



PASCO Structures System  
**Advanced Structures Set**  
ME-6992B



The PASCO Advanced Structures Set includes the ME-6988A Force Structures Bracket for connecting a structure to a PASCO Force Platform.

## Table of Contents

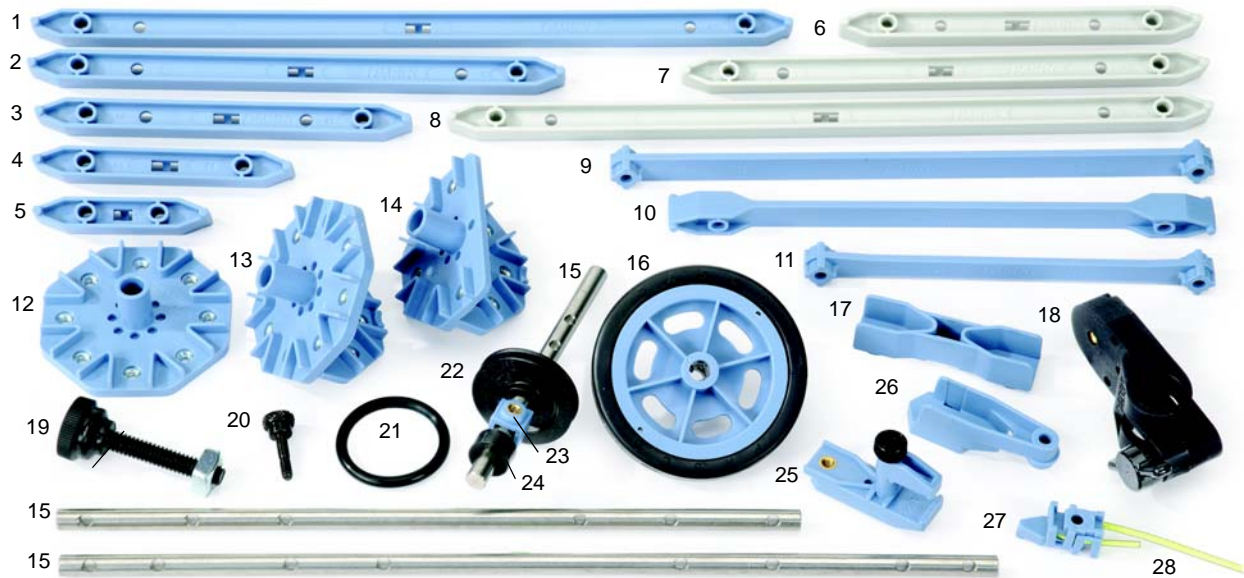
Included Items . . . . .	1
Related and Recommended Equipment . . . . .	2
Introduction . . . . .	2
About the Components . . . . .	3
Adding Load Cells . . . . .	5
Properties of I-Beams . . . . .	6
Simple Triangles . . . . .	6
Trusses . . . . .	7
Common Truss Bridges . . . . .	8
Different Scales . . . . .	8
Measuring Bridge Deflection Under Load . . . . .	9
Bridge Challenges for Students . . . . .	10
Measuring Static and Dynamic Loading . . . . .	10
Forces on a Boom . . . . .	11
Human Leg Model . . . . .	13
Teeter Totter . . . . .	15
Human Back Model . . . . .	17
Tower Crane . . . . .	19
Human Arm Model . . . . .	21
Angle Crane . . . . .	23
Catapult . . . . .	25
Camelback Truss Bridge and Multilength Combinations . . . . .	27
Truss Bridge with Cross Bracing and Trestle with Cross Bracing . . . . .	28
PAstrack Trestle with Cross Bracing . . . . .	29
Tower with Cross Bracing . . . . .	30
Rubber Band Powered “Car” . . . . .	31

Spares Part Numbers and Summary of Extra Equipment . . . . .	32
Bridges That Require an Advanced Set and a Bridge Set. . . . .	33
I-Beam Suspension Bridge Details . . . . .	34
I-Beam Suspension Bridge End Assembly . . . . .	35
I-Beam Suspension Bridge Tower. . . . .	36
I-Beam Suspension Bridge Road Bed Assembly. . . . .	37
Flexible I-Beam Suspension Bridge. . . . .	37
Flat Beam Suspension Bridge . . . . .	38
Cable Stayed Bridge . . . . .	39
Cable Stayed Bridge Details . . . . .	40
Baltimore Bridge and Arched Causeway Bridge Details 1. . . . .	41
Arch Truss Bridge . . . . .	42
Cantilevered Truss Bridge . . . . .	43
Tied Arch Bridge with Cross Bracing . . . . .	44
Double Tied Arch Bridge with Flexible I-Beams. . . . .	45
PAStack Cable Stayed Bridge . . . . .	46
Cable Stayed Bridge Construction Suggestions . . . . .	47
Resonance Structures: Beam and Tower . . . . .	48
Force Platform Structures Bracket. . . . .	51
Technical Support, Warranty, and Copyright. . . . .	54



# Advanced Structures Set

ME-6992B



Included Items	Qty	Included Items	Qty
1. #5 Beam (24 cm long)	24	16. Drive Wheel and Tire	4
2. #4 Beam (17 cm long)	54	17. Straight Connector	24
3. #3 Beam (11.5 cm long)	54	18. Structures Rod Clamp	2
4. #2 Beam (8 cm long)	24	19. Nut and Bolt for PAStack	6
5. #1 Beam (5.5 cm long)	24	20. Screw (6-32)	300
6. #3 Flexible Beam (11.5 cm)	16	21. "O" Ring	12
7. #4 Flexible Beam (17 cm)	16	22. Pulley	12
8. #5 Flexible Beam (24 cm)	16	23. Collet	24
9. Flat 3 X 4 Beam (19 cm)	16	24. Spacer	12
10. Flat #4 Beam (17 cm)	16	25. Sliding Connector	12
11. Flat 2 X 3 Beam (12.5 cm)	16	26. Angle Connector	24
12. Flat Connector	6	27. Cord Tensioning Clip	32
13. Full Round Connector	6	28. Yellow Cord	1 roll
14. Half Round Connector	42	Force Structures Bracket (not shown)	2
15. Axle (2 each of 3 lengths)	6	Storage Box (not shown)	1

The ME-6992B Advanced Structures Set consists of items from the following components of the PASCO Structures System.

ME-6985 Flexible I-Beam Set	ME-6996 Cord Lock Spares
ME-6986 Structures Rod Clamp (2)	ME-6997 Full Round Connectors
ME-6987 Flat Structures Members	ME-6998A Axle Spares
ME-6993 Truss Set Members	ME-6999A Angle Connectors
ME-6994 Truss Set Screws	740-162 Storage Box (12 quart)

Other PASCO equipment is closely related to the Advanced Structures Set..

Related Equipment	Related Equipment
PS-2198 Load Cell Amplifier	ME-6989 Physics Structures Set
PS-2199 Load Cell and Amplifier Set	ME-6990 Truss Set
PS-2200 100-N Load Cell	ME-6991 Bridge Set
PS-2201 5-N Load Cell	ME-6995 Road Bed Spares
PS-2205 Displacement Sensor	PASPORT Interfaces*
PS-2206 Dual Load Cell Amplifier	Data Acquisition Software*

\*See the PASCO catalog or PASCO web site ([www.pasco.com](http://www.pasco.com)) for more information

Recommended Equipment	Recommended Equipment
Hooked Mass Set (SE-8759)	Large Slotted Mass Sets (ME-7566 and ME-7589)
Mass and Hanger set (ME-8979)	Angle Indicator (ME-9495A)
PASPORT Force Platform (PS-2141)	2-Axis Force Platform (PS-2142)

## Introduction

The ME-6992B Advanced Structures Set is one part of the PASCO Structures System. The Advanced Structures Set can be used as a stand-alone set and it can also be combined with other parts of the PASCO Structures System. The Load Cell and Amplifier Set (PS-2199) can be added to measure compression and tension forces in the structure members and other sets of plastic parts are available.

Other parts of the PASCO Structures System include the following:

**Physics Structures Set (ME-6989)** - A set of structure items (e.g., beams, connectors, screws) and other equipment designed for studying kinematics, momentum, energy, and rotation.

**Truss Set (ME-6990)** - A small set of beams, connectors, and screws for building trusses.

**Bridge Set (ME-6991)** - A larger set with road bed and cables for building bridges and roller coasters.

**Load Cell Amplifier (PS-2198)** - Can plug in up to six Load Cells; requires a PASPORT interface to connect to the USB port of a computer.

**Load Cell and Amplifier Set (PS-2199)** - Load Cell Amplifier (PS-2198) with four 100 N Load Cells (PS-2200).

**100 N Load Cell (PS-2200)** - Strain gauges mounted on a beam with no electronics so a Load Cell requires a Load Cell Amplifier (PS-2198) or Dual Load Cell Amplifier PS-2206).

**5 N Load Cell (PS-2201)** - Strain gauges mounted on a beam with no electronics so a Load Cell requires a Load Cell Amplifier or Dual Load Cell Amplifier.

**Displacement Sensor (PS-2205)** - A PASPORT Sensor and a digital displacement indicator designed to measure the deflection of parts of a structure such as a truss or a bridge.

**Dual Load Cell Amplifier (PS-2206)** - Can plug in one or two Load Cells; requires a PASPORT interface to connect to the USB port of a computer.

## About the Components

### Beams

There are five sizes of plastic I-Beams, labeled #1 through #5. Beam #1 is the shortest beam. There are three sizes of *Flexible* I-Beams labeled #3, #4, and #5, and three sizes of *Flat* Beams labeled 2 X 3, F4, and 3 X 4.

### Assembling Beams

All beams attach to connectors in the same way. Use the included screws (6-32, slotted) to attach beams to a connector (such as the half round connector) as illustrated.

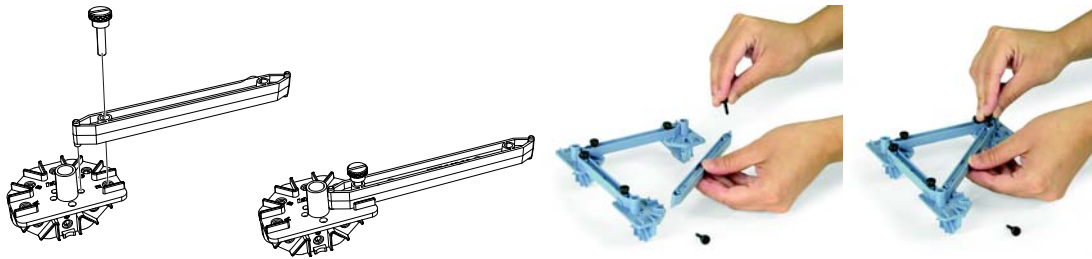


Figure 1: Attaching beams to connectors

### Flexible I-Beams

Flexible I-Beams are the same size as the #3, #4, and #5 I-Beams, but they can be used to dramatically demonstrate structure failure under a heavy load. The beams will return to their original shape when the load is removed.



Figure 2: Flexible I-Beams

Flexible I-Beams are also used in the construction of suspension bridge models.

## Flat Beams

Flat Beams are used for cross-bracing.

## Attaching Cords

When attaching cords for lateral bracing or for suspension or cable-stayed bridges, Cord Tensioning Clips are used to assist in adjusting the tension in the cords.

