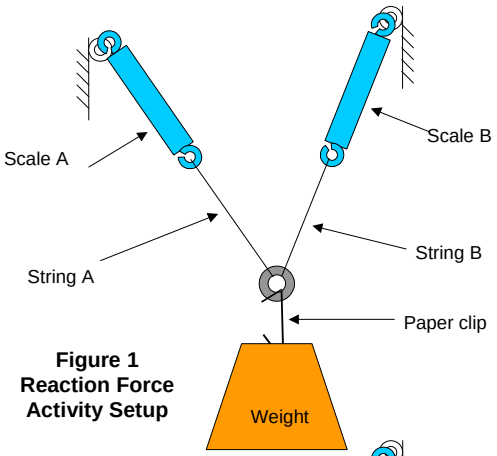


Figure 1 Reaction Force Activity Setup

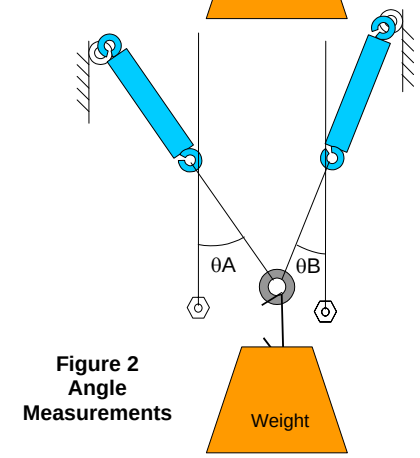


Figure 2 Angle Measurements

Observations and Conclusions

1. Name of object you suspended:

2. Draw the free-body diagram of the washer here.

3. Complete the table shown below. Calculate the weight of your object using the formulas you learned in class.

	Scale A	Scale B
Angle	θ_A=	θ_B=
Force	F_A=	F_B=
Vertical (Y) force component	F_{AY}=	F_{BY}=
Weight	W=	

4. Weight of object obtained by weighing on a scale:

5. Are the measurements and the calculations actually the same? If not, what are your thoughts on why they aren't?

Student Resource 2.1.4

Worksheet: Truss Calculations

Directions: A truss is formed by connecting members to one another with pin connections. We calculate the forces on a truss to accurately predict the type and amount of force each member must carry. The sizing of members determines the weight of the truss and is a factor in the final cost.

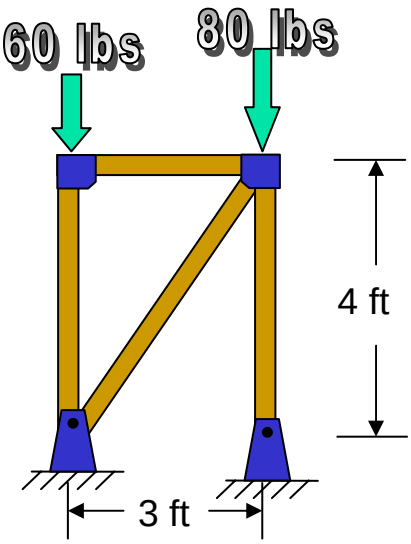
Sketch a diagram for each truss replacing the supports with the appropriate reaction forces.

Predict which beams would be in tension, which would be in compression, and which would be supporting the most force.

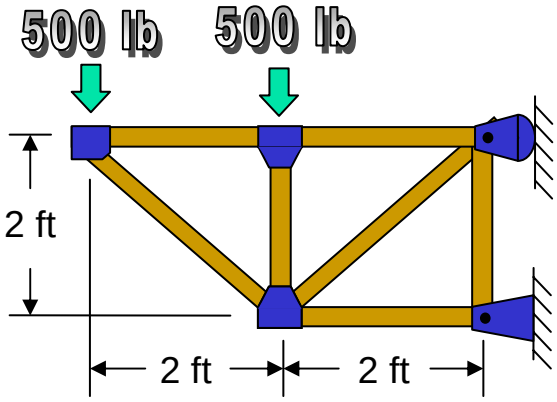
Draw the truss in the MDSolids program.

Record the forces at the supports and in each beam.

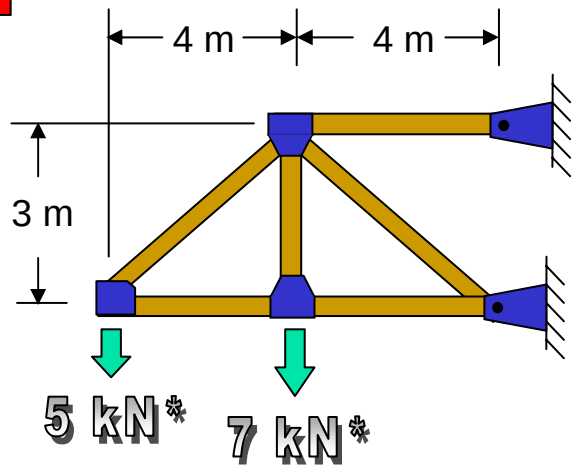
#1



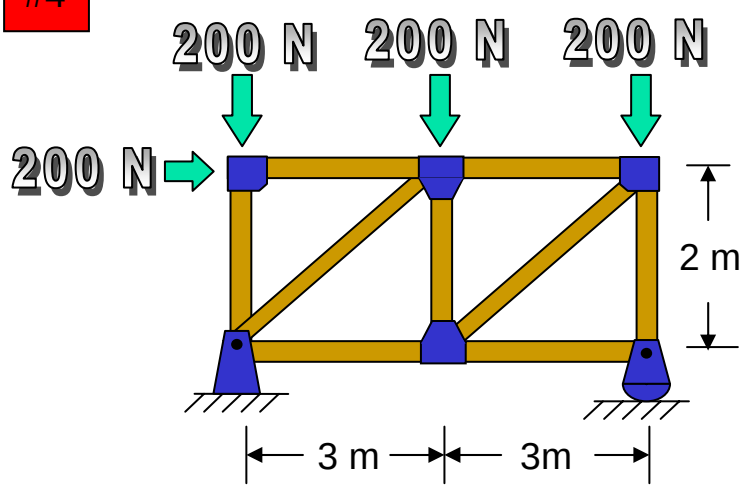
#2



#3



#4



Conclusions

1. Were your predictions for the forces accurate? If not, why were your predictions inaccurate?

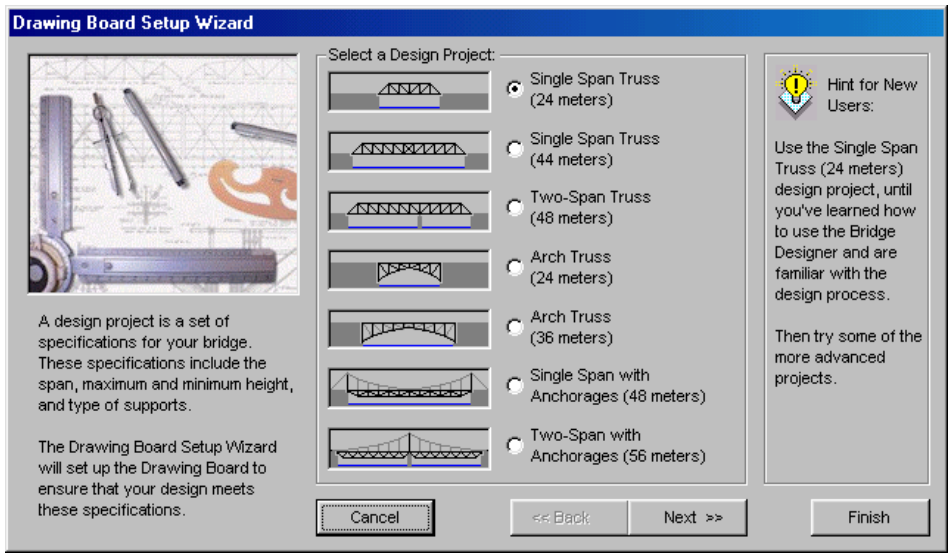
2. How would your analysis help you in the selecting the size and kind of material for the truss?

Student Resource 2.1.5

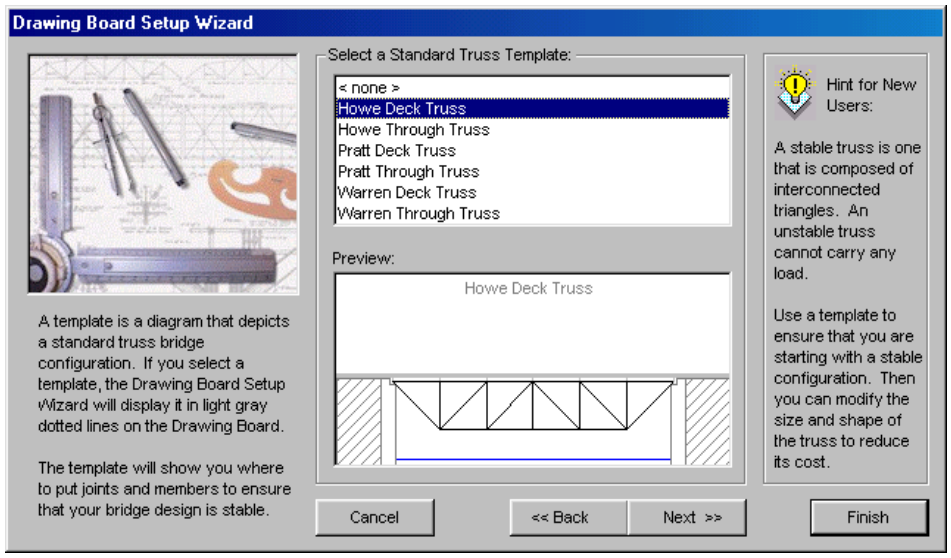
Worksheet: West Point Bridge Designer Introduction

When building projects are designed, the engineer or designer works to minimize the amount of resources used. Since resources consist of time, people, capital, and material, frequently a balancing act must be done. West Point Bridge Designer is a program that helps demonstrate that very concept. Your goals are to design a bridge that passes the load test and to optimize the design at minimum cost.

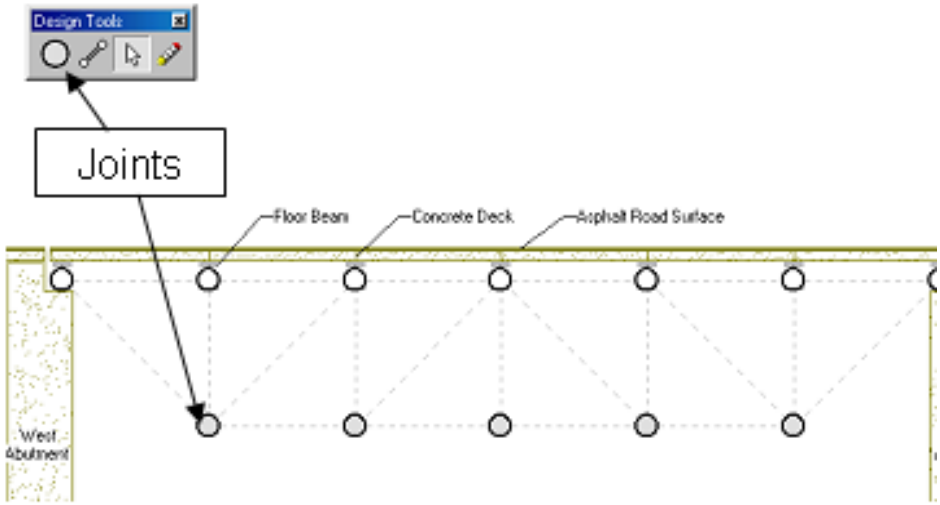
1. Select a design project.



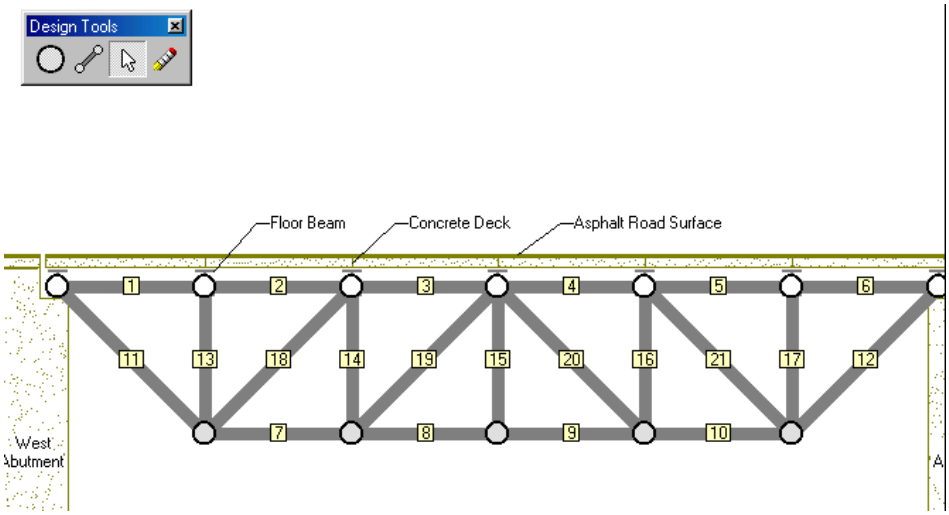
2. Select a truss configuration.



3. Draw joints first, using the Design Tool menu.

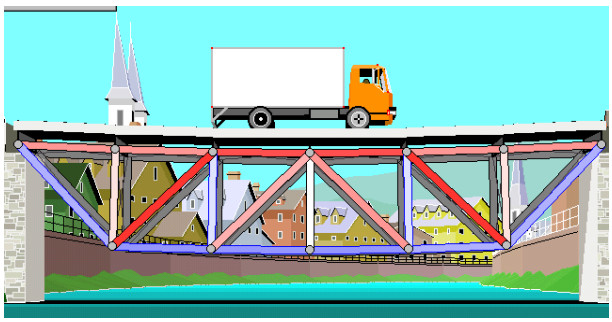


4. Draw members between the joints by selecting the member tool and then clicking and dragging from one joint to the next. Note that the joint numbers are shown in the figure below. To follow the example step by step, create the members in the same order as shown. Member numbers are displayed by using this icon:

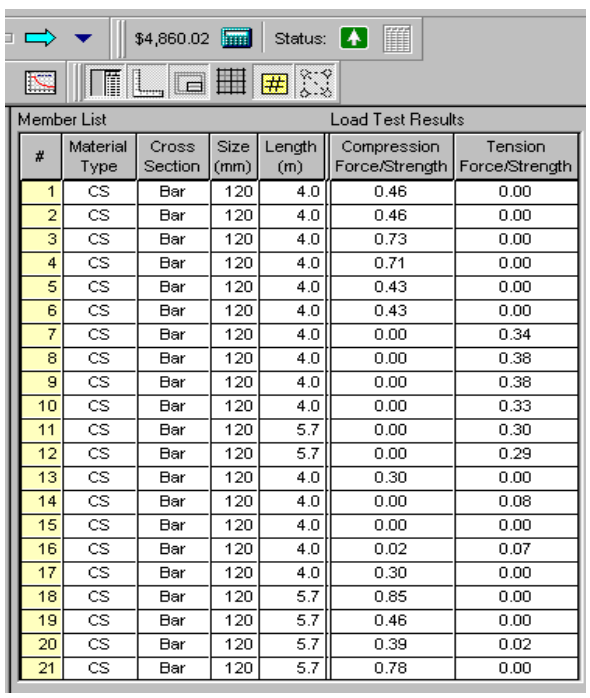


5. Run a load test of the current configuration. In the main menu select Mode > Load Test.

   Note: The program is using default properties for the members: 120 mm square bar made of carbon steel. These properties can be changed later. Watch the color of the member during the load test. Red indicates compression; blue is tension. The intensity of the color shows the force-to-strength ratio. Brighter colors show members that are loaded close to the maximum strength. If the force-to-strength ratio is greater than 1, the bridge collapses. For this example the bridge passes the load test on the first try. We were lucky!



6. Now begin to optimize the design to minimize the cost of the bridge. On the right side of the screen, drag the edge of the member list to see the details of the load test. The cost is shown on the top of the screen. For this example the starting cost is $4,860.02.



#	Material Type	Cross Section	Size (mm)	Length (m)	Compression Force/Strength	Tension Force/Strength
1	CS	Bar	120	4.0	0.46	0.00
2	CS	Bar	120	4.0	0.46	0.00
3	CS	Bar	120	4.0	0.73	0.00
4	CS	Bar	120	4.0	0.71	0.00
5	CS	Bar	120	4.0	0.43	0.00
6	CS	Bar	120	4.0	0.43	0.00
7	CS	Bar	120	4.0	0.00	0.34
8	CS	Bar	120	4.0	0.00	0.38
9	CS	Bar	120	4.0	0.00	0.38
10	CS	Bar	120	4.0	0.00	0.33
11	CS	Bar	120	5.7	0.00	0.30
12	CS	Bar	120	5.7	0.00	0.29
13	CS	Bar	120	4.0	0.30	0.00
14	CS	Bar	120	4.0	0.00	0.08
15	CS	Bar	120	4.0	0.00	0.00
16	CS	Bar	120	4.0	0.02	0.07
17	CS	Bar	120	4.0	0.30	0.00
18	CS	Bar	120	5.7	0.85	0.00
19	CS	Bar	120	5.7	0.46	0.00
20	CS	Bar	120	5.7	0.39	0.02
21	CS	Bar	120	5.7	0.78	0.00

The cost optimization procedure is outlined below:

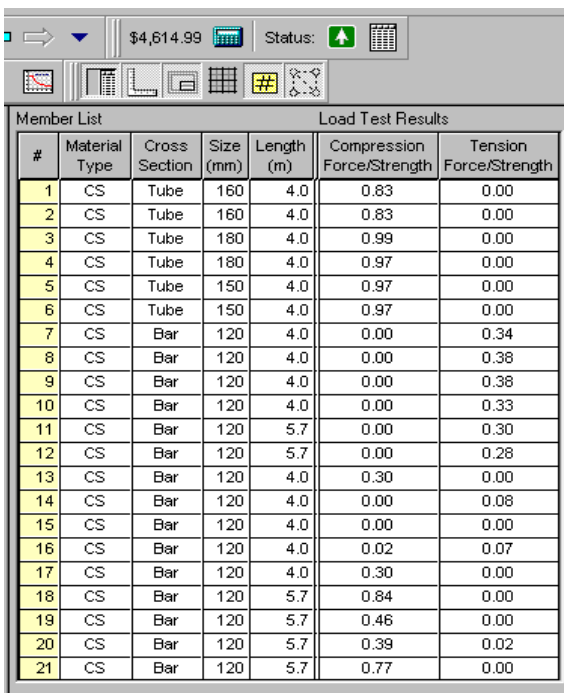
- Change compression members from bars to tubes.
- Members in both compression and tension should be also be changed to tubes. (In most cases this will reduce the cost.)
- Change the size of the tubes to maximize the force-to-strength ratio for each member.

- Run a load test after each modification.
- Change the size of tension members to maximize the force-to-strength ratio for each member.
- Group members to reduce product cost.
- Modify the material of each product and reduce size for further cost reduction.

Going through the optimization process does take some time and may require dozens of runs. It is a trial-and-error process. Suggestions for success include

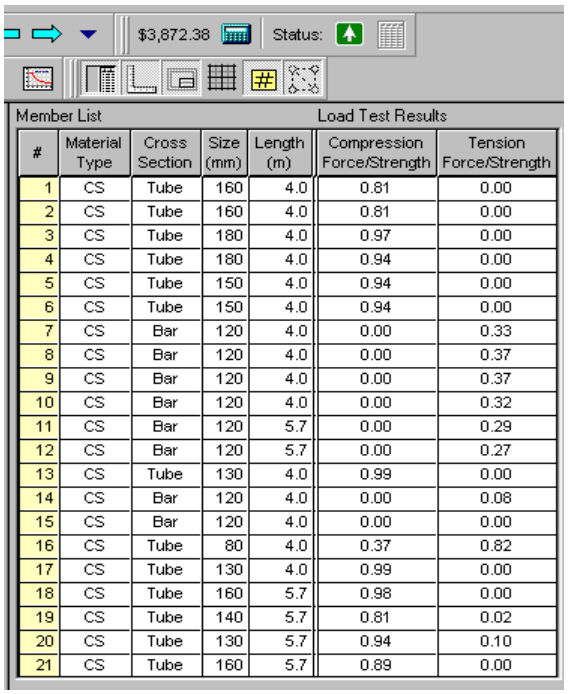
- Work on one subgroup of members at a time; for example, do compression and tension members separately.
- Change only one variable at a time.
- Take notes on what changes were made and the results of each run.
- Use the main toolbar to go back to previous iterations, if necessary.

7. Begin optimizing by selecting the top members, 1–6, which are all in compression. Modify members 1–6 to be hollow tubes. You can select members in the graphics window or in the member list. Use the Shift key to select adjacent members in the list or the Ctrl key to select multiple members. Modify the size of each tube as needed to pass the load test. With members 1–6 optimized as tubes, the cost is reduced to $4,614.99.



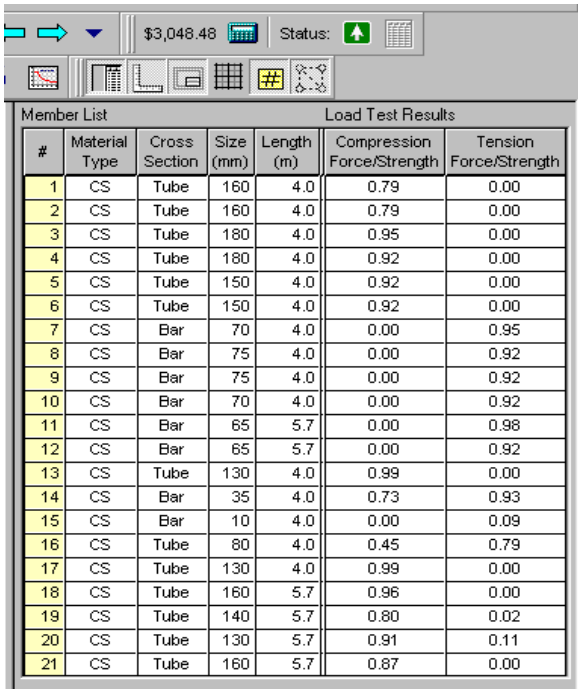
#	Material Type	Cross Section	Size (mm)	Length (m)	Compression Force/Strength	Tension Force/Strength
1	CS	Tube	160	4.0	0.83	0.00
2	CS	Tube	160	4.0	0.83	0.00
3	CS	Tube	180	4.0	0.99	0.00
4	CS	Tube	180	4.0	0.97	0.00
5	CS	Tube	150	4.0	0.97	0.00
6	CS	Tube	150	4.0	0.97	0.00
7	CS	Bar	120	4.0	0.00	0.34
8	CS	Bar	120	4.0	0.00	0.38
9	CS	Bar	120	4.0	0.00	0.38
10	CS	Bar	120	4.0	0.00	0.33
11	CS	Bar	120	5.7	0.00	0.30
12	CS	Bar	120	5.7	0.00	0.28
13	CS	Bar	120	4.0	0.30	0.00
14	CS	Bar	120	4.0	0.00	0.08
15	CS	Bar	120	4.0	0.00	0.00
16	CS	Bar	120	4.0	0.02	0.07
17	CS	Bar	120	4.0	0.30	0.00
18	CS	Bar	120	5.7	0.84	0.00
19	CS	Bar	120	5.7	0.46	0.00
20	CS	Bar	120	5.7	0.39	0.02
21	CS	Bar	120	5.7	0.77	0.00

8. Modify the remaining compression members—13, 16, 17, 18, 19, 20, and 21—to be tubes, and then rerun the load test. This will reduce the cost to $3,872.38, as shown here.



#	Material Type	Cross Section	Size (mm)	Length (m)	Compression Force/Strength	Tension Force/Strength
1	CS	Tube	160	4.0	0.81	0.00
2	CS	Tube	160	4.0	0.81	0.00
3	CS	Tube	180	4.0	0.97	0.00
4	CS	Tube	180	4.0	0.94	0.00
5	CS	Tube	150	4.0	0.94	0.00
6	CS	Tube	150	4.0	0.94	0.00
7	CS	Bar	120	4.0	0.00	0.33
8	CS	Bar	120	4.0	0.00	0.37
9	CS	Bar	120	4.0	0.00	0.37
10	CS	Bar	120	4.0	0.00	0.32
11	CS	Bar	120	5.7	0.00	0.29
12	CS	Bar	120	5.7	0.00	0.27
13	CS	Tube	130	4.0	0.99	0.00
14	CS	Bar	120	4.0	0.00	0.08
15	CS	Bar	120	4.0	0.00	0.00
16	CS	Tube	80	4.0	0.37	0.82
17	CS	Tube	130	4.0	0.99	0.00
18	CS	Tube	160	5.7	0.98	0.00
19	CS	Tube	140	5.7	0.81	0.02
20	CS	Tube	130	5.7	0.94	0.10
21	CS	Tube	160	5.7	0.89	0.00

9. Now optimize all the tension members—7, 8, 9, 10, 11, 12, and 14—by *reducing* the bar size so that the force-to-strength ratio is maximized. This change reduces the cost to $3,048.48, as shown here.



#	Material Type	Cross Section	Size (mm)	Length (m)	Compression Force/Strength	Tension Force/Strength
1	CS	Tube	160	4.0	0.79	0.00
2	CS	Tube	160	4.0	0.79	0.00
3	CS	Tube	180	4.0	0.95	0.00
4	CS	Tube	180	4.0	0.92	0.00
5	CS	Tube	150	4.0	0.92	0.00
6	CS	Tube	150	4.0	0.92	0.00
7	CS	Bar	70	4.0	0.00	0.95
8	CS	Bar	75	4.0	0.00	0.92
9	CS	Bar	75	4.0	0.00	0.92
10	CS	Bar	70	4.0	0.00	0.92
11	CS	Bar	65	5.7	0.00	0.98
12	CS	Bar	65	5.7	0.00	0.92
13	CS	Tube	130	4.0	0.99	0.00
14	CS	Bar	35	4.0	0.73	0.93
15	CS	Bar	10	4.0	0.00	0.09
16	CS	Tube	80	4.0	0.45	0.79
17	CS	Tube	130	4.0	0.99	0.00
18	CS	Tube	160	5.7	0.96	0.00
19	CS	Tube	140	5.7	0.80	0.02
20	CS	Tube	130	5.7	0.91	0.11
21	CS	Tube	160	5.7	0.87	0.00

10. This last iteration is the “minimized material cost” stage, where each member is made as small as possible while meeting the requirements of the load test. If you select Report Cost Calculations from the main menu, you can see a cost report that, not surprisingly, includes many different sizes for the members. The report shows 11 products that are needed. From a practical point of view, it would be challenging and costly to have so many different sizes to deal with as the builder of the bridge. Note that the West Point Bridge Designer program includes a $100 fee for each product listed in the cost report. To reduce this cost, the engineer has to standardize the products and reduce the total number of products.

Cost Calculations Report (Design Iteration #24)

Type of Cost	Product	Cost Calculation	Cost
Material Cost	Carbon Steel Bars	(1077.8 kg) x ($0.42 per kg) =	$452.68
	Carbon Steel Tubes	(1898.1 kg) x ($0.63 per kg) =	$1,195.80
	High Strength Steel Bars	(0.0 kg) x ($0.48 per kg) =	$0.00
	High Strength Steel Tubes	(0.0 kg) x ($0.72 per kg) =	$0.00
	Quenched & Tempered Steel Bars	(0.0 kg) x ($0.70 per kg) =	$0.00
	Quenched & Tempered Steel Tubes	(0.0 kg) x ($1.06 per kg) =	$0.00
Connection Cost		(12 Joints) x ($25.00 per Joint) =	$300.00
Product Cost	4 - 160 x 160 x 8 Carbon Steel Tubes	($100.00 per Product) =	$100.00
	2 - 180 x 180 x 9 Carbon Steel Tubes	($100.00 per Product) =	$100.00
	2 - 150 x 150 x 7 Carbon Steel Tubes	($100.00 per Product) =	$100.00
	2 - 70 x 70 Carbon Steel Bars	($100.00 per Product) =	$100.00
	2 - 75 x 75 Carbon Steel Bars	($100.00 per Product) =	$100.00
	2 - 65 x 65 Carbon Steel Bars	($100.00 per Product) =	$100.00
	3 - 130 x 130 x 6 Carbon Steel Tubes	($100.00 per Product) =	$100.00
	1 - 35 x 35 Carbon Steel Bar	($100.00 per Product) =	$100.00
	1 - 10 x 10 Carbon Steel Bar	($100.00 per Product) =	$100.00
	1 - 80 x 80 x 4 Carbon Steel Tube	($100.00 per Product) =	$100.00
	1 - 140 x 140 x 7 Carbon Steel Tube	($100.00 per Product) =	$100.00
Total Cost			$3,048.48

Close

11. In general, you can standardize the products by increasing the size of the smaller members to match some of the larger members. Yes, the members will become heavier and less efficient, but if the cost can be reduced while meeting the load test requirement, then the trade-off is favorable. After a few iterations, the products can be standardized to reduce the cost to $2,683.13.

Cost Calculations Report (Design Iteration #34)

Type of Cost	Product	Cost Calculation	Cost
Material Cost	Carbon Steel Bars	(1559.3 kg) x ($0.42 per kg) =	$654.91
	Carbon Steel Tubes	(2108.3 kg) x ($0.63 per kg) =	$1,328.21
	High Strength Steel Bars	(0.0 kg) x ($0.48 per kg) =	$0.00
	High Strength Steel Tubes	(0.0 kg) x ($0.72 per kg) =	$0.00
	Quenched & Tempered Steel Bars	(0.0 kg) x ($0.70 per kg) =	$0.00
	Quenched & Tempered Steel Tubes	(0.0 kg) x ($1.06 per kg) =	$0.00
Connection Cost		(12 Joints) x ($25.00 per Joint) =	$300.00
Product Cost	4 - 160 x 160 x 8 Carbon Steel Tubes	($100.00 per Product) =	$100.00
	2 - 180 x 180 x 9 Carbon Steel Tubes	($100.00 per Product) =	$100.00
	7 - 150 x 150 x 7 Carbon Steel Tubes	($100.00 per Product) =	$100.00
	8 - 75 x 75 Carbon Steel Bars	($100.00 per Product) =	$100.00
Total Cost			$2,683.13

Close

12. Another possible method of reducing cost is to select a higher grade material, such as high-strength low-alloy steel (HSLA) or quenched and tempered (Q&T) steel and reduce the size of the member. The cost per pound of material is higher, but the greater strength may allow you to reduce the size of the members and get an overall cost reduction. Modifying the material of the bars to HSLA steel reduces the cost to $2,590.40. Changing to Q&T bars and HSLA tubes shows no cost benefits even when the sizes are reduced.

    So we see that $2,590.40 is the optimized cost for this bridge geometry.

Cost Calculations Report (Design Iteration #38)

Type of Cost	Product	Cost Calculation	Cost
Material Cost	Carbon Steel Bars	(0.0 kg) x ($0.42 per kg) =	$0.00
	Carbon Steel Tubes	(2108.3 kg) x ($0.63 per kg) =	$1,328.21
	High Strength Steel Bars	(1171.2 kg) x ($0.48 per kg) =	$562.19
	High Strength Steel Tubes	(0.0 kg) x ($0.72 per kg) =	$0.00
	Quenched & Tempered Steel Bars	(0.0 kg) x ($0.70 per kg) =	$0.00
	Quenched & Tempered Steel Tubes	(0.0 kg) x ($1.06 per kg) =	$0.00
Connection Cost		(12 Joints) x ($25.00 per Joint) =	$300.00
Product Cost	4 - 160 x 160 x 8 Carbon Steel Tubes	($100.00 per Product) =	$100.00
	2 - 180 x 180 x 9 Carbon Steel Tubes	($100.00 per Product) =	$100.00
	7 - 150 x 150 x 7 Carbon Steel Tubes	($100.00 per Product) =	$100.00
	8 - 65 x 65 High-Strength Low-Alloy Steel Bars	($100.00 per Product) =	$100.00
Total Cost			$2,590.40

Close

    If the geometry of the bridge is changed—if, for example, the joint locations and member length changes—then the procedure must be repeated.

Conclusions

1. In the design process, why is it necessary to try several different options?

2. What other factors besides materials can affect the final cost of a project?

Student Resource 2.1.6

Worksheet: West Point Bridge Designer Problem

Purpose

Design a truss bridge that is safe, meets all the design requirements, and costs as little as possible.

Equipment

West Point Bridge Designer software

Design Constraints

- Bridge abutments are 24 meters apart.
- The bridge must safely carry two lanes of traffic.
- A truss design must be used.
- The bridge will be made of steel.
- The cost of the bridge must be minimized due to a limited budget for this project.

Procedure

Use the design process to guide you during the bridge design. Use the West Point Bridge Designer program to create your design. The steps to follow are:

1. Select a truss configuration.

2. Draw the joints.

3. Draw the members.

4. Load test your design.

5. Modify your design as needed to pass the load test. (Remember that no design is ever accomplished on the first attempt.)

6. Optimize the design to minimize the cost of the bridge. The design of the members can be changed as follows: material, cross section, and size. During the load test, members in tension turn blue and members in compression turn red. The intensity of the color depends on the force-to-strength ratio. If the color is bright red or blue, it means the internal force of that member is nearly equal to the strength. An optimized design has the members loaded close to their strength.

7. If time allows, try a different truss configuration (Pratt Deck Truss, Warren Deck Truss, etc.) to see if the cost can be further reduced.

8. Present your design:
   - Submit a drawing of the design with dimensions.
   - Submit a materials list including itemized costs and total cost for the bridge.
   - Submit an evaluation of the truss you used in your design.
   - Deliver a presentation to the class that describes your design, its advantages, truss analysis, the cost, and a self-evaluation of the process you used to arrive at the final design.

Conclusions

1. How does the type and direction of stress applied affect the selection of the material and the cross section?

2. How can the forces of compression and tension work together to make a stronger bridge?

3. Why is it more expensive to use many different materials and sizes rather than just a few in your design?

AOE POE Integrated Curriculum Unit: Bridge Builder

Lesson 2.1

Science of Bridge Structure

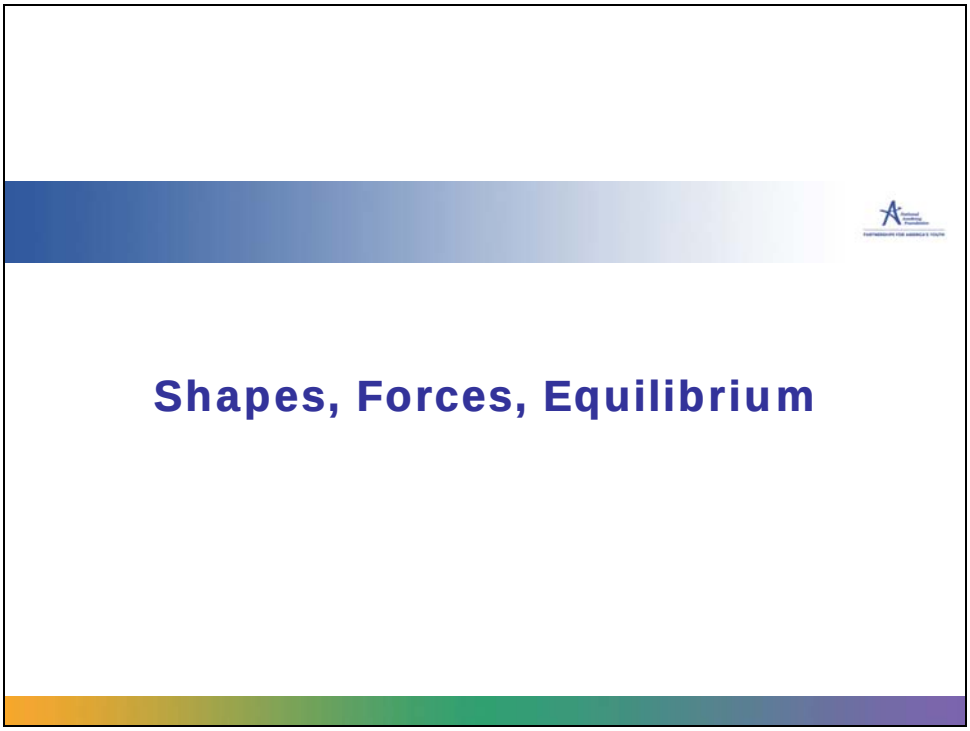
Teacher Resources

Resource	Description
Teacher Resource 2.1.1	Presentation: Shapes, Forces, and Equilibrium
Teacher Resource 2.1.2	Answer Key: Working with X and Y Components of Vectors
Teacher Resource 2.1.3	Presentation: Free-Body Diagrams
Teacher Resource 2.1.4	Answer Key: Free-Body Diagrams
Teacher Resource 2.1.5	Presentation: Truss Bridge Math
Teacher Resource 2.1.6	Presentation: Truss Calculations Answers
Teacher Resource 2.1.7	Presentation: Vector Calculations

Teacher Resource 2.1.1

Presentation: Shapes, Forces, and Equilibrium

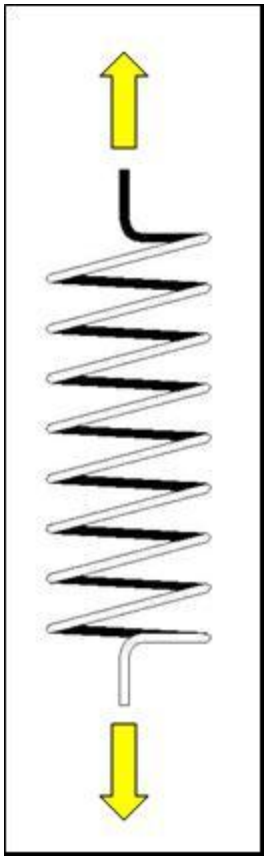
To open the presentation, right-click on the image below, then select Presentation Object/Open from the menu.



Shapes, Forces, Equilibrium

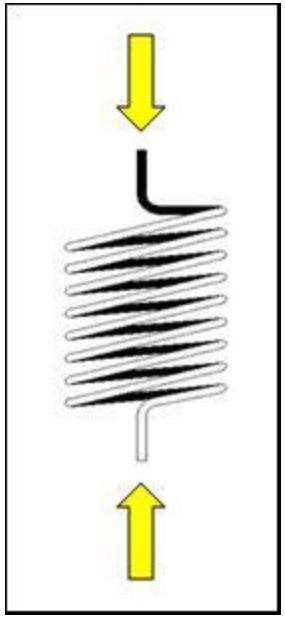
Forces in Tension and Compression

A force is a push or pull exerted by one object on another.



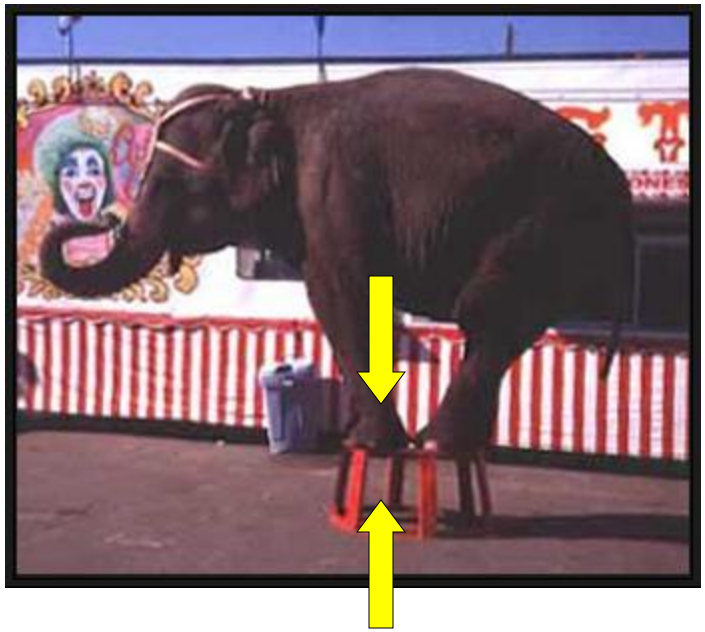
A tensile force expands or lengthens the object it is acting on.