The Cord Clip does not come apart. It is best to thread the cord through the clip before the clip is installed on the bridge or structure. Prepare to thread the cord by holding the top half of the clip as shown in Figure 4a so the two halves of the clip will separate, leaving an opening through which the cord is threaded. The cord is inserted into the end opposite the pointed end of the clip. The cord should be looped back through the clip as shown in Figure 4c. Then the Cord Clip can be used in the structure, using the attachment screw to tighten the clip shut. To adjust the cord tension, loosen the screw and pull on the cord to the desired tension and then tighten the screw.

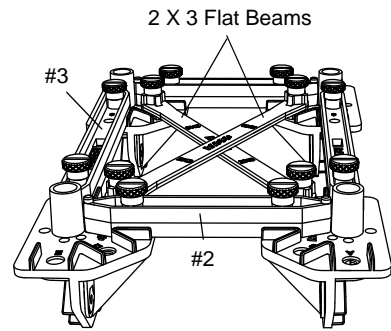


Figure 3: Flat Beams

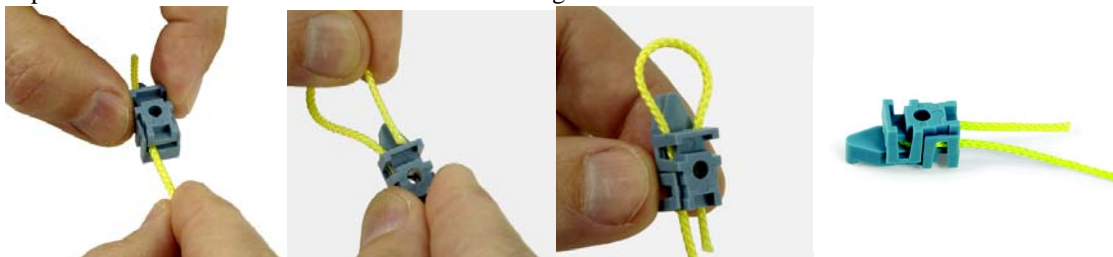


Figure 4a: Hold half of the cord clip so the two halves separate

Figure 4b: Loop the cord back through the cord clip

Figure 4c: The cord goes around the screw hole

Figure 4d: The cord clip is ready to be attached to the structure using a screw

## Connectors

**Half Round Connector:** The half round connector has eight slots, labeled A through H, for accepting beams.

**Full Round Connector:** The full round connector has eleven slots, labeled A through H and X, Y, and Z, for attaching beams

**Flat Connector:** The flat connector has eight slots, labeled A through E, and X, Y, and Z, for attaching beams.

**Straight Connector:** The straight connector can connect two beams to make a longer beam.

**Angle Connector:** The angle connector can allow a beam to be connected to a half round connector, full round connector, or flat connector at an angle different than zero, 45, or 90 degrees. The Angle Connector also allows for a small adjustment of the length of the beam.

**Sliding Connector:** The sliding connector allows one beam to be connected to another beam at any position along the length of the second beam. To use the sliding connector, loosen the thumbscrew and rotate the top “jaw” to the side. Place the beam onto the lower part of the connector, rotate the top “jaw” into place, and tighten the thumbscrew.

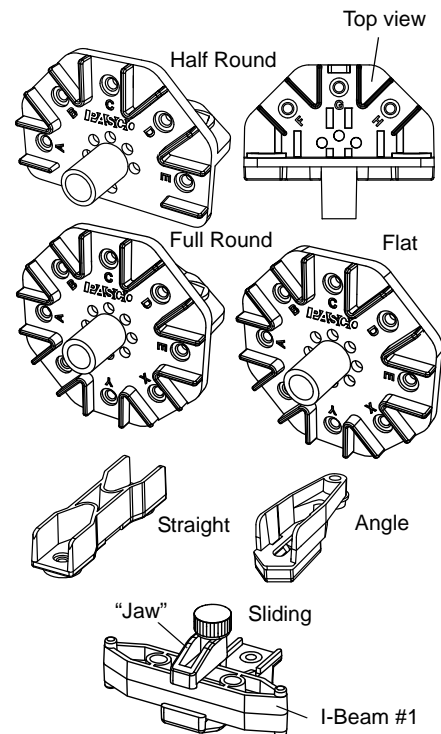


Figure 5: Connectors

Nut and Bolt for PAStack: The square nut and bolt can be used with a flat connector to fasten a bridge or other structure to the PASCO PAStack (see the PASCO catalog or web site at [www.pasco.com](http://www.pasco.com) for information about PAStack equipment.)

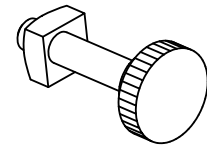


Figure 6: Nut and Bolt for PAStack

## Axles, Pulleys, Spacers, Collets, and Drive Wheels

**Axles:** There are two each of three different lengths: 10.4 cm (4.1 in), 21.3 cm (8.4 in), and 26.6 cm (10.5 in). Each axle is 0.635 cm (0.250 in) in diameter.

**Pulleys:** There are twelve pulleys, each 3.175 cm (1.250 in) in diameter and 0.558 cm (0.220 in) wide. To make a wheel, put one of the “O” rings into the pulley’s groove.

**Spacers:** There are twelve spacers, each 0.635 cm (0.250 in) inside diameter, 1.25 cm (0.50 in) outside diameter, and 0.635 cm (0.250 in) wide. **Collets:** There are twenty-four collets that can be used with screws (6-32) to hold pulleys and spacers in place on an axle.

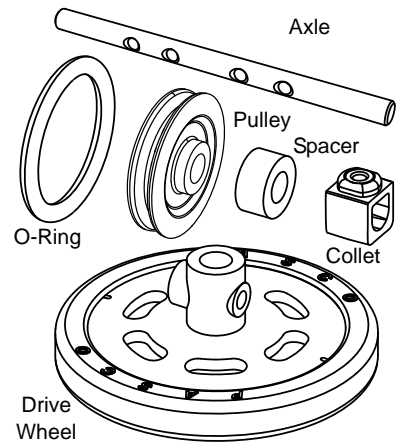


Figure 7: Axle items

**Drive Wheel with Tire:** There are four drive wheels with tires. The drive wheel can be attached to an axle using a thumbscrew. To attach the wheel firmly to the axle, line up a hole on the axle with the thumbscrew hole on the wheel. If the rubber tire is removed, the wheel can be used as a large pulley.

## Force Platform Structure (ME-6988A)

The PASCO model ME-6988A Force Platform Structures Bracket includes two brackets and four thumbscrews. The adapter bracket is designed to connect members of the PASCO Structures System to a PASCO Force Platform (not included). The brackets can also serve as foundation plates for larger structure models. (Please see the Force Platform Structures Bracket instruction sheet for more information.)

## Adding Load Cells

To measure the compression and tension forces in individual members, add load cells (e.g., PASCO Model PS-2200) to any PASCO Structure. Replace a beam with two shorter beams and a load cell.

#5 beam = load cell + two #3 beams

#4 beam = load cell + two #2 beams

#3 beam = load cell + two #1 beams

Use thumbscrews to attach two beams to a load cell as shown in Figure 8.

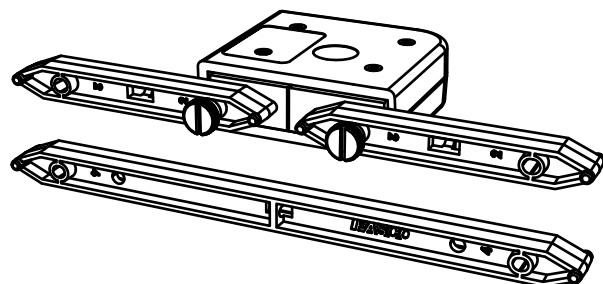


Figure 8: A load cell combined with two #2 beams is the same length as a #4 beam

*When using load cells, assemble your structure with the screws loose.* This will simplify the analysis by ensuring that the members experience only tension and compression without moments.

See the instructions that came with the load cells for details about how to connect the load cells to an interface or datalogger and collect data.



### Example: Bridge with Load Cells

The bridge shown in Figure 9 incorporates six load cells to measure the tension or compression in various members. A hanging mass is used to apply load. The mass is adjusted so that the compression in one of the legs is 1.0 N. Compression is registered as a positive value and tension as a negative value.

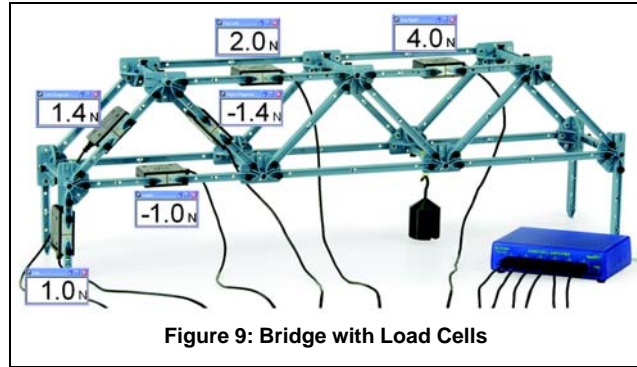


Figure 9: Bridge with Load Cells

If the screws are loose, the theoretical analysis of the bridge can be carried out by assuming that the net force at each node is zero. Thus, the vertical component of compression in the left-most diagonal member must be 1 N (to oppose the force applied by the leg). The horizontal component must also be 1 N since the member is at a 45° angle. The predicted resultant force is:

$$\sqrt{(1.0\text{ N})^2 + (1.0\text{ N})^2} = 1.4\text{ N}$$

The actual measured force confirms the theory.

### Calibration of Load Cells

Load cells are factory calibrated; however, you can re-calibrate them in software or on the datalogger. Assemble the fixture shown in Figure 10 to support the load cell. See the documentation for your software or datalogger for instructions.

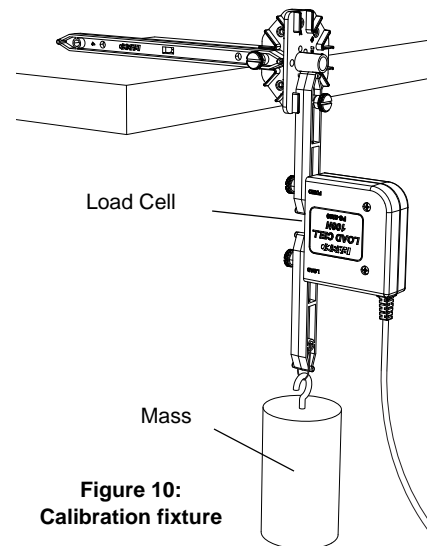


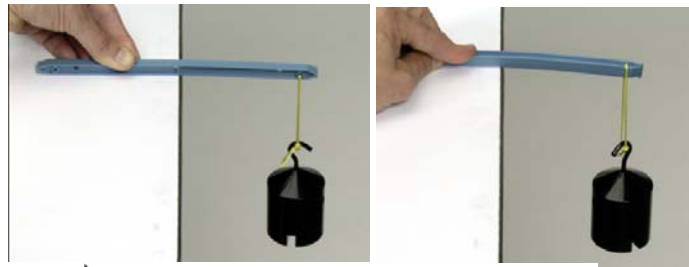
Figure 10: Calibration fixture

When calibrating a load cell, it is necessary to apply a known load. Hold or clamp the fixture at the edge of a table and hang a mass from it as shown.

Note that the hanging mass applies tension to the load cell; therefore the known force that you enter into the software or datalogger should be a negative value. For example, if the mass is 1.0 kg, the applied force is -9.8 N.

## Properties of I-beams

Figure 11 shows the difference between the X and Y bending moments of an I-beam.



## Simple Triangles

Most structures are made of isosceles right triangles as shown in Figure 12.

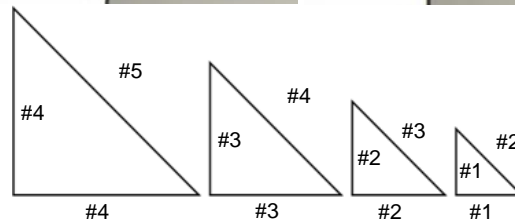
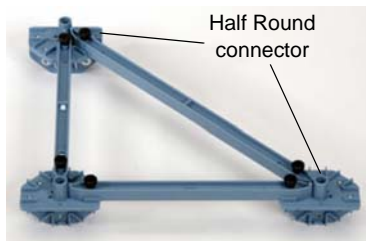


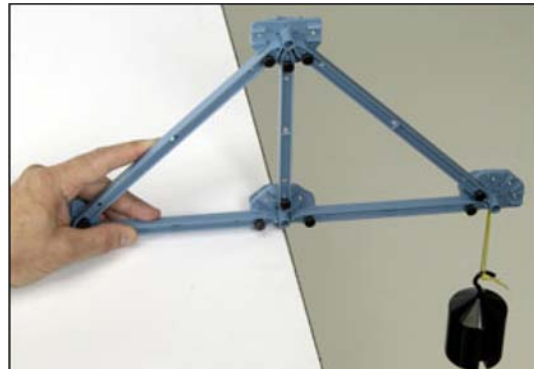
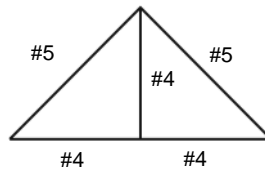
Figure 12: (Left) A triangle made from a #5 beam and two #4 beams. (Right) Combinations of beams to make triangles.

# Trusses

## Kingpost Truss

Figure 13 shows a simple kingpost truss made from #5 and #4 beams. Use a hanging mass to apply a load.

Lay the kingpost truss on the table to compare its horizontal and vertical stiffness.



**Figure 13: A simple kingpost truss**

To build a three-dimensional structure, connect two trusses with #4 beams (Figure 14).

Add cross bracing to increase stiffness.

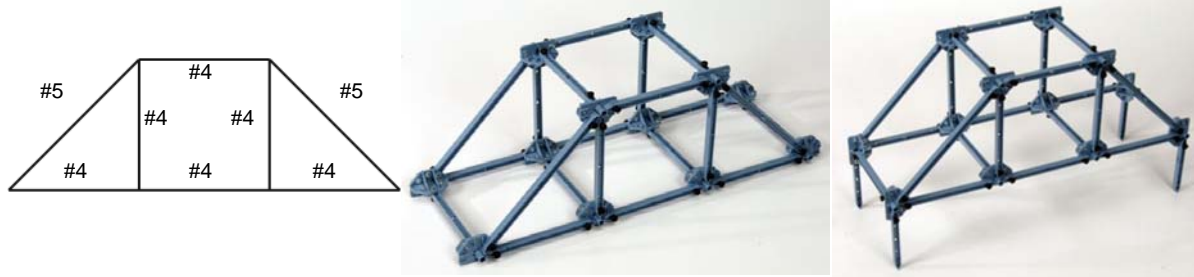


**Figure 14: (Left) A three-dimensional kingpost truss structure. (Right) Kingpost truss with cross bracing.**

## Queenpost Truss

To make a queenpost truss, separate the kingpost truss in the middle and add a square section.

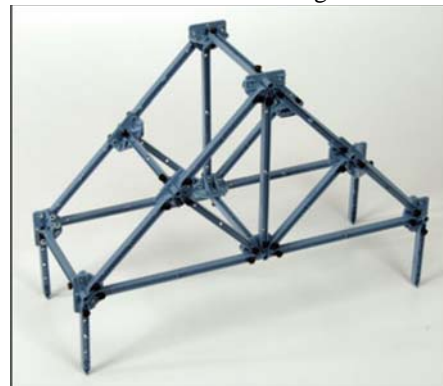
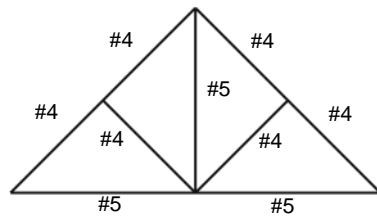
Legs can be added to any truss or bridge (Figure 15).



**Figure 15: (Left) Diagram of queenpost truss (Middle) Queenpost truss (Right) Queenpost truss with legs**

## Roof Truss

Use #4 and #5 beams to build a simple roof truss or a roof truss structure with legs.



**Figure 16: Roof truss**

# Common Truss Bridges

## Warren Bridge

The Warren Bridge (Figure 17) is a simple type of bridge consisting of a series of triangles. However, a simple Warren Bridge is not practical for supporting a deck (road bed). Vertical members can be added to support the deck. Additional verticals can support an upper deck.

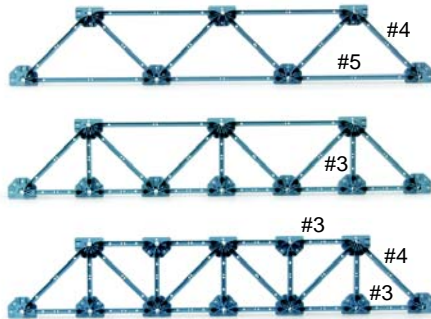


Figure 17: (Top) Warren bridge (Middle) Warren with deck verticals (Bottom) Warren with verticals

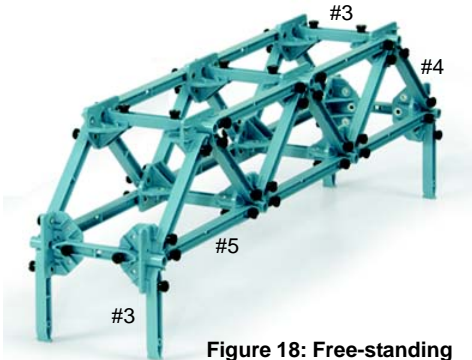


Figure 18: Free-standing Warren bridge

To make a free-standing bridge, begin by laying out one side of the bridge on a table. Then build the other side of the bridge. Join the two sides of the bridge attaching the floor beams and the top cross beams. Use additional members as piers to support the bridge. (Figure 18).

## Different Scales

It is possible to build bridges of two different scales. Figure 19 shows a Warren with Verticals built to two different scales.

In spanning a particular distance, why wouldn't you use the smaller scale bridge and add more panels? An examination of the forces in the members of each size bridge will give the answer. If the smaller and larger bridges have the same number of panels and experience the same load, the forces in any member of the smaller bridge is the same as the same member in the larger bridge. Each additional panel is submitted to larger forces. This can be explored using load cells. See the section on **Measurement of Static and Dynamic Loads**

Figures 20 and 21 show different bridges. Investigate how the forces in these bridges differ from the Warren.



Figure 19: Smaller and larger scale Warren with verticals

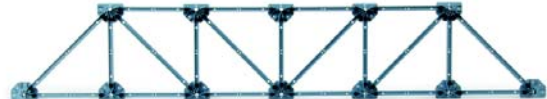


Figure 20: (Top) Pratt. (Bottom) Howe

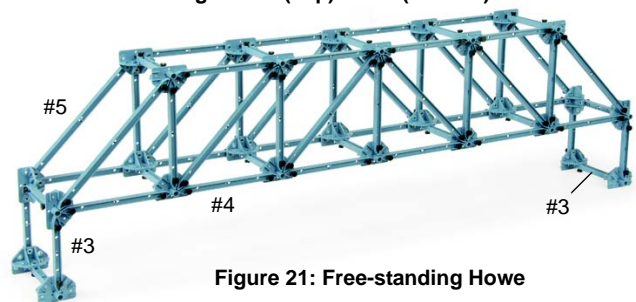


Figure 21: Free-standing Howe



## Measuring Bridge Deflection Under Load

Because the members are made of plastic, it is easy to show bending in a bridge using relatively small loads.

NOTE: Do not attempt to load the bridge to the point of breaking.

### Using a Motion Sensor

In Figure 22, the bridge is loaded by hanging a weight (Large Slotted Mass Set, PASCO Model ME-7566) from the center of the bridge. A Motion Sensor (PS-2103) is placed on the floor and pointed up toward the bottom of the weight hanger. A PASPORT interface (in this case, the Xplorer GLX, PS-2002) is used to record the amount of mass and the distance to the bottom of the weight hanger. A graph of the deflection as a function of the load is shown next to Figure 22.

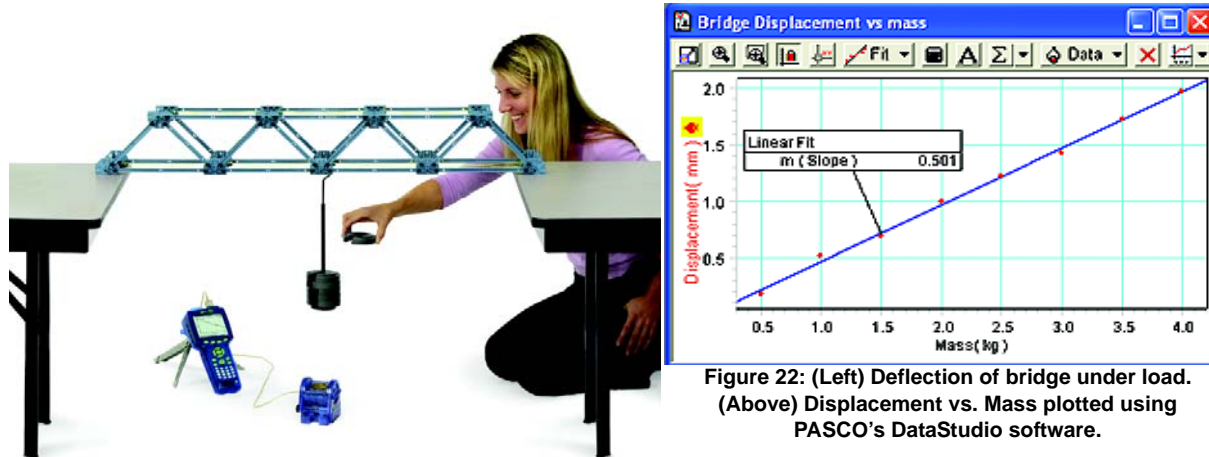


Figure 22: (Left) Deflection of bridge under load. (Above) Displacement vs. Mass plotted using PASCO's DataStudio software.

Hint: For the GLX, set the Motion Sensor sample rate to 50 Hz. In the Sensor Setup window, change the 'Reduce/Smooth Averaging' from 'Off' to '5 points'.

### Using Load Cells

Figure 23 shows two bridges of the same type but different scale. For a given load the deflection is different. Also note that the forces in some of the members are being measured using load cells to discover the difference caused by the size of the bridge.