A compressive force compresses or shortens the object it is acting on.



Forces in Tension and Compression

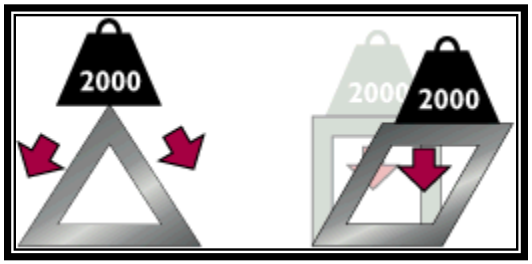
The rope is in tension.



The stand is in compression.

Forces on Shapes

Engineers consider shapes under heavy loads when building large structures.



Triangles are the only shapes that cannot be deformed without changing the length of one of the sides.

Arches are strong because the force resulting from a heavy load placed at the top spreads down the sides to the foundation.

A group of arches placed around a central point creates a dome, which distributes loads down through curving sides to the foundation.

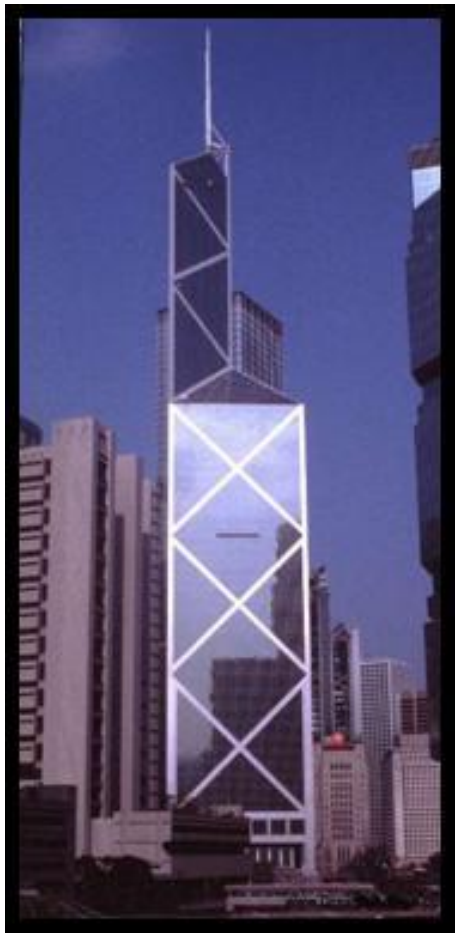
Triangles

Eiffel Tower

Stansted Airport

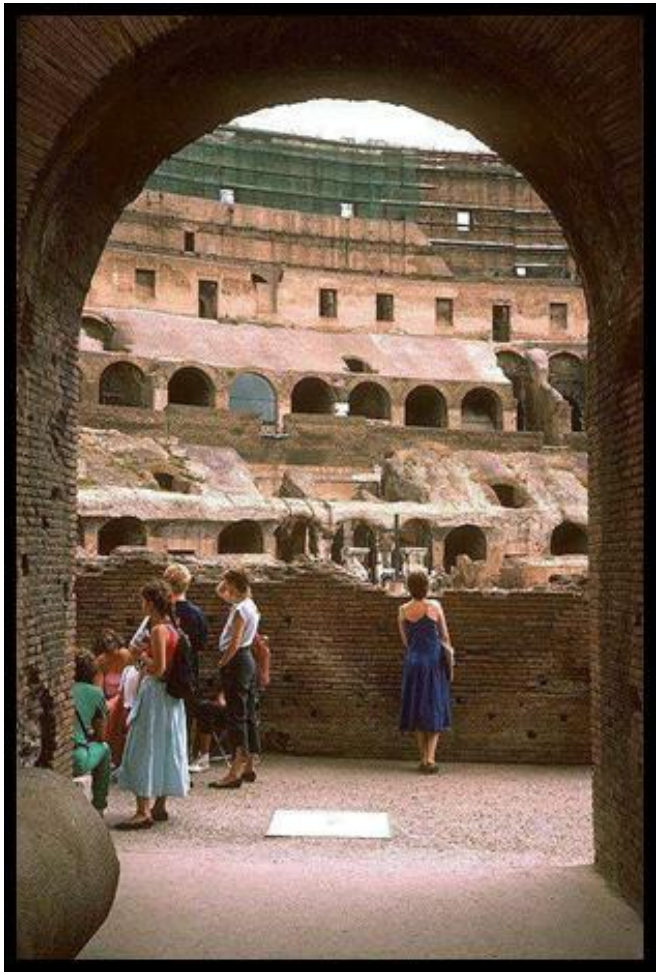
Centre Pompidou

Bank of China Tower



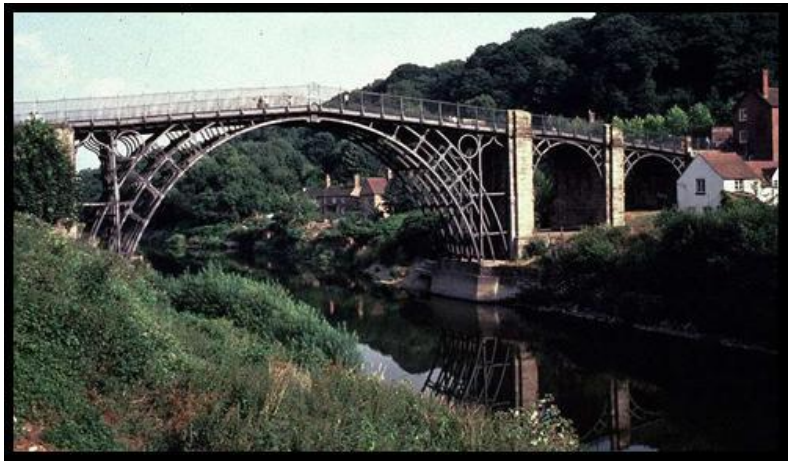
Arches

Roman Colosseum



San Lorenzo, Florence

Musee d'Orsay

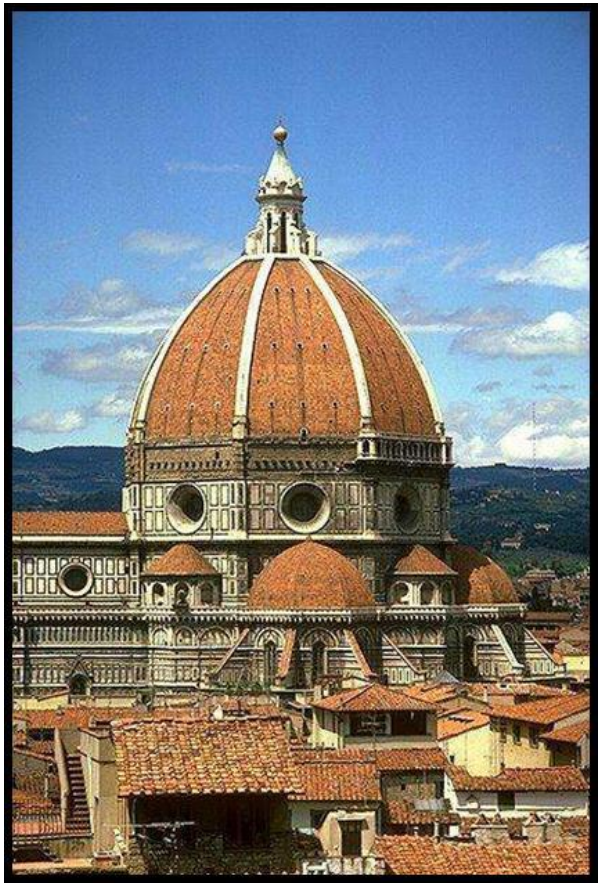


Iron Bridge at Coalbrookdale

Domes

Suleyman Mosque

Florence Cathedral



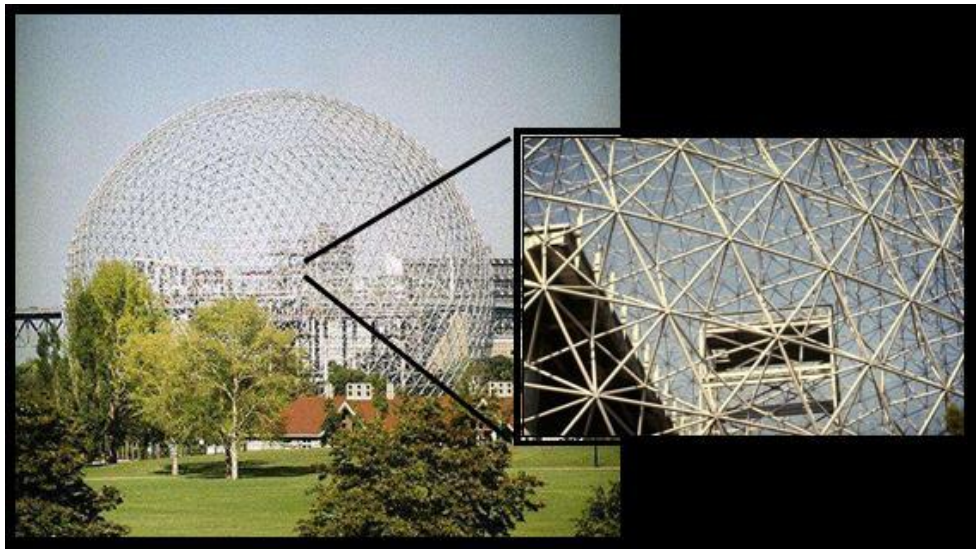
Applications

Dome tent – poles bent into arches with nylon fabric in tension

Psyclone Rollercoaster – triangles in structure

US Pavilion at Expo '67 – spherical structure made of triangles

Campo Volantin Footbridge – arch with cables in tension



Review of the Laws of Motion

1. When an object is at rest or moving with a constant velocity, it will stay at rest or moving with a constant velocity until it is subjected to an unbalanced force.

2. If an unbalanced force, F, is applied to a mass, m, then the mass will experience an acceleration, **F = ma**.

3. Every force of action between objects has an equal, opposite, and collinear reaction.

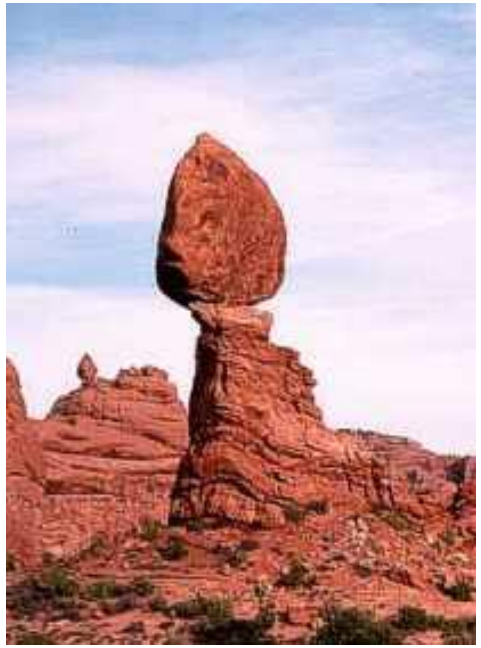
Sir Isaac Newton

Balanced Rock Example

1. This rock is at rest. It will stay at rest unless something really big tries to force it off!

2. Right now there is no outside force acting on it. Therefore it's acceleration is zero.

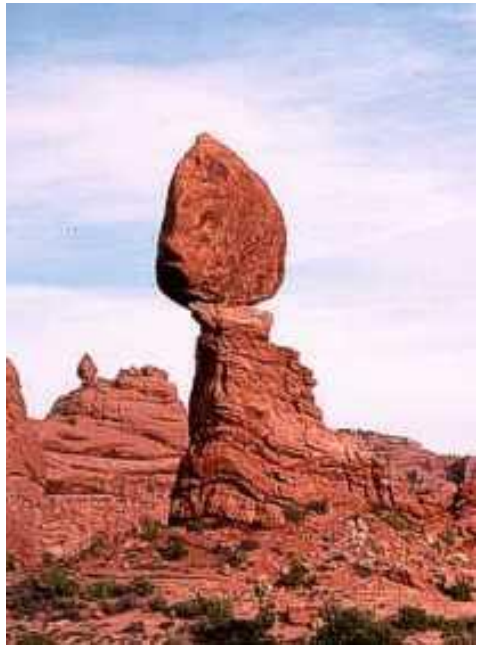
3. The only thing acting on the object here is gravity. As the rock's weight pushes down on the mountain, the mountain is equally pushing up on the rock.



Balanced Rock Example

- Static Equilibrium is the state of an object when it is at rest or moving with a constant velocity. There may be several forces acting on the object. If they are canceling each other out and the object is not accelerating, then it is in a state of static equilibrium!

- The forces here are canceling each other out. It is in a state of static equilibrium.



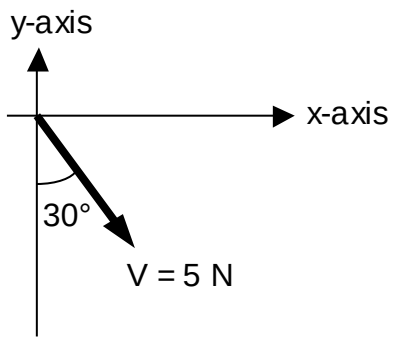
Teacher Resource 2.1.2

Answer Key: Working with X and Y Components of Vectors

Directions

Solve the following problems. Show your work in the space provided.

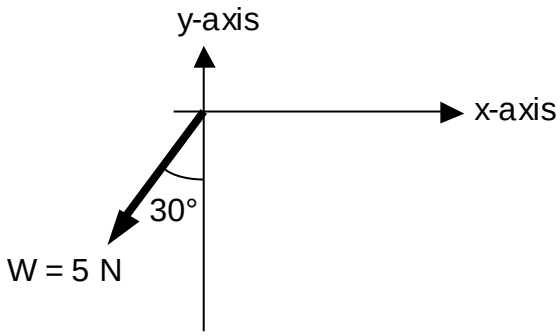
1. Find the x and y components of vector V. Solution hint: Think of the vector as pointing southeast. You will need to split it up into its y component (pointing south) and its x component (pointing east).



V_X = 5 N x sin 30 = 2.5 N east

V_Y = 5 N x cos 30 = 4.3 N south

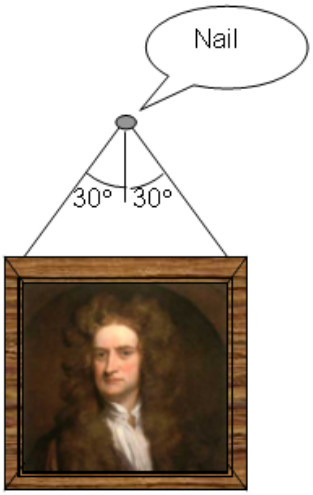
2. Find the x and y components of vector W. Can you predict the solution based on problem 1? Solution hint: Think of the vector as pointing southwest. You need to split it up into its y component (pointing south) and its x component (pointing west).

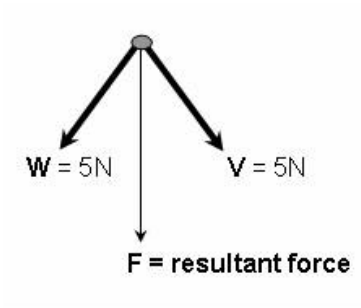


WX = 5 x sin 30 = –2.5 N west

WY = 5 x cos 30 = –4.3 N south

3. This picture is hung from a nail with wire. The nail supports two forces V = 5N and W = 5N. If the resultant of these forces acts vertically downward, find its x and y components (using your solutions from problems 1 and 2).



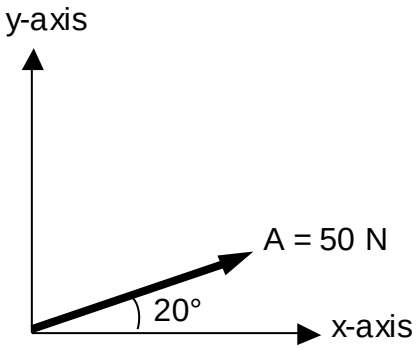


Remember that:
V_X = + 2.5 N
V_Y = - 4.3 N
W_X = - 2.5 N
W_Y = - 4.3 N

$F_X = V_X + W_X$ = 2.5 N + (–2.5 N) = 0 N

$F_Y = V_Y + W_Y$ = (–4.3 N) + (-4.3 N)
= –8.6 N south

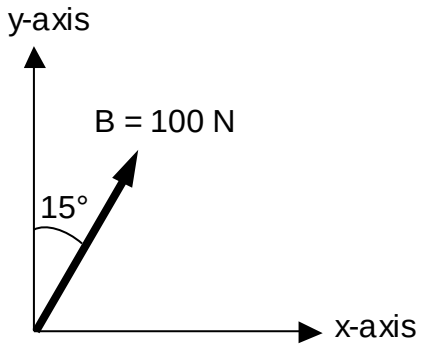
4. Find the x and y components of vector A. Solution hint: Think of the vector as pointing northeast. You need to split it up into the y component (pointing north) and the x component (pointing east).



A_X = 50 N x cos 20 = 47 N east

A_Y = 50 N x sin 20 = 17 N north

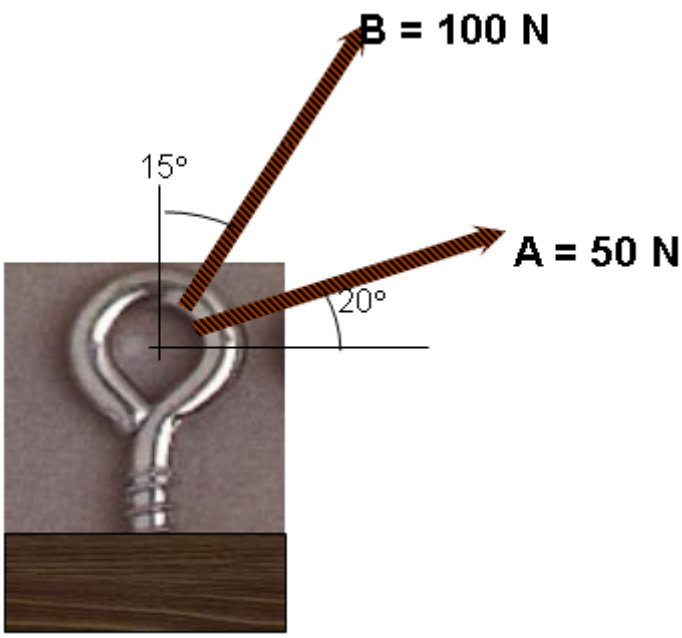
5. Find the x and y components of vector B. Solution hint: Think of the vector as pointing northeast. You need to split it up into the y component (pointing north) and the x component (pointing east).



B_X = 100 N x sin 15 = 26 N east

B_Y = 100 N x cos 15 = 97 N north

6. Two ropes are attached to the screw eye hook in this picture. Robe B is being pulled with a force of 100 N at an angle of 15 degrees to the y-axis. Rope A is being pulled with a force of 50 N at an angle of 20 degrees to the x-axis. Use your solutions from problems 4 and 5 to find the x and y components of the resultant force, F.



Remember that:
A_X = 47 N
A_Y = 17 N
B_X = 26 N
B_Y = 97 N

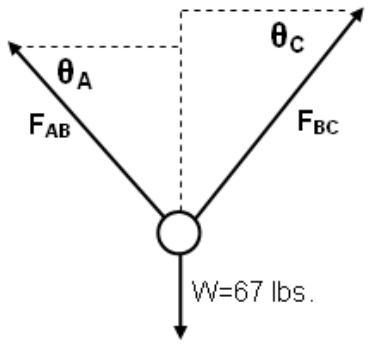
$F_X = A_X + B_X$ = 47 N + 26 N = 73 N east

$F_Y = A_Y + B_Y$ = 17 N + 97 N
= 114 N north

Conclusions

1. When you are opening a classroom door what are the forces acting on it, and how are they balanced out so the door does not slam shut when released?

2. You have been asked to hang a mirror ball in the center of the gym, 10 feet from the ceiling. There are beams that run across the gym, but they are not centered. One beam is 10 feet off-center and the other is 7 feet from the center. The mirror ball weighs 67 pounds. How long should each cable be, and how much force should each one be able to hold?



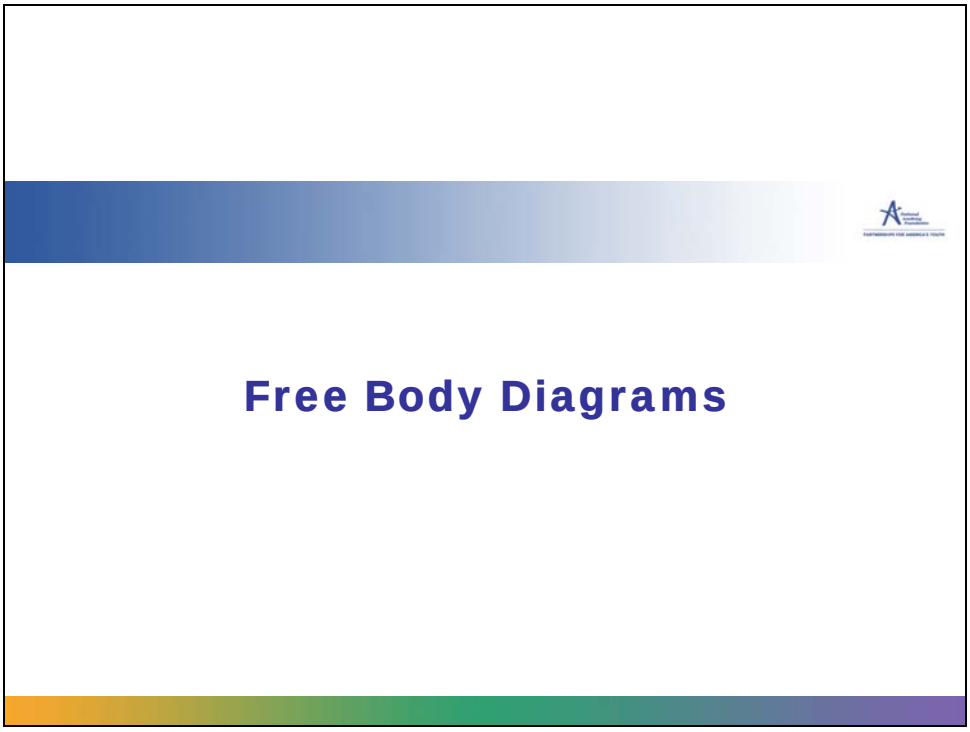
F_{AB} = 39.0 lbs

F_{BC} = 48.1 lbs

Teacher Resource 2.1.3

Presentation: Free-Body Diagrams

To open the presentation, right-click on the image below, then select Presentation Object/Open from the menu.



Free Body Diagrams

Gravity

- Weight, **W**, is a force.
- Gravity, **g**, is an acceleration.
- The acceleration of gravity on earth is approximately:
  - 9.81 m/s² in SI units and
  - 32.2 ft/s² in US Customary units.
- We know from Newton's 2nd law that
  - Force = mass * acceleration

    F = m * a
  - Therefore we can write:

    W = m * g

Gravity

The Statue of Liberty has a mass of 225,000 kg. How much does she weigh?

Write the formula: $W = m * g$

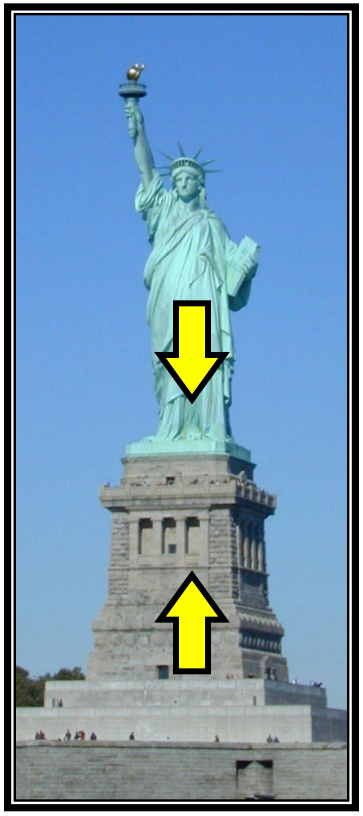
Substitute known values: $W = (225{,}000\ kg) * 9.81\ m/s^2$

Present solution with units: $W = 2207250\ N$

Gravity

The Statue of Liberty weighs 2207250 Newtons, which is 496,210 pounds!

If she is exerting a 496210 lb force down, how much does Liberty Island have to push up on her to maintain static equilibrium?



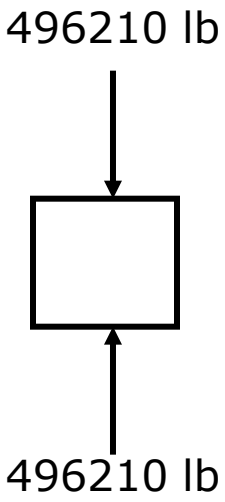
496210 lb, according to Newton's 3rd law

Free Body Diagram

- A scalar is simply a number, a magnitude alone.
- A force is usually shown as a vector, which includes both magnitude and a direction.
- Force (or free-body) diagrams show the relative magnitude and direction of all forces acting upon an object. The object must be isolated and "free" of its surroundings.

Free Body Diagram

This is a free-body diagram of the Statue of Liberty. She is represented by a simple box. The forces acting on her are labeled with a magnitude and the arrow shows direction. Notice the surrounding objects are stripped away and the forces acting on the object are shown.

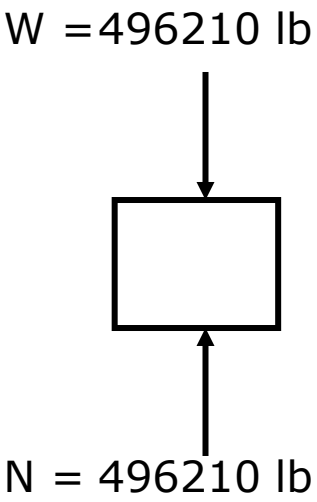


Free Body Diagram

W represents the force of the weight of the statue.

N is the <u>normal force</u>, which represents the force Liberty Island is pushing back up on the statue.

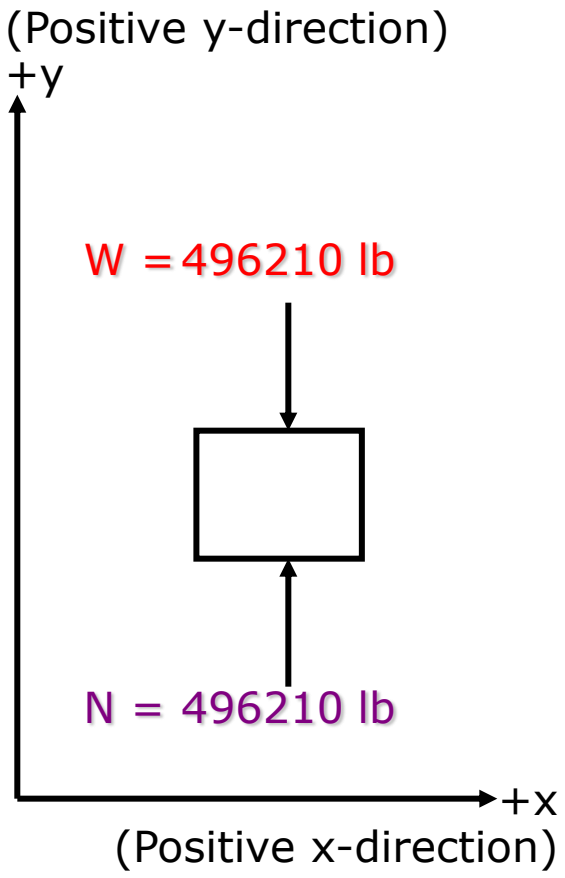
The island has a great resistance to compression. The ground is exerting a force upward on the statue perpendicular, or normal, to the surface.



Free Body Diagram

Think of the diagram on an XY plane.

If "up" is assumed to be the positive direction, then N is positive and W is negative.



Free Body Diagram

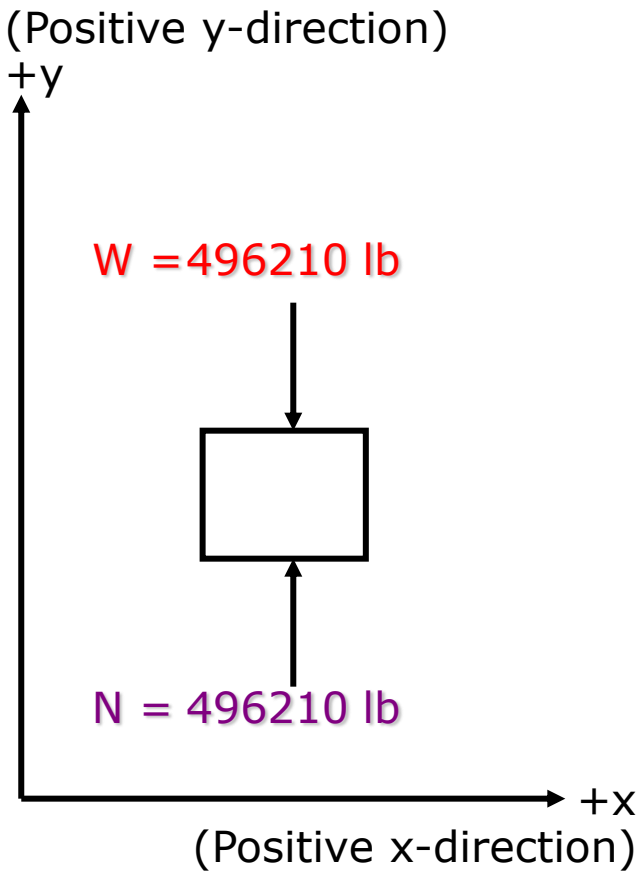
The first line of this calculation reads,

"The sum of the Forces in the positive y direction is W + N"
(Σ is the Greek symbol for "sum")

$$+\uparrow \quad \Sigma F_y = W + N$$

$$\Sigma F_y = (-496210 \text{ lb}) + (+496210 \text{ lb})$$

$$\Sigma F_y = 0$$



The sum of the forces in the y is zero.

The forces acting on the object cancel each other out.

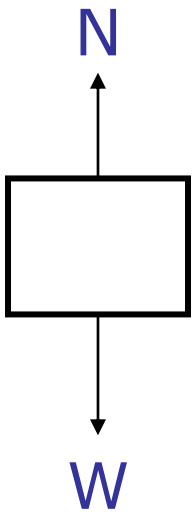
Static Equilibrium Review

- We know $F = m * a$, where "a" is acceleration.
- If $a = 0$, then $F = m * 0 = 0$.
- When $\Sigma F = 0$, the object is not accelerating.
- We can then say that the forces acting on the object cancel each other out and it is in a state of static equilibrium.

Example 1 – Sitting Object

Create a free body diagram (FBD) for each of the following situations. Draw a FBD of the gorilla:

Sitting Gorilla

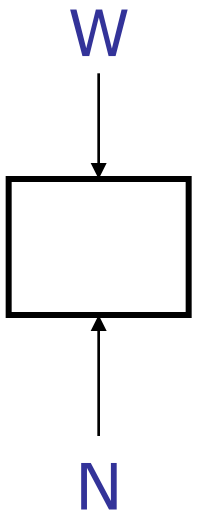


Free Body Diagram of the Sitting Gorilla (The box represents the gorilla, W = weight of the gorilla, N = Normal force)

Example 1 – Sitting Object

Create a free body diagram (FBD) for each of the following situations. Draw a FBD of the gorilla:

Sitting Gorilla

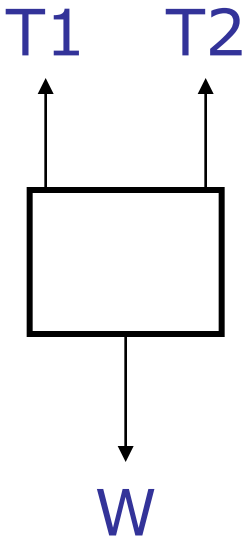


This diagram is also acceptable

Example 2 – Swing

Draw a FBD of the wooden swing:

Parrot on wooden swing hung by ropes

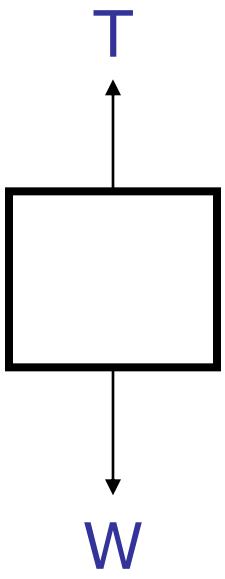


Free Body Diagram of the wooden swing (The box represents the wooden swing, W = weight of the swing and the parrot, T represents the ropes that are in tension supporting the weight)

Example 3 – Bungee Jumper

Draw a FBD of the bucket the bungee jumper leaped from:

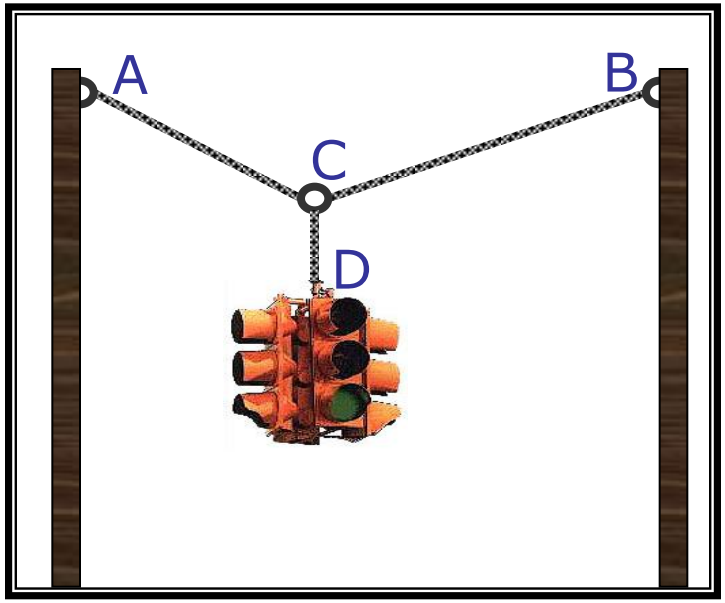
Bungee jumping from crane



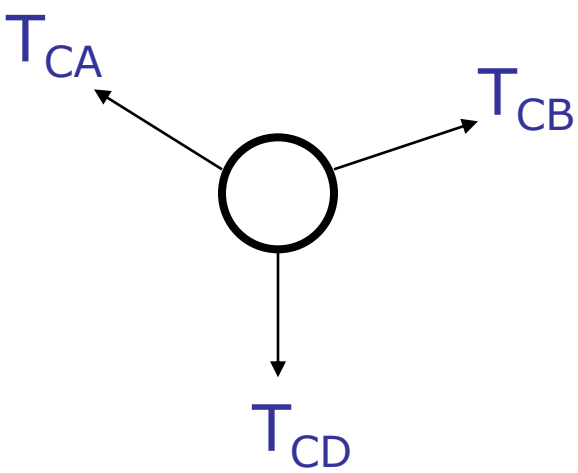
Free Body Diagram of the bucket (T represents the tensile force of the cable the bucket is suspended from, and W is the weight of the diver and the bucket)

Example 4 – Traffic Light

Draw a FBD of the ring at point C:



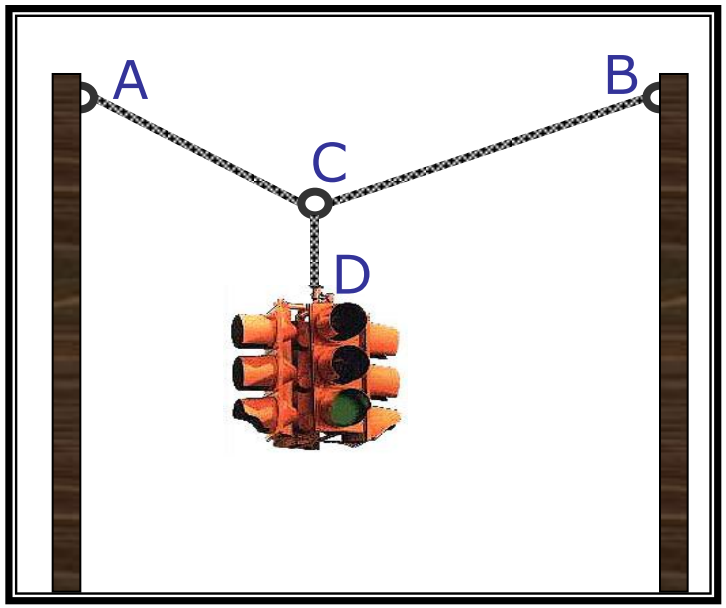
Traffic Light supported by cables



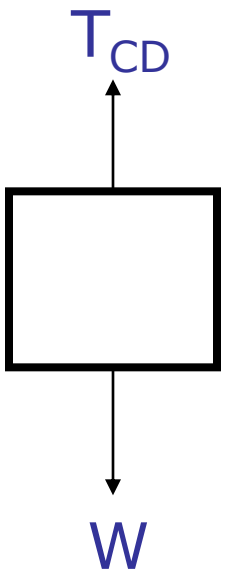
Free Body Diagram of the ring at point C (T represents the force of the cables that are in tension acting on the ring)

Example 4 – Traffic Light

Draw a FBD of the ring at point C:



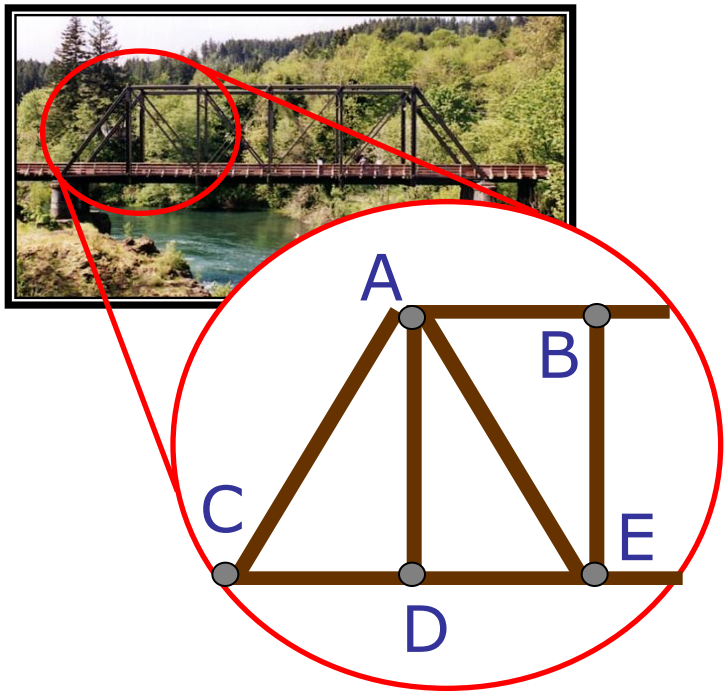
Traffic Light supported by cables



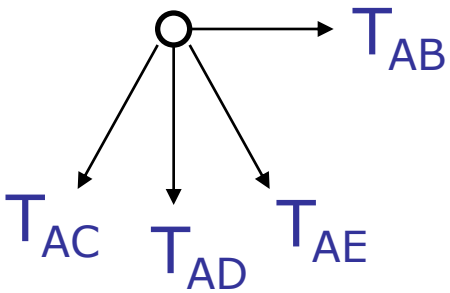
Free Body Diagram of the traffic light (T_{CD} represents the force of the cables acting on the light and W is the weight acting on the light)

Example 5 – Bridge Truss

Draw a FBD of the pin at point A:



Pin-Connected Pratt Through Truss Bridge

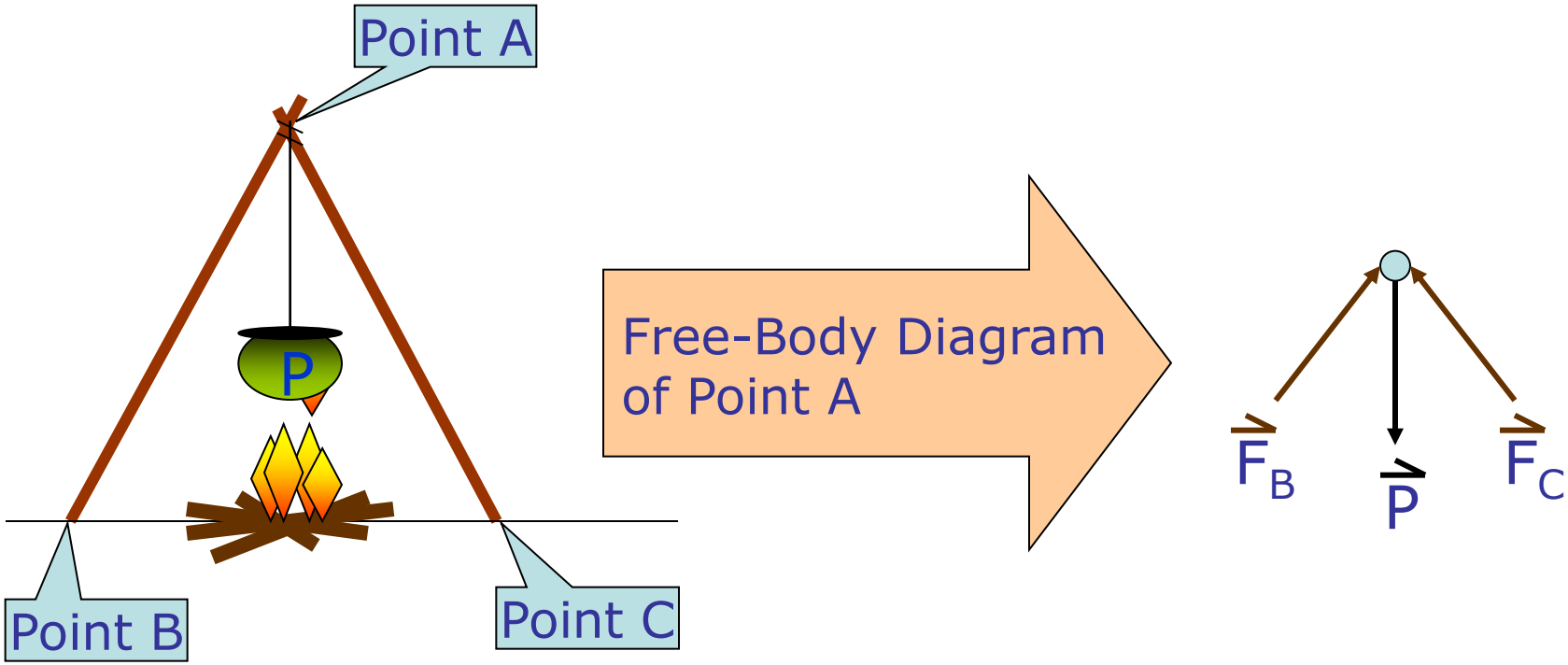


Free Body Diagram of pin A

(If you consider the third dimension, then there is an additional force acting on point A into the paper: The force of the beam that connects the front of the bridge to the back of the bridge.)

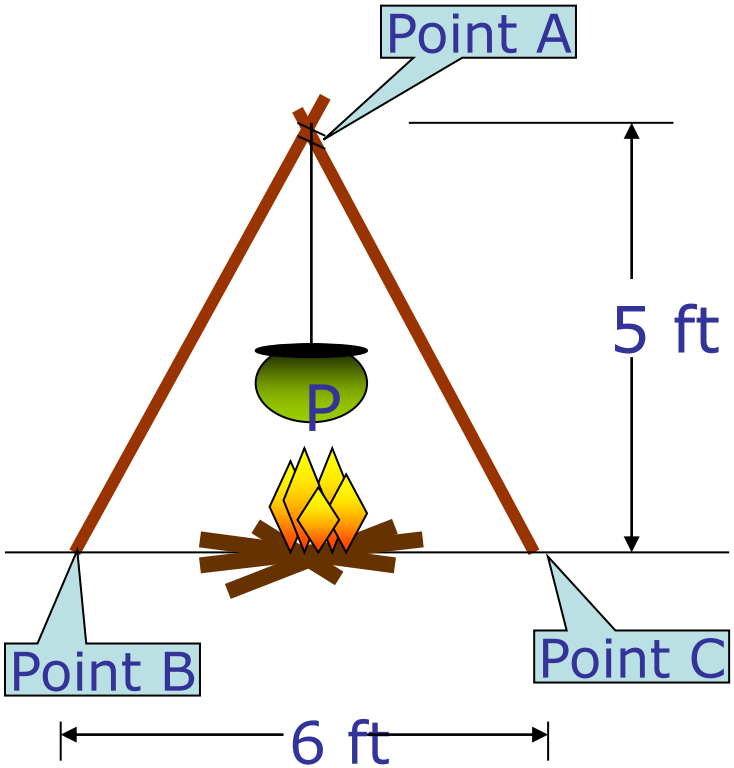
Reaction Forces

Let's suppose some campers have pitched their tents and are ready to prepare their supper. They build a structure to support their pot over the campfire to cook:



Reaction Forces

The weight of the pot, P, is 50 lbs. The pot hangs from a rope that bisects the symmetric structure that is 5 ft tall and 3 ft wide. We need angle theta in order to solve for the x and y components.

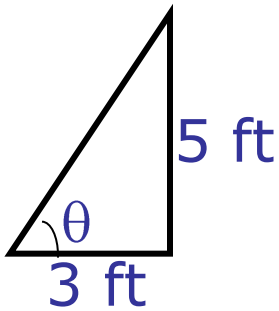


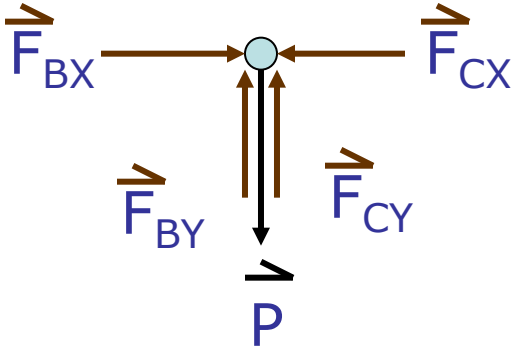
$\tan\theta = \text{opp} / \text{adj}$

$\theta = \tan^{-1}(\text{opp} / \text{adj})$

$\theta = \tan^{-1}(5\text{ ft} / 3\text{ ft})$

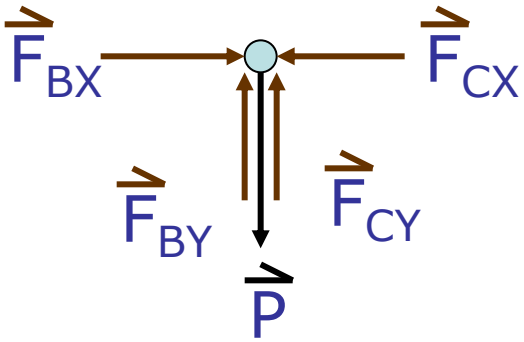
$\theta = 59°$

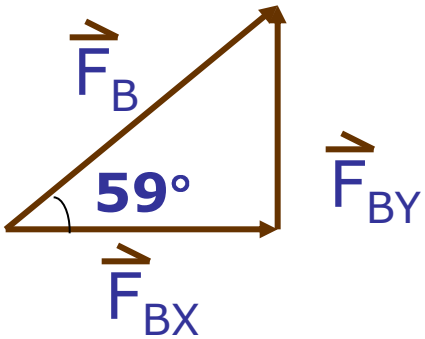




Reaction Forces

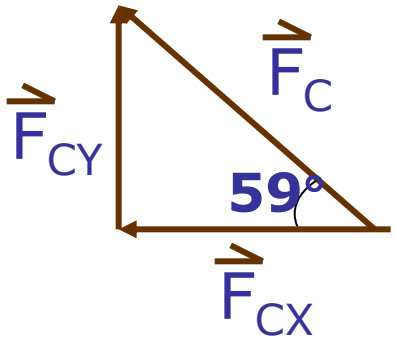
Solve for the scalar, x and y components of each force:





$$F_{BX} = F_B \cos(59)$$

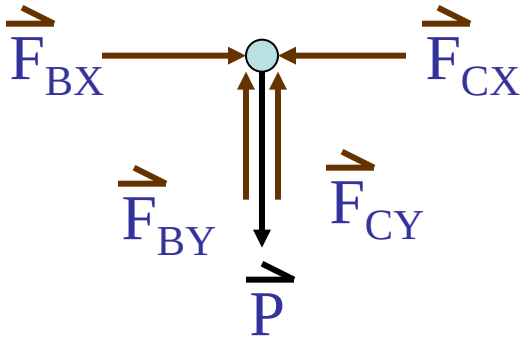
$$F_{BY} = F_B \sin(59)$$



$$F_{CX} = F_C \cos(59)$$

$$F_{CY} = F_C \sin(59)$$

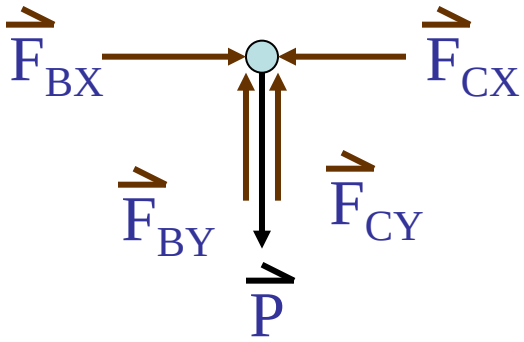
Reaction Forces



Sum the forces in the positive x and y directions. Assume the positive y-direction is up (+↑), and the positive x direction is to the right (→).

***Remember the forces will sum to zero because we are assuming that the structure is in static equilibrium.

Reaction Forces



Solve for the two unknowns using these two equations.

$\overset{+}{\rightarrow} \Sigma F_X = 0; \qquad F_{BX} - F_{CX} = 0$

$F_B \cos(59) - F_C \cos(59) = 0$

$+\uparrow \Sigma F_Y = 0; \qquad F_{BY} + F_{CY} - P = 0$

$F_B \sin(59) + F_C \sin(59) - 50 = 0$

Reaction Forces

Equation 1: $F_B \cos(59) - F_C \cos(59) = 0$

Equation 2: $F_B \sin(59) + F_C \sin(59) - 50 = 0$

Equation 1 shows that F_B equals F_C :

$$\frac{F_B \cos(59)}{\cos(59)} = \frac{F_C \cos(59)}{\cos(59)}$$

Replace F_C with F_B in Equation 2 since they are the same:

$$F_B \sin(59) + F_B \sin(59) - 50 = 0$$

$$\frac{2 F_B \sin(59)}{2 \sin(59)} = \frac{50}{2 \sin(59)}$$

$$F_B = 29.16 \text{ lbs}$$

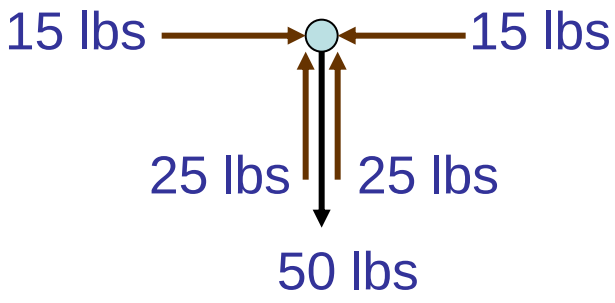
Reaction Forces

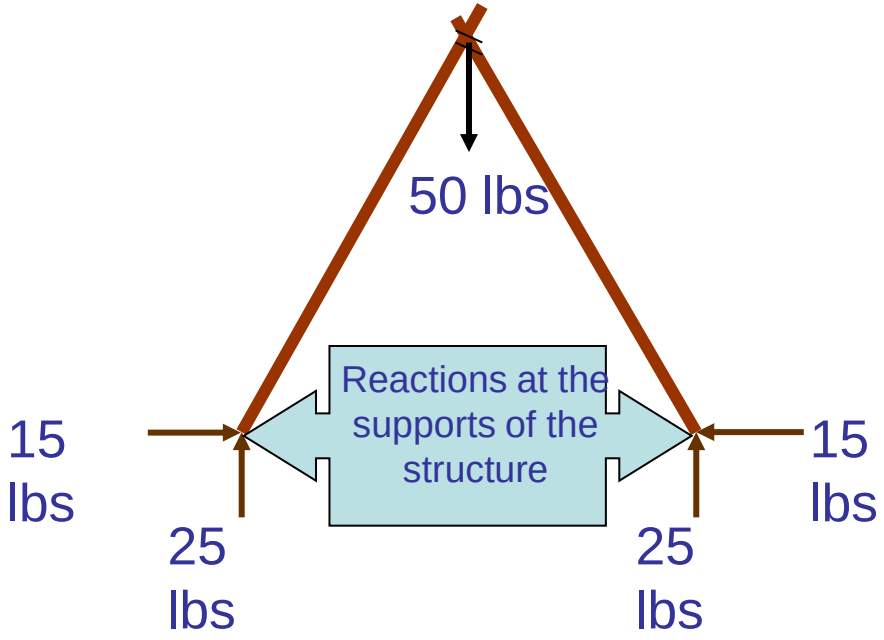
If F_B = 29.16 lbs, then F_C = 29.16 lbs because of Equation 1.
Solve for the scalar x and y components:

$F_{BX} = F_B \cos(59)$ = 29.16 lbs * cos (59) = 15 lbs

$F_{BY} = F_B \sin(59)$ = 29.16 lbs * sin (59) = 25 lbs

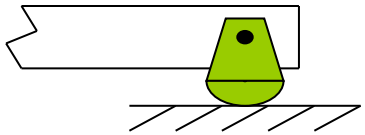
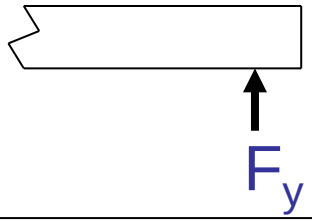
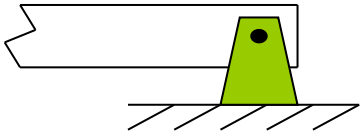
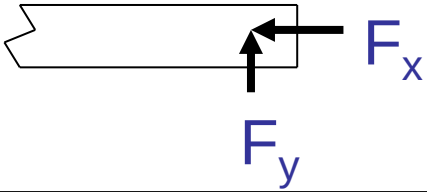
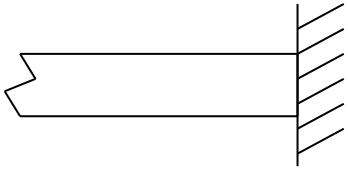
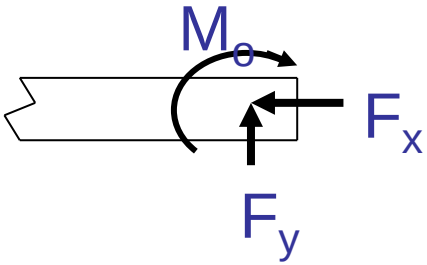
These scalar quantities are the same for the components of F_C.





Force and Free Body Diagrams

Supports are translated into forces and moments in free body diagrams. The following are three common supports and the forces and moments used to replace them.

Roller:		
Pin Connection:		
Fixed Support:		

Moments

A ***moment*** of a force is a measure of its tendency to cause a body to rotate about a point or axis.

It is the same as torque.

A moment (M) is calculated using the formula:

Moment = Force * Distance

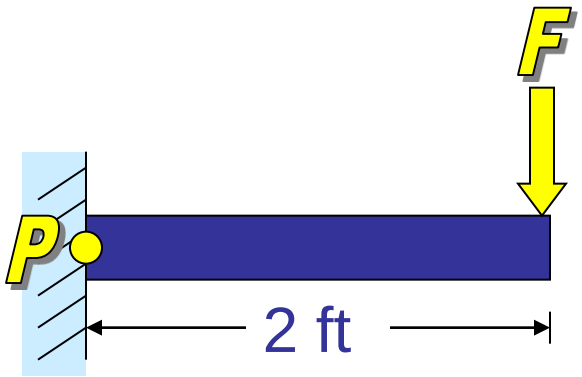
M = F * D

Always use the perpendicular distance between the force and the point!

Moments

Moment = Force * Distance

M = F * D



What distance would you use here?

F = 20 lb

D = 2 ft

Find the moment about point P:

M = F * D

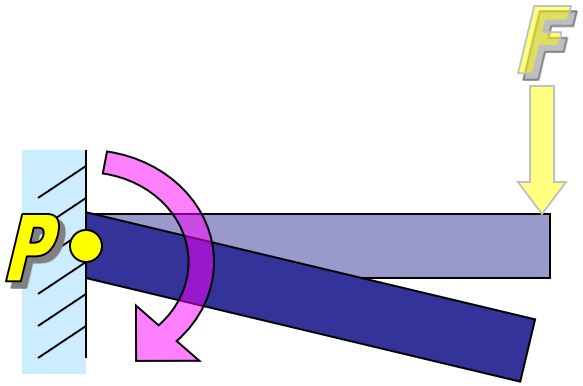
M = (20 lb) * (2 ft)

M = 40 ft-lb

Moments

Moment = Force * Distance

M = F * D



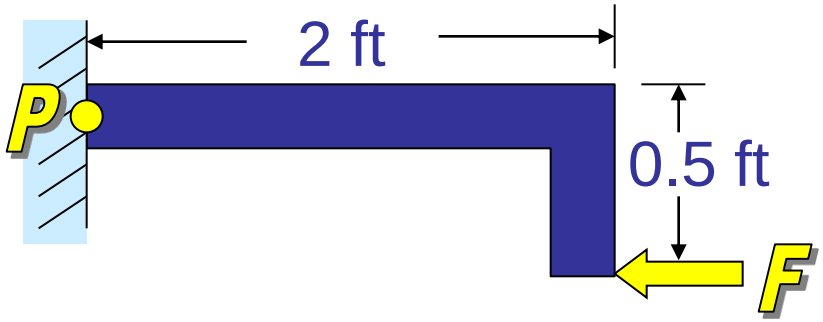
Can you visualize the result of the force acting on the beam?

The beam has a tendency to rotate clockwise about point P.

Moments

Moment = Force * Distance

M = F * D



F = 20 lb

D = 0.5 ft

Find the moment about point P:

M = F * D

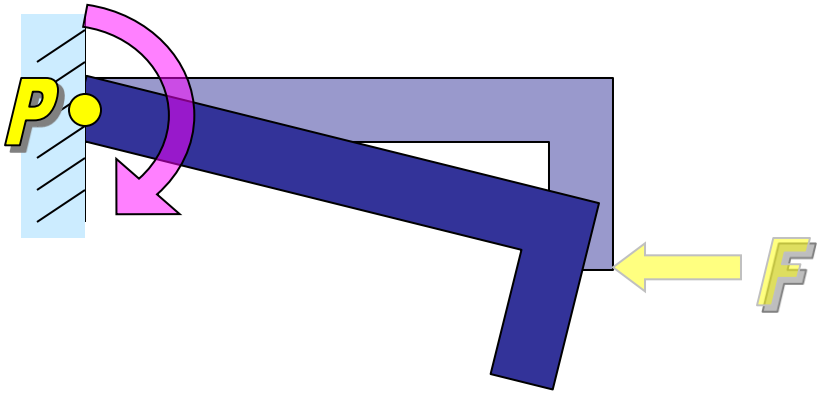
M = (20 lb) * (0.5 ft)

M = 10 ft-lb

Moments

Moment = Force * Distance

M = F * D



Can you visualize the result of the force acting on the beam?

The beam has a tendency to rotate clockwise about point P.

Moments

You have seen how a see-saw will balance on its fulcrum if equal weight is applied at both ends.

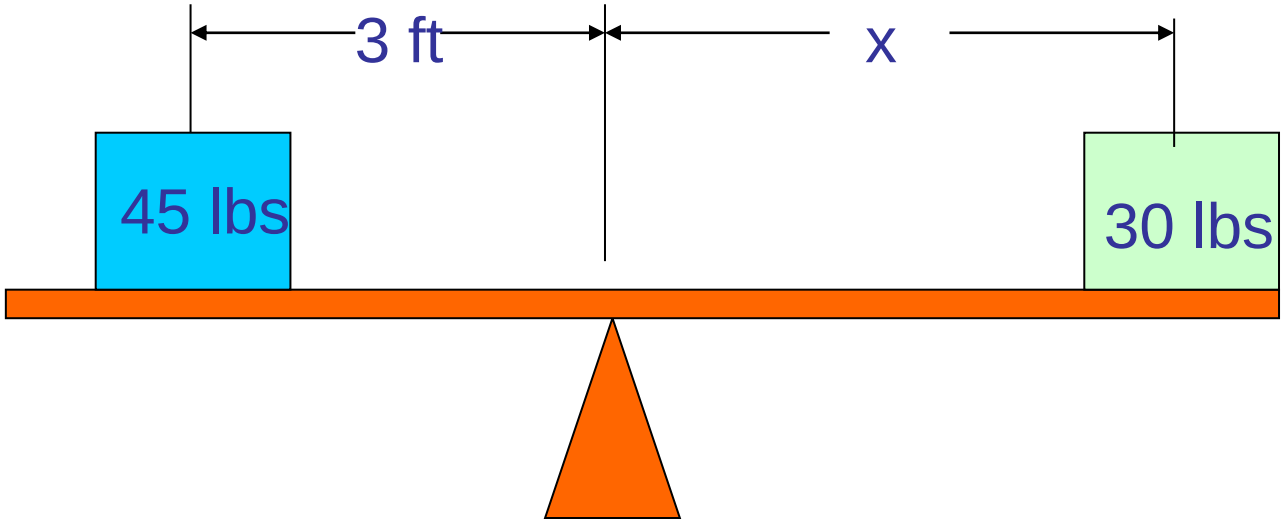
If two people of unequal weight are on the see-saw, it will rotate about its fulcrum to the side with the heavier person.

Fulcrum

Moments

A see-saw can also be balanced by moving the smaller person further from the fulcrum.

If a 45-pound child sat on one end 3 ft from the fulcrum, then how far from the fulcrum would a 30-pound child have to sit in order for the see-saw to be balanced?



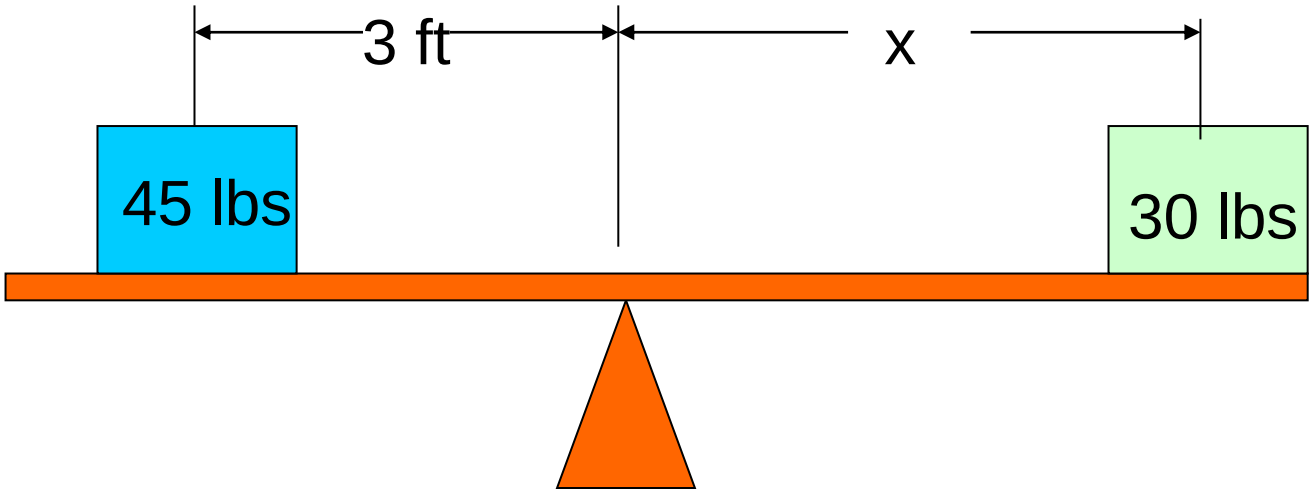
Moments

$$M_1 = M_2$$

$$45 \text{ lbs} * 3 \text{ ft} = 30 \text{ lbs} * x$$

$$\frac{135 \text{ ft-lbs}}{30 \text{ lbs}} = \frac{\cancel{30 \text{ lbs}} * x}{\cancel{30 \text{ lbs}}}$$

$$4.5 \text{ ft} = x$$



Moments

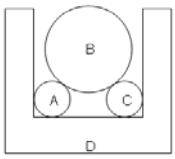
- Typically it is assumed:
  - A moment with a tendency to rotate counter clockwise (CCW) is considered to be a positive moment.
  - A moment with a tendency to rotate clockwise (CW) is considered to be a negative moment.

Teacher Resource 2.1.4

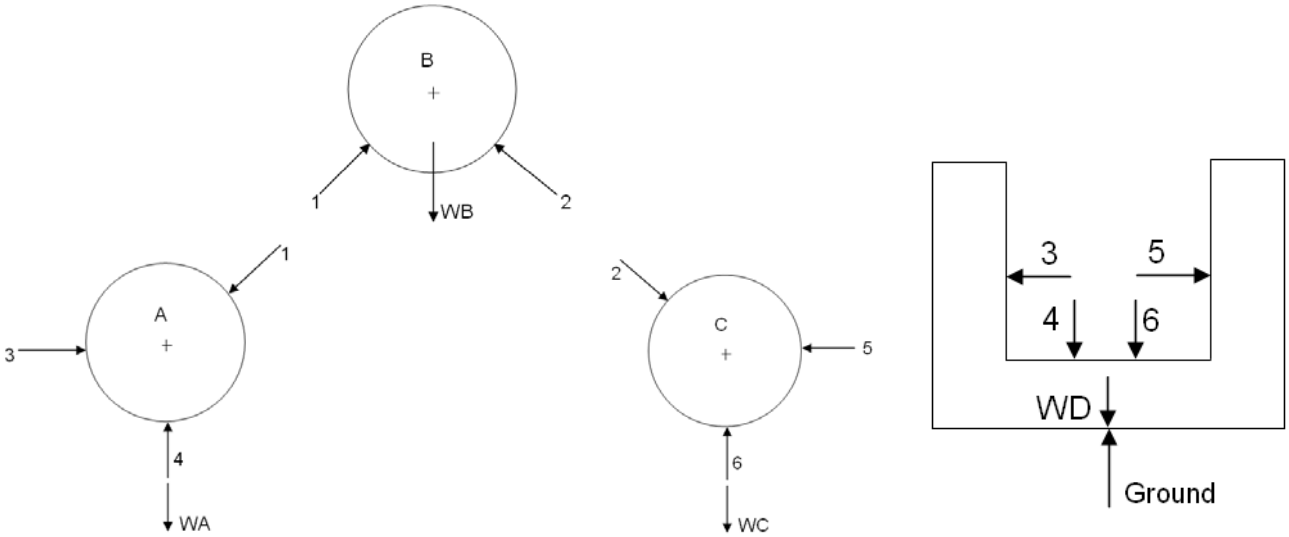
Answer Key: Free-Body Diagrams

Directions: Free-body diagrams are drawings used to show the relative magnitude and direction of all forces acting upon an object in a given situation. A free-body diagram is a special example of a vector diagram. Draw free-body diagrams (force diagrams) for each of the following.

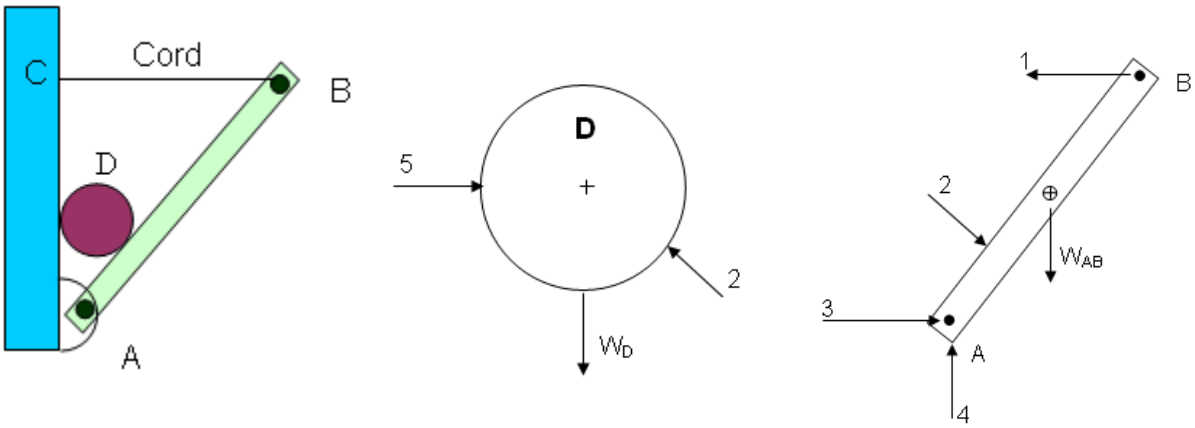
1. Draw free-body diagram for items A, B, C, D.



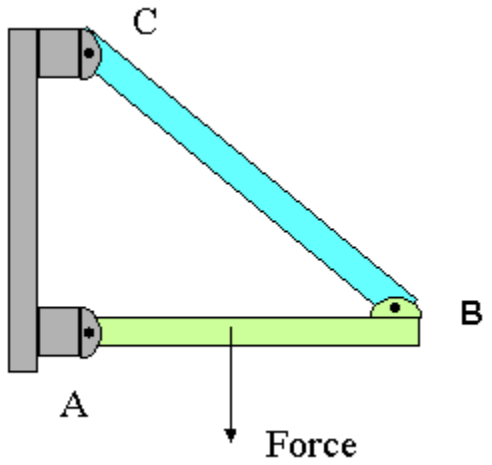
W = weight of object

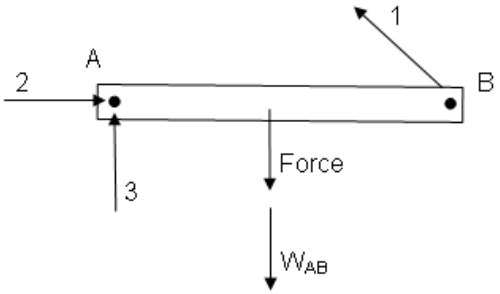


2. Draw a free-body diagram for member AB and cylinder D.



3. Draw a free-body diagram for member AB that is pin-connected at A and supported by member BC.





Conclusions

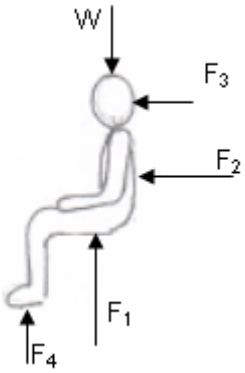
4. What is the point behind creating a free-body diagram of an object?

A free-body diagram isolates a structural element from its surroundings for the purpose of exposing the forces acting between objects. Free-body diagrams are useful in solving for the forces acting on objects.

5. Sketch a free-body diagram of a person sitting in the seat of a car. Which force arrows do you think would be the largest? Why?

System Diagram

Free-Body Diagram

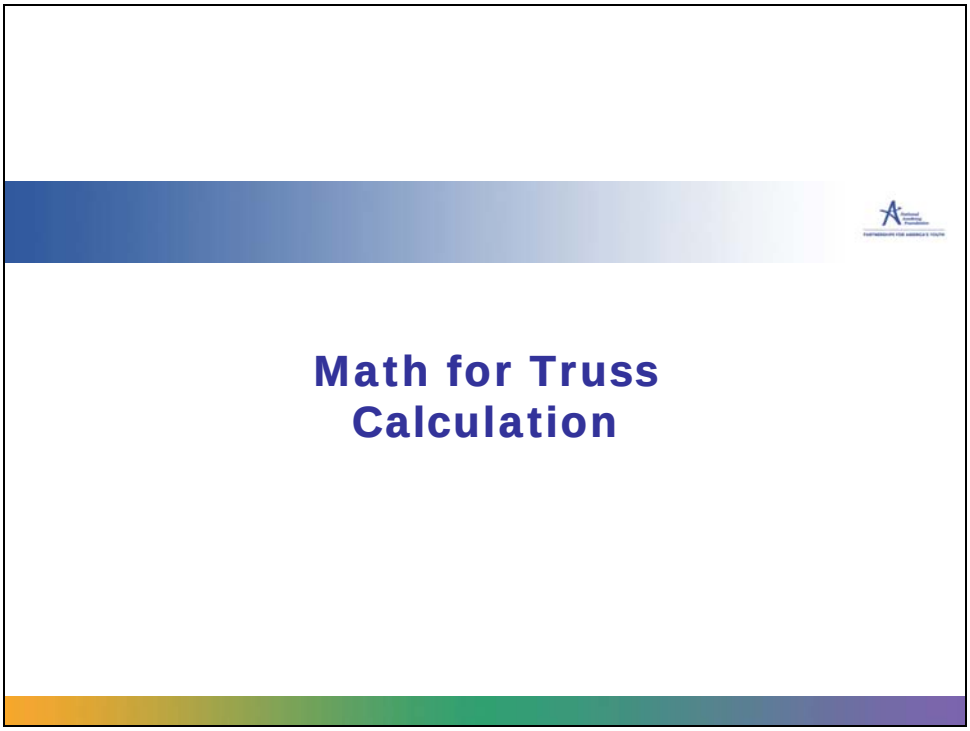


F1 would be the largest because most of the weight is transferred to the bottom of the seat.

Teacher Resource 2.1.5

Presentation: Truss Bridge Math

To open the presentation, right-click on the image below, then select Presentation Object/Open from the menu.



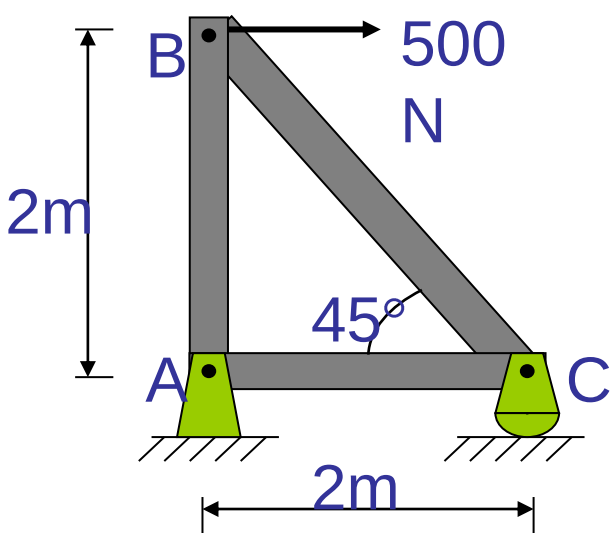
Math for Truss Calculation

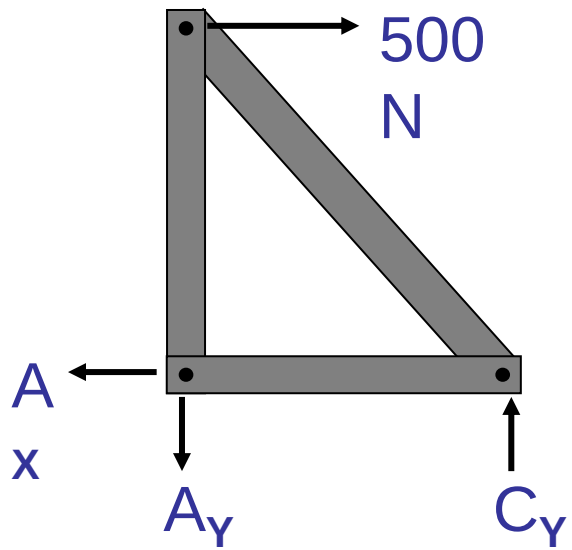
Trusses

Trusses are structures made up of beams joined together at their endpoints.

Solve for the force in each member of the truss in this example to find whether the members are in tension or compression.

Start by replacing the supports with reaction forces:



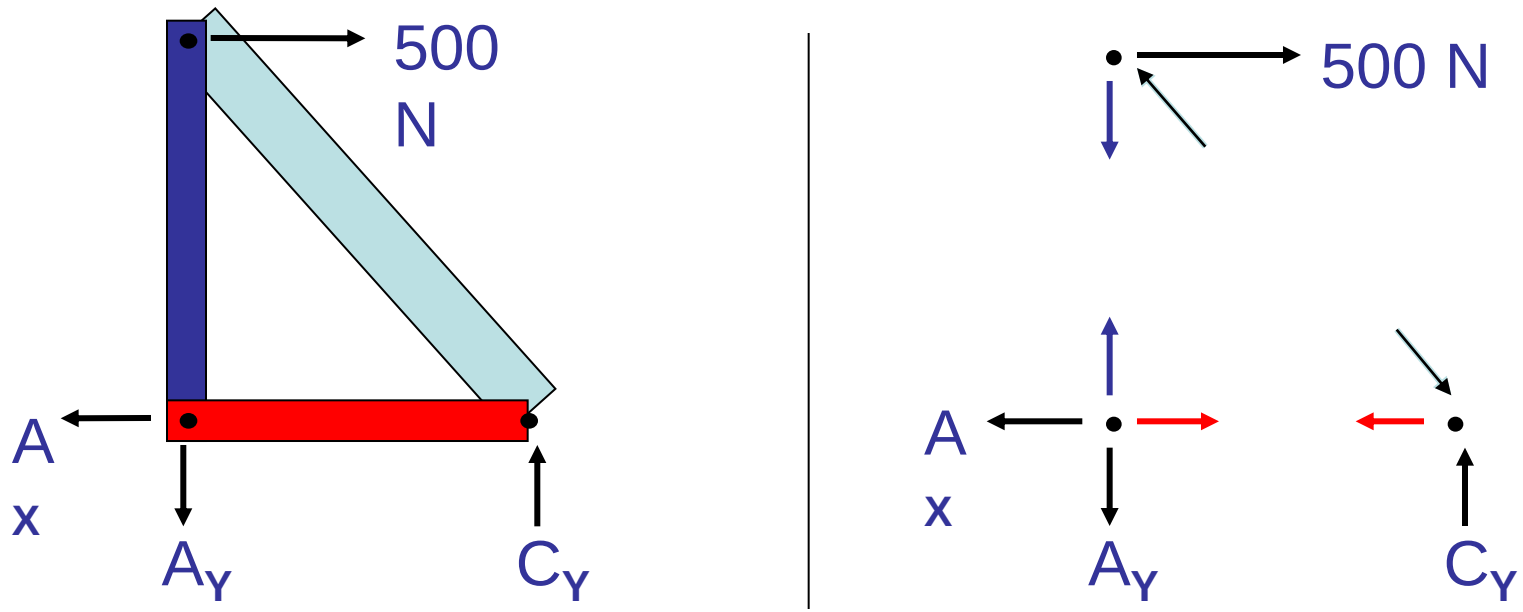


Trusses

This truss consists of:

- 2 unknown member forces and 1 unknown external force at joint B
- 2 unknown member forces and 2 unknown reaction forces at joint A
- 2 unknown member forces and 1 unknown reaction force at joint C

Draw the free-body diagrams for each pin:

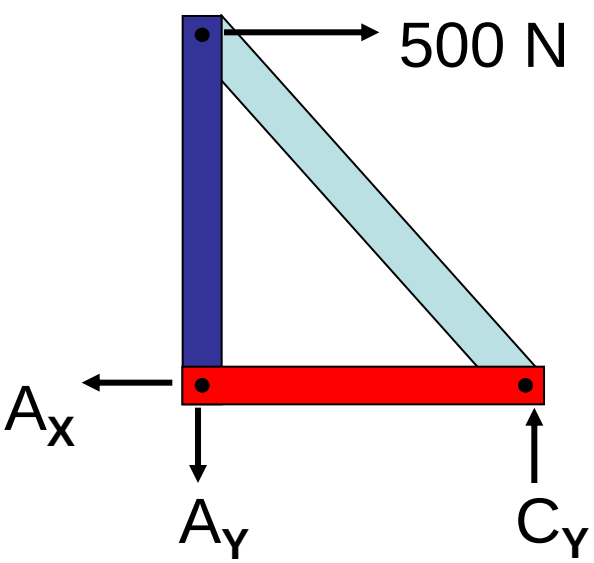


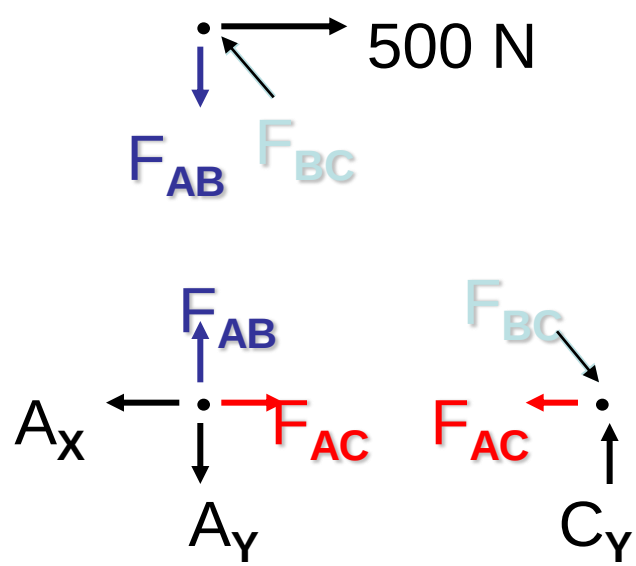
Trusses

These three separate free-body diagrams <u>assume</u> that:

- Member AB is in tension
- Member BC is in compression
- Member AC is in tension

If these assumptions are <u>incorrect</u>, then our solution will show a <u>negative</u> quantity for force.