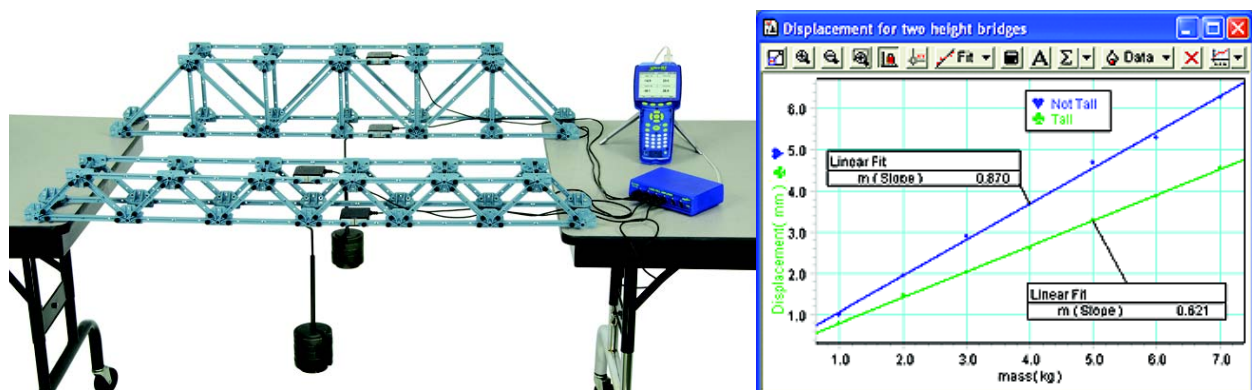


Figure 23: (Above) Same load for different scale bridges. (Right) Displacement vs. Mass

## Bridge Challenges for Students

Perhaps the best way for students to learn about bridges is to give them a task to accomplish with limited resources by any means possible. Here are two suggestions to challenge your students.

## Span a Gap

Give each group a set of plastic, half of a Bridge Set or a Truss Set. The goal is to span a gap of 60 cm. Then find the member with the greatest compression and change the design of the bridge to minimize the maximum compression.

## Least Deflection Under Load

Give each group a Bridge Set. The goal is to span a given distance with a bridge that has the least deflection under load. The bridge is loaded with a particular load that the bridge must be able to bear. The bridge that has the least deflection is the winner.

# Measuring Static and Dynamic Loading

## Static Load

Apply a static load to the bridge by hanging a hooked mass from one of the floor beams and insert load cells into the structure as shown in Figure 24. Loosen all the screws in the structure so the members are resting on their pins. This will eliminate any extra moments due to the screws and the tension and compression readings will agree with the calculated values.

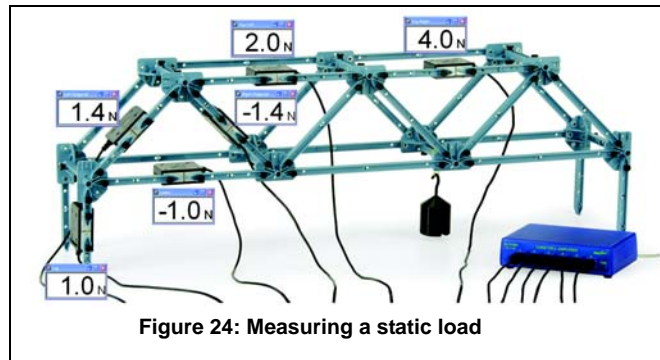


Figure 24: Measuring a static load

## Dynamic Load

With the load cells inserted as shown in Figure 25, push the Dynamics Cart with its extra mass across the bridge. Zero the load cells before the measurement. Examine which members are under tension or compression.

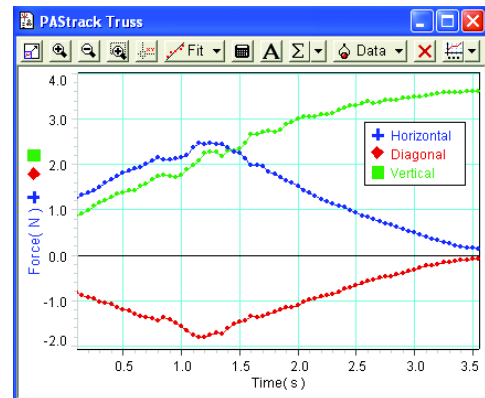
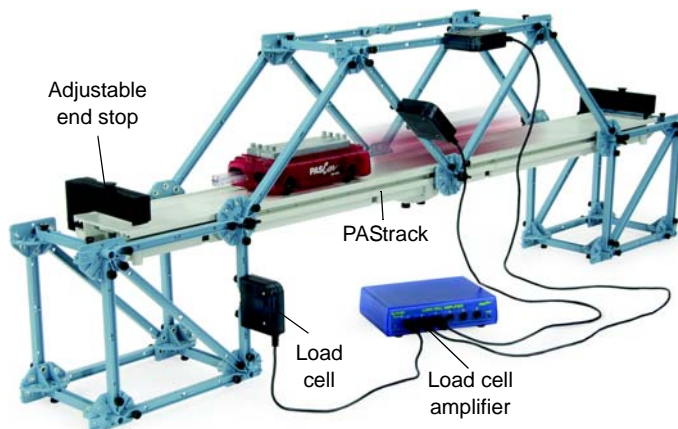
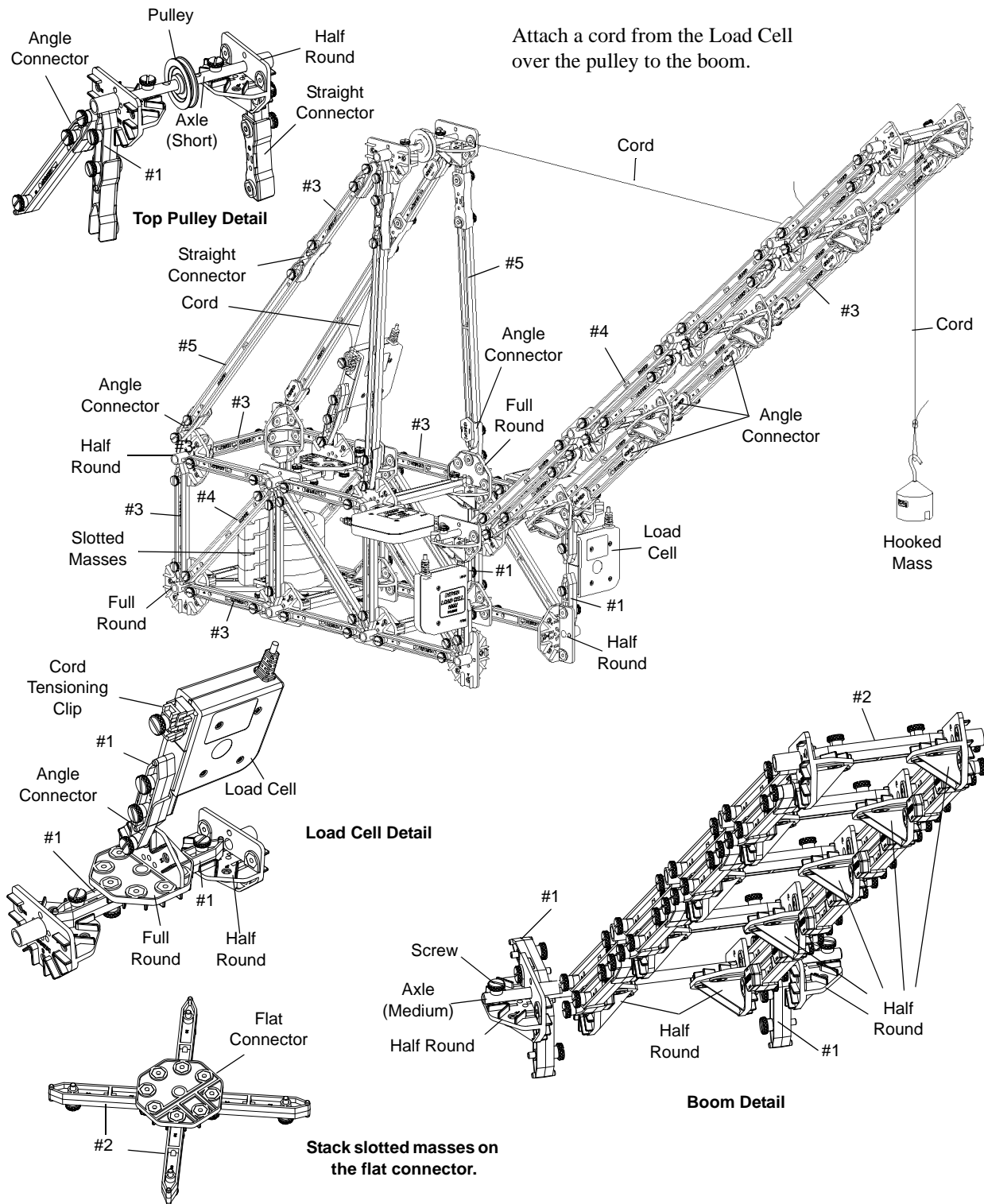


Figure 25: (Above) Recording the forces measured by the load cells as the cart traverses the PASTrack bridge. (Right) DataStudio plot of load cell data.

# Forces on a Boom



Extra Equipment	Model	Extra Equipment	Model
Hooked Mass Set	SE-8759	Angle Indicator	ME-9495
Large Slotted Mass Set	ME-7566	Load Cell & Amplifier Set	PS-2199

## Forces on a Boom: Details

### Load Cells

The “Forces on a Boom” structure is shown with four Load Cells measuring the horizontal and vertical forces of the axle on the base of the boom. The experiment can be performed using only two Load Cells on the base, both on one side, but care must be given to ensure that the boom is centered and balanced side-to-side. The actual force will be two times the measured value.

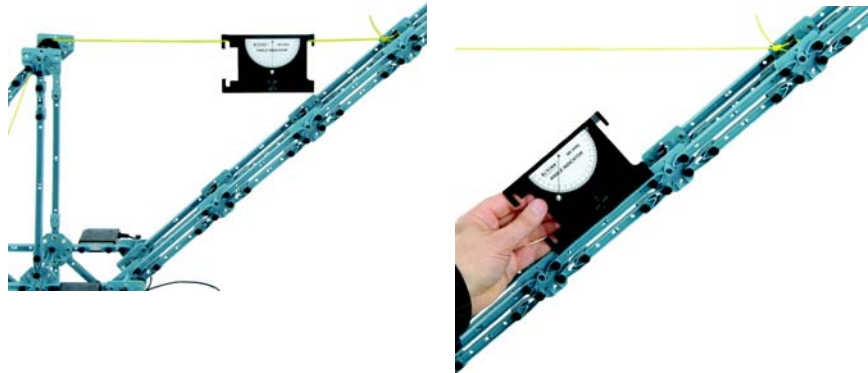
### Suggestions

The triangular support structure for the upper pulley is constructed to allow the cord to be horizontal. By using different components, students can change the height of the pulley and thus vary the angle of the cord. How does that affect the measured forces?

The supporting cord is shown tied to a cross member near the end of the boom. What changes if the cord is moved to the end of the boom or to a cross member closer to the base of the boom?

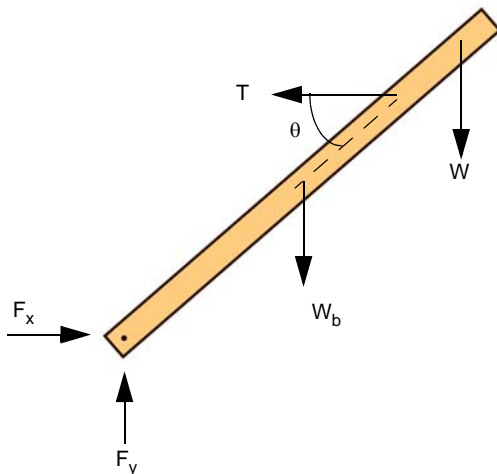
### Angle Indicator

The ME-9495 Angle Indicator can be used both on the cord and on the boom itself.