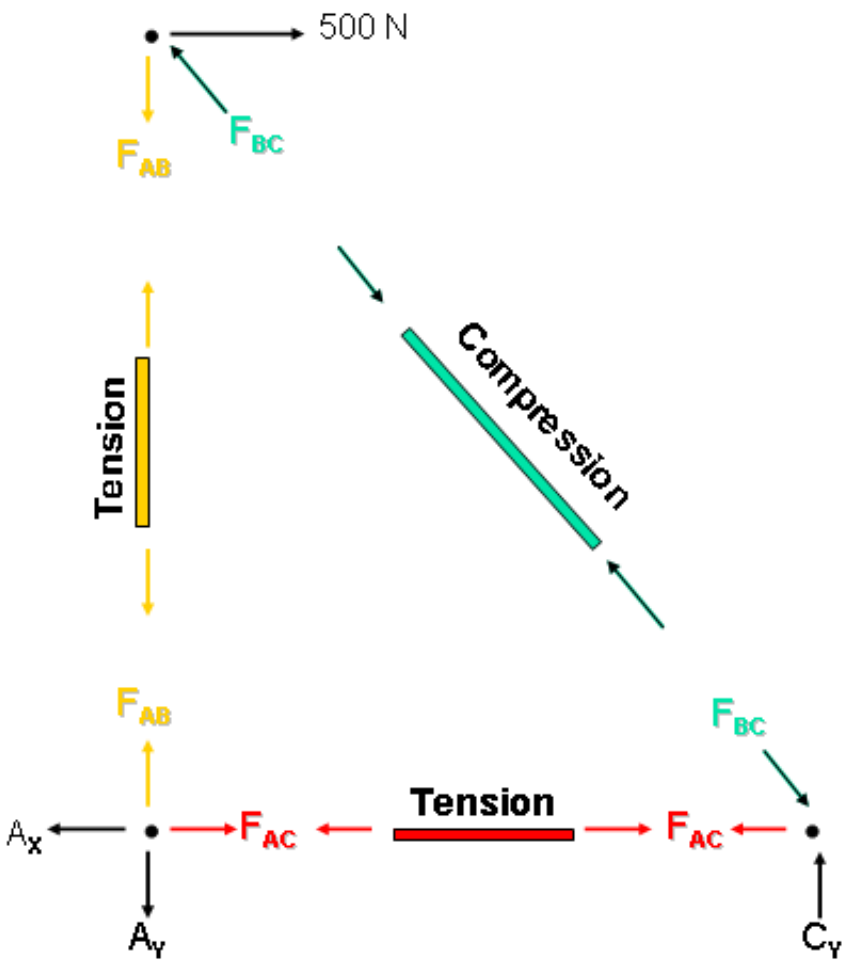


Trusses

To really “see” that

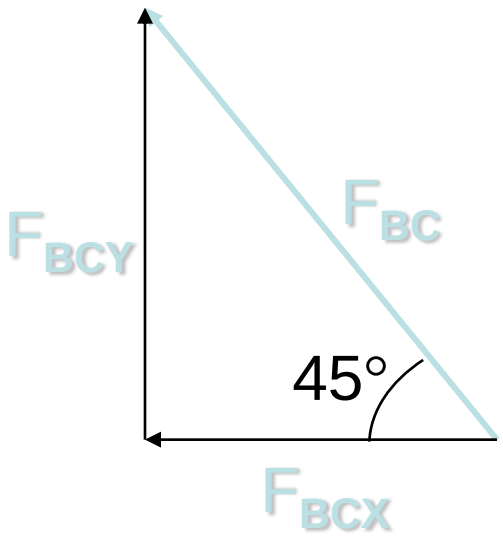
- Member AB is in tension
- Member BC is in compression
- Member AC is in tension

We must look at the free-body diagrams of the beams, which show the effects of the pins on the beams.



Trusses

Before we can solve for the forces, we must break F_{BC} into its x and y components:

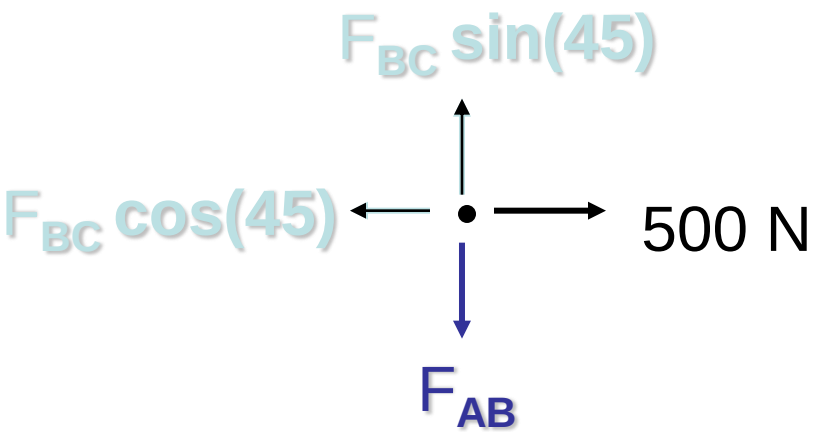


$$F_{BCX} = F_{BC} * \cos(45)$$

$$F_{BCY} = F_{BC} * \sin(45)$$

Trusses

The following is the free-body diagram of joint B. The force F_{BC} has been replaced with its x and y components:



$\pm\rightarrow \Sigma F_X = 0$;

$$500N - F_{BC}\cos(45) = 0$$

$$\frac{F_{BC}\cos(45)}{\cos(45)} = \frac{500N}{\cos(45)}$$

$$F_{BC} = 707.1 \text{ N (C)}$$

$+\uparrow \Sigma F_Y = 0$;

$$F_{BC}\sin(45) - F_{AB} = 0$$

$$707.1*\sin(45) - F_{AB} = 0$$

$$F_{AB} = 707.1*\sin(45)$$

$$F_{AB} = 500 \text{ N (T)}$$

Trusses

The (T) indicates tension and the (C) indicates compression. Both solutions were positive therefore our initial assumptions were correct. *(If the solution had been a negative number, then we would simply reverse our assumption from tension to compression or vice versa)*

$$\overset{+}{\rightarrow}\sum F_X = 0\ ;$$

$$500N - F_{BC}\cos(45) = 0$$

$$\frac{F_{BC}\cancel{\cos(45)}}{\cancel{\cos(45)}} = \frac{500N}{\cos(45)}$$

$$F_{BC} = 707.1\ N\ (C)$$

$$+\uparrow\sum F_Y = 0\ ;$$

$$F_{BC}\sin(45) - F_{AB} = 0$$

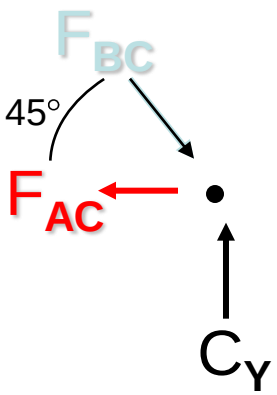
$$707.1*\sin(45) - F_{AB} = 0$$

$$F_{AB} = 707.1*\sin(45)$$

$$F_{AB} = 500\ N\ (T)$$

Trusses

The following is the free-body diagram of joint C. The force F_{BC} has been replaced with its x and y components:



$\overset{+}{\rightarrow}\sum F_X = 0$;

$$-F_{AC} + F_{BC}\cos(45) = 0$$

$$-F_{AC} + 707.1\cos(45) = 0$$

$$F_{AC} = 707.1\cos(45)$$

$$F_{AC} = 500\text{ N (T)}$$

$+\uparrow\sum F_Y = 0$;

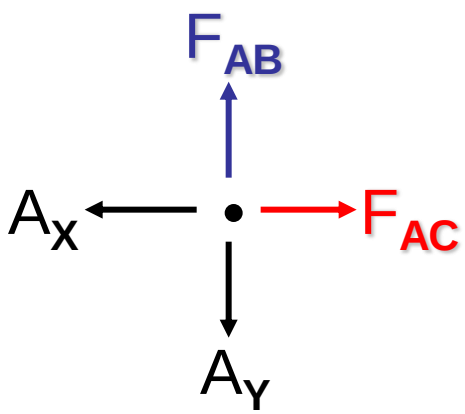
$$C_Y - F_{BC} * \sin(45) = 0$$

$$C_Y - 707.1 * \sin(45) = 0$$

$$C_Y = 500\text{ N}$$

Trusses

The following is the free-body diagram of joint A:



$\overset{+}{\rightarrow}\Sigma F_X = 0$;

$$F_{AC} - A_x = 0$$

$$500\text{ N} - A_x = 0$$

$$A_X = 500\text{ N}$$

$+\uparrow\Sigma F_Y = 0$;

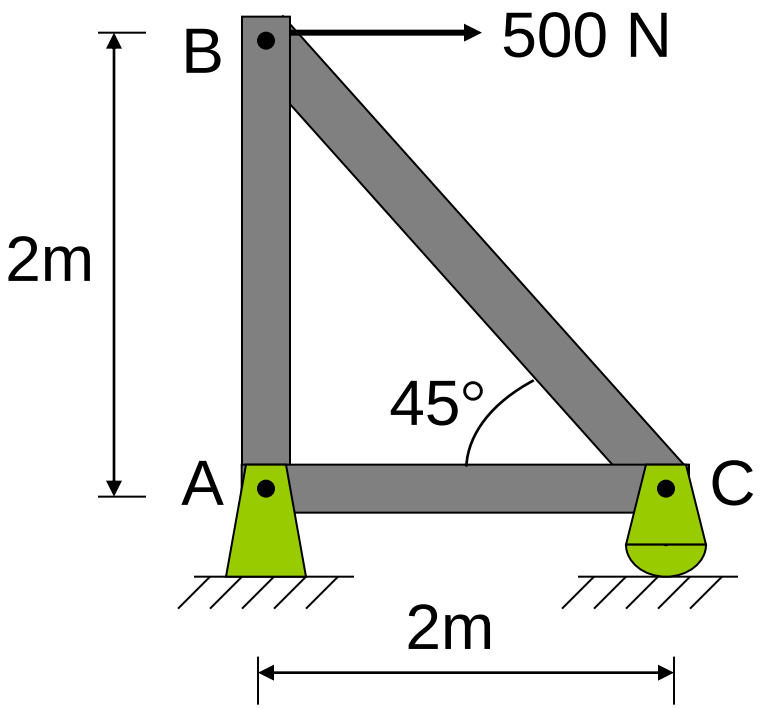
$$F_{AB} - A_Y = 0$$

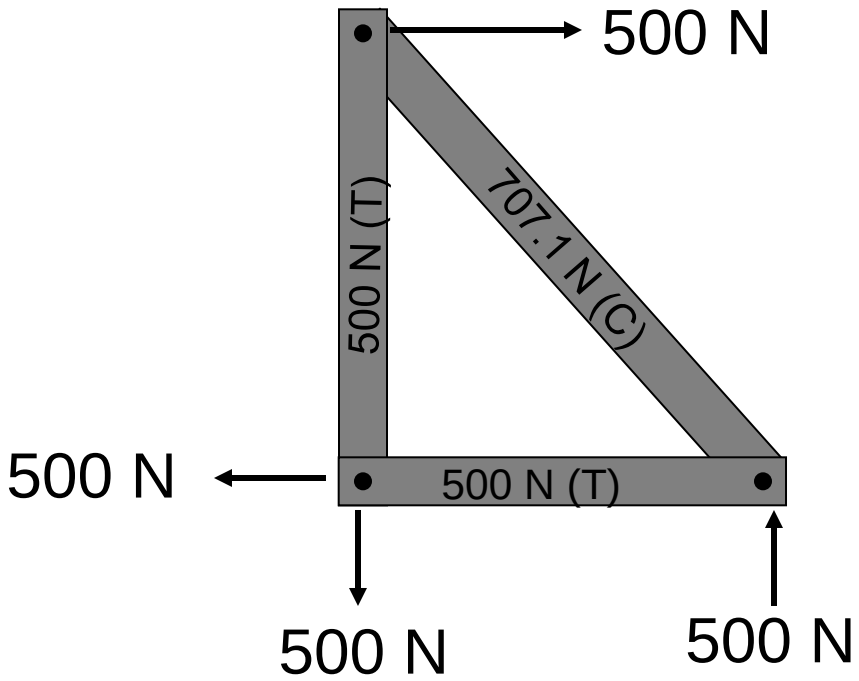
$$500\text{ N} - A_Y = 0$$

$$A_Y = 500\text{ N}$$

Trusses

Solved!!!

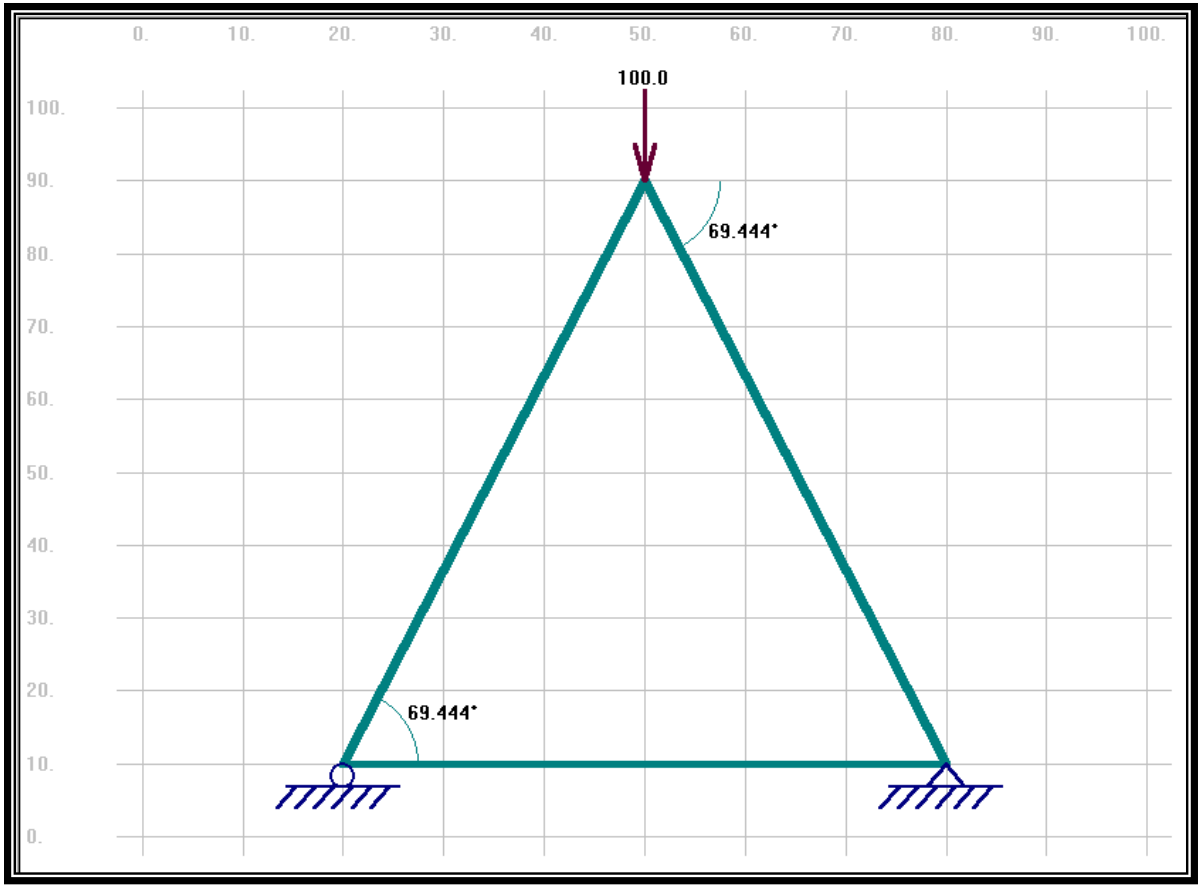




Truss Calculations with MD Solids

National Academy Foundation
PARTNERSHIPS FOR AMERICA'S YOUTH

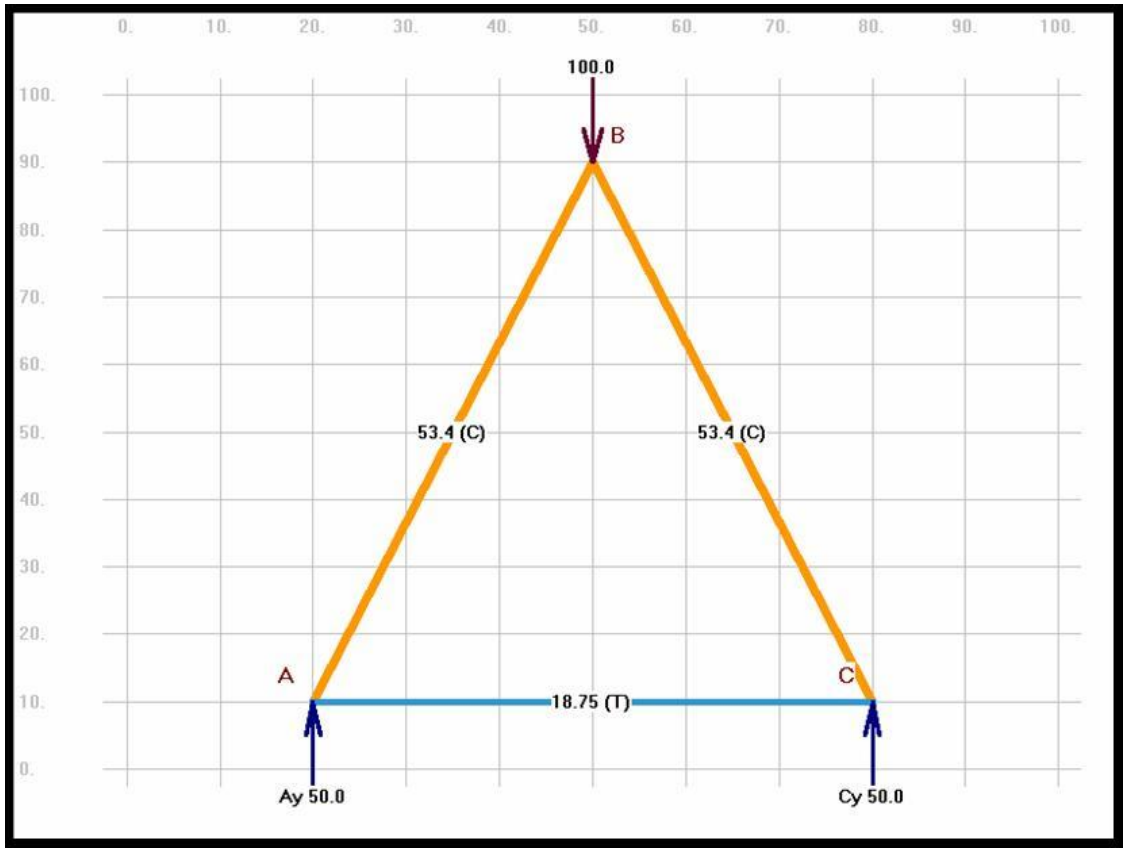
Trusses



Enter the information into MD Solids. Before you press "Compute," try to predict which members are in compression and which are in tension.*

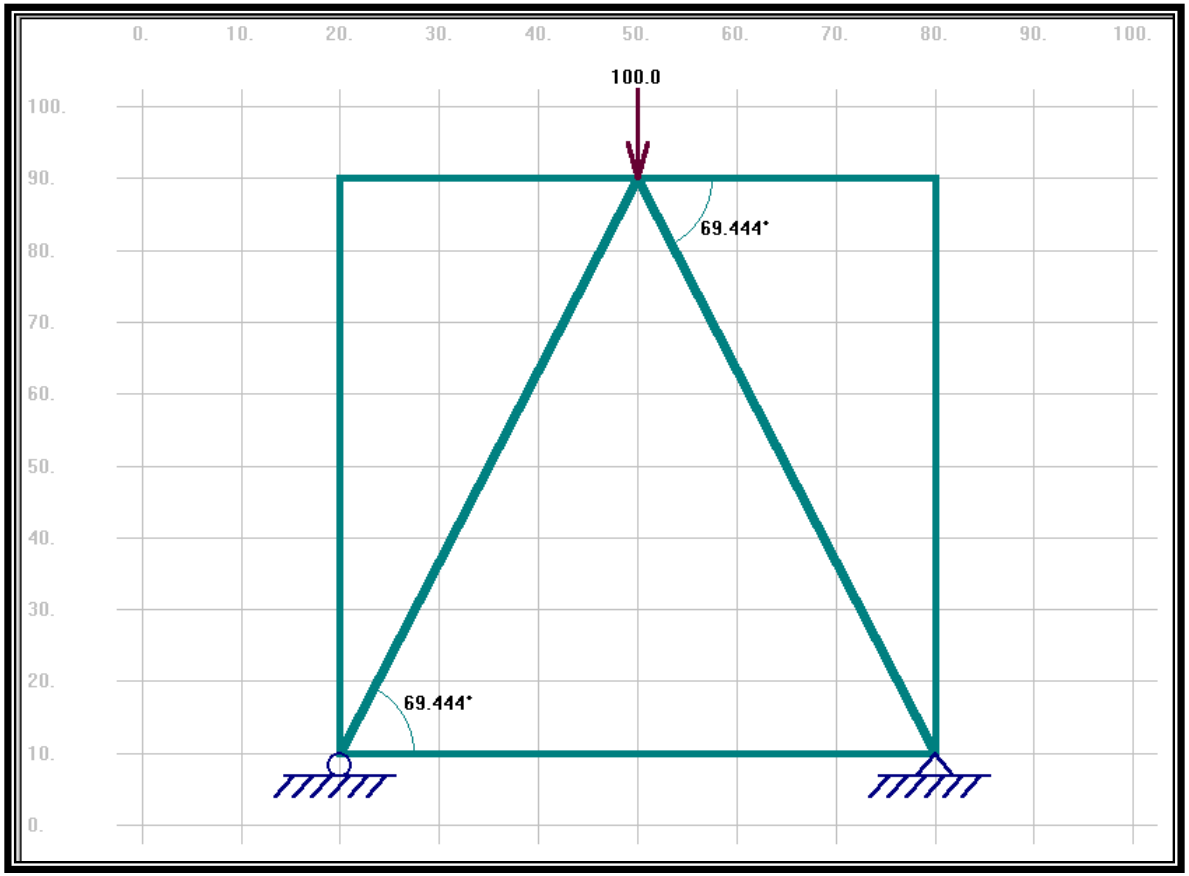
*If necessary, refer to the wide variety of "MD Solids Help Documents" included in the MD Solids software to help you get started.

Trusses



Notice the gold colored members labeled with a (C) are in compression, and the blue colored members labeled with a (T) are in tension. Did you guess correctly?

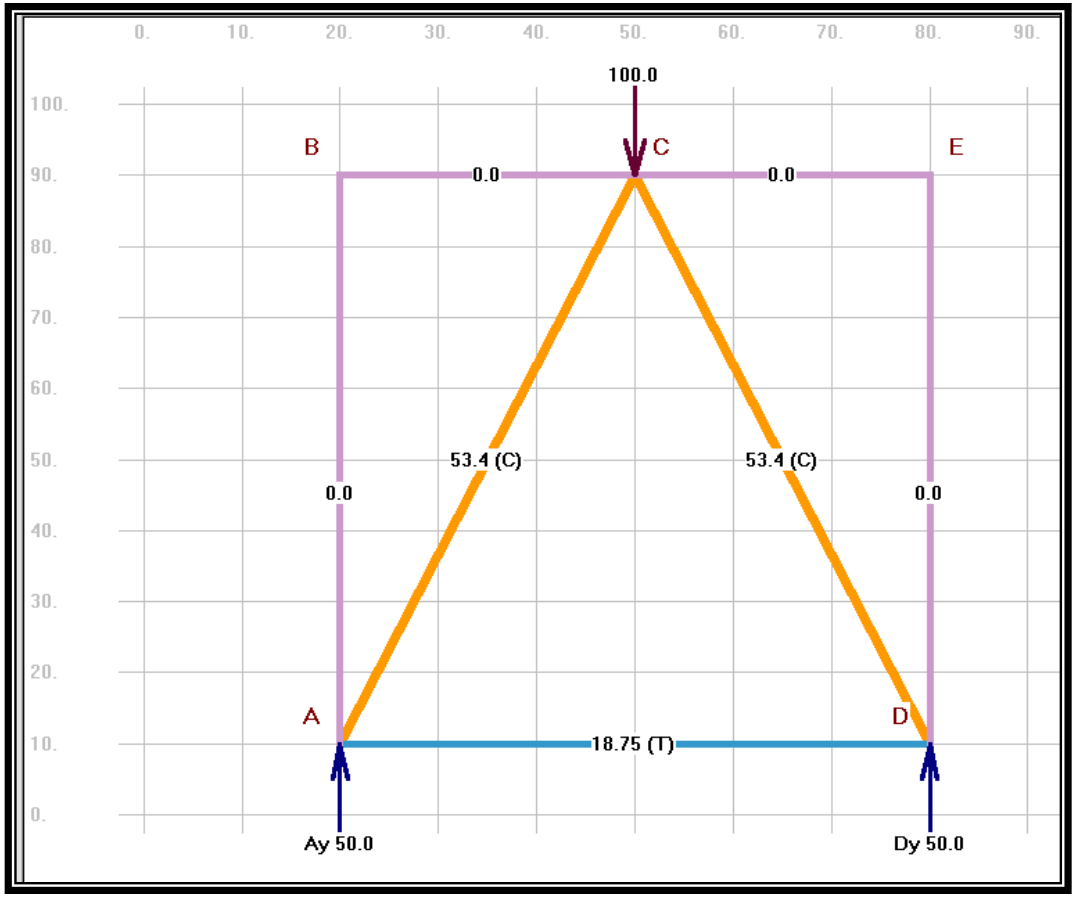
Trusses



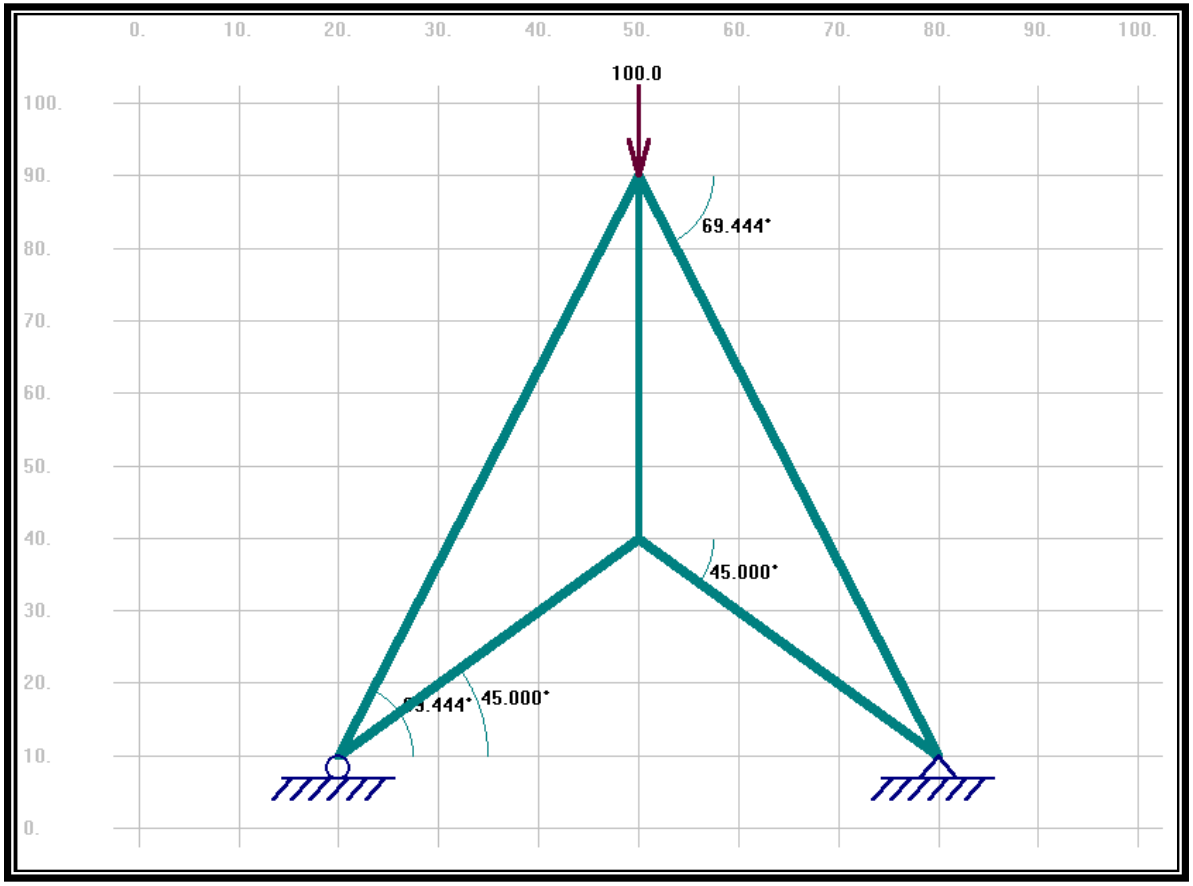
Try to predict which members here are in tension and which are in compression.

Trusses

The members in purple are in neither tension or compression. Sometimes, additional members do not help to support a load. These are called zero-force members.

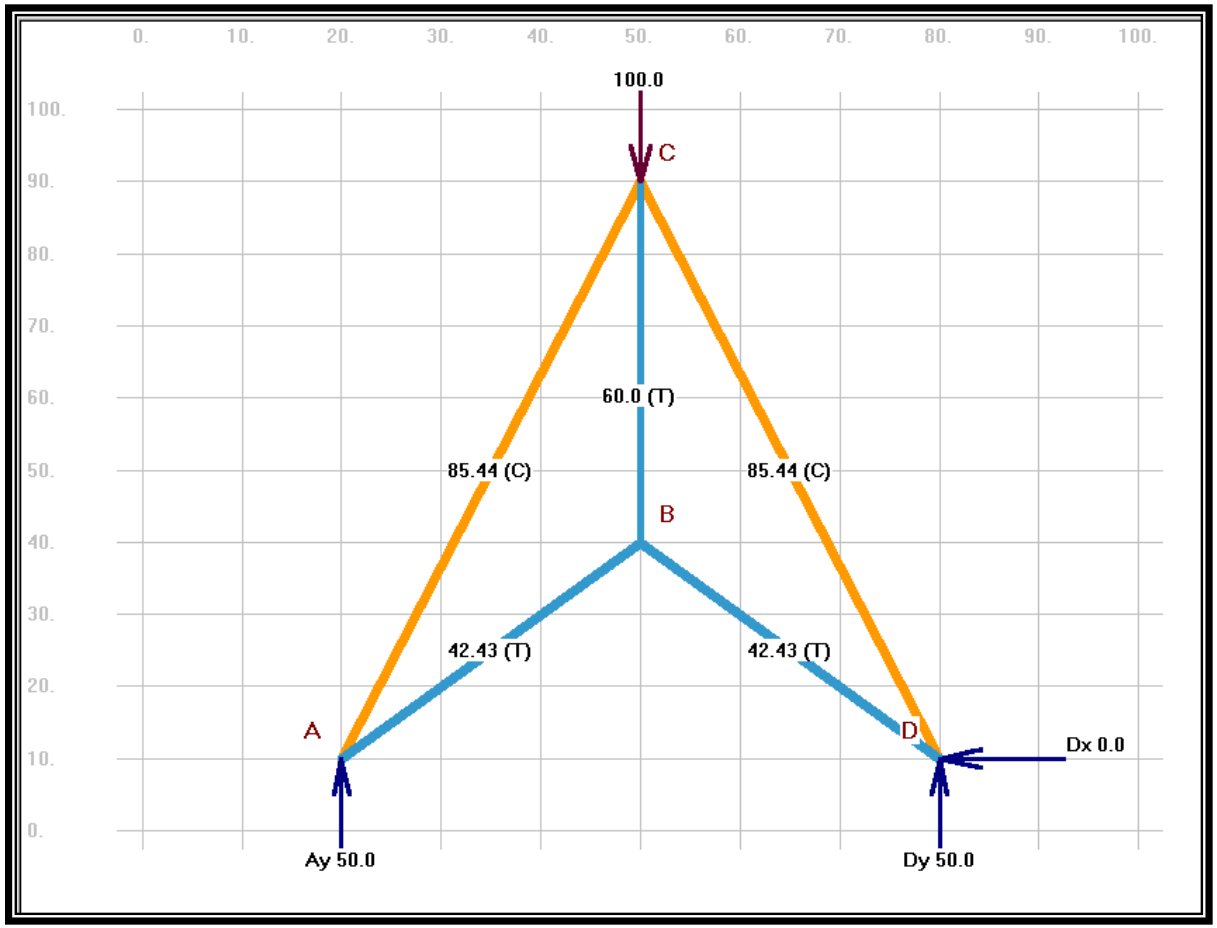


Trusses



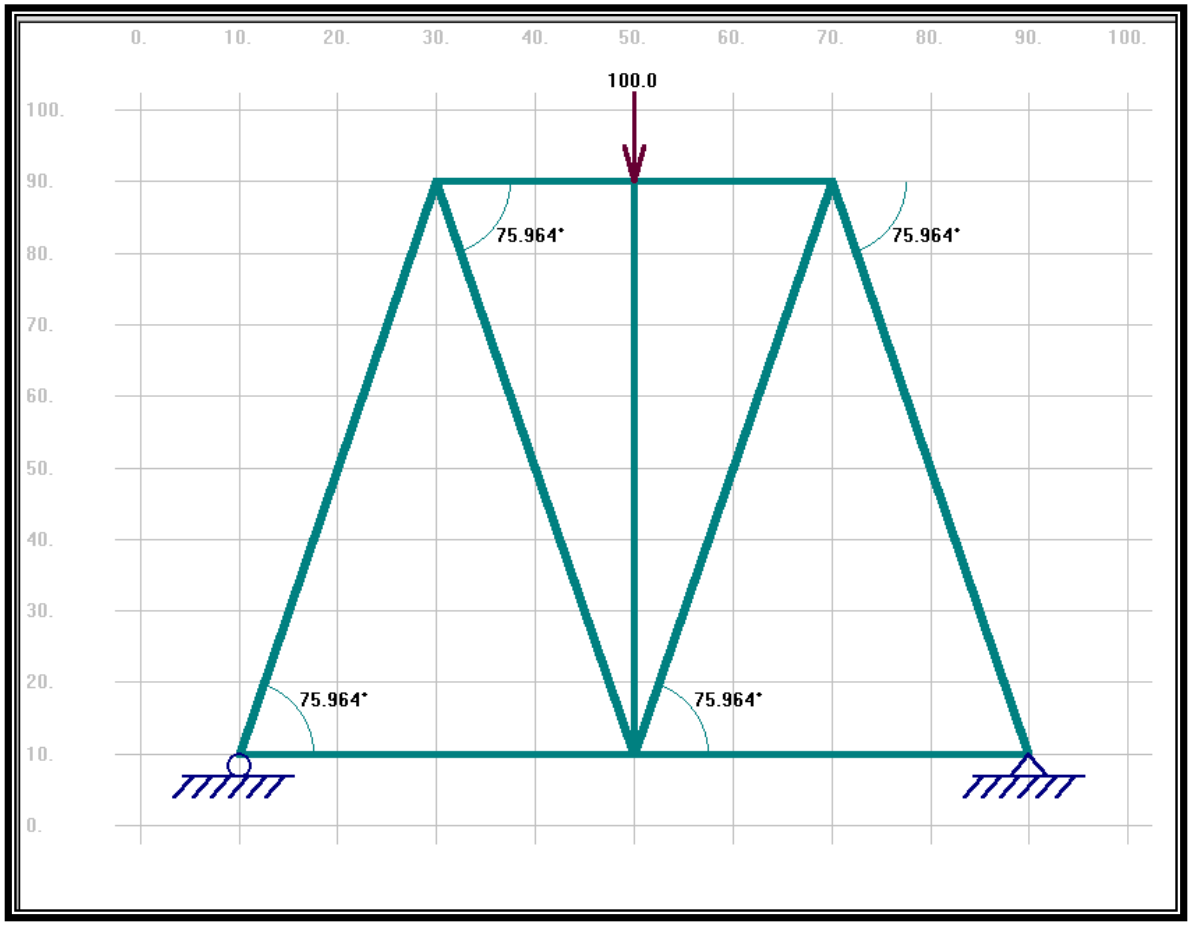
Try to predict which members here are in tension and which are in compression.

Trusses

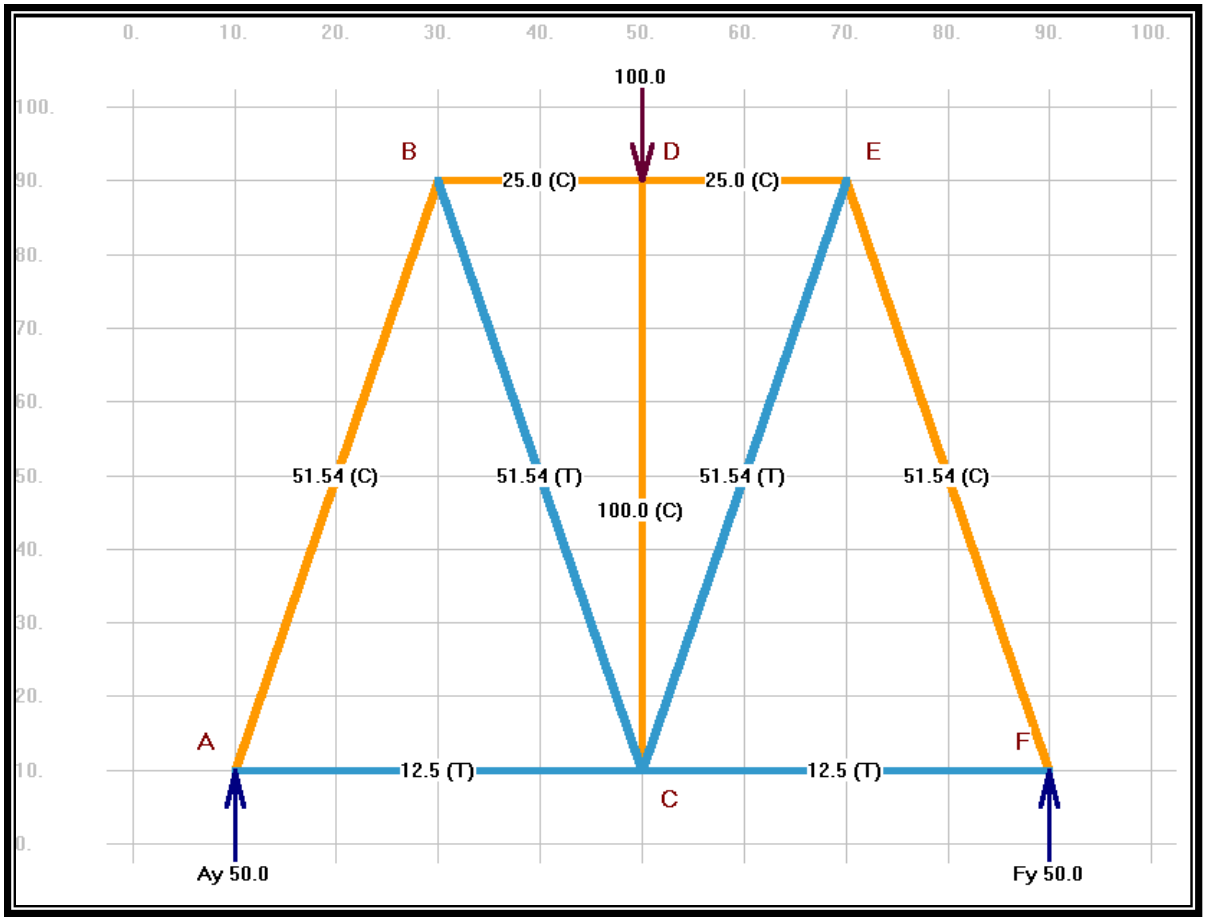


Compare your predictions with the solution.

Trusses



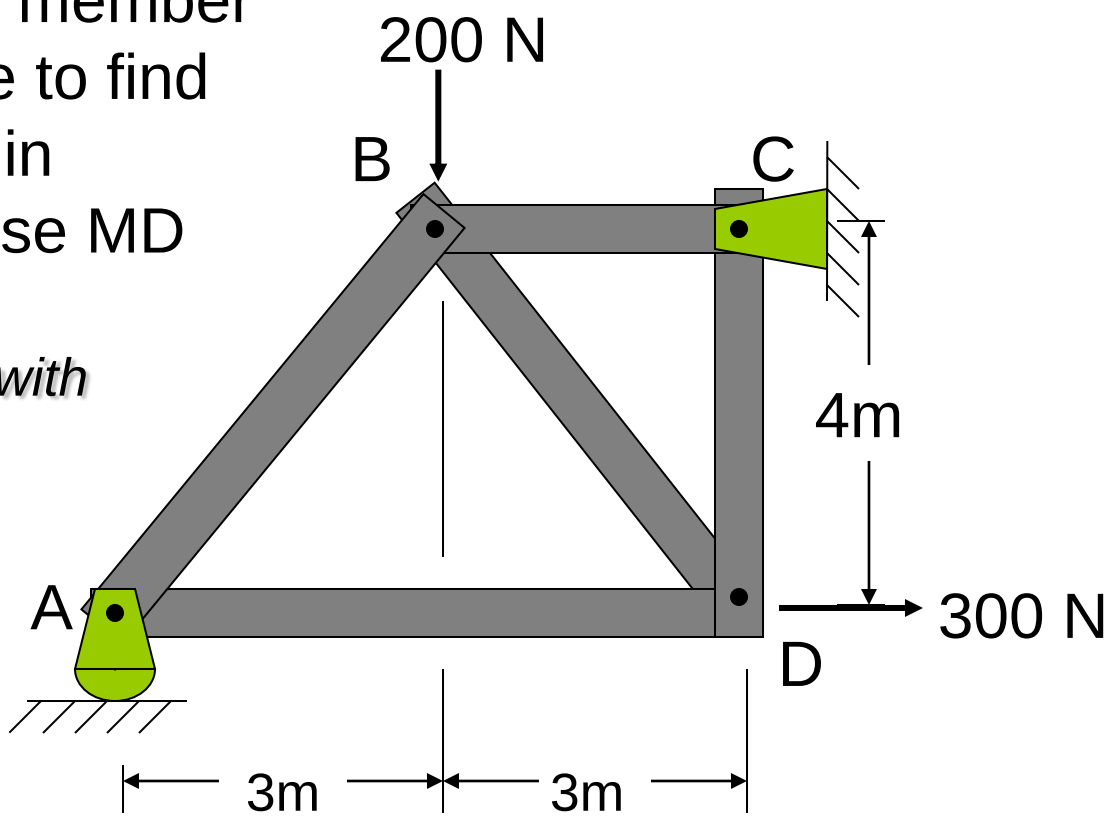
Trusses


0.
10.
20.
30.
40.
50.
60.
70.
80.
90.
100.
100.
90.
80.
70.
60.
50.
40.
30.
20.
10.
0.
100.0
B
D
E
25.0 (C)
25.0 (C)
51.54 (C)
51.54 (T)
51.54 (T)
51.54 (C)
100.0 (C)
A
F
12.5 (T)
12.5 (T)
C
Ay 50.0
Fy 50.0

Trusses

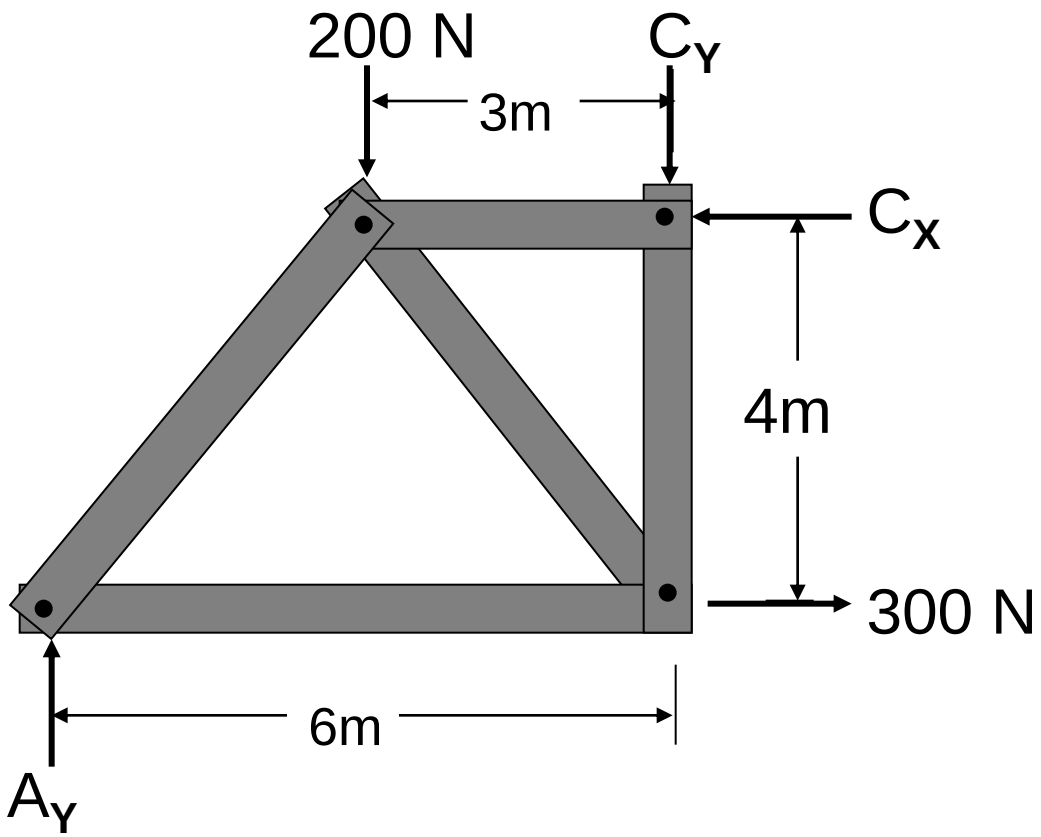
Solve for the force in each member of the truss in this example to find whether the members are in tension or compression. Use MD Solids software.

Start by replacing the supports with reaction forces:



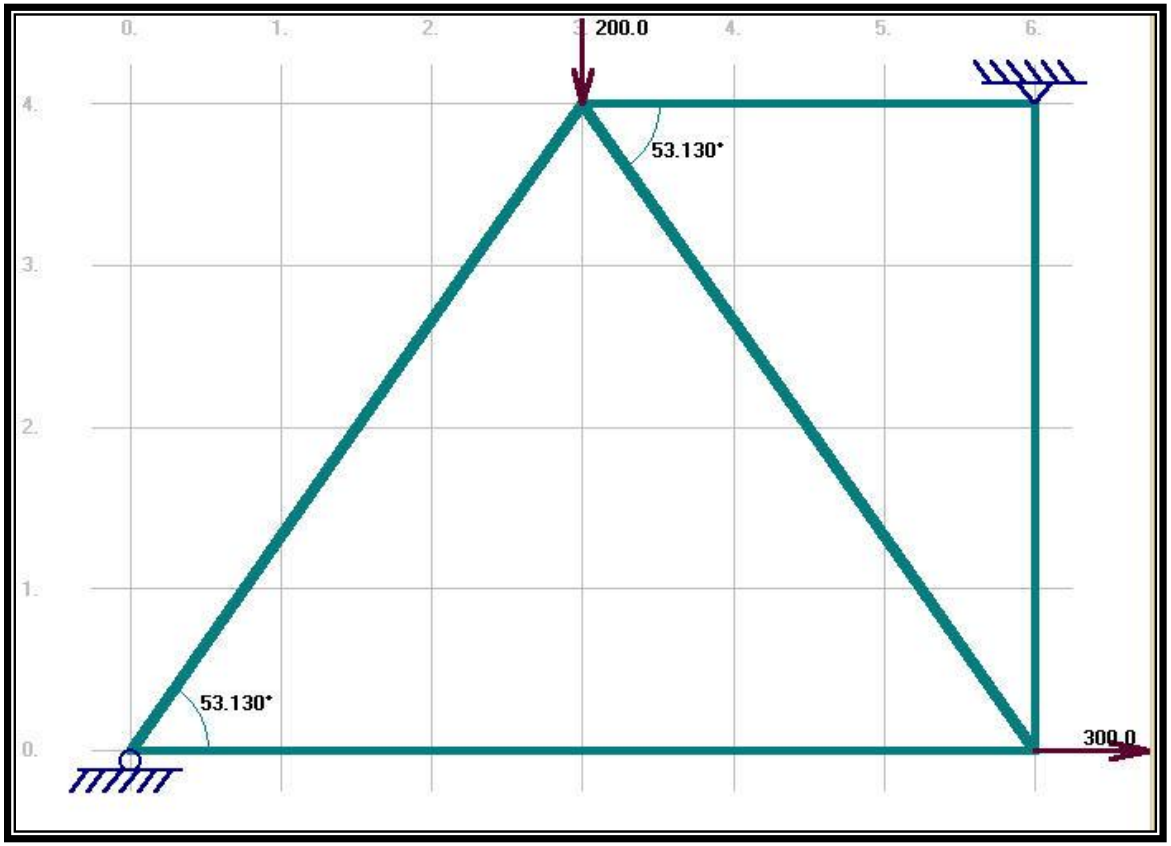
Trusses

Here the supports have been replaced with reaction forces:



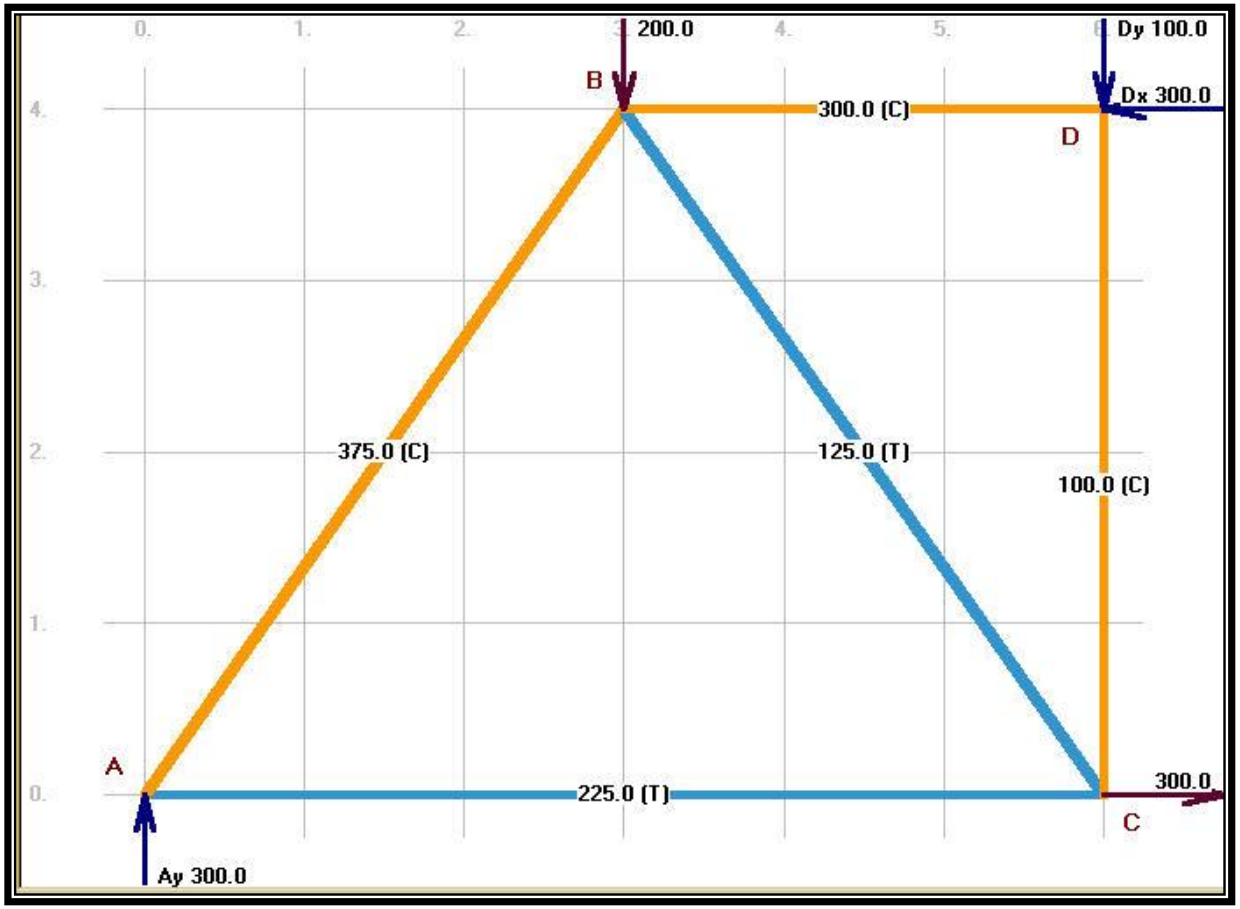
Trusses

This is how the problem looks when entered into MD Solids.



Trusses

The solution shows forces in each member and at each support.



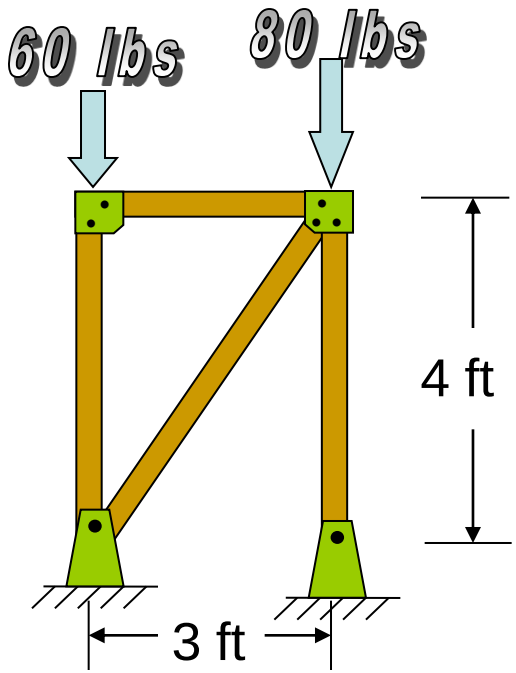
Trusses

For the following trusses:

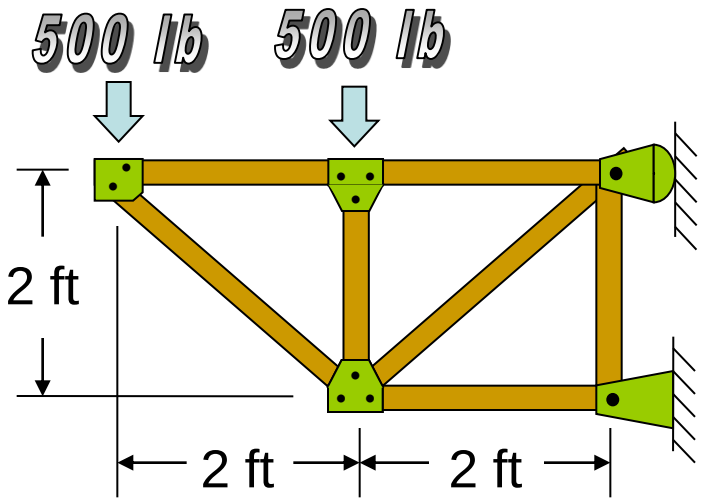
1. Replace the supports with the appropriate reaction forces.
2. Predict which beams would be in tension, which would be in compression, and which would be supporting the most force.
3. Draw the truss in MD Solids.
4. Record the forces at the supports and in each beam.
5. Were your predictions correct?