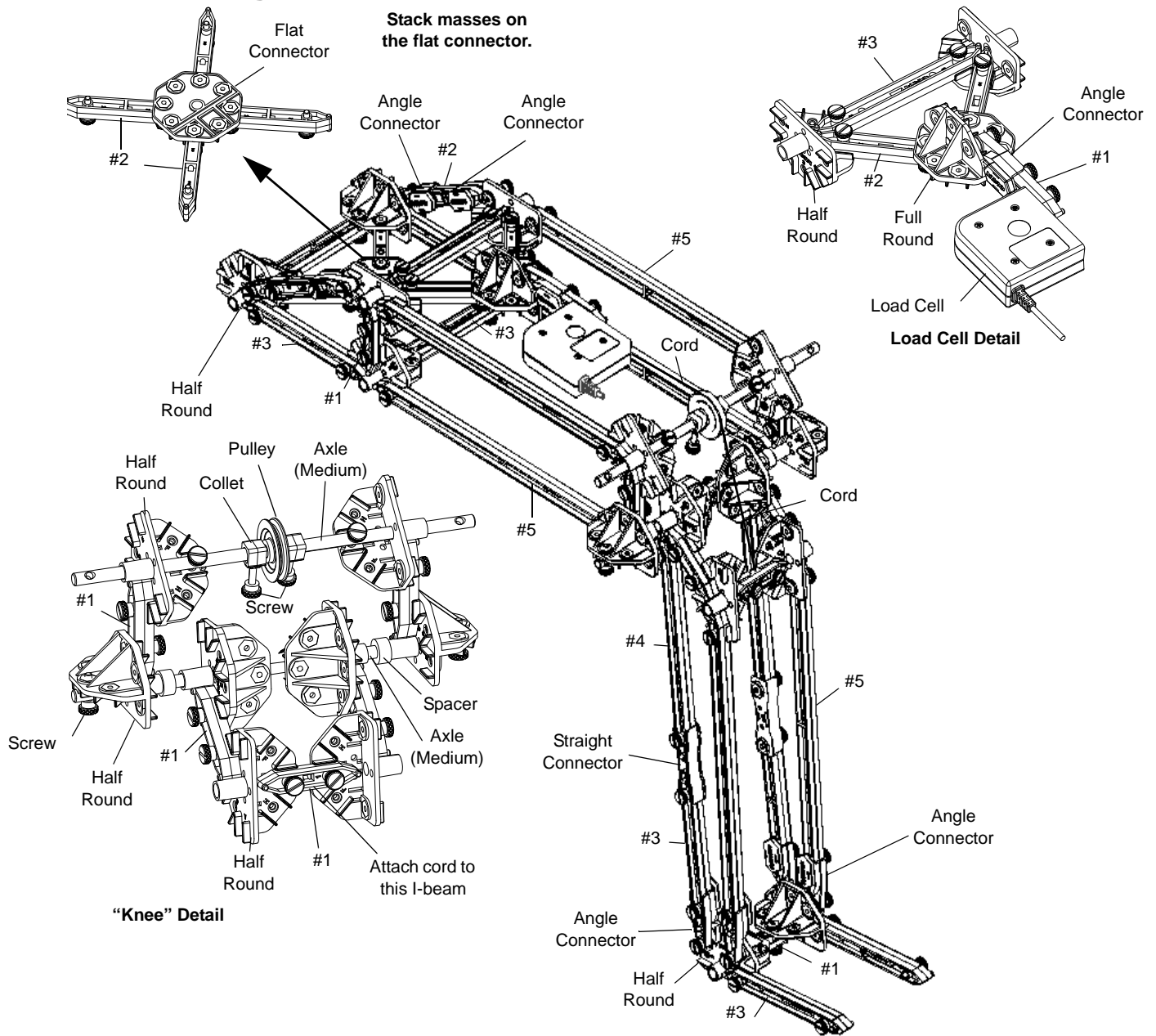


### Force Vector Diagram

The following diagram shows the various forces acting on the boom.



# Human Leg Model



Use a cord tensioning clip to connect a cord to the Load Cell. Put the cord over the pulley and attach the end to the front cross-member of the “knee”.

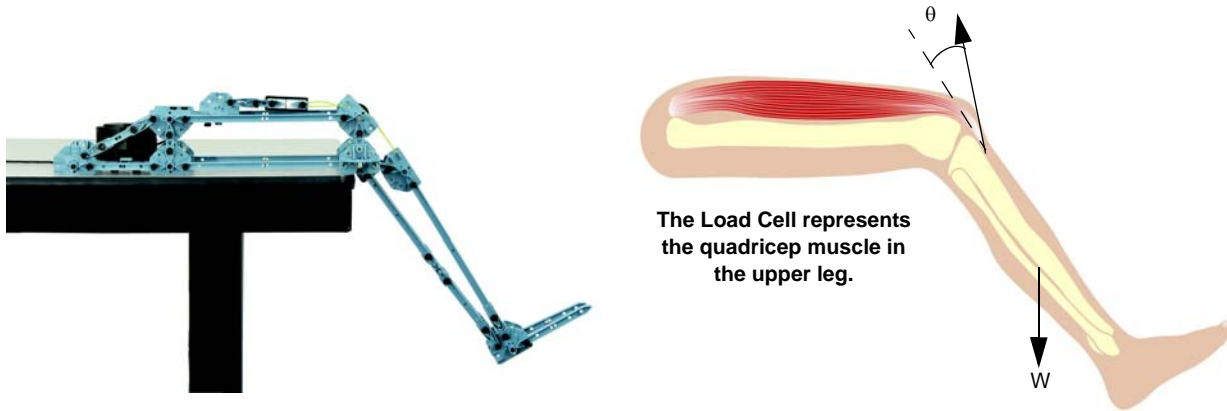
Extra Equipment	Model
Large Slotted Mass Set	ME-7566
Large Table Clamp	ME-9472
Load Cell & Amplifier Set	PS-2199



## Human Leg Model: Details

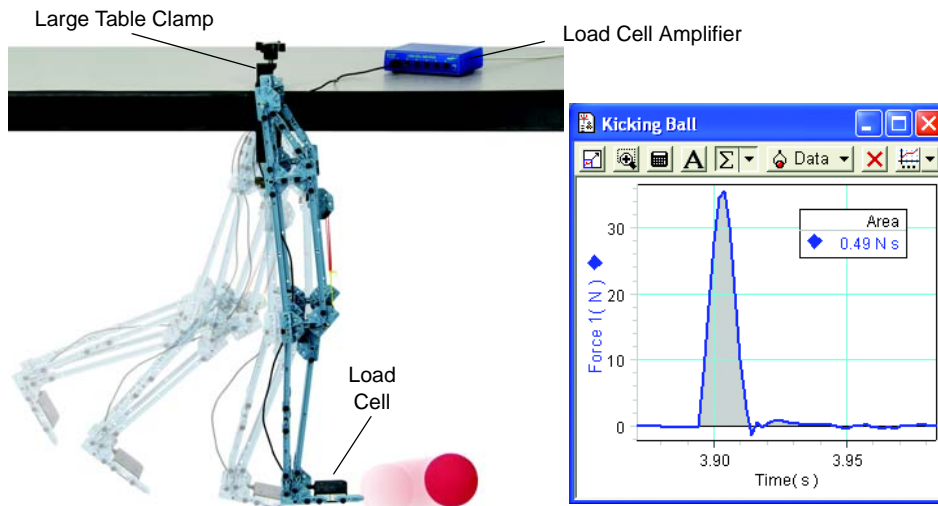
### Knee Forces

Directly measure the force needed to support the leg at various angles.

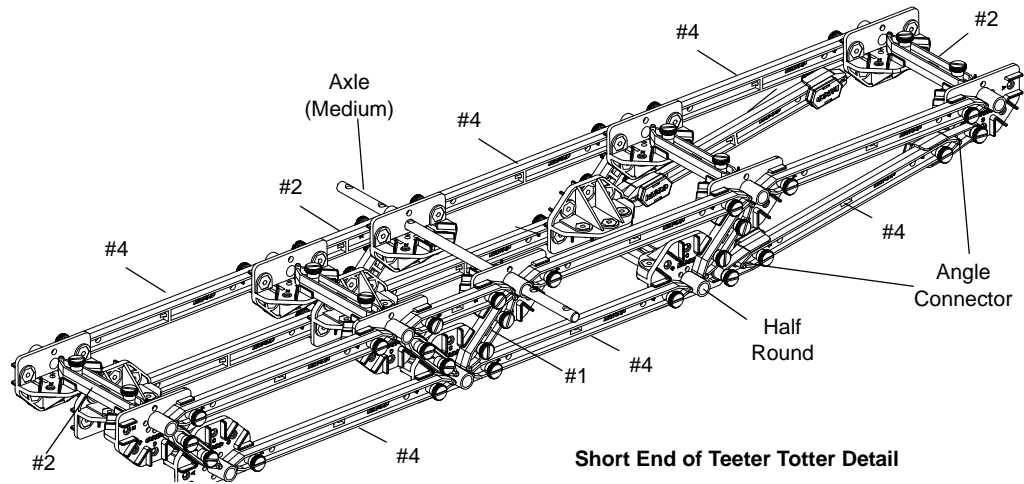


### Leg Model

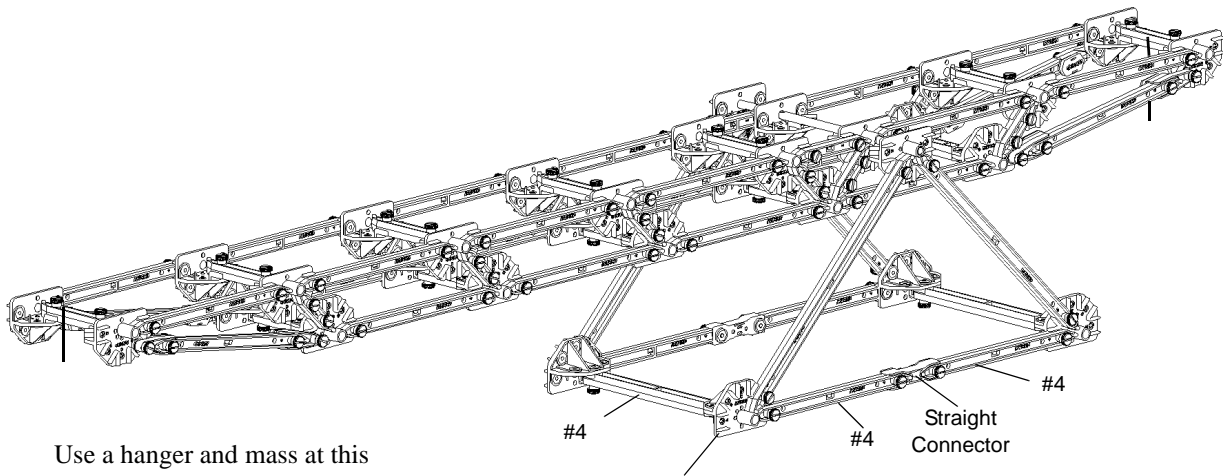
The articulated leg uses a rubber band (not included) as the quadriceps muscle and has a Load Cell on the foot to measure the force that the “toe” exerts on the ball. The impulse (area under the curve of force versus time) is equal to the resulting momentum of the ball.