Trusses

#1

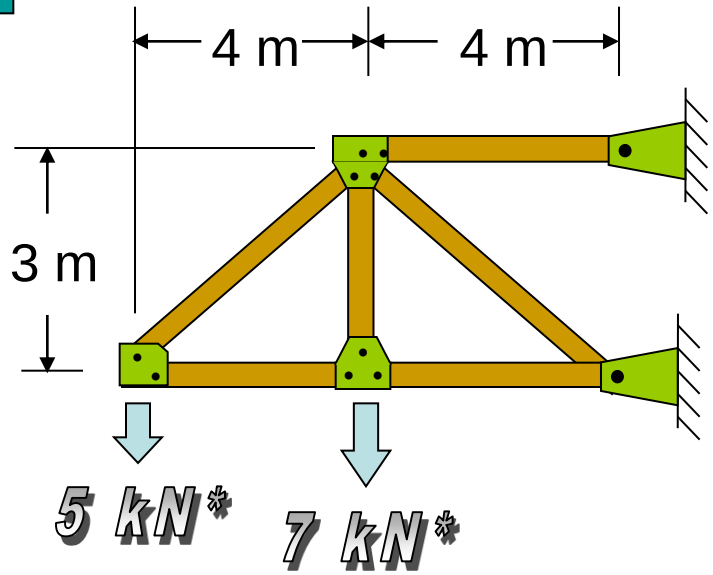


#2

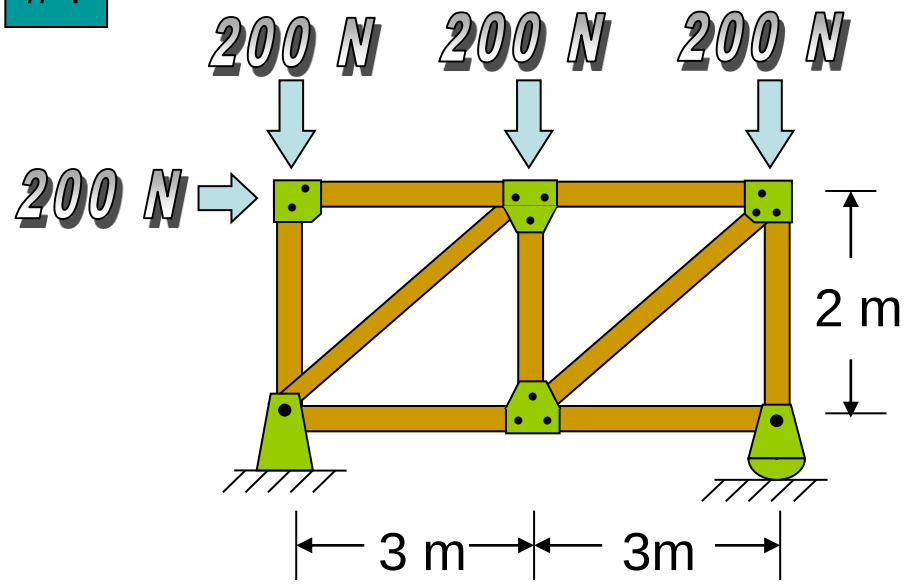


Trusses

#3



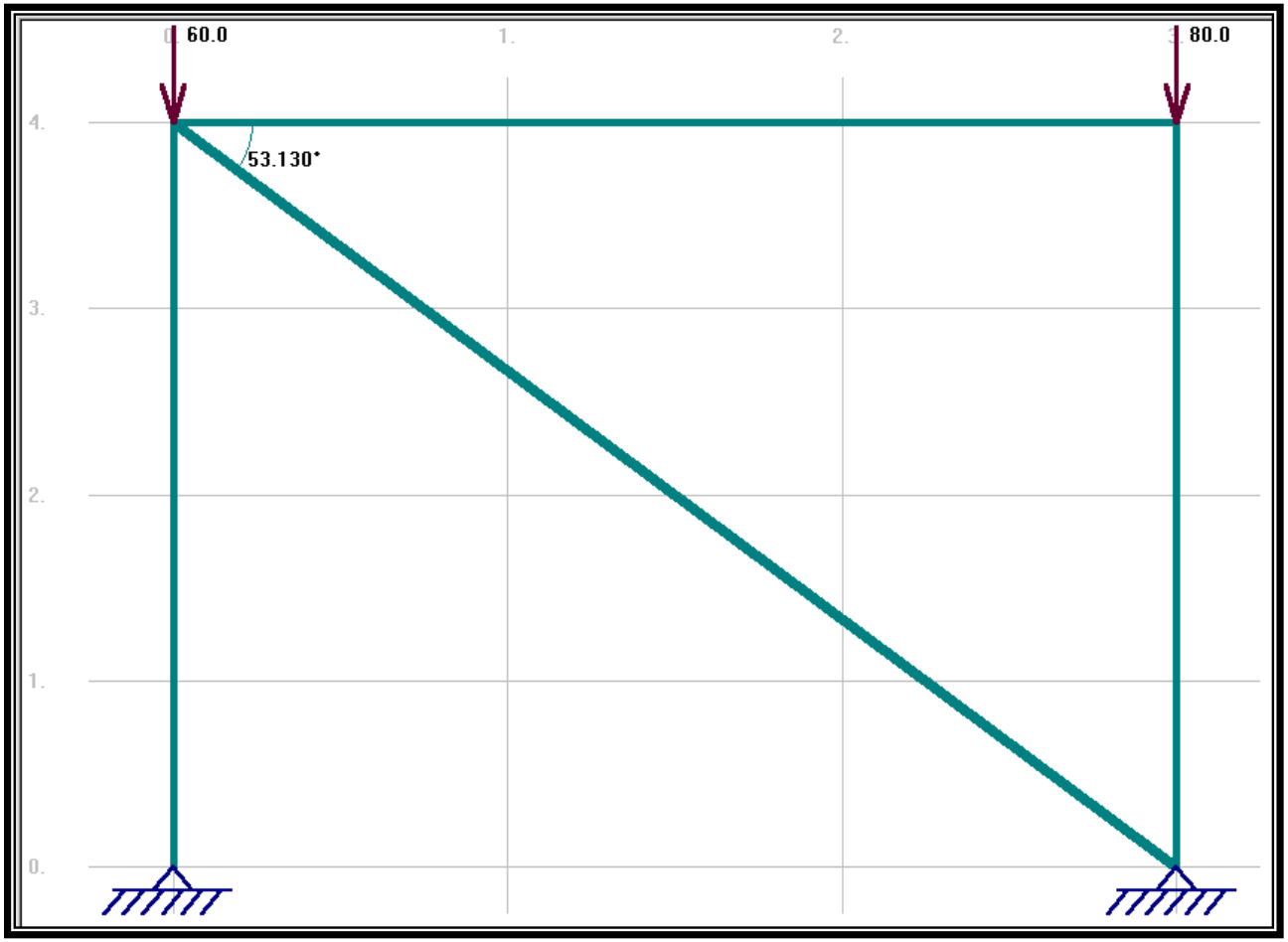
#4



* 1 KN = 1000N, therefore 5kN = 5000N

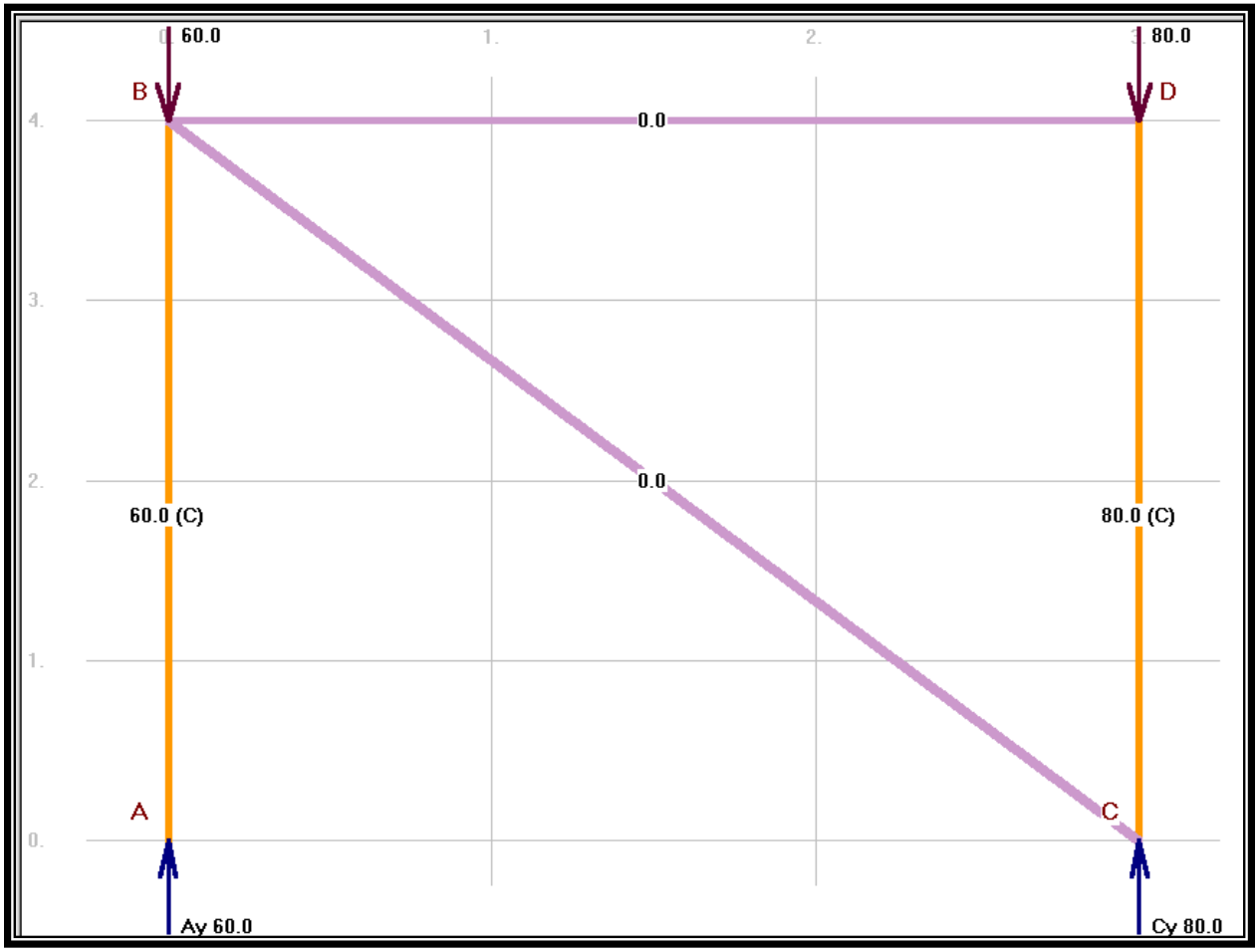
Trusses

Solution for #1



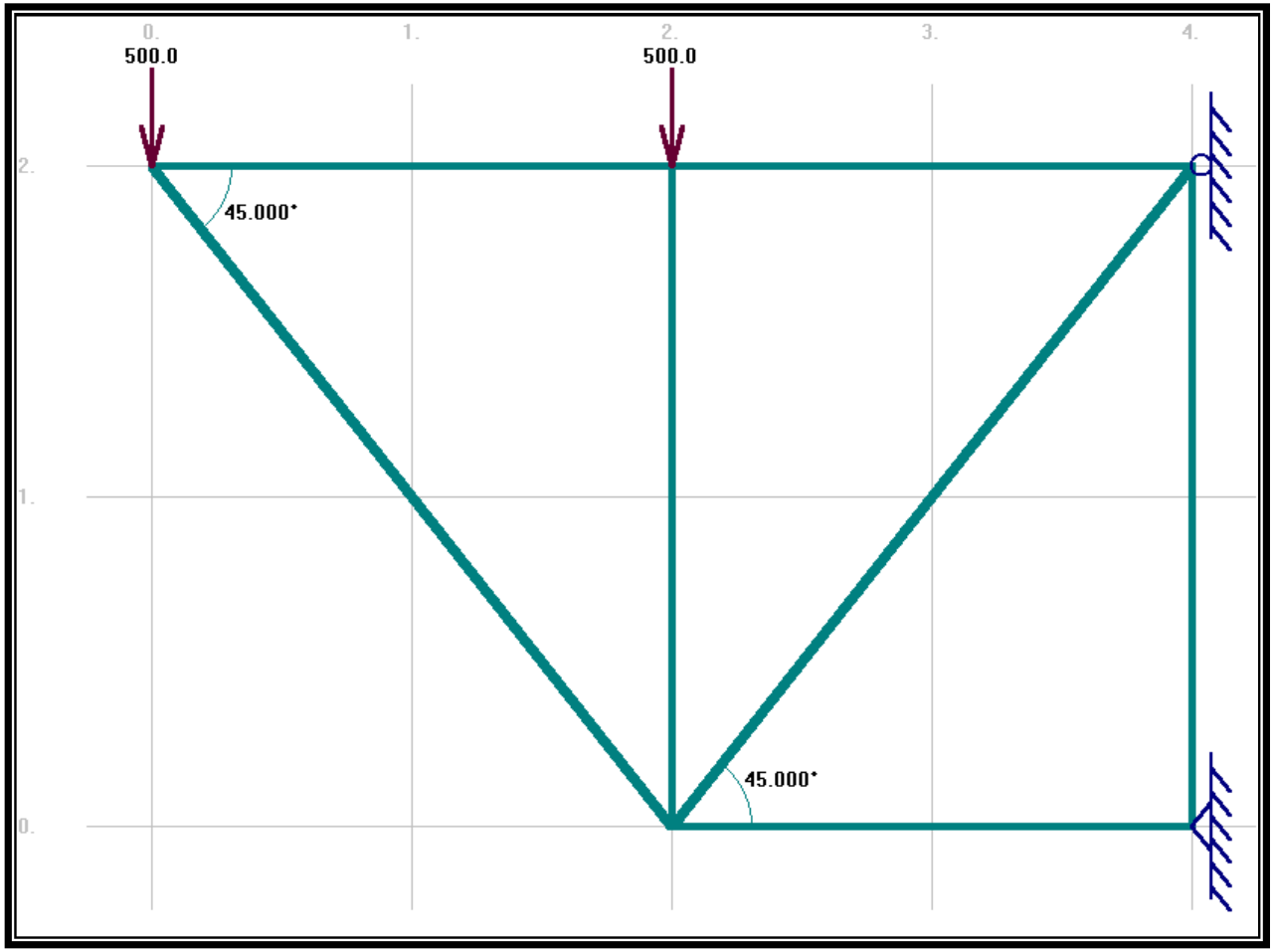
Trusses

Solution for #1



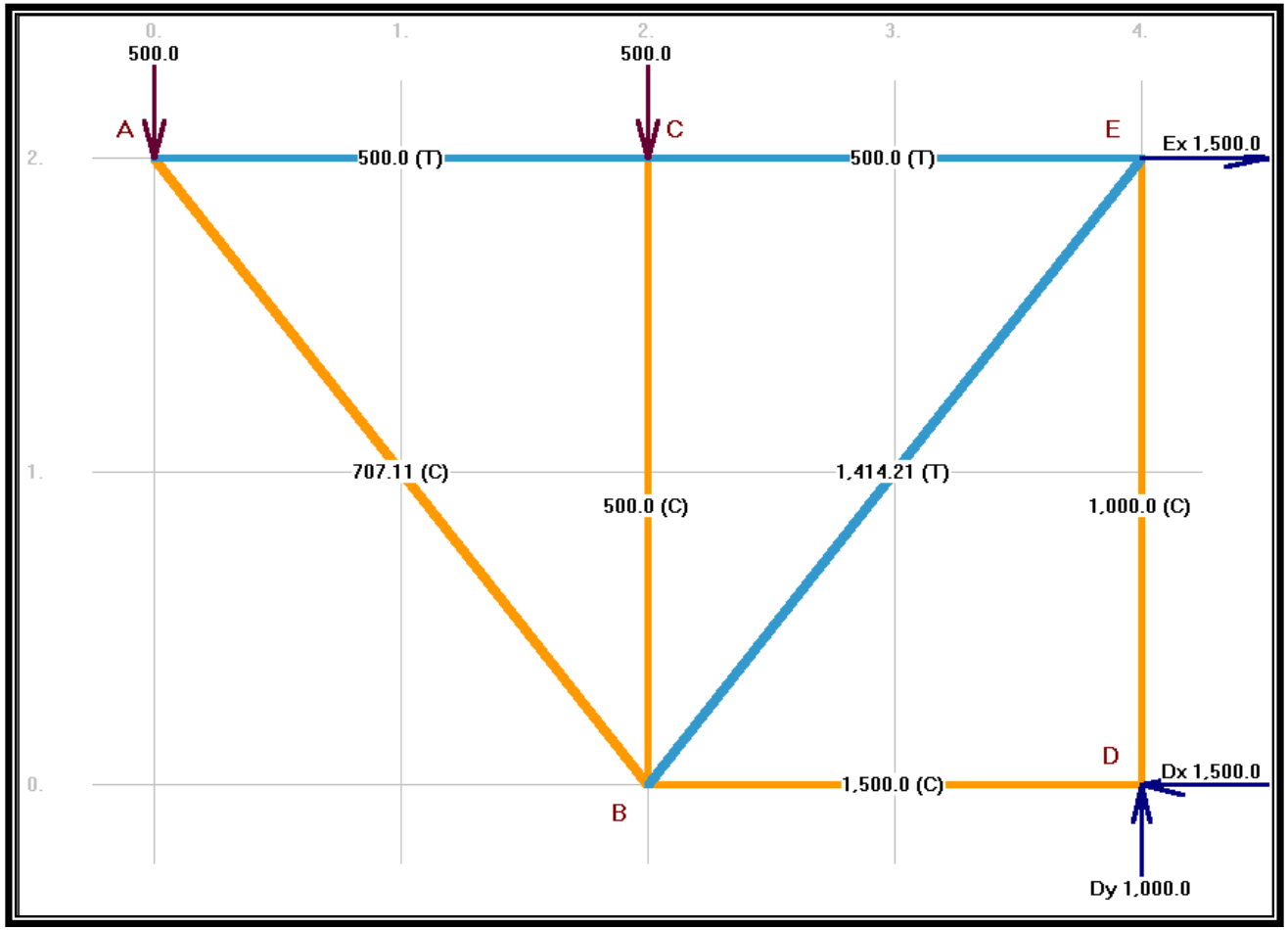
Trusses

Solution for #2



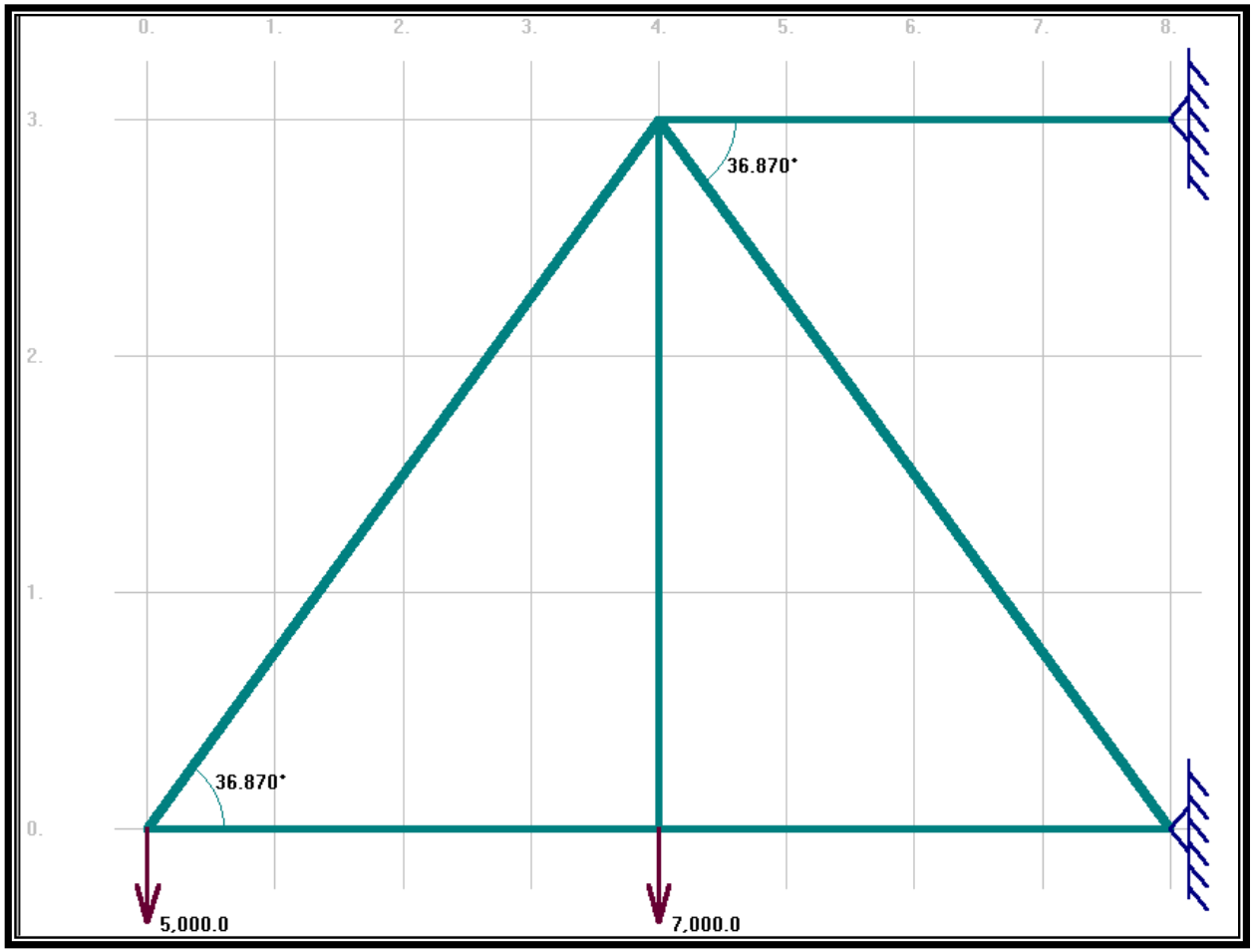
Trusses

Solution for #2



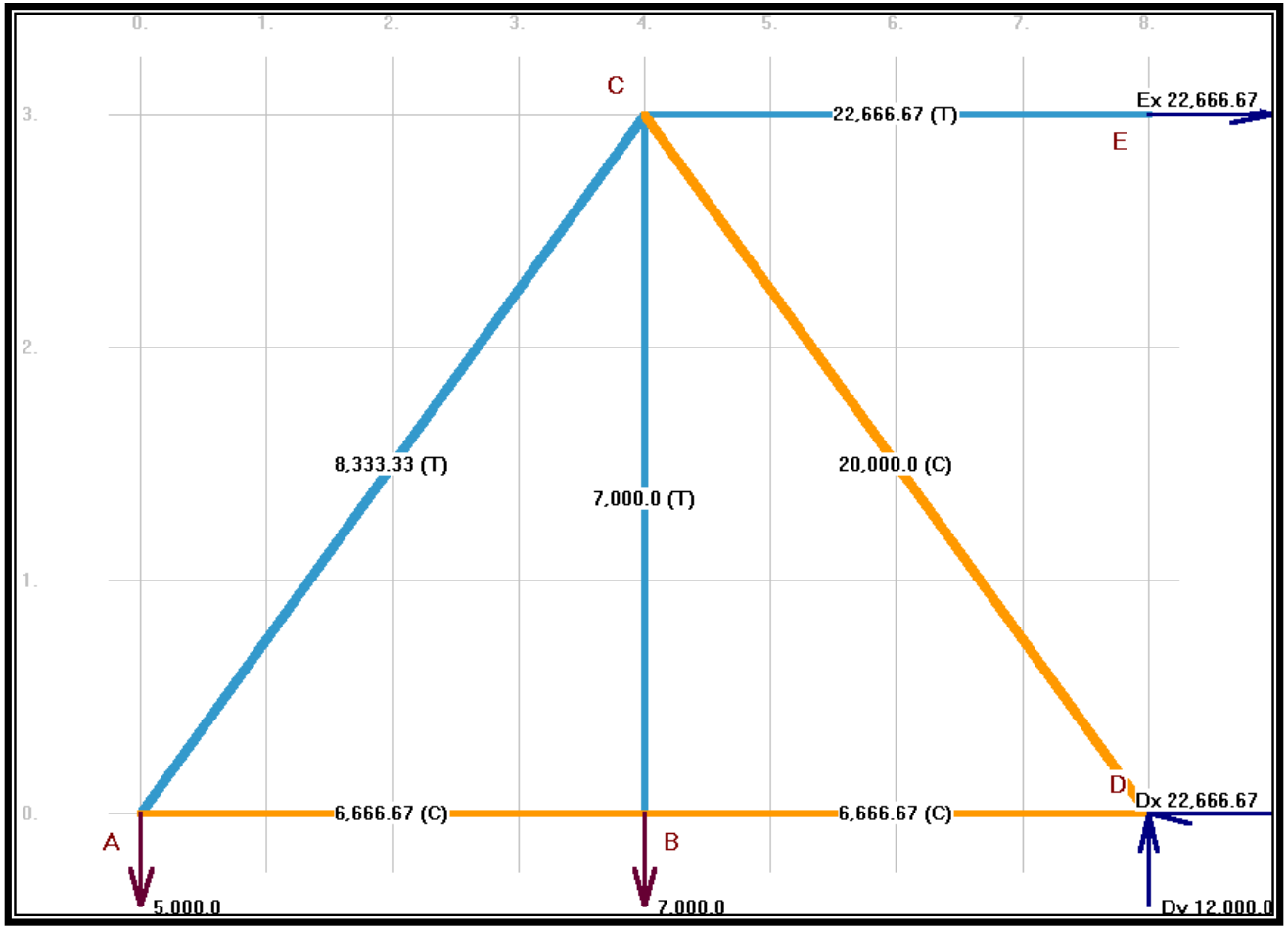
Trusses

Solution for #3



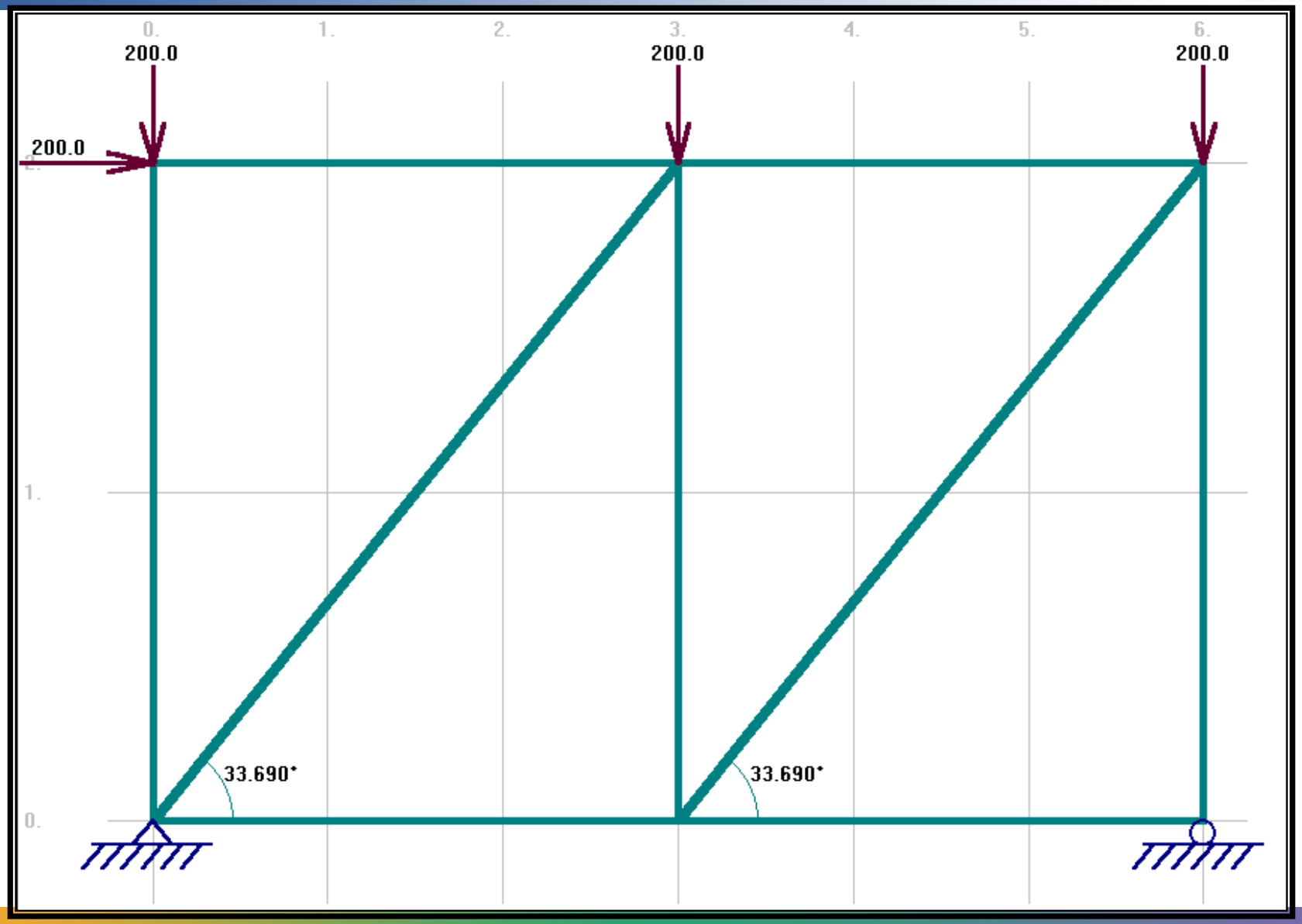
Trusses

Solution for #3



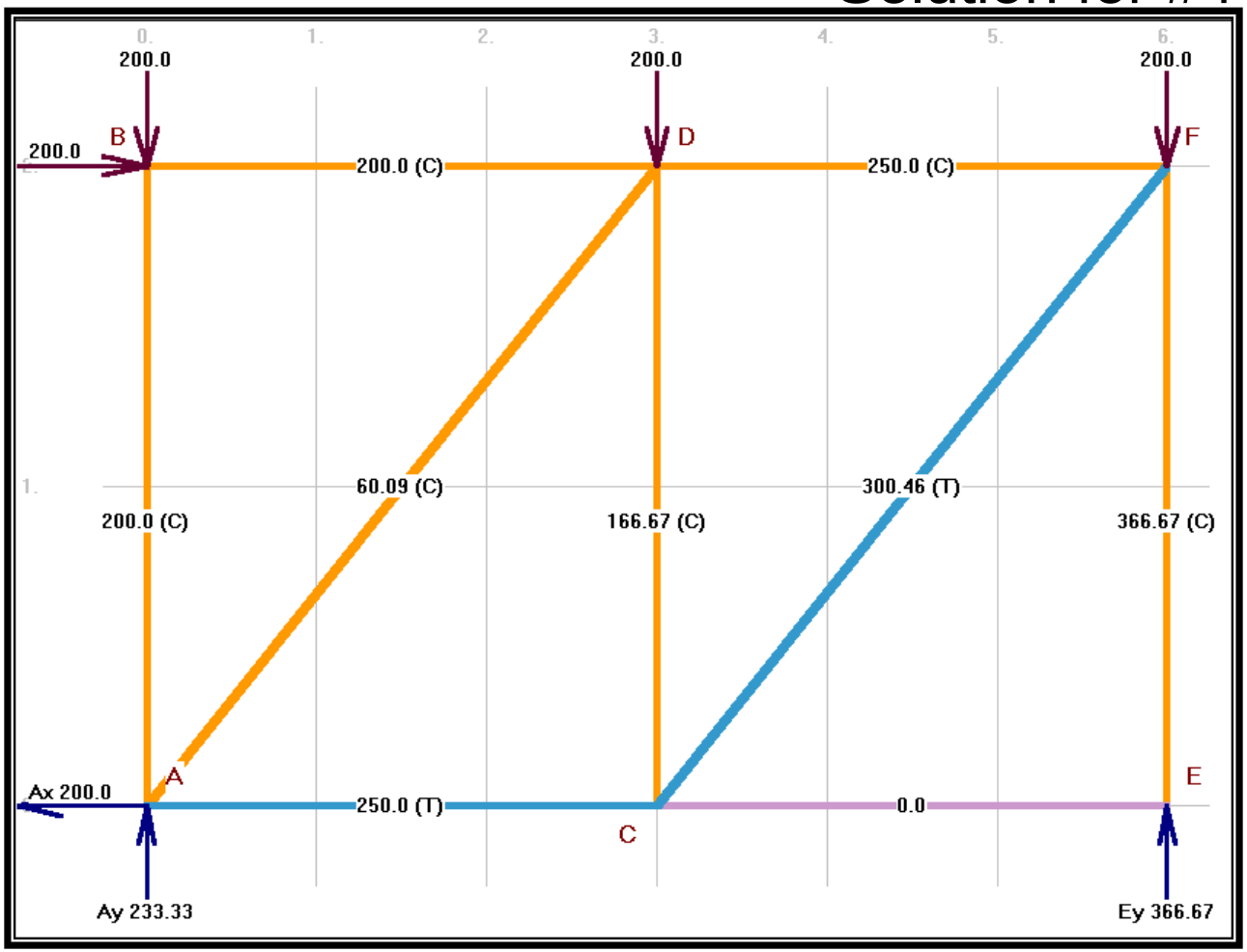
Trusses

Solution for #4



Trusses

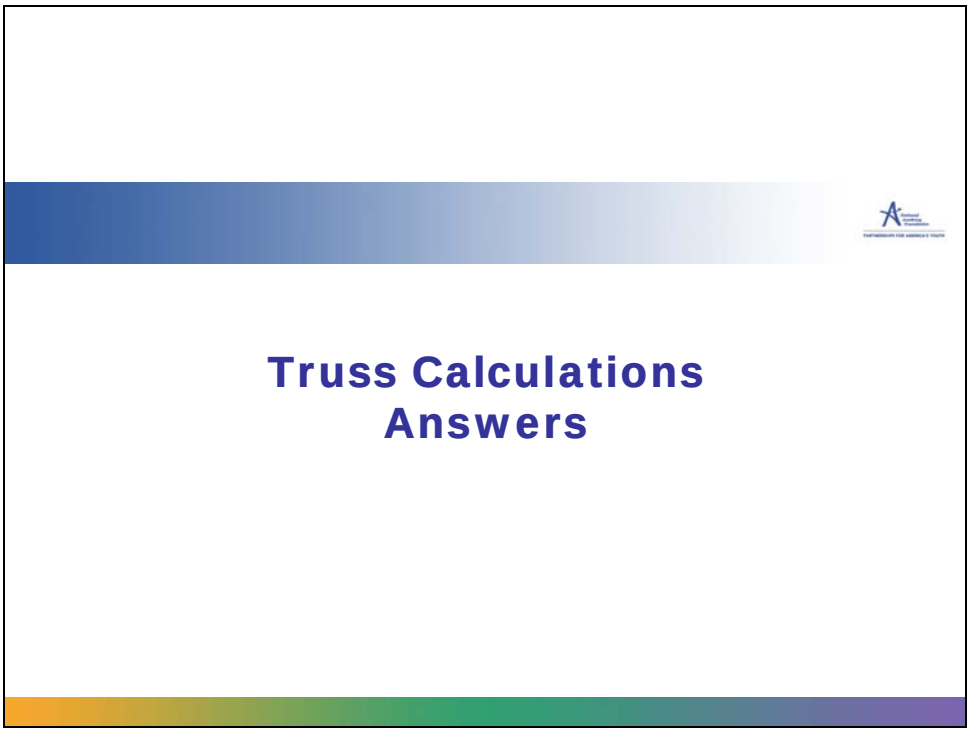
Solution for #4



Teacher Resource 2.1.6

Presentation: Truss Calculations Answers

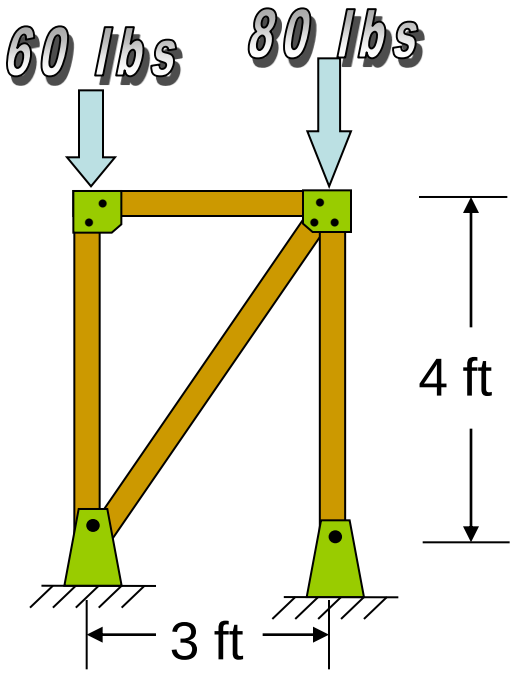
To open the presentation, right-click on the image below, then select Presentation Object/Open from the menu.



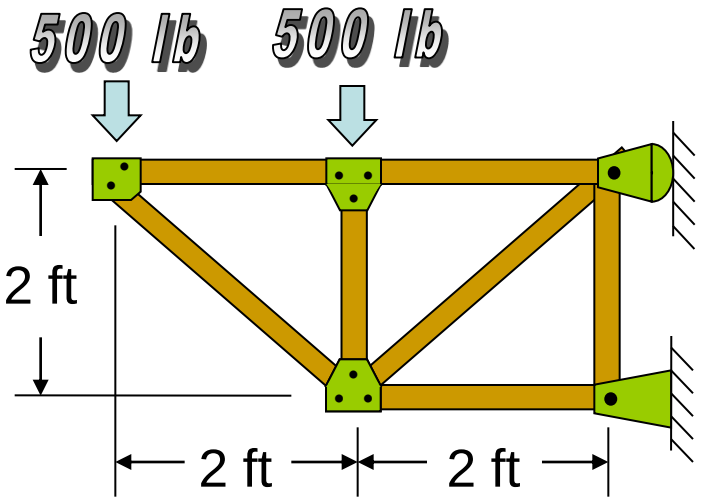
Truss Calculations Answers

Truss Problems

#1

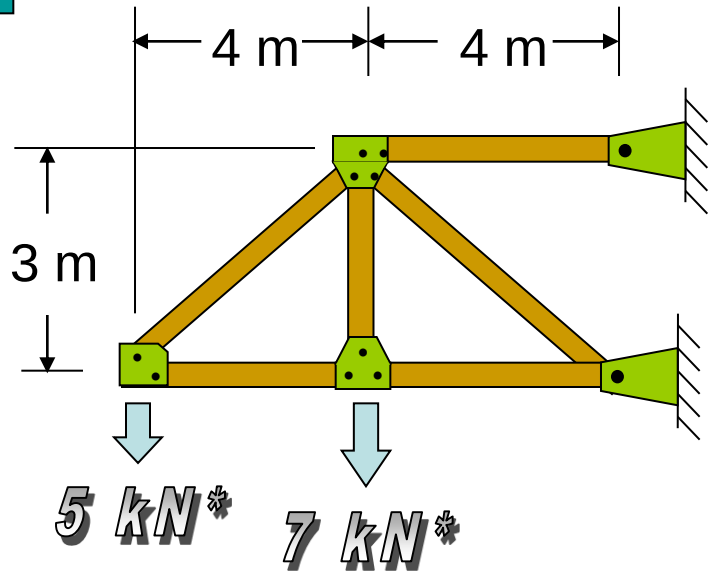


#2

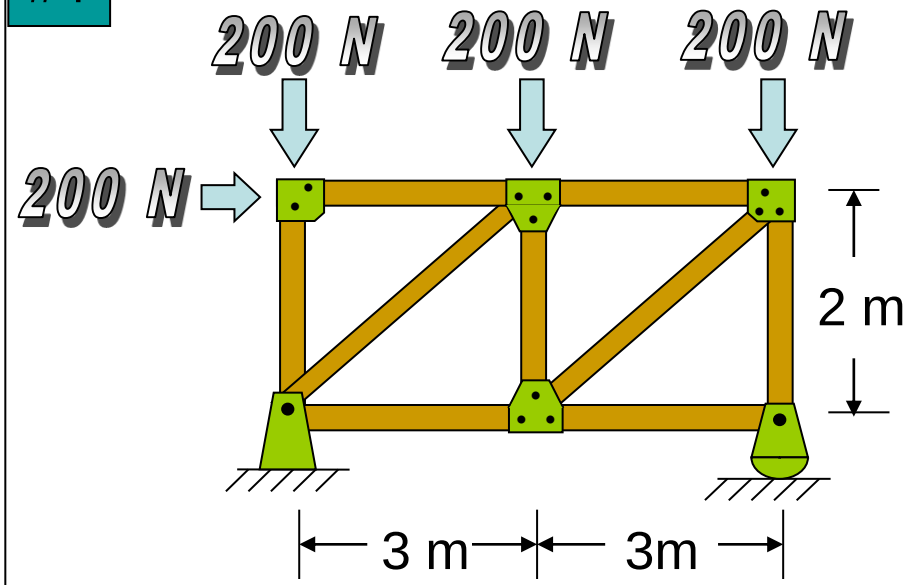


Truss Problems

#3

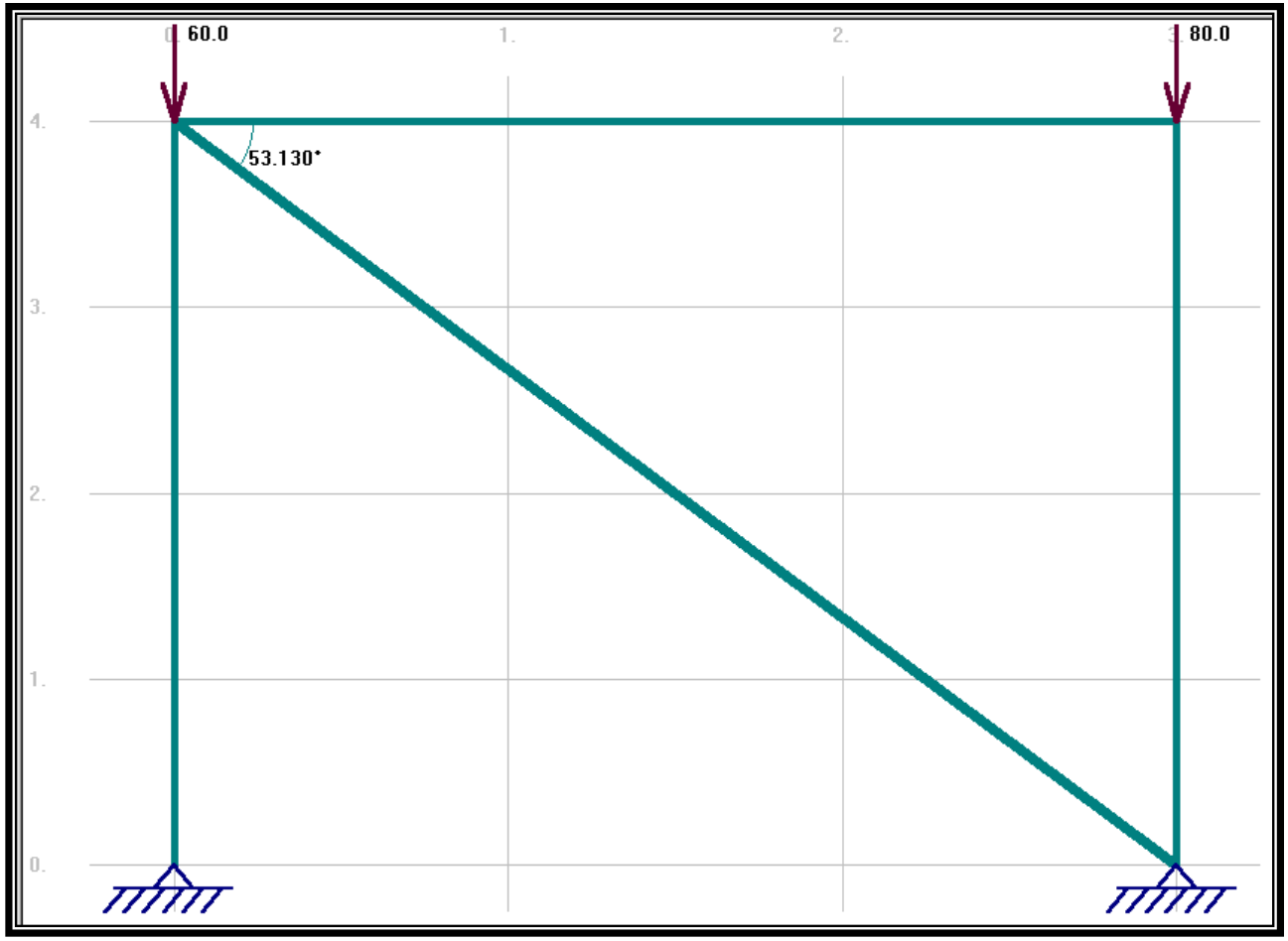


#4

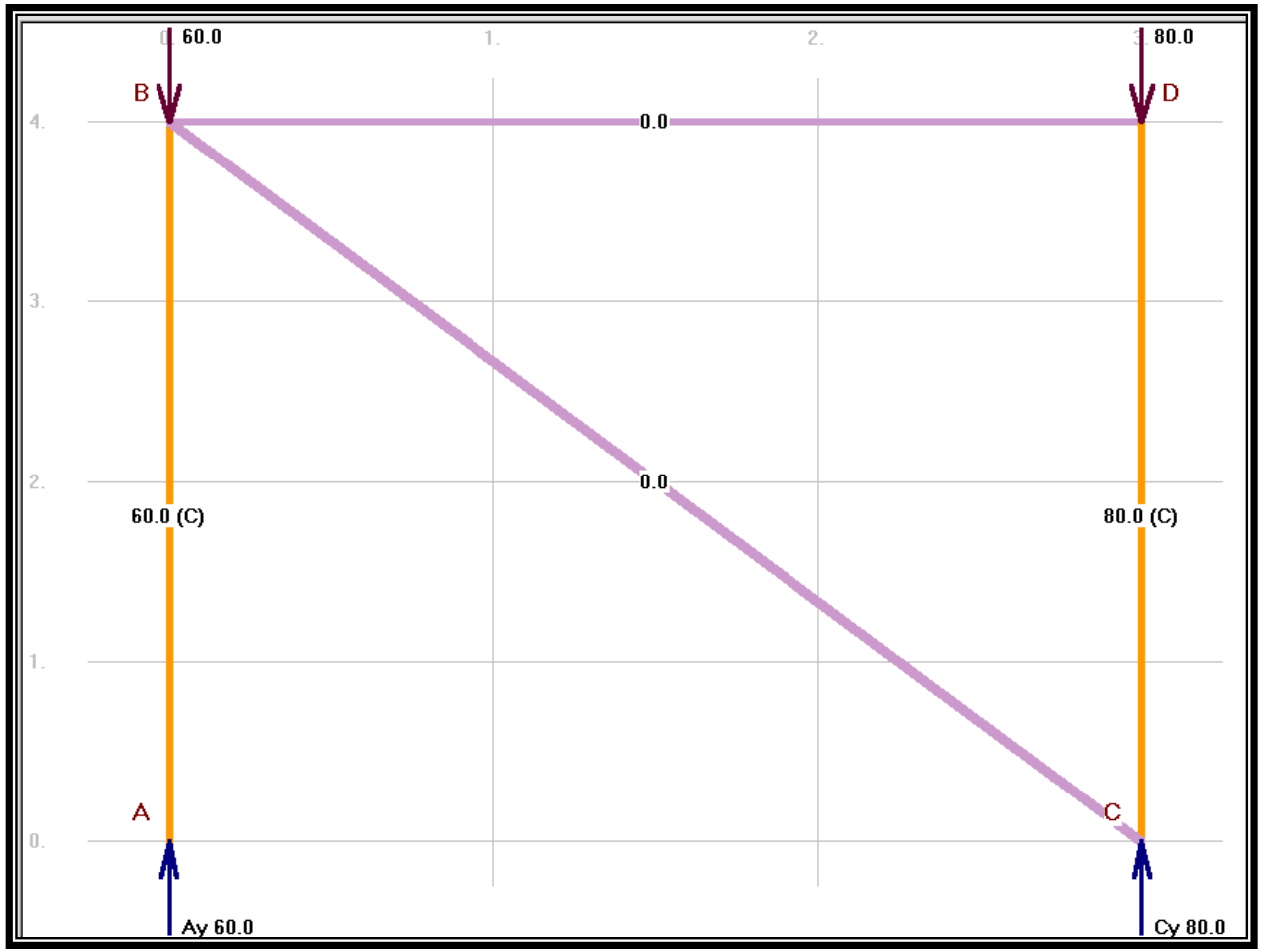


* 1 KN = 1000N, therefore 5kN = 5000N

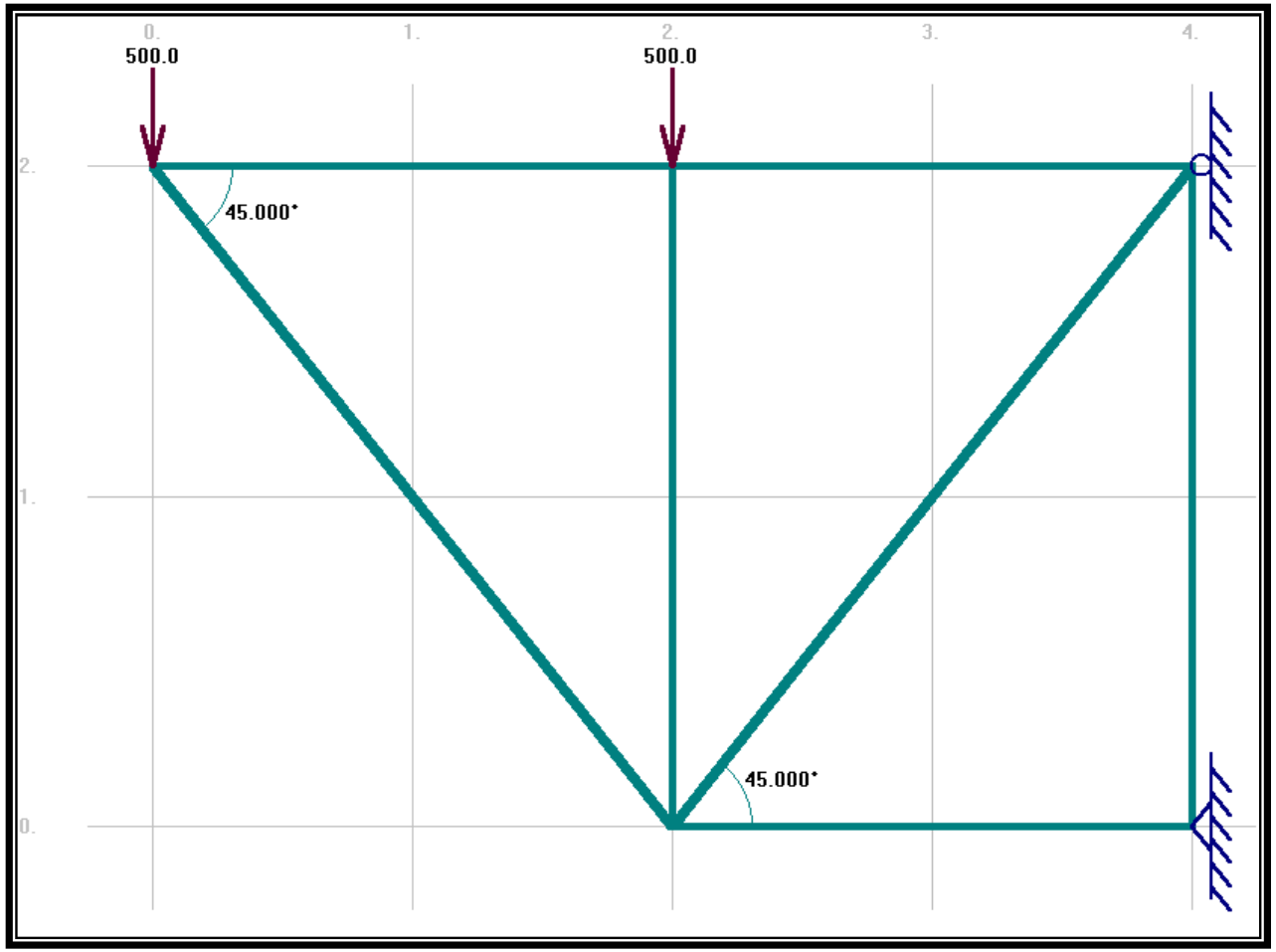
Solution for #1



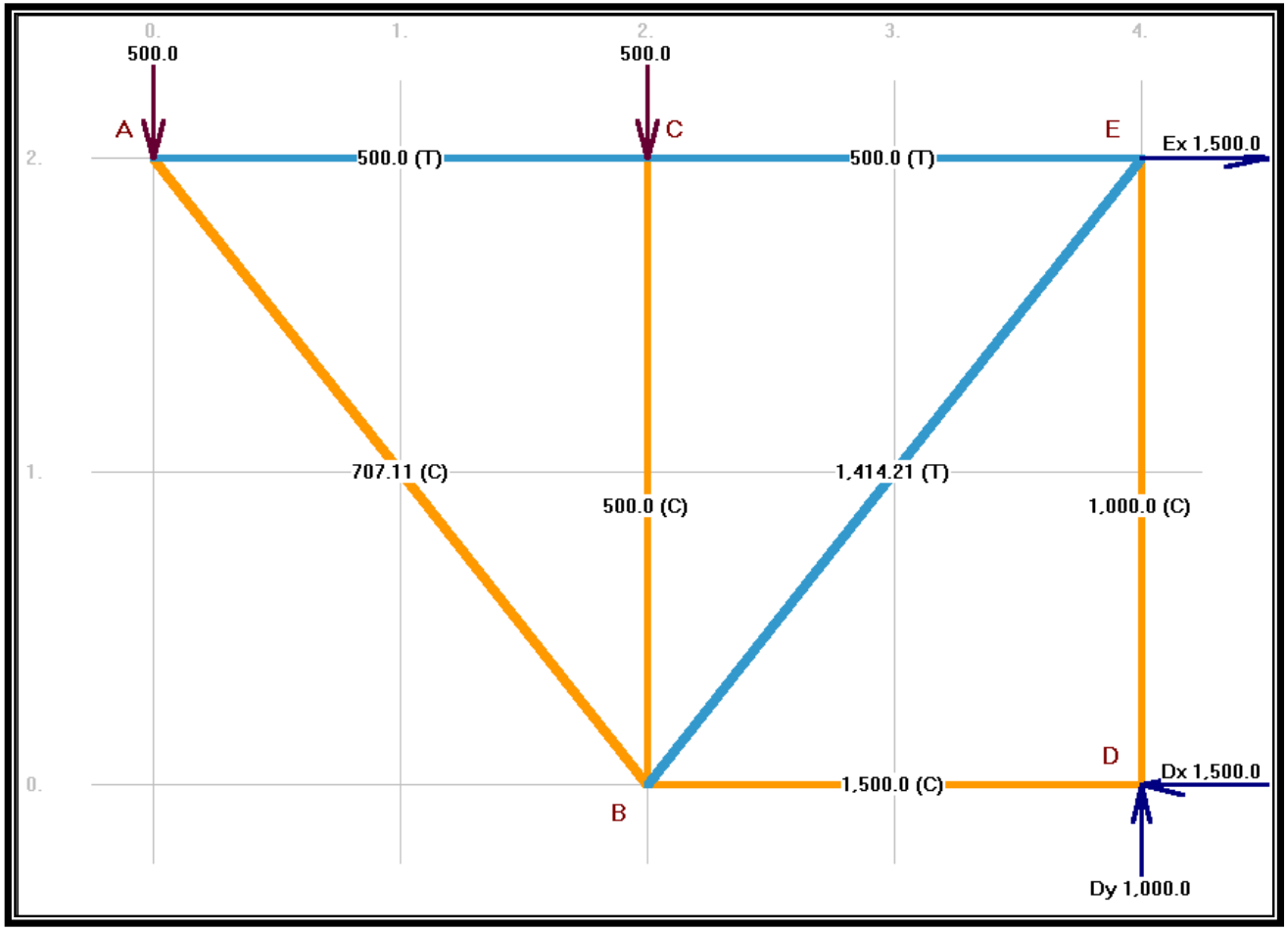
Solution for #1



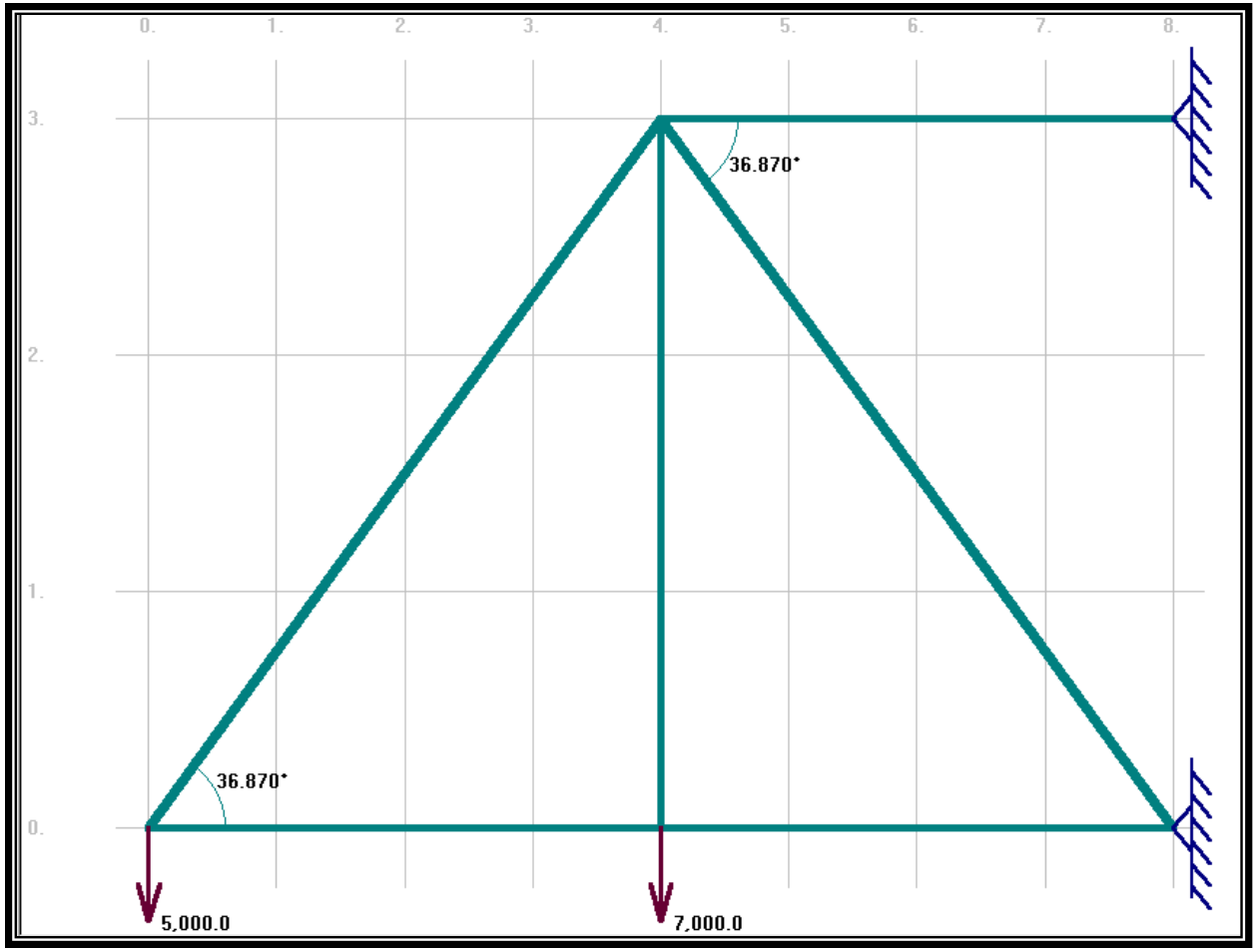
Solution for #2



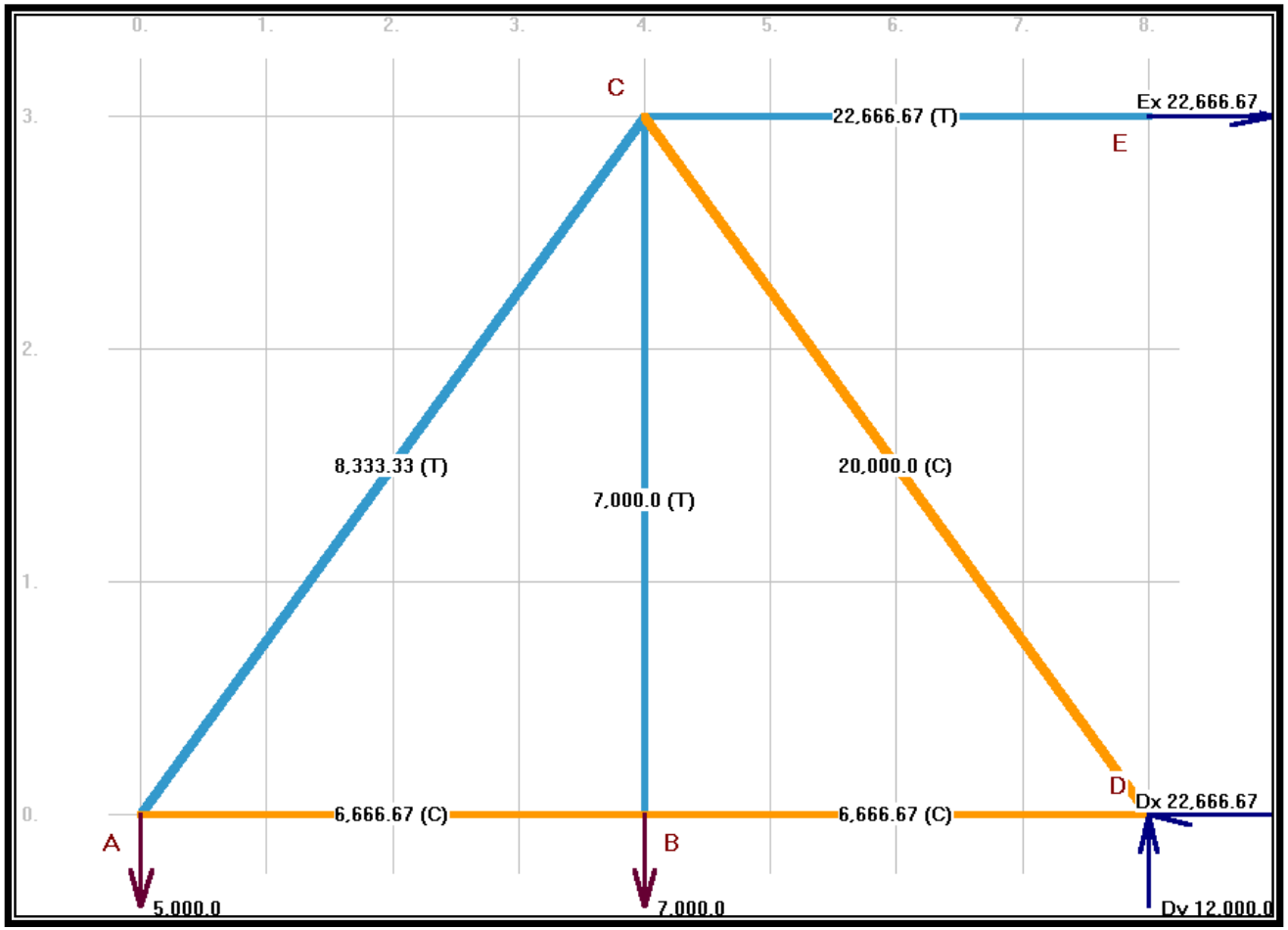
Solution for #2



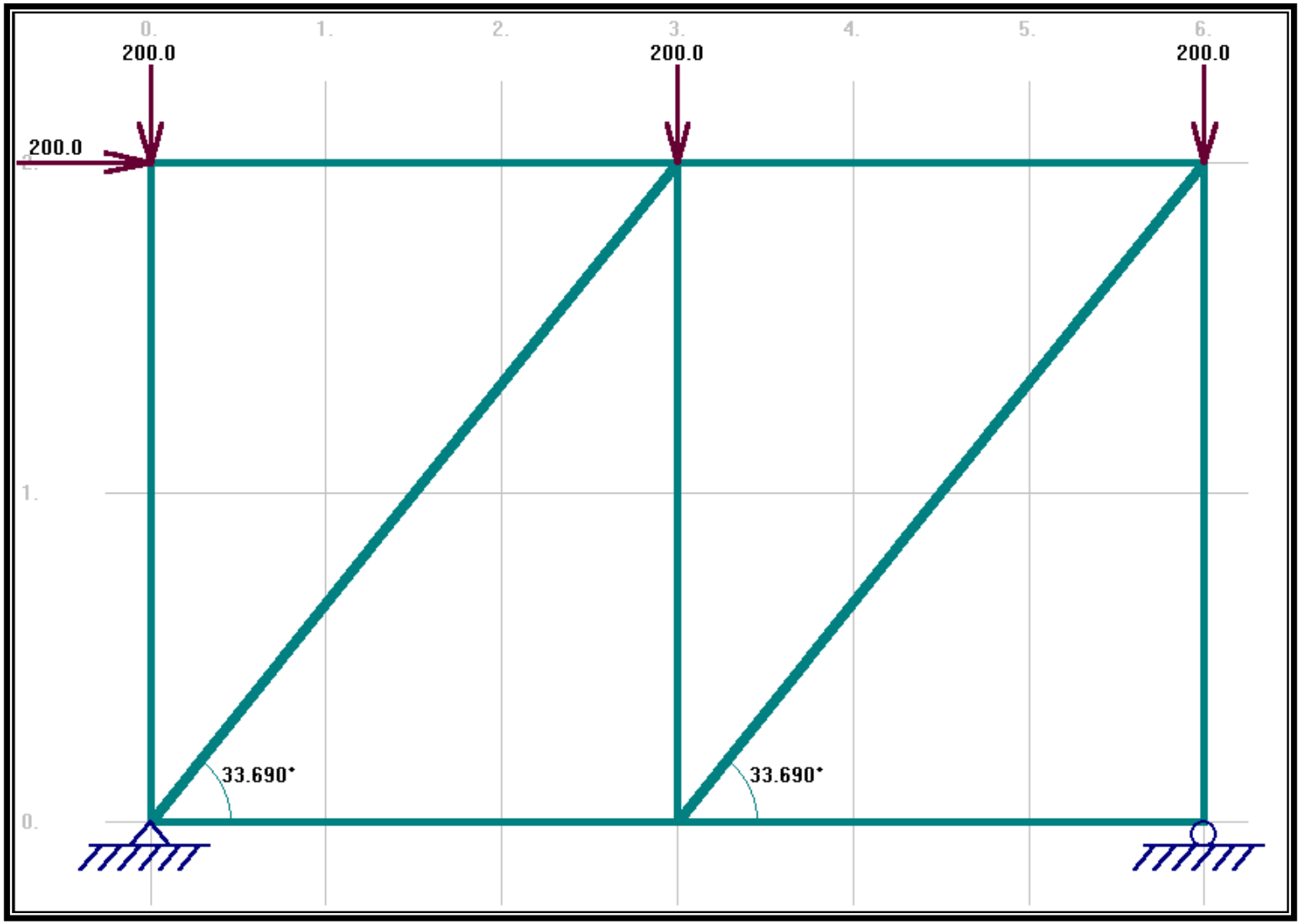
Solution for #3



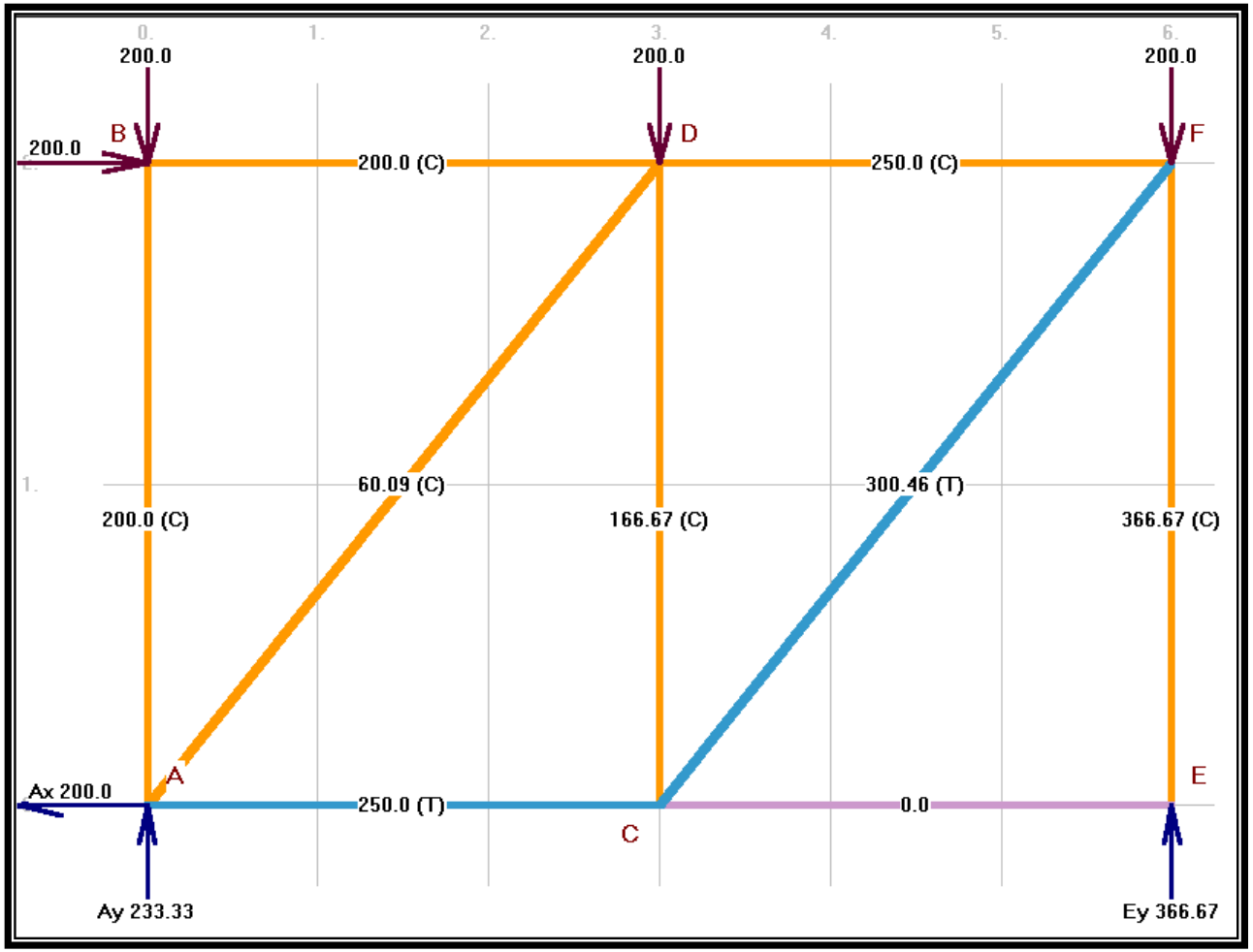
Solution for #3



Solution for #4



Solution for #4



Teacher Resource 2.1.7

Presentation: Vector Calculations

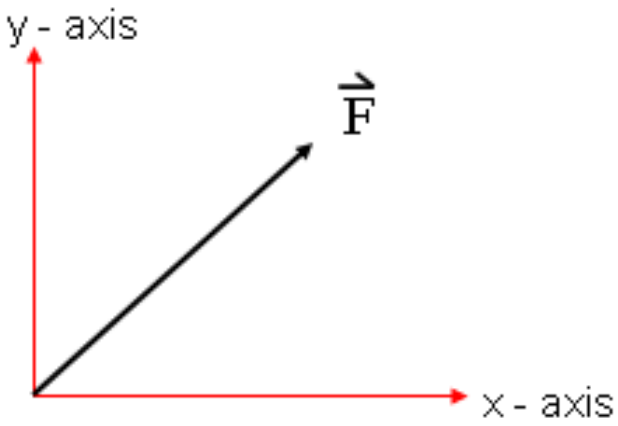
To open the presentation, right-click on the image below, then select Presentation Object/Open from the menu.

project lead the way®

Forging new generations of engineers

Vector Calculations

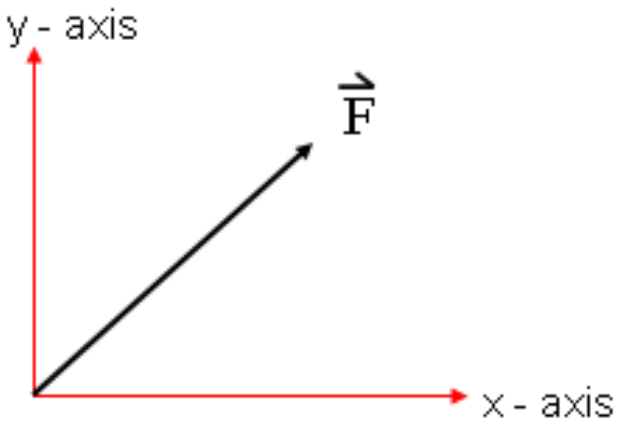
Vectors

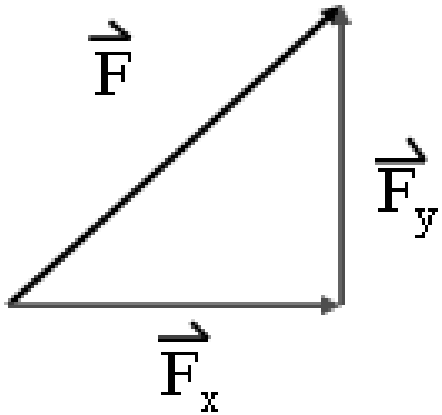


A force is often shown as a vector. A force that is not parallel to the x or y axis can be broken up into its x and y components.

(The arrow symbol indicates that force, F, is a vector.)

Vectors

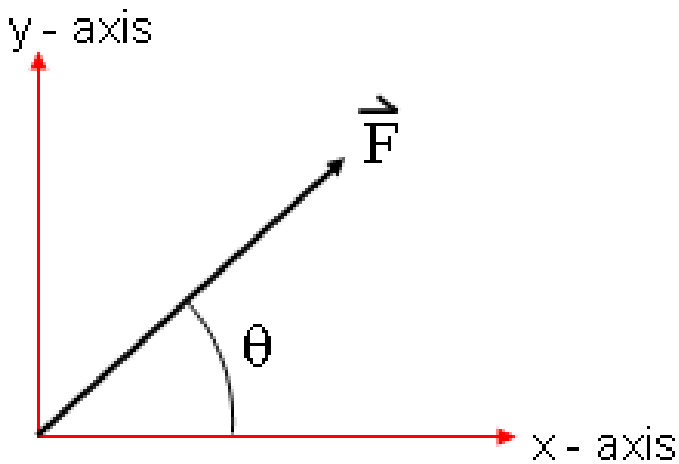


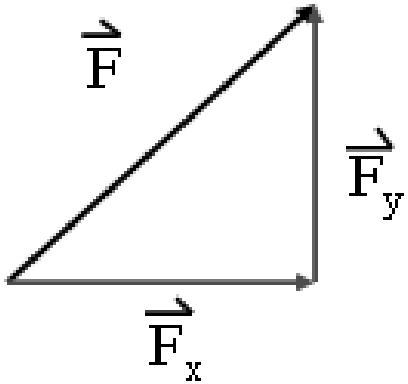


$\vec{F}_x$ is the x-component of force, F.

$\vec{F}_y$ is the y-component of force, F.

Vectors



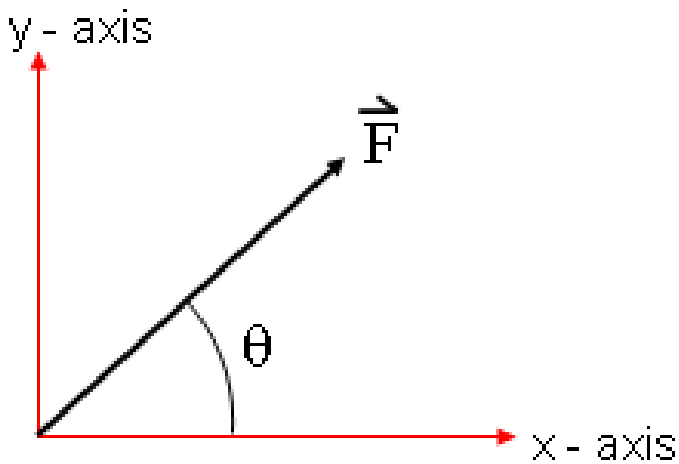


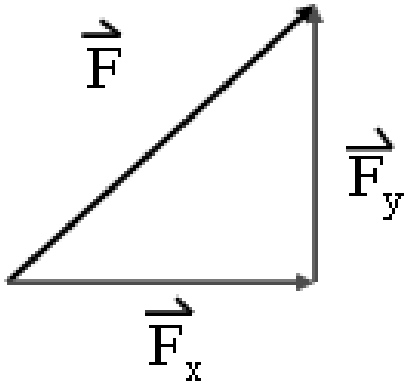
If we know

- the angle, θ, of F from an axis, and
- the magnitude of F,

we can further define its components.

Vectors



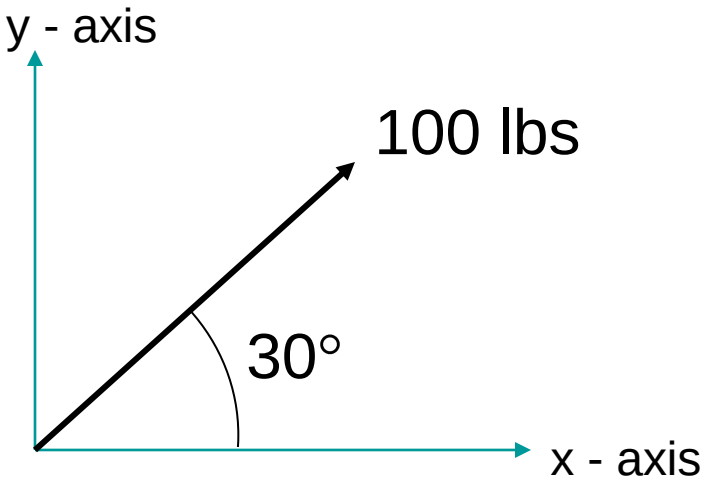


$F_x = F * \cos \theta$

$F_y = F * \sin \theta$

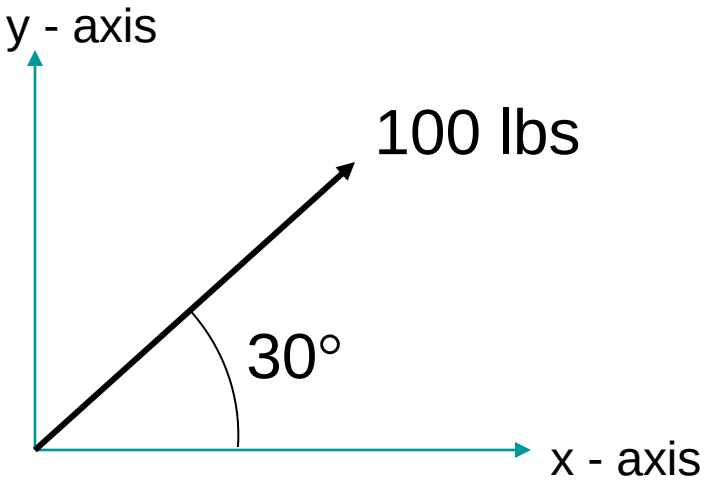
Notice the arrow-symbol does not appear above the “F” in these formulas. This indicates that we are solving for the magnitudes (the scalar quantities only) of these forces.

Vectors



In this example, F is 100lbs, and θ is 30.

Vectors



$F_x = F * \cos\theta$

$F_x = 100\text{lbs} * \cos 30$

$F_x = 87$ lbs

The x-component of F is a vector. Its magnitude is 87 lbs, and its direction is the x-direction.

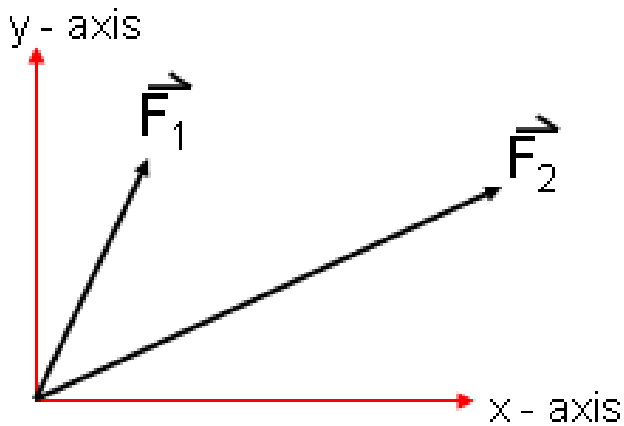
$F_y = F * \sin\theta$

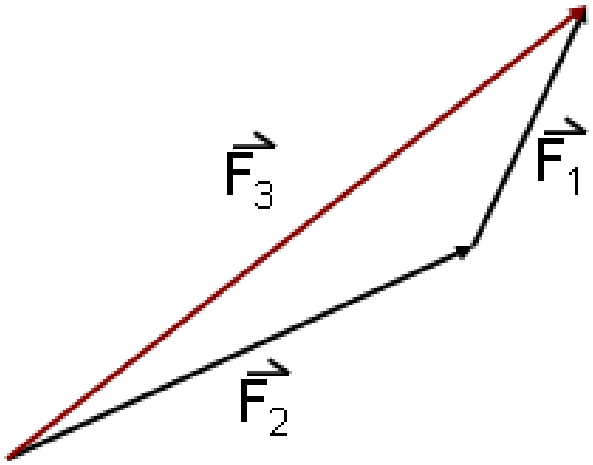
$F_y = 100\text{lbs} * \sin 30$

$F_y = 50$ lbs

The y-component of F is also vector. Its magnitude is 50 lbs, and its direction is the y-direction.

Vectors

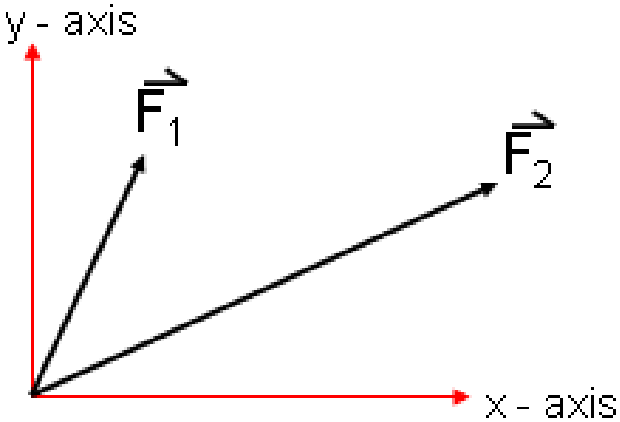


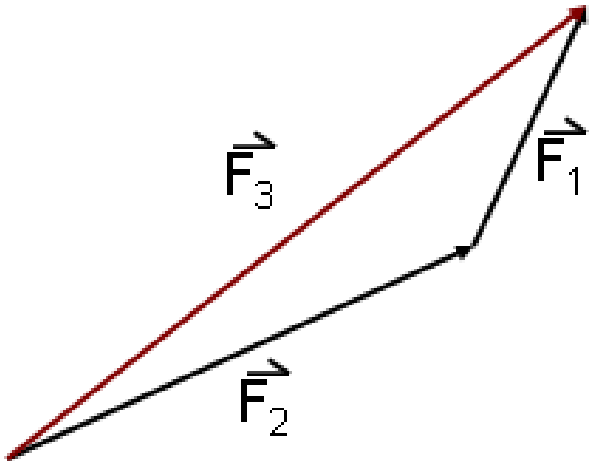


Vectors can be combined. The <u>resultant force</u> is the result of adding or subtracting vectors.

Here, vectors $\vec{F}_1$ and $\vec{F}_2$ are being graphically added together. The resultant vector will be called $\vec{F}_3$.

Vectors

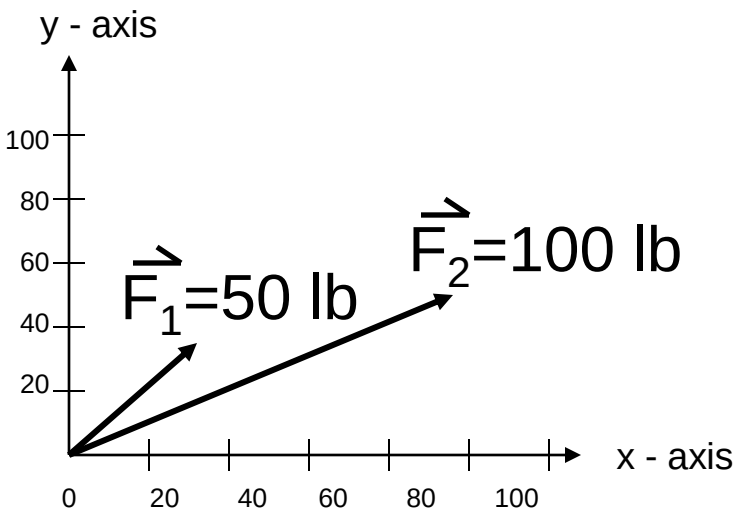


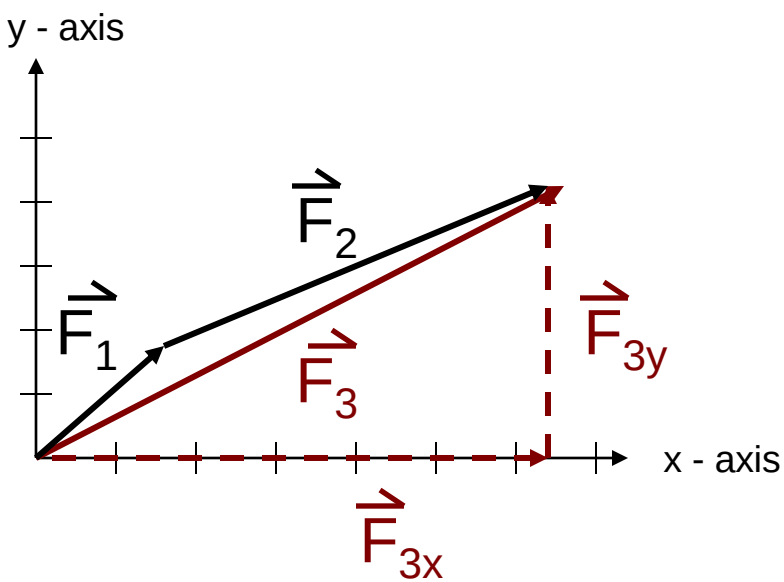


To add the vectors graphically, place them head to tail ($\vec{F}_2$ first, then $\vec{F}_1$ -*The head of the vector is the end with the arrow head).* Draw the resultant vector from the first tail to the last head. Try starting with $\vec{F}_1$ instead. Is the resultant vector different?

Vectors

To solve a vector problem using graph paper, label an x- and y-axis and label a scale along each axis. For example:

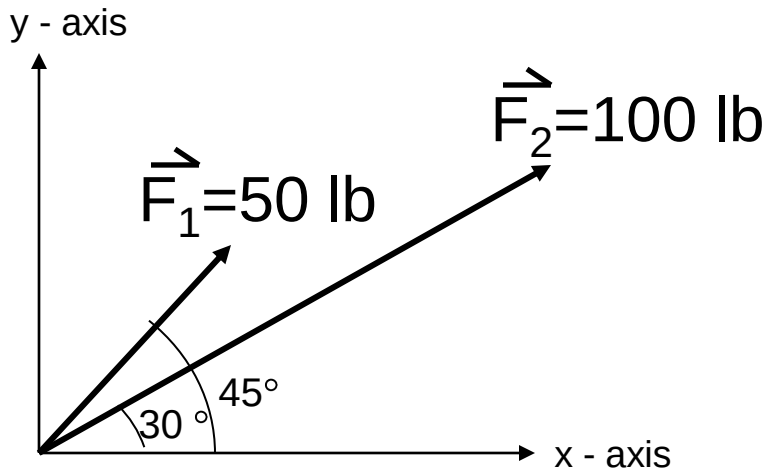




After you draw the resultant force, F3, find the magnitudes of its x and y components by measuring them against the axes.

Vectors

In this example, $\vec{F}_1$ and $\vec{F}_2$ are being mathematically added together. The resultant vector will be called $\vec{F}_3$.



Vectors

In this example, $\vec{F}_1$ = 50 lbs at an angle of 45 degrees and,
$\vec{F}_2$ = 100 lbs at an angle of 30 degrees.

Find the x and y components of vector $\vec{F}_1$:

$F_{1x} = F_1 * \cos \theta_1$

F_{1x} = 50 lbs * cos 45

F_{1x} = 35 lbs

Find the x and y components of vector $\vec{F}_2$:

$F_{2x} = F_2 * \cos \theta_2$

F_{2x} = 100 lbs * cos 30

F_{2x} = 87 lbs

x-components of each

Vectors

In this example, $\vec{F}_1$ = 50 lbs at an angle of 45 degrees and,
$\vec{F}_2$ = 100 lbs at an angle of 30 degrees.

Find the x and y components of vector $\vec{F1}$:

$F_{1y} = F_1 * \sin \theta_1$

F_{1y} = 50 lbs * sin 45

F_{1y} = 35 lbs

Find the x and y components of vector $\vec{F2}$:

$F_{2y} = F_2 * \sin \theta_2$

F_{2y} = 100 lbs * sin 30

F_{2y} = 50 lbs

y-components of each

Vectors

In this example, $\vec{F}_1$ = 50 lbs at an angle of 45 degrees and,
$\vec{F}_2$ = 100 lbs at an angle of 30 degrees.

Now, find the x and y components of the resultant vector. To do this add the x components together, then the y components together.

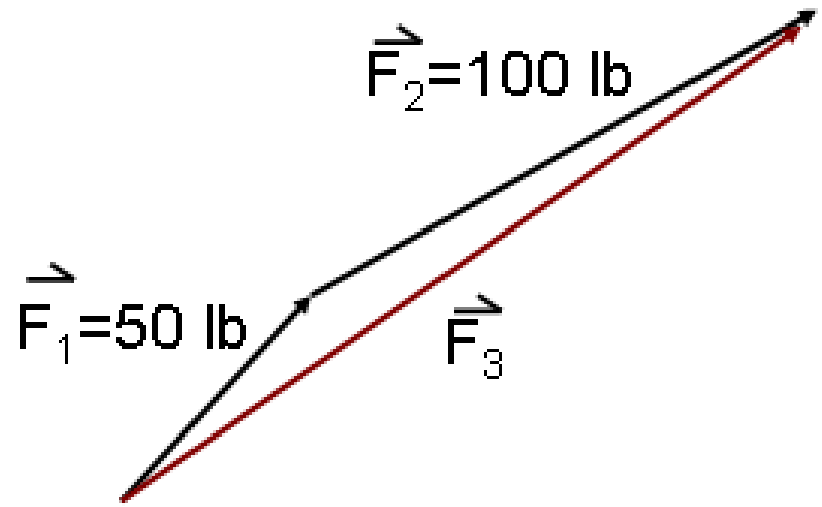
Vectors

$F_{3x} = F_{1x} + F_{2x}$

Combine x-components

$F_{3x} = 35 \text{ lbs} + 87 \text{ lbs}$

$F_{3x} = 122 \text{ lbs}$



$F_{3y} = F_{1y} + F_{2y}$

Combine y-components

$F_{3y} = 35 \text{ lbs} + 50 \text{ lbs}$

$F_{3y} = 85 \text{ lbs}$

AOE POE Integrated Unit: Bridge Builder

Lesson 2.2

Algebra I

Estimating Live Loads

In this lesson, students estimate and graph the number of cars and buses that would fill a bridge span given the average lengths of each type of vehicle. They express the relationship between the number of different vehicles and the live load on the bridge as a graph and an equation. The class then finds the range of live loads that the bridge could be expected to withstand.

This lesson is expected to take two and a half class periods.

Lesson Framework

Learning Objectives

Each student will:

- Create an equation modeling the relationship between the lengths of cars and buses and the number of vehicles that can fit on a bridge span.
- Graph the relationship between the number of cars and buses that can fit on a certain span, given their lengths.
- Calculate the range of expected live loads on a bridge span, assuming full capacity.

Academic Standards

- Represent, analyze, and generalize a variety of patterns with tables, graphs, words, and, when possible, symbolic rules. (Algebra, National Council of Mathematics)
- Relate and compare different forms of representation for a relationship. (Algebra, National Council of Mathematics)
- Explore relationships between symbolic expressions and graphs of lines, paying particular attention to the meaning of intercept and slope. (Algebra, National Council of Mathematics)
- Use symbolic algebra to represent situations and to solve problems, especially those that involve linear relationships. (Algebra, National Council of Mathematics)
- Model and solve contextualized problems using various representations, such as graphs, tables, and equations. (Algebra, National Council of Mathematics)

Assessment

Assessment Product	Assessment Criteria
Student Resource 2.2.2—Estimating Live Loads worksheet	Check worksheet for accuracy and completion

Prerequisites

- Students should be able to set up and solve one-variable equations.
- Students should be able to create a data table and graph linear equations.

Instructional Materials

Teacher Resources

- There are no teacher resources for this lesson.

Student Resources

- Student Resource 2.2.1—Worksheet: How Many Vehicles Will Fit?
- Student Resource 2.2.2—Worksheet: Estimating Live Loads

Equipment and Supplies

- Unifix Cubes
- Calculators
- Graph paper
- Rulers

Lesson Steps

Step	Min.	Activity
		CLASS PERIOD 1
1	**5**	**Lesson Introduction** Remind students of the difference between live and dead loads on structures. A dead load is weight on a structural element contributed by building materials. A live load is a

Step	Min.	Activity
		moving, variable weight on a structure. For example, the roof of a building is a dead load while the furniture in the building is a live load. Ask students to consider why it is necessary to estimate the live load on a structure such as a bridge. The obvious answer is that it is necessary to design a structure that can withstand the maximum estimated load. Students may ask, “Why not design the bridge to be as strong as possible in every case?” Engineers must balance safety and cost. Building the structure to the maximum estimated load prevents time and money from being wasted on over designing and using more materials than is necessary under realistic conditions.
2	**40**	**Group Activity: How Many Vehicles Will Fit?** Before the class can work directly with loads on bridges, they must first consider what combination of objects can sit on the bridge at the same time (in this simplified case, only cars and buses). This activity has students use Unifix Cubes to explore the idea of packing vehicles of different lengths onto a fixed span. Divide the class into pairs or groups of four. Distribute Unifix Cubes, graph paper, rulers, calculators, and the How Many Vehicles Will Fit? worksheet to each group. Go over the directions and clarify any questions. Allow groups time to work on the assignment. Each student should have a copy of the answers, and produce their own graphs. Students may wonder why fractions of a vehicle are acceptable answers for the worksheet. Tell students that when vehicles are moving along a road, at any given time a car might be partially off the section of road that is being measured. The part of the vehicle that is on the measured span of road should still be counted in live load calculations.
3	**5**	**Cleanup** Be sure to reserve time at the end of the class period to collect the cubes and other supplies. Students can finish the worksheet as homework if it is not completed by the end of the period.
		CLASS PERIOD 2
4	**10**	**Discussion: How Many Vehicles Will Fit?** Go over the answers to the How Many Vehicles Will Fit? worksheet. If the class is not in agreement about any of the answers, make sure to allow students to discuss the disagreement and come to a satisfactory conclusion. Discuss the equations and slopes of the graphs. Have students explain why the slopes are negative and why it makes sense that the magnitudes of the slopes are the ratios of the vehicle lengths.

Step	Min.	Activity
5	**40**	**Group Activity: Estimating Live Loads** Divide the class into pairs or groups of four. Distribute the Estimating Live Loads worksheet and give groups time to complete it. Each student should have a copy of the answers and produce their own individual graph. The questions are very similar to the previous worksheet, except that the numbers are more difficult to work with and the assignment is extended to estimate live load on the structure. Students can complete the worksheet for homework if it is not completed in class.
		CLASS PERIOD 3
6	**25**	**Discussion: Estimating Live Loads** Discuss the answers to the Estimating Live Loads worksheet. Problem 4 is likely to be challenging for students and is worth plenty of discussion. Have students share the two different graphs that could have been produced for question 5. Students can contrast the graphs and explain why they differ even though they describe the same situation.

Extensions

- There is a difference between how moving and stationary masses affect a structure's stability. This lesson could lead to a discussion about those differences and how complicated real structural engineering can be.
- Students can figure out what happens to their live load model when more variables are added to the situation, such as pedestrians, freight trucks, and so on.
- Students can figure out the rate at which people cross the bridge given the average number of passengers per car and bus and how that rate changes depending on the ratio of cars to buses.

AOE POE Integrated Curriculum Unit: Bridge Builder

Lesson 2.2

Estimating Live Loads

Student Resources

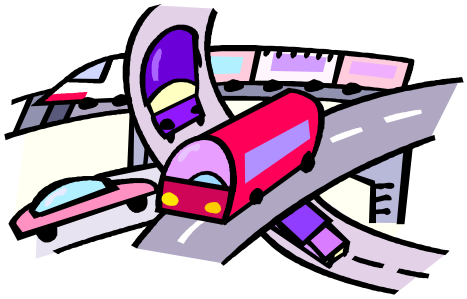
Resource	Description
Student Resource 2.2.1	Worksheet: How Many Vehicles Will Fit?
Student Resource 2.2.2	Worksheet: Estimating Live Loads

Student Resource 2.2.1

Worksheet: How Many Vehicles Will Fit?

Directions

On a blank piece of paper, draw a two-lane road that is 10 inches long, with each lane wide enough to accept vehicles made of Unifix Cubes. The road can be filled with cars and buses. A car is two Unifix Cubes long, while a bus is three Unifix Cubes long. Using the cubes to help you reason, answer the following questions on a separate sheet of paper. Be sure to include all your work.



1. What is the maximum number of cars that can fill both lanes of the road? Include fractions of a car.

2. What is the maximum number of buses that can fill both lanes of the road? Include fractions of a bus.

3. Answer questions 1 and 2 again, this time for a one-lane road that is 20 inches long. Are your answers the same or different depending on how the length of road is arranged? Explain why.

4. Find at least five combinations of quantities of cars and buses that will fill the original two-lane road. Show your answer in an organized data table. Fractions of a vehicle are acceptable.

5. Now assume that each car is three Unifix Cubes long, and each bus is four Unifix Cubes long. Find at least five combinations of quantities of cars and buses that will fill the original two-lane road. Show your answer in an organized data table. Fractions of a vehicle are acceptable.

6. Let C be the number of cars on the road and B be the number of buses. Create equations that represent all possible combinations for the situations in problems 4 and 5.

7. Create graphs of both equations you created. Make the number of cars the x-axis, and the number of buses the y-axis. State the slope of each line.

Student Resource 2.2.2

Worksheet: Estimating Live Loads

Directions

Consider a bridge whose live load primarily consists of cars and buses. Engineers must figure out how many of each kind of vehicle can be on the bridge at once to design a structure that can withstand the range of weight that might be placed on it. Use the following information to complete the worksheet. Be sure to include all your work.

Assume the following:

- An average passenger car is 17 feet long and weighs 4,000 pounds.
- An average bus is 38 feet long and weighs 30,000 pounds with passengers.
- The longest span of a certain bridge is 2,350 feet. This span has five lanes, and is generally used by cars and buses (no large freight trucks).

1. Let C be the number of passenger cars on the bridge span, and B be the number of buses. Write an equation that expresses the total number of passenger cars and buses that can fit on the span of the bridge at one time.

2. Create a data table of possible combinations of cars and buses that can fit on the bridge span. Since cars and buses are continuously moving along the bridge span, we are talking about average numbers, so it is reasonable to include fractions of a vehicle. Include at least five data points in your table.

3. Graph your data table. Make the number of cars the x-axis and the number of buses the y-axis.

4. Write an equation that expresses the relationship between the span's live load at full capacity and the number of buses on the span. Now write another equation, this time relating the span's live load at full capacity with the number of cars on the span.

5. Graph one of the two equations you created in problem 4. Make the bridge's live load at full capacity the y-axis.

6. What is the range of live loads that can be on the bridge span at any given time? Explain your reasoning.

AOE POE Integrated Unit: Bridge Builder

Lesson 2.2

Estimating Live Loads

Teacher Resources

There are no teacher resources for this lesson.

AOE POE Integrated Curriculum Unit: Bridge Builder

Lesson 2.3

Chemistry

Rusty Truss

In this lesson, students investigate the corrosion of metals. Students observe the effects of various solutions on iron to determine factors contributing to corrosion. Students will also conduct a lab experiment that allows them to visualize the location of oxidation and reduction of the corrosion process. Students conclude by doing research on how actual bridges are protected and maintained from corrosion.

This lesson is expected to take up to four class periods.

Lesson Framework

Learning Objectives

Each student will:

- Observe and describe the corrosive nature of oxidation-reduction reactions.
- Summarize the causes of metal corrosion in regard to electrochemical processes.
- Compare and contrast the effects of corrosion on various types of metals.
- Describe factors that affect the rate of corrosion.
- Describe methods used to inhibit corrosion on bridges.