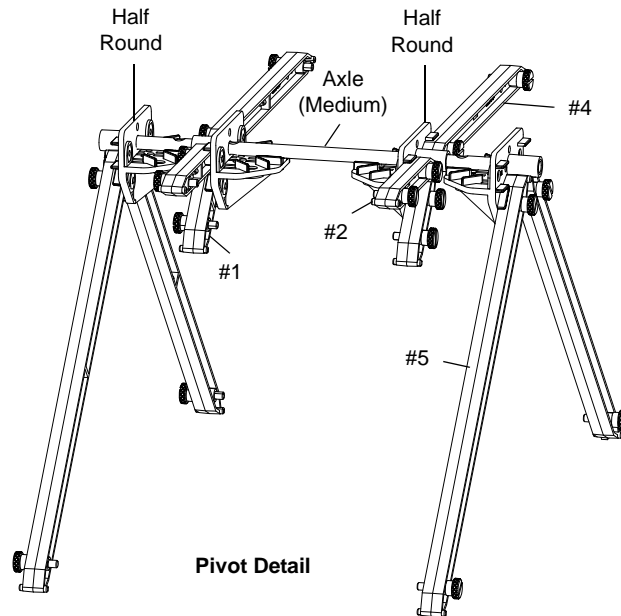
# Teeter Totter



Short End of Teeter Totter Detail



Use a hanger and mass at this end and a hooked mass at the other end.



Pivot Detail

Extra Equipment	Model
Hooked Mass Set	SE-8759
Mass and Hanger Set	ME-8979

## Teeter Totter: Details

### Suggestions

Vary the length of the teeter totter by increasing or decreasing the number of segments or sections.

Vary the placement of the pivot: it does not have to be as shown.

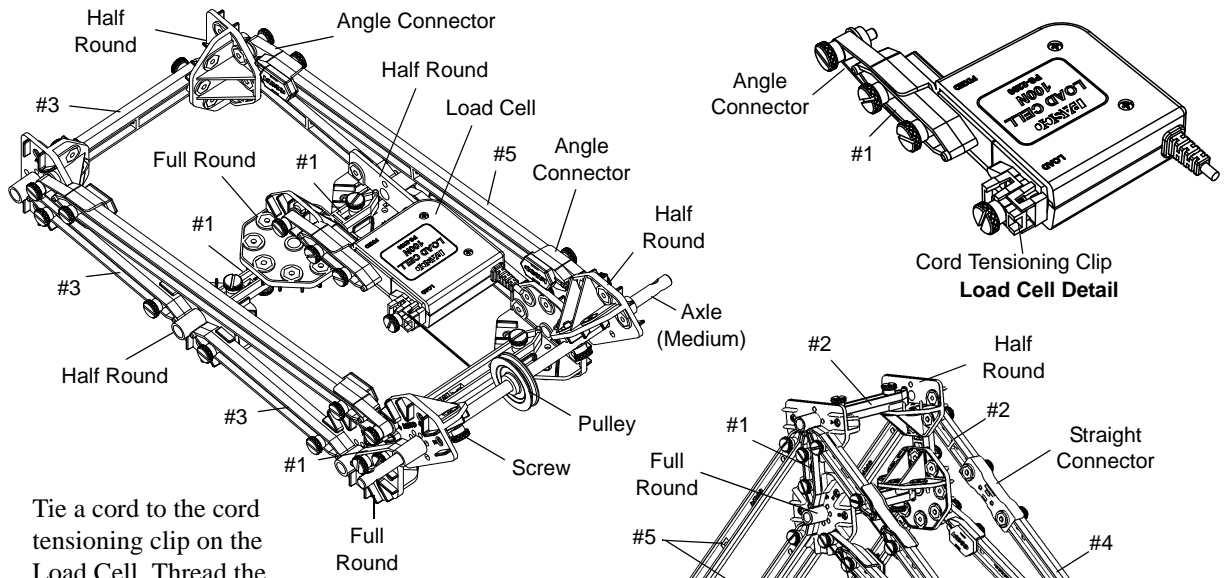
Place the hanging masses at different locations.



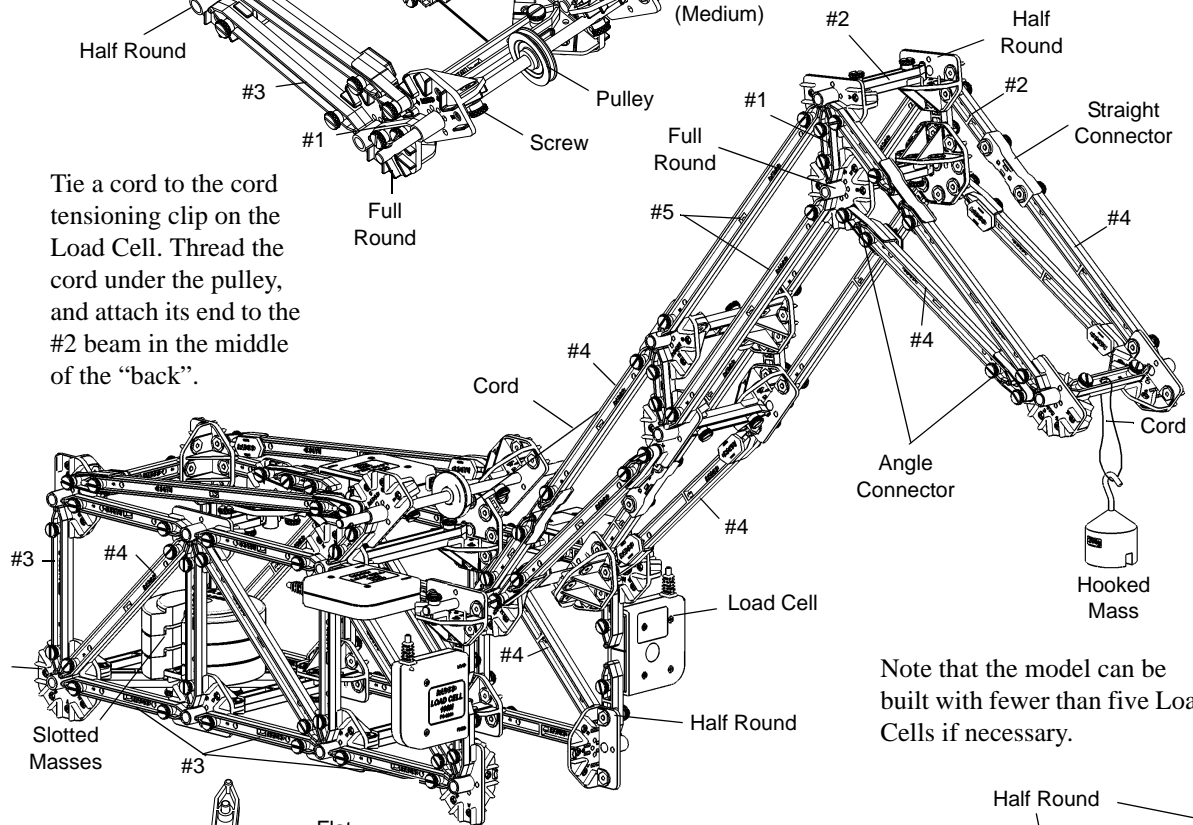
How will you know that the torque on the right side equals the torque on the left side?



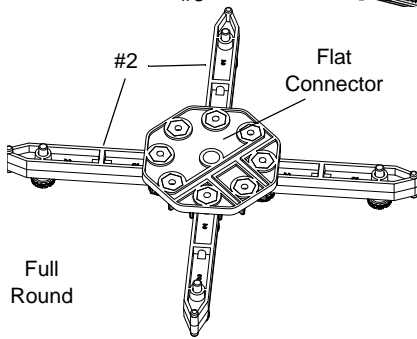
# Human Back Model



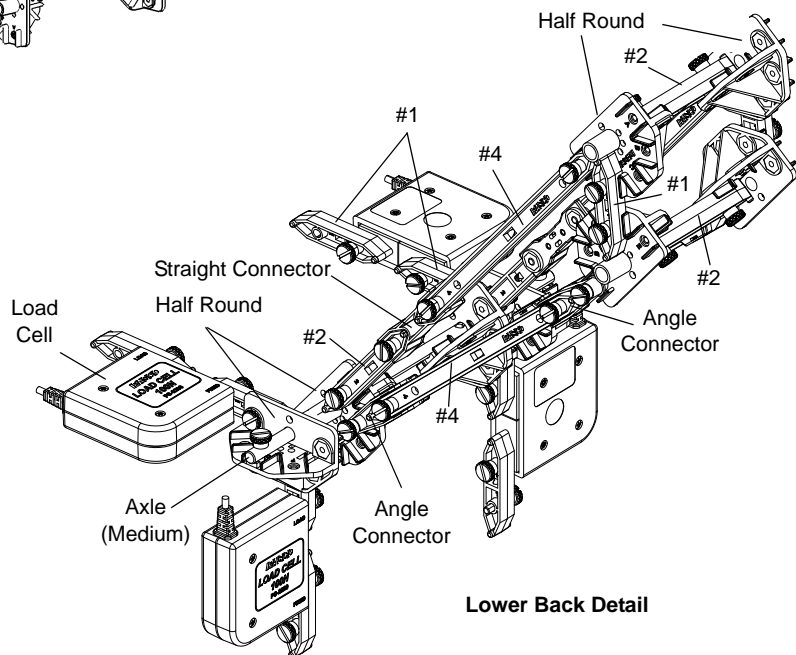
Tie a cord to the cord tensioning clip on the Load Cell. Thread the cord under the pulley, and attach its end to the #2 beam in the middle of the "back".



Note that the model can be built with fewer than five Load Cells if necessary.



Support for slotted masses

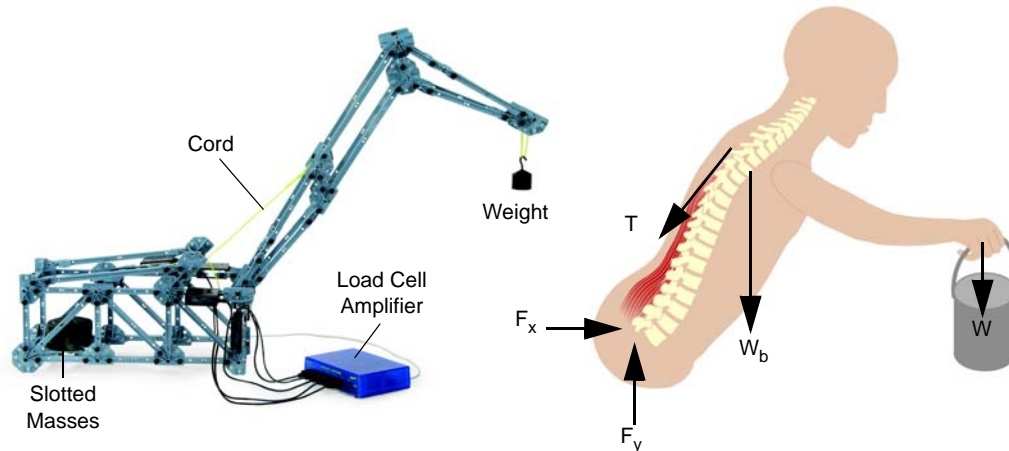


Lower Back Detail

## Human Back Model: Details

### Force Vector Diagram

The following diagram shows the force vectors acting on the human back model.



### Load Cells

The Load Cells directly measure the forces exerted on the back model. The structure is shown with four Load Cells measuring the horizontal and vertical forces of the axle at the base of the 'spine'. The experiment can be performed using only two Load Cell (both on one side) but care must be taken to ensure that the 'spine' is centered and balanced side-to-side. The actual force is thus twice the measured value.

### Suggestions

Experiment with the 'back' at different angles and use the Load Cell to measure the tension in the cord.

What is the affect of increasing or decreasing the angle of the 'back'?

Experiment with the amount of weight attached to the end of the 'arm'.

Does doubling the weight also double the tension in the cord attached to the Load Cell?

What happens to the horizontal and vertical forces at the base of the 'spine'?



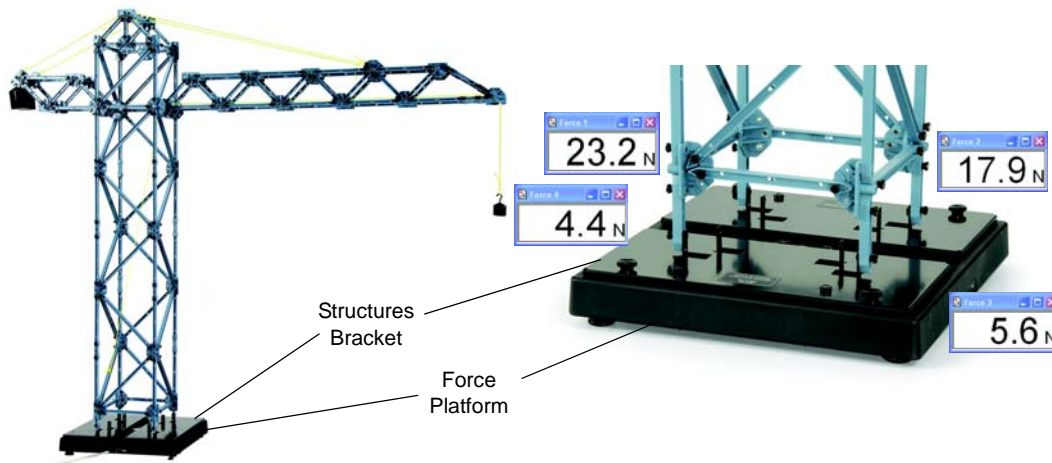
## Tower Crane: Details

Extra Equipment	Model
Hooked Mass Set	SE-8759
Force Platform	PS-2141 or CI-6461
Force Platform Structures Bracket	ME-6988

### Force Platform

The Tower Crane is shown with #1 I-beam members at the bottom of the base. They are needed only when the structure is used with a Force Platform and the ME-6988 Force Platform Structures Bracket.

The Force Platform is supported by four individual Load Cells that combine to measure the total vertical force on the platform. The ME-6988 Force Platform Structures Bracket is needed to attach the I-beam members of the Tower Crane to the Force Platform.



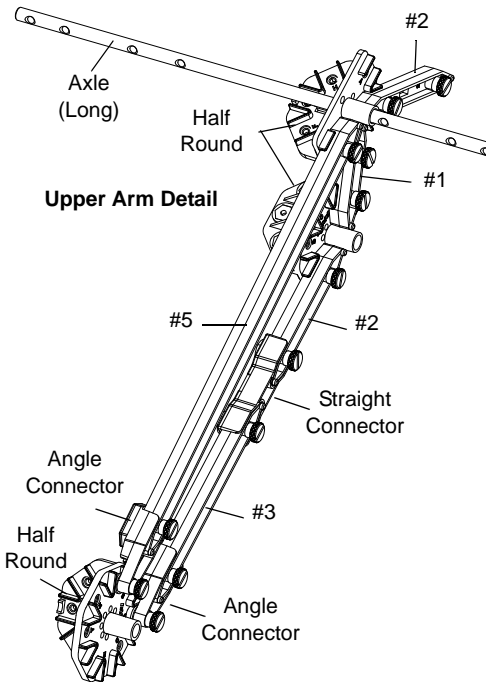
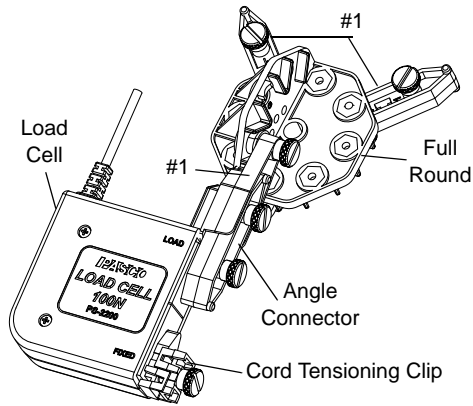
### Suggestions

The drawing shows the supporting cords attached to the front most cross beam of the long end of the boom. If the support cords are attached closer to the tower, as shown in the photograph above, how does that affect the tension?

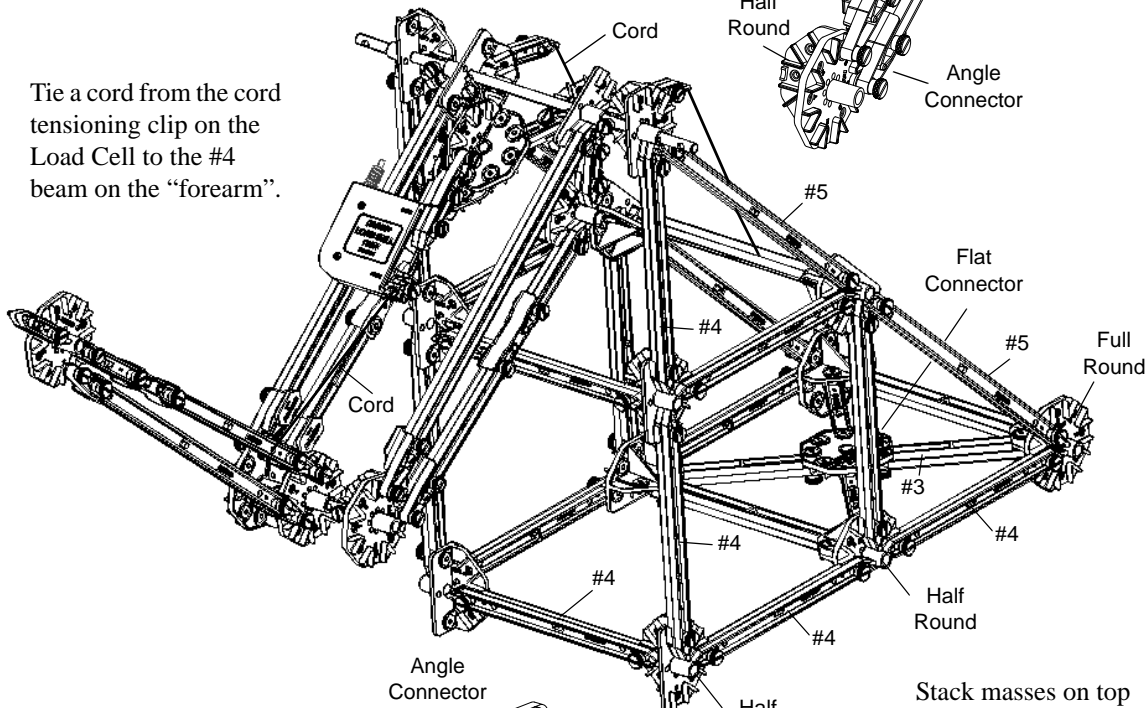
The answer is not obvious because although the lever arm is shorter, the angle that the support cords make with the boom is larger.

What is the optimal distance that minimizes the tension?

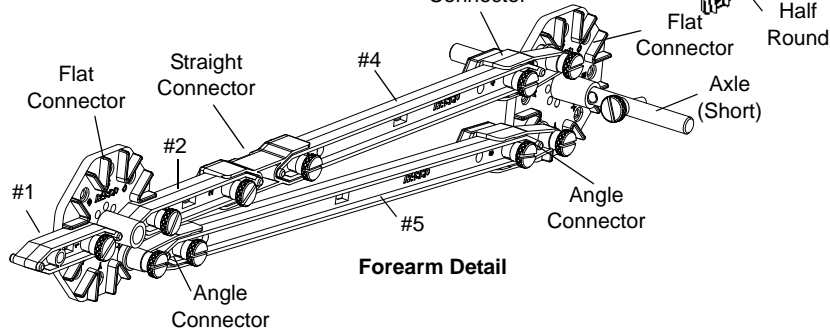
# Human Arm Model



Tie a cord from the cord tensioning clip on the Load Cell to the #4 beam on the "forearm".



Stack masses on top of the flat connector.

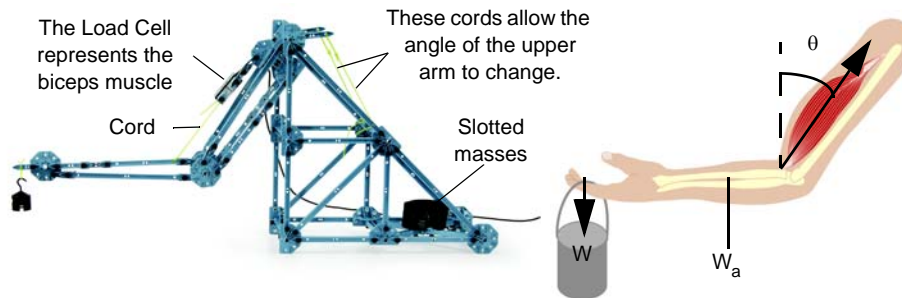




## Human Arm Model: Details

Extra Equipment	Model
Hooked Mass Set	SE-8759
Large Slotted Mass Set	ME-7566
Load Cell	PS-2200
Load Cell Amplifier	PS-2198

### Force Vector Diagram



The Advanced Structures Set allows students to build a realistic arm model and directly measure the forces exerted by the biceps muscle (tension in the cord).

The diagram shows the forces acting on the lower arm.

### Suggestions

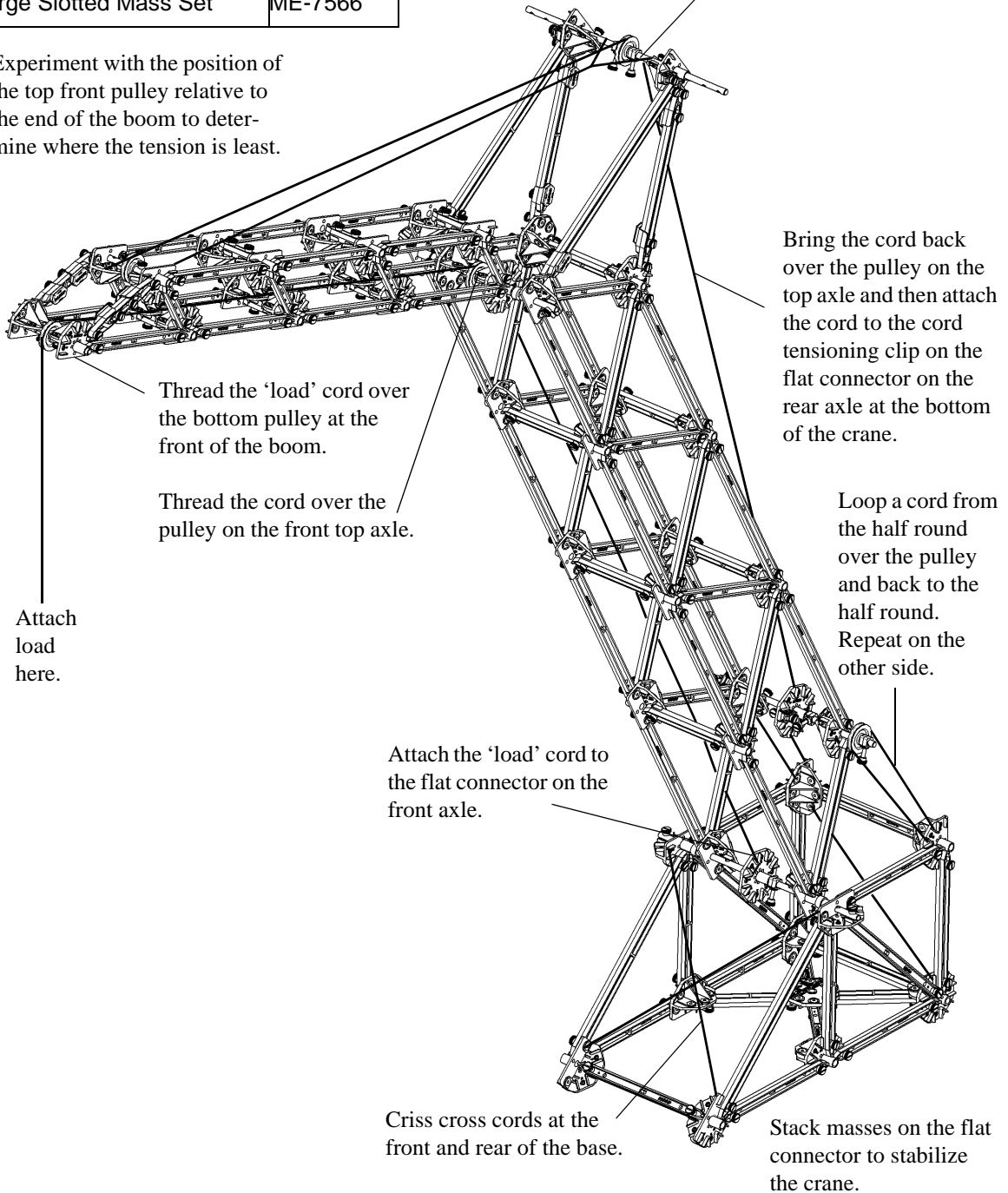
Vary the length and angle of the upper and lower arm, as well as the point of attachment of the cord connected to the Load Cell.