Academic Standards

- A large number of important reactions involve the transfer of either electrons (oxidation/reduction reactions) or hydrogen ions (acid/base reactions) between reacting ions, molecules, or atoms. In other reactions, chemical bonds are broken by heat or light to form very reactive radicals with electrons ready to form new bonds. Radical reactions control many processes such as the presence of ozone and greenhouse gases in the atmosphere, burning and processing of fossil fuels, the formation of polymers, and explosions. (NRC National Science Education Standards, Content Standard B)
- Chemical reactions can take place in time periods ranging from the few femtoseconds (10^{-15} seconds) required for an atom to move a fraction of a chemical bond distance to geologic time scales of billions of years. Reaction rates depend on how often the reacting atoms and molecules encounter one another, on the temperature, and on the properties—including shape—of the reacting species. (NRC National Science Education Standards, Content Standard B)

Assessment

Assessment Product	Assessment Criteria
Corrosion Chemistry Lab Questions	Teacher Resource 2.3.2—Answer Key: Corrosion Chemistry Lab
Poster describing the corrosion protection plan of well-known or local bridge	Teacher Resource 2.3.3—Assessment Criteria: Corrosion Protection Plan Poster

Prerequisites

- Working knowledge of electrochemical cells
- Working knowledge of traditional chemistry instruction up to redox reactions
- Working knowledge of lab safety procedures

Instructional Materials

Teacher Resources

- Teacher Resource 2.3.1—Demonstration: Iron Corrosion
- Teacher Resource 2.3.2—Answer Key: Corrosion Chemistry Lab
- Teacher Resource 2.3.3—Assessment Criteria: Corrosion Protection Plan Poster

Student Resources

- Student Resource 2.3.1—Observations: Iron Corrosion
- Student Resource 2.3.2—Lab: Corrosion Chemistry
- Student Resource 2.3.3—Reading: Steel Bridge Corrosion

Equipment and Supplies

- See materials list in Teacher Resource 2.3.1—Demonstration: Iron Corrosion
- See materials list in Student Resource 2.3.2—Lab: Corrosion Chemistry

Lesson Steps

Step	Min.	Activity
		PRIOR TO LESSON
1	**varies**	**Demonstration Setup: Iron Corrosion** Get 10 long uncoated steel (iron) nails. Buff the surface with sandpaper to remove any surface protection. Assemble the following setup one or two days before you plan to do the Corrosion Chemistry Lab, perhaps at the beginning of your standard oxidation/reduction instruction: 1. Test tube with one nail, filled with distilled water. 2. Stoppered test tube with one nail, filled with water that has been boiled and cooled. 3. Test tube with one nail, filled with a saltwater solution. 4. Test tube with one nail, half filled with water (nail is not completely submerged). 5. Petri plate with one straight nail and one bent nail set in 150 ml of agar gel and 10 ml of 0.1M KSCN. 6. Petri plate with three nails set in agar/KSCN gel. One nail should be wrapped in copper wire, one wrapped in magnesium ribbon, and one should be bare. Let the six setups sit for several days. Students will be making observations during the Corrosion Chemistry Lab. You may have students set up these reactions as a way to generate interest.
		CLASS PERIOD 1
2	**10**	**Teaser Problem: Redox Reaction** Inform students that the process of metals oxidizing into positive ions due to interaction with their environment is termed **corrosion** and the process of metal ions reducing to form metal atoms is termed **deposition.** Write the following reactions on the board: • Iron (s) + Oxygen (g) → Iron (III) oxide (s) • Aluminum (s) + Oxygen (g) → Aluminum oxide (s) • Chromium (s) + Oxygen (g) → Chromium (III) oxide (s) For each reaction, have students: • Determine the formula of each element and compound • Determine which substance has been oxidized or reduced • Determine which substance is the oxidizing agent and which is the reducing agent
3	**5**	**Demonstration: Iron Corrosion** Bring out the six reactions you set up prior the lesson. Set them up around the

Step	Min.	Activity
		room. Have students visit each station and record their observations about each reaction on Student Resource 2.3.1, the Iron Corrosion handout. After students have completed their observations, discuss the following questions about just the four test tubes: • Which system rusted the most? • Why do you think this is? • When the water was boiled, what was removed? • How did this affect the corrosion? By the conclusion of the discussion, students should recognize that iron rusts much faster in the presence of water, and faster still in the presence of saltwater. But what is actually happening? You can tell students that they will revisit the nails in the petri dishes after the upcoming lab.
4	**35**	**Lab: Corrosion Chemistry** Pass out Student Resource 2.3.2—Lab: Corrosion Chemistry. Read and review the introduction and procedures together as a class. Have students follow the lab procedure for parts A and B. Direct students to record their observations in the space provided. When they are completed with parts A and B, they should clean up their lab station. If time allows, have them continue on to the rest of the lab. Conclusion: The corrosion process may be slowed by coating the metals with other metals or polymers in order to protect the metal from the corrosive environment. Examples of this can be seen in food cans that have a polymer coating and in galvanized steel, where iron is coated with zinc.
		CLASS PERIOD 2
5	**25**	**Lab: Corrosion Chemistry continued** Direct students to assemble their lab materials for the uncompleted portion of the Corrosion Chemistry Lab and finish the remaining procedures in class. Have students clean up their lab station after they finish and then begin work on the discussion questions. Allow students to work until the last group has finished cleaning up. Assign any remaining questions for homework.
6	**25**	**Class Discussion: Rust** Bring out the nails in agar that you prepared prior to the lesson and display the straight nail in the first dish to the class. Ask students to explain how the Corrosion Chemistry Lab relates to the nail in the petri plate. Use this opportunity to review the redox reactions taking place on rusting iron: When iron is the presence of water, an electrochemical cell is created that has

Step	Min.	Activity
		a distinct anode and cathode. If an iron nail is placed in agar or gel in which ferricyanide ions and phenolphthalein indicator have been placed, the ends of the nail turn blue and the middle of the nail turns red. The blue color is caused by a ferricyanide indicator reaction with the iron ions, and the red (or pink) color is due to reaction between hydroxide ions and phenolphthalein. At one spot on the nail (the anodic site of our electrochemical cell), iron loses electrons (is oxidized) to form iron (II) ions. $Fe\ (s) \text{ ------> } Fe^{2+}\ (aq) + 2e-$ At another spot on the nail, the oxygen in the air combines with water and forms hydroxide ions. $\frac{1}{2}O_2\ (g) + H_2O\ (l) + 2e- \text{ ------> } 2OH^-\ (aq)$ In the presence of oxygen, the iron further oxidizes at the anode (loses electrons) to become iron (III) ions. $Fe^{2+}\ (aq) \text{ ------> } Fe^{3+}\ (aq) + e-$ The iron (III) ions and the hydroxide combine to form rust. $Fe\ (s) \text{ ------> } Fe^{2+}\ (aq) + 2e-$ $2Fe^{3+}\ (aq) + 6OH-\ (aq) \text{ ------> } Fe_2O_3\ (s) + 3\ H_2O\ (l)$ Notice that both the O_2 and H_2O are needed to cause the rusting of the iron. In regions where humidity is low, rust does not form quickly. As with electrochemical cells, the electrons flow from the anode to the cathode. The presence of dissolved salts greatly accelerates the corrosion process. This is why rust can form rapidly on bridges over saltwater and on cars in cold weather climates where salt is used to melt road ice. Discuss the following questions about the petri plates: • Compare the bent nail with the straight nail. Explain the difference. • Compare the clean iron nail with the copper-wound nail and the nail with the magnesium ribbon. Can you explain the difference you see? • How do you think chemists use this information to work to prevent corrosion of metals like iron?
		CLASS PERIOD 3
7	**20**	**Homework Review: Corrosion Chemistry** Review the answers to the Corrosion Chemistry Lab discussion questions. By the end of the discussion, students should have concluded that the iron corrosion process may be slowed by coating it with other metals or polymers in order to protect the metal from the corrosive environment. Examples of this can be seen in food cans that have a polymer coating and in galvanized steel, where iron is

Step	Min.	Activity
		coated with zinc. Based on their experiment, ask students to speculate on what would occur if they performed procedure B on two pennies, one pre-1982 and one post-1982. Pre-1982 pennies are made of copper; post-1982 pennies are copper-plated zinc. If you have time, let students try this experiment as well.
8	**20**	**Reading: Steel Bridge Corrosion** Pass out Student Resource 2.3.3—Reading: Steel Bridge Corrosion. Read together as a class or individually. Based on the article and the lab, discuss how what they have learned about corrosion relates to bridges. What might the effect of corrosion be on a bridge, in the short term as well as the long term? What types of bridges are most likely to suffer from corrosion, what types of locations are most likely to contribute to corrosion, and what can be done?
9	**10**	**Research: Corrosion Protection Plan** Pair students up. Have each student select a well-known or local bridge and research how the bridge is protected from corrosion. Research will be compiled into a poster and should include • Name of bridge • Location of bridge • Primary environmental factors contributing to corrosion • What is used to protect the bridge • How often the bridge is checked or maintained for corrosion • How much does corrosion prevention cost Provide additional time in class for research at the computer lab, or assign the research for homework. If it is assigned entirely for homework, give students time in class to divide up the research responsibilities.
		CLASS PERIOD 4
10	**30**	**Gallery Walk: Corrosion Protection Plan** Tell students to bring the research and poster materials to class. Give the student pairs some time to assemble their poster, and then display posters around the classroom. Have students walk around and read each poster. Regroup the class and categorize the different materials and/or strategies used to protect bridges from corrosion described in the posters. Which bridge has the best corrosion protection plan? Which bridge has the worst? Have the class come up with a list of suggestions for the bridge with the worst corrosion protection plan.

Extensions

- Add additional test tubes to the initial demonstration set of four. Other solutions you may wish to include in the set include sodium hydroxide, potassium hydroxide, hydrochloric acid, potassium nitrate, and sulfuric acid. Have students test the tubes' pH before you leave them to sit. Which reagents contributed to corrosion, and which did not? How is corrosion affected by pH, and what might explain the pattern?

AOE POE Integrated Curriculum Unit: Bridge Builder

Lesson 2.3

Rusty Truss

Student Resources

Resource	Description
Student Resource 2.3.1	Observations: Iron Corrosion
Student Resource 2.3.2	Lab: Corrosion Chemistry
Student Resource 2.3.3	Reading: Steel Bridge Corrosion

Student Resource 2.3.1

Observations: Iron Corrosion

Record your observations about the appearance of each of the following:

Test Tube 1: Nail submerged in distilled water

Test Tube 2: Nail submerged in boiled water with stopper

Test Tube 3: Nail submerged in salt water

Test Tube 4: Nail partially submerged in distilled water

Petri Plate 1: Two nails

Straight nail:

Bent nail:

Petri Plate 2: Three nails

Copper-covered nail:

Magnesium-covered nail:

Plain nail:

Student Resource 2.3.2

Lab: Corrosion Chemistry

Introduction

Corrosion reactions are redox reactions in which a metal is attacked by some substance in its environment and converted to an unwanted compound. Corrosion reduces the lifetime of steel products such as bridges and automobiles. Billions of dollars are spent each year replacing rusty metal parts. This turnover also consumes approximately 20 percent of all new iron produced in the United States. In this experiment we can watch the corrosion reaction by using substances that produce a color change when they react with the products of the iron oxidation or oxygen reduction.

Materials

- Colored pencils
- Watch glasses
- Dropper
- Fine sandpaper
- Triangular file
- 0.1 M $K_4Fe(CN)_6$
- 0.1 M $K_3Fe(CN)_6$
- 0.1 M NaCl solution
- Phenolphthalein
- Mild steel bar, 2.5 by 6 cm
- Galvanized steel sheet, 4 by 4 cm
- Steel can (food) lids, polymer coated
- Steel can, tin-coated (use Hunt's tomato sauce can)
- (optional) Pennies, new and old (pre-1982)

Procedures

A. Plain Steel

1. Add 10 drops of phenolphthalein to 100 ml of 0.1M NaCl solution.
2. On a section of mild steel, combine 4 drops of this solution and 3 drops of potassium ferricyanide.
3. On a different part of the bar, combine 4 drops of the salt-phenolphthalein solution and 3 drops of ferrocyanide.
4. Cover each area with a watch glass and observe for at least 5 minutes. What changes occur? In the Observations section below, color in the appropriate diagram and record your observations.

B. Polymer-Coated Steel

1. Use a triangular file to place a deep scratch on one area of a polymer-coated steel can lid.
2. Place 3 drops of ferricyanide and 4 drops of salt solution on the scratch.
3. On a second area of the polymer coated lid, place the same drops as in step 2, and cover with a watch glass.
4. Observe both areas of the lid for at least 5 minutes. What changes occur? In the Observations section below, color in the appropriate diagram and record your observations.

C. Tin-Coated Steel

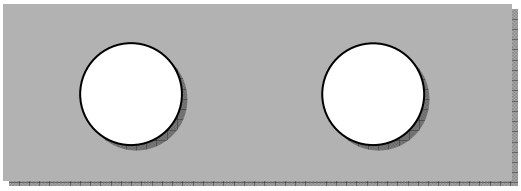
1. Repeat procedure B using a piece of tin-plated steel can, tin side up.
2. Observe for at least 8 minutes. What changes occur? In the Observations section below, color in the appropriate diagram and record your observations.

D. Zinc-Plated Steel

1. Repeat procedure B using a piece of galvanized steel.
2. Observe for 5 minutes. What changes occur? Is the iron rusting? In the Observations section below, color in the appropriate diagram and record your observations.

Observations

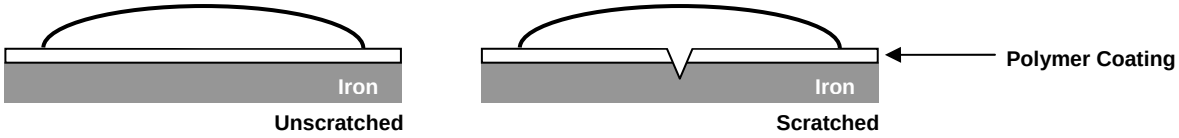
A. Plain Steel



Potassium Ferricyanide $K_3Fe(CN)_6$

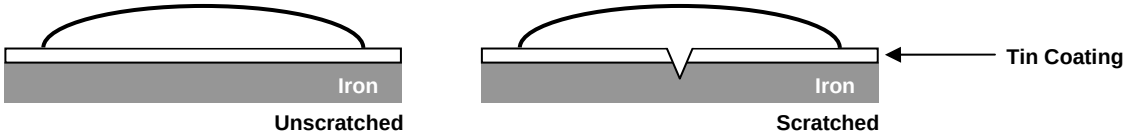
Potassium Ferrocyanide $K_4Fe(CN)_6$

B. Polymer-Coated Steel



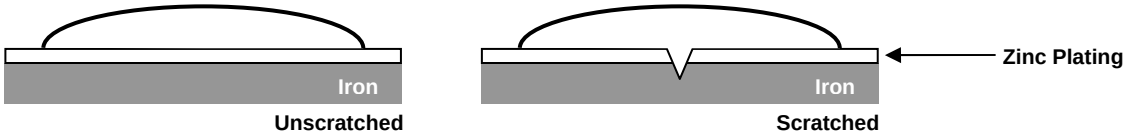
Unscratched **Scratched**

C. Tin-Coated Steel



Unscratched **Scratched**

D. Zinc-Plated Steel



_____

_____

_____

Discussion

1. What kind of reaction is occurring where the intense pink color is forming? How do you know?

   _____

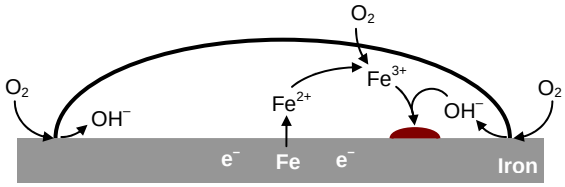
   _____

2. If the potassium compound in the salt-drop solution turns blue in the presence of Fe^{2+}, then the potassium compound is an indicator for what type of reaction?

   _____

   _____

3. As it turns out, ions are spatially separated in this salt-drop experiment because the drop is thicker in the middle than at the edges. Electrochemical reduction reactions that produce OH^- occur at the edges due to readily available oxygen from the air. Electrochemical oxidation reactions occur at the middle of the drop due to the lack of oxygen. Based on your observations in Part A, which chemical reagent (ferro or ferri) would you use to check for rust on iron? Why?



   _____

   _____

4. What is indicated when no blue color appears when using potassium ferricyanide?

   _____

   _____

5. Based on your observations, what is the best protective coating for iron to prevent rust? Why?

   _____

   _____

   _____

   _____

Student Resource 2.3.3

Reading: Steel Bridge Corrosion

Adapted from http://www.corrosion-doctors.org

In 1997, it was reported that 101,518 of the 581,862 bridges in the U.S. federal-aid system were structurally deficient. Most of these bridges were not in danger of collapse, but in many cases, overweight trucks were not allowed to cross, meaning they would need to find a longer, alternative route.

The average cost of maintaining current bridge conditions is estimated at $5.2 billion a year. That is just to keep bridges in their existing deficient state. It has been estimated that it would take $78 to $112 billion to correct the backlog of structural and functional problems. The longer the problem is left, the more expensive it will become. The corrosion of steel is not the only factor contributing to structural problems, but it is a major factor.

The primary cause of corrosion of steel bridges is the exposure of the steel to atmospheric conditions. This corrosion is accelerated by marine exposures (salt spray) and industrial environments. The only corrosion prevention method for these structures is to provide a barrier coating (paint).

Increased awareness and updates in environmental protection regulation have significantly changed the way corrosion protection for steel bridges are approached. Until the mid- to late-1970s, virtually all steel bridges were protected from corrosion by multiple thin coats of lead- and chromate-containing alkyd paints applied directly over steel. Maintenance painting for prevention of corrosion was rare and usually only done for larger bridge structures. The majority of the steel bridges in the interstate highway system were constructed between 1950 and 1980. Most of these structures were originally painted in this manner, and so their protective coating is now probably beyond its useful service life.

Moreover, the paint system commonly used for steel bridge members contains chromium and lead and can no longer be used because of the effects those chemicals have on humans and the environment. Bridge engineers have a choice of either replacing the lead-based paints with a different coating or painting over the deteriorating areas. Removal of lead-based paint incurs high costs due to the requirements to contain all the hazardous waste and debris.

Developments include (1) improved and environmentally safe coating systems and (2) methodologies to optimize the use of these systems, such as “zone” painting (adjusting coating types and maintenance schedules based on the environmental conditions in effect at different zones of the bridge). Overpainting techniques to eliminate the cost of expensive paint removal also have been developed.

AOE POE Integrated Curriculum Unit: Bridge Builder

Lesson 2.3

Rusty Truss

Teacher Resources

Resource	Description
Teacher Resource 2.3.1	Demonstration: Iron Corrosion
Teacher Resource 2.3.2	Answer Key: Corrosion Chemistry Lab
Teacher Resource 2.3.3	Assessment Criteria: Corrosion Protection Plan Poster

Teacher Resource 2.3.1

Demonstration: Iron Corrosion

Set up the six iron corrosion reactions described below a day or two before day one of this lesson.

Materials

- 9 long (5–8 cm) uncoated steel nails
- Sandpaper or steel wool
- 4 large test tubes
- 1 test tube rack
- 1 rubber stopper
- Salt
- 2 petri plates
- 2 g powdered agar
- 0.1M potassium ferricyanide
- Phenolphthalein
- Copper wire
- Magnesium ribbon
- Distilled water

Steel Nails

Prepare the steel (iron) nails by buffing the surface with fine sandpaper or steel wool to remove any surface protection.

Test Tube Setup

Add one iron nail to each of the four test tubes. Then

1. Cover the nail in the first test tube with distilled water.
2. Cover the nail in the second test tube with water that has been boiled and then cooled for 10 minutes. Stopper the test tube after the water is added.
3. Cover the nail in the third test tube with distilled water to which you have added 5 grams of NaCl.
4. Fill the fourth test tube with distilled water only until the nail is half submerged.

Place the test tubes in a rack and set it aside for at least 24 hours.

Petri Plate Setup

Make an agar gel by heating 200 ml of water to a gentle boil. Remove from heat and dissolve 2 g of powdered agar or gelatin in the water. After the agar is dissolved, add 10 drops of 0.1M potassium ferricyanide and 6 drops of phenolphthalein.

Prepare two petri plates. Place a straight nail and a bent nail in one of the petri plates. Place three iron nails in the second petri plate: one nail with copper wire wound around it, a second with magnesium ribbon wound around it, and a third clean iron nail. Wind the magnesium and the copper tightly so that there is contact between the nail and the metal. Pour 100 ml of gel into each petri plate and set it aside.

Teacher Resource 2.3.2

Answer Key: Corrosion Chemistry Lab

Introduction

Corrosion reactions are redox reactions in which a metal is attacked by some substance in its environment and converted to an unwanted compound. Corrosion reduces the lifetime of steel products such as bridges and automobiles. Billions of dollars are spent each year replacing rusty metal parts. This turnover also consumes approximately 20 percent of all new iron produced in the United States. In this experiment we can watch the corrosion reaction by using substances that produce a color change when they react with the products of the iron oxidation or oxygen reduction.

Materials

- Colored pencils
- Watch glasses
- Dropper
- Fine sandpaper
- Triangular file
- 0.1 M $K_4Fe(CN)_6$
- 0.1 M $K_3Fe(CN)_6$
- 0.1 M NaCl solution
- Phenolphthalein
- Mild steel bar 2.5 by 6 cm
- Galvanized steel sheet, 4 by 4 cm
- Steel can (food) lids, polymer coated
- Steel can side, tin-coated (use Hunt's tomato sauce can)
- (optional) Pennies, new and old (pre-1982)

Procedures

A. Plain Steel

1. Add 10 drops of phenolphthalein to 100 ml of 0.1M NaCl solution.
2. On a section of mild steel, combine 4 drops of this solution and 3 drops of potassium ferricyanide
3. On a different part of the bar, combine 4 drops of the salt/phenolphthalein solution and 3 drops of ferrocyanide.
4. Cover each area with a watch glass and observe for at least 5 minutes. What changes occur? In the Observations section below, color in the appropriate diagram and record your observations.

B. Polymer Coated Steel

1. Use a triangular file to place a deep scratch on one area of a polymer-coated steel can lid.
2. Place 3 drops of ferricyanide and 4 drops of salt solution on the scratch.
3. On a second area of the polymer coated lid, place the same drops as in step 2, and cover with a watch glass.
4. Observe both areas of the lid for at least 5 minutes. What changes occur? In the Observations section below, color in the appropriate diagram and record your observations.

C. Tin-Coated Steel

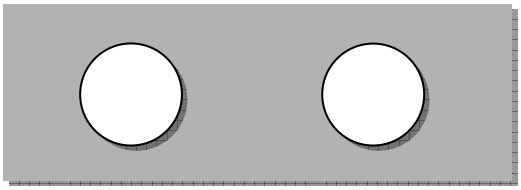
1. Repeat procedure B using a tin-plated steel can side, tin side up.
2. Observe for at least 8 minutes. What changes occur? In the Observations section below, color in the appropriate diagram and record your observations.

D. Zinc-Plated Steel

1. Repeat procedure B using a piece of galvanized steel.
2. Observe for 5 minutes. What changes occur? Is the iron rusting? In the Observations section below, color in the appropriate diagram and record your observations.

Observations

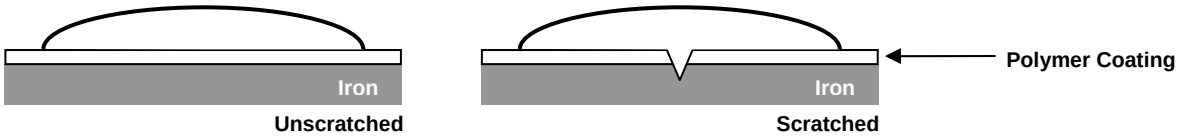
A. Plain Steel



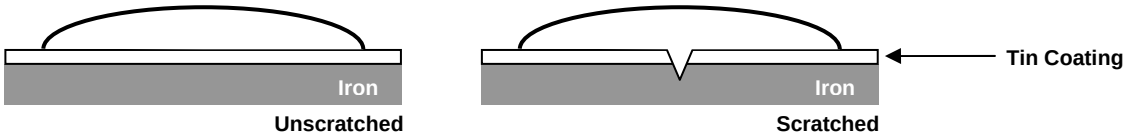
Potassium Ferricyanide $K_3Fe(CN)_6$

Potassium Ferrocyanide $K_4Fe(CN)_6$

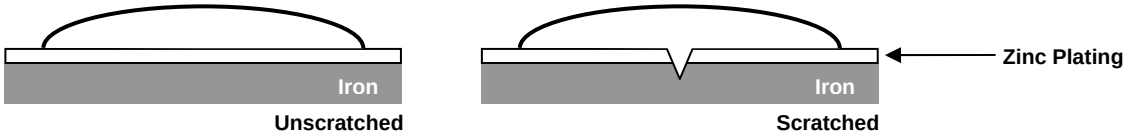
B. Polymer-Coated Steel



C. Tin-Coated Steel



D. Zinc-Plated Steel



Discussion

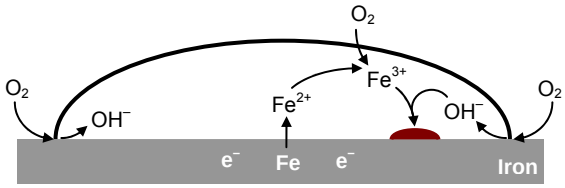
1. What kind of reaction is occurring where the intense pink color is forming? How do you know?

   A reduction reaction is occurring. A base is produced where the pink color is forming, since phenolphthalein turns pink in the presence of a base.

2. If potassium compound in the salt-drop solution turns blue in the presence of Fe^{2+}, then the potassium compound is an indicator for what type of reaction?

   The potassium compound is an indication for an oxidation reaction, since Fe is losing electrons to become Fe^{2+}.

3. As it turns out, ions are spatially separated in this salt-drop experiment because the drop is thicker in the middle than at the edges. Electrochemical reduction reactions that produce OH^- occur at the edges due to readily available oxygen from the air. Electrochemical oxidation reactions occur at the middle of the drop due to the lack of oxygen. Based on your observations in Part A, which chemical reagent (ferro or ferri) would you use to check for rust on iron? Why?



   Potassium ferricyanide would be used to check for rust on iron, since it turns blue in the presence of Fe^2 ions, which are the precursor to rust.

4. What is indicated when no blue color appears when using potassium ferricyanide?

   If no blue color appears when using potassium ferricyanide, then the iron is not oxidizing, and that means rust formation is not occurring (or is being inhibited).

5. Based on your observations, what is the best protective coating for iron to prevent rust? Why?

   Zinc appears to be the best rust-preventing protective coating for iron. It showed the least blue color, which is the indication of iron oxidation. Zinc is used as a protective coating because it oxidizes more easily than iron. The zinc gives up its electrons instead of the iron, thereby preventing the iron from oxidizing.

Teacher Resource 2.3.3

Assessment Criteria: Corrosion Protection Plan Poster

Student name(s): _____

Date: _____

Using the following criteria, assess whether the students met each one.

	Met	Partially Met	Not Met
Poster includes name and location of bridge.	☐	☐	☐
Poster includes attractive graphic of bridge.	☐	☐	☐
Poster text communicates the major environmental factors contributing to corrosion.	☐	☐	☐
Poster text includes what strategies and material are used to protect the bridge from corrosion and maintain its structural integrity, including a schedule for maintenance.	☐	☐	☐
Poster includes the cost necessary for protecting the bridge from corrosion.	☐	☐	☐
The poster is neat, legible, and presentable	☐	☐	☐

Additional comments:

_____

_____

_____

_____

AOE POE Integrated Curriculum Unit: Bridge Builder

Lesson 2.4

English Language Arts

Bridge Disaster News Report

In this lesson, students will learn about the straight news format by reading about contemporary bridge disasters. Students will apply that knowledge to research and writing news reports on the 1940 Tacoma Narrows bridge collapse.

This lesson is expected to take two class periods.

Lesson Framework

Learning Objectives

Each student will:

- Research and record the facts of a bridge disaster using a variety of media sources.
- Write an newspaper article on the bridge disaster event in traditional straight news format

Academic Standards

- Students read a wide range of print and non-print texts to build an understanding of texts, of themselves, and of the cultures of the United States and the world; to acquire new information; to respond to the needs and demands of society and the workplace; and for personal fulfillment. Among these texts are fiction and nonfiction, classic and contemporary works. (NCTE Standards for the English Language Arts, Standard 1)
- Students adjust their use of spoken, written, and visual language (e.g., conventions, style, vocabulary) to communicate effectively with a variety of audiences and for different purposes. (NCTE Standards for the English Language Arts, Standard 4)
- Students employ a wide range of strategies as they write and use different writing process elements appropriately to communicate with different audiences for a variety of purposes. (NCTE Standards for the English Language Arts, Standard 5)

Assessment

Assessment Product	Assessment Criteria
Newspaper article on bridge disaster	Teacher Resource 2.4.1—Rubric: Bridge Disaster News Article

Prerequisites

- Familiarity with the concept that writing must adjusted to account for intended audience.
- Internet research skills, including critical evaluation of source reliability.

Instructional Materials

Teacher Resources

- Teacher Resource 2.4.1—Rubric: Bridge Disaster News Article

Student Resources

- Student Resource 2.4.1—Handout: Writing News Articles
- Student Resource 2.4.2—Template: Straight News Article
- Student Resource 2.4.3—News Report: Tacoma Narrows Bridge Disaster

Equipment and Supplies

- Computer with Internet access
- LCD projector
- Computer lab

Lesson Steps

Step	Min.	Activity
		CLASS PERIOD 1
1	**20**	**Video: Tacoma Narrows Bridge Collapse** Tell students that when bridges are not designed carefully, disaster can ensue. Set the stage for showing a video of the Tacoma Narrows bridge collapse from 1940 by giving a brief history. The first Tacoma Narrows bridge was built in 1940 to connect the Washington State mainland (including Tacoma and Seattle) to the Olympic peninsula. At the time it opened, the Tacoma Narrows bridge was the third longest suspension bridge in the world. Almost immediately after construction was completed, it was discovered that bridge had a alarming tendency to sway and buckle, even in relatively light winds. This up and down motion inspired the bridge's nickname, Galloping Gertie. Despite this unexpected motion, the bridge was still considered structurally sound because it was so massive. However, on November 7, 1940, the bridge began an additional twisting motion which would eventually lead to its collapse. A detailed history of the collapse can be found on the Washington State Department of Transportation website: **http://www.wsdot.wa.gov/tnbhistory/Connections/connections3.htm** Show a video clip of the bridge's oscillations and collapse. You can find many video clips of the bridge's oscillation and collapse by doing an Internet search for "Tacoma Narrows Bridge". After viewing the video, ask students to speculate on what the problem might have been. Tell students that they will be researching this bridge disaster and writing a newspaper article that reports on this event.
2	**20**	**Reading: Minnesota Bridge Disaster News Article** Tell student that though the Tacoma Narrows collapse was unusual (since the bridge was new), bridge collapse are not necessarily uncommon events. Search the Internet for articles on recent bridge collapses, otherwise print and hand out the following article on the collapse of the 1-35W bridge in Minnesota: **http://www.nytimes.com/2007/08/02/us/02bridge.html?scp=2&sq=august+2%2C+2007&st=nyt** Tell students that this article is about a bridge in Minnesota and their goal is to summarize the article in one sentence. Have the students read the article to themselves and write their summary sentences a separate pieces of paper. After everyone has finished, as for several volunteers to read their sentences. Ask students how long it took to get the main point of the article, and which sentence caught their interest. Discuss with the class how the all the key information was provided in the first paragraph, but that additional interesting facts were provided as the article progressed. Explain that different writing techniques are used for newspaper articles, just as the

Step	Min.	Activity
		report writing and creative writing are quite different. The goal of a piece of writing and the intended audience all should be considered. Pass out Student Resource 2.4.1—Handout: Writing News Articles. Introduce or review the characteristics of news reporting.
3	**10**	**Direct Instruction: Writing News Articles** Pass out Student Resource 2.4.2—Template: Straight News Article. Distribute another newspaper article and walk students through the identification of the key elements and point out how the article conforms to the straight news format. For **homework**, have students find their own article of interest. They should read through the article to see closely it adheres to the inverted pyramid format. Have them identify the 5 W's and H of the article.
		CLASS PERIOD 2
4	**50**	**Research: Tacoma Narrows Bridge Disaster** Assign students the role of reporting on the Tacoma Narrows bridge disaster. There are many excellent websites with historical information and interviews on that event. Give them time in class to conduct some research and then write a news article using the straight news format. Alternatively, you can have students research more modern bridge disasters of their choosing. However, the Tacoma Narrows collapse is a good topic since there is great deal of general information available online, but it is difficult to get actual news articles on the event since it took place many decades ago. There are a few (free) articles available, for your reference: • Newspaper article describing the reaction of Leon Moisseiff, designer of the Tacoma Narrows Bridge span, to the collapse of the bridge **http://content.lib.washington.edu/cdm4/item_viewer.php?CISOROOT=/farquharson&CISOPTR=151&CISOBOX=1&REC=19** • Newspaper article describing studies by University of Washington of the rippling movements of the Tacoma Narrows Bridge **http://content.lib.washington.edu/cdm4/item_viewer.php?CISOROOT=/farquharson&CISOPTR=148&CISOBOX=1&REC=7** • Time Magazine account of the collapse **http://www.time.com/time/magazine/article/0,9171,777504,00.html** The first two articles are straight news articles, and third is a more in-depth article.

AOE POE Integrated Curriculum Unit: Bridge Builder

Lesson 2.4

Bridge Disaster News Report

Student Resources

Resource	Description
Student Resource 2.4.1	Handout: Writing News Articles
Student Resource 2.4.2	Template: Straight News Article
Student Resource 2.4.3	News Report: Tacoma Narrows Bridge Disaster

Student Resource 2.4.1

Handout: Writing News Articles

5 Ws and H

Students need to be able to identify the following elements within their assigned news topic. In a straight news article, the lead will contain as many of these elements as is necessary to communicate what the issue is:

- **Who**: who did it, who is responsible, who is charged?
- **What**: what is the situation, what is the issue here?
- **When**: when did this event or situation happen?
- **Where**: where did this event or situation occur?
- **Why**: why did this event or situation happen or occur?
- **How**: how did this happen? This usually requires some explanation or analysis.

Inverted pyramid

- The traditional way of writing daily news articles presents the most important information to the reader first. Picture an upside-down triangle—one with the narrow tip pointing downward and the broad base pointing upward. The broad base represents the most newsworthy information in the news story, and the narrow tip represents the least newsworthy information in the news story. When you write a story in inverted pyramid format, you put the most newsworthy information at the beginning of the story and the least newsworthy information at the end. This form was created to allow a busy reader to read only the first part of the story and understand the gist of the article if he or she didn't have time to finish.
- This structure allow stories to be cut to fit space requirements easier; editors would cut from the bottom up, since the most important information was presented from the top down.
- Inverted pyramid is becoming less and less important to daily papers because of the increased presence of 24-hour news sources. Written articles must present more analytical and substantial articles to compete with the deluge of constant information on breaking news.

Length of paragraphs

- In a straight news article using inverted pyramid style, the paragraphs tend to be shorter rather than longer. Sometimes they are only three sentences in length. Remember that the reader is busy and hurried and that providing information quickly and clearly is the focus of this style of writing.
- In-depth news articles tend to have longer paragraphs, since the assumption is that the reader has more time to read an article like this.

News leads

- The news lead that contains the 5 Ws and the H is called a summary lead.
- Often a summary lead may also be called a "hard news lead." The emphasis here is still on the facts of the story.
- A “soft lead” is a more creative lead. It can employ creative writing strategies to grab the reader’s interest and encourage them to read more. It is often used on “softer” stories like features, human interest stories, profiles, sports stories, and sometime in-depth news articles.

Sources

- All types of articles require sources to be identified and titled.
- Use first and last name, along with a descriptive phrase that explains what that person does that would allow him or her to have this opinion or knowledge on this topic. The reader must understand why this person quoted has knowledge in this area.
- Examples:
  - “The murder is solved,” said Captain Joe Smith of the Forestville Police Department.
  - “Prices for medication are exploding,” said Spokane CVS pharmacist Jane Jones.
- After the first mention of a source, refer to that same source any other time by last name only.
- Don’t rely on anonymous sources. If a source doesn’t want his or her name printed, don’t promise that you won’t. Explain your assignment. Consult your teacher.
- For news articles, whether straight news or in-depth, try to stick with using attribution words like “said” or “stated” or “declared” or “reported.” Avoid more descriptive attribution words that belong in feature articles, like “sing-songed” or “whispered” or “shouted” or “laughed.”
- Even short news articles need direct quotes to give them life and believability. The longer the article, the more direct quotes you need. For a short news article (five paragraphs), you should try to have at least two or three strong direct quotes. Add in more as your article grows.
- You should also include indirect quotation, where you attribute information to the source who said it, but you don’t use their exact words. You are attributing the ideas, the substance of what they said.

Student Resource 2.4.2

Template: Straight News Article

Directions: Use this inverted pyramid template to plan the organization of your news story.

Begin your article about your topic using a summary lead containing the most important elements from the 5Ws and the H.
Paragraph 2: The next most important information after the lead goes here.
Paragraph 3: Information that is slightly less important than that contained in Paragraph 2 goes here. You might want to start including quotes at this point.
Paragraph 4: Information that is less important than that contained in Paragraph 3 goes here. A quote should probably appear in this paragraph.
Paragraph 5: You should be wrapping up your article at this point. Final, least important information can go in this paragraph. Quotes can go here too.

Student Resource 2.4.3

News Report: Tacoma Narrows Bridge Disaster

Directions

Write a news article covering the 1940 Tacoma Narrows bridge disaster. Follow the standard straight news format, using traditional inverted pyramid writing. Your article should include:

- The five Ws and the H
- Supporting details in decreasing importance/interest
- At least two actual quotes
- Consult minimum of three sources of varying types (Internet, books, magazines, etc.) to prepare your article, and include your sources on a separate sheet of paper.
- Your news article should be at least 300 words.

Resources

The following online resources may be useful in your research. Remember to consult other Internet and print sources (books, magazines, etc.) as well.

- University of Washington Libraries, History of the Tacoma Narrows Bridge
  http://www.lib.washington.edu/specialcoll/exhibits/tnb/
- Mark Ketchum's Bridge Collapse Page
  http://www.ketchum.org/bridgecollapse.html
- Underwater Atmospheric Systems, Tacoma Narrows Bridge
  http://www.nwrain.com/~newtsuit/recoveries/narrows/narrows.htm
- Audio interview with Howard Clifford, the last man off the Tacoma Narrows Bridge before it collapsed
  http://www.thenewstribune.com/news/projects/narrows_bridge/

AOE POE Integrated Curriculum Unit: Bridge Builder

Lesson 2.4

Bridge Disaster News Report

Teacher Resources

Resource	Description
Teacher Resource 2.4.1	Rubric: Bridge Disaster News Report

Teacher Resource 2.4.1

Rubric: Bridge Disaster News Report

	Exemplary	Solid	Developing	Needs Attention
Headline	Article has a headline that captures the reader's attention and accurately describes the content.	Article has a headline that accurately describes the content.	Article has a headline that does not describe the content.	Article is missing headline.
5 Ws and H	Article adequately addresses the 5 Ws and H.	The article is missing one of the 5 Ws or H.	The article is missing 2 of the 5 Ws or H.	The article is missing 3 or more of the 5 Ws.
Supporting Details	The details in the article are clear and supportive of the topic.	The details in the article are clear but need to be developed more. Some details may not fit in with the topic.	Most details in the article are clear, but the article does not focus on the topic well.	The details of the article are neither clear nor related to the topic.
Lead Sentence	Lead sentence grabs the reader's attention and focuses the reader on the topic.	Lead sentence tells most important details.	Lead sentence is not clearly connected to the article.	There is no clear lead sentence in the article.
Quotes	At least two quotes, properly attributed	Two quotes, without attribution, or only one attributed quote.	One quote without proper attribution.	No quotes in the article.
Spelling and Grammar	No spelling or grammar errors.	No more than two spelling or grammar errors.	No more than 3 spelling or grammar errors.	Several spelling or grammar errors.