### Angle Crane: Cord Details

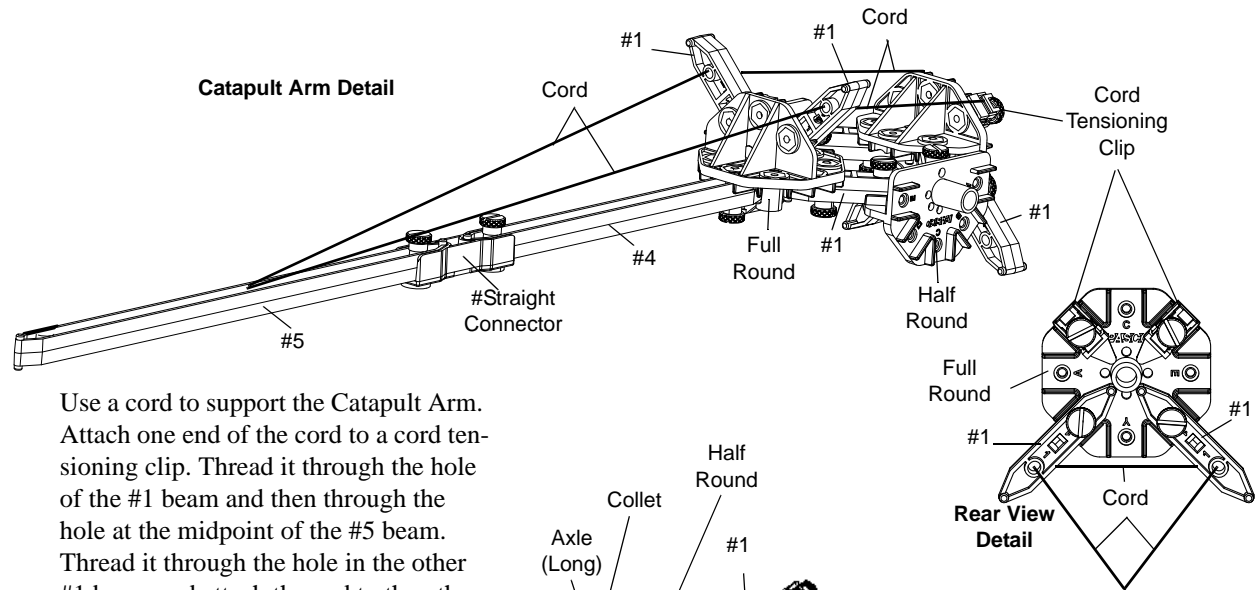
Extra Equipment	Model
Hooked Mass Set	SE-8759
Large Slotted Mass Set	ME-7566

Experiment with the position of the top front pulley relative to the end of the boom to determine where the tension is least.



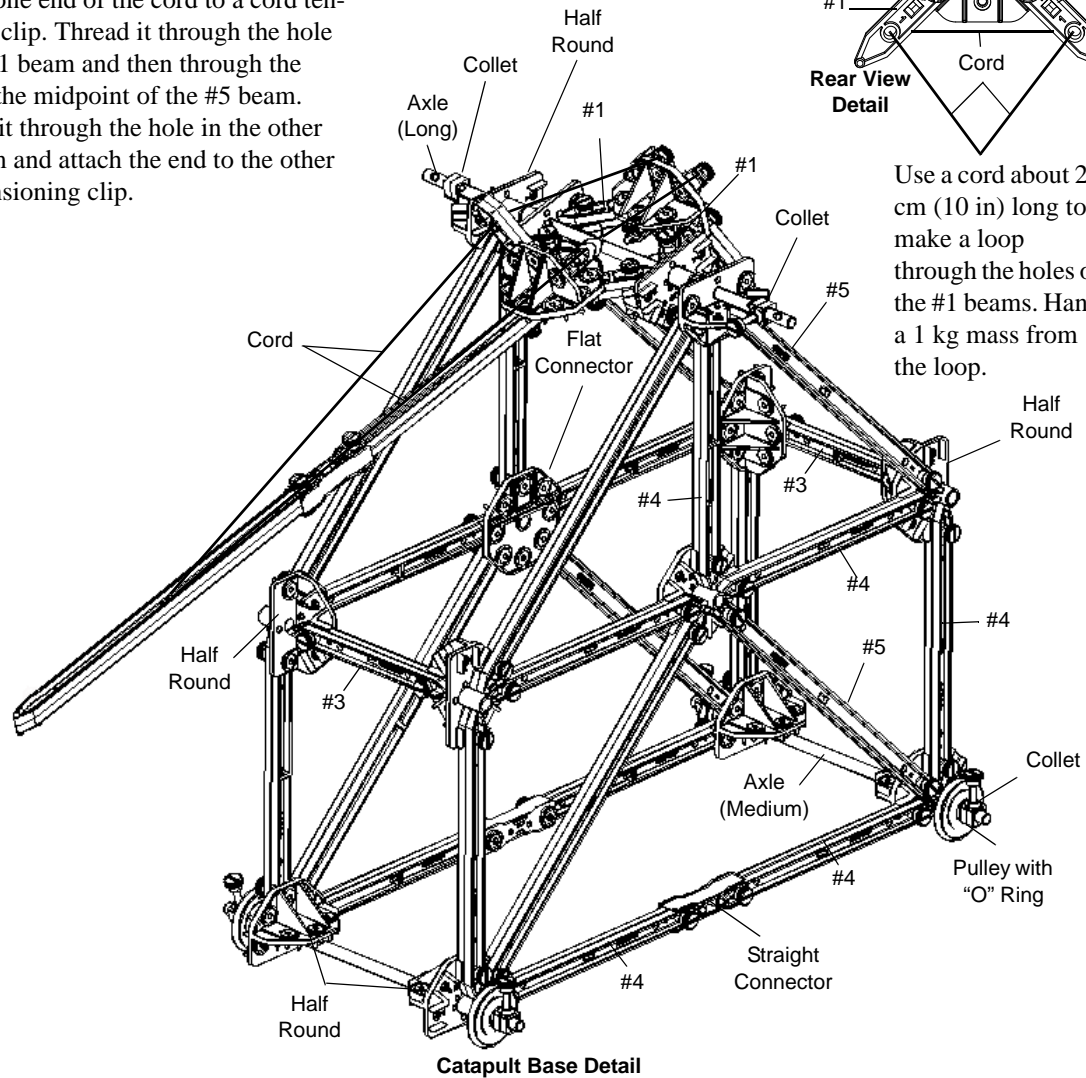


# Catapult



Use a cord to support the Catapult Arm. Attach one end of the cord to a cord tensioning clip. Thread it through the hole of the #1 beam and then through the hole at the midpoint of the #5 beam. Thread it through the hole in the other #1 beam and attach the end to the other cord tensioning clip.

Use a cord about 24 cm (10 in) long to make a loop through the holes of the #1 beams. Hang a 1 kg mass from the loop.



Extra Equipment	Model
Hooked Mass Set	SE-8759

## Catapult: Details

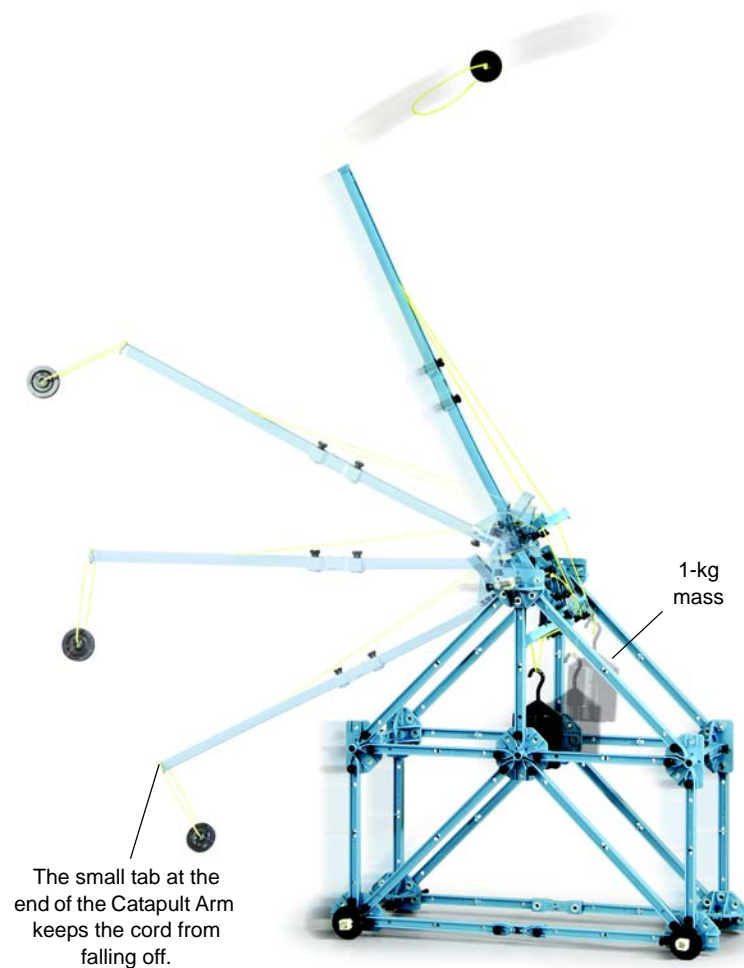
### Operation

Hang a 1 kg mass from the loop of cord shown in the Rear View Detail.

Thread a piece of cord about 20 cm in length through a pulley and tie the cord so it makes a loop. Hang the loop at the end of the catapult arm.

Pull the catapult arm down so that the pulley/projectile is near the table top and the catapult arm is touching the front of the base.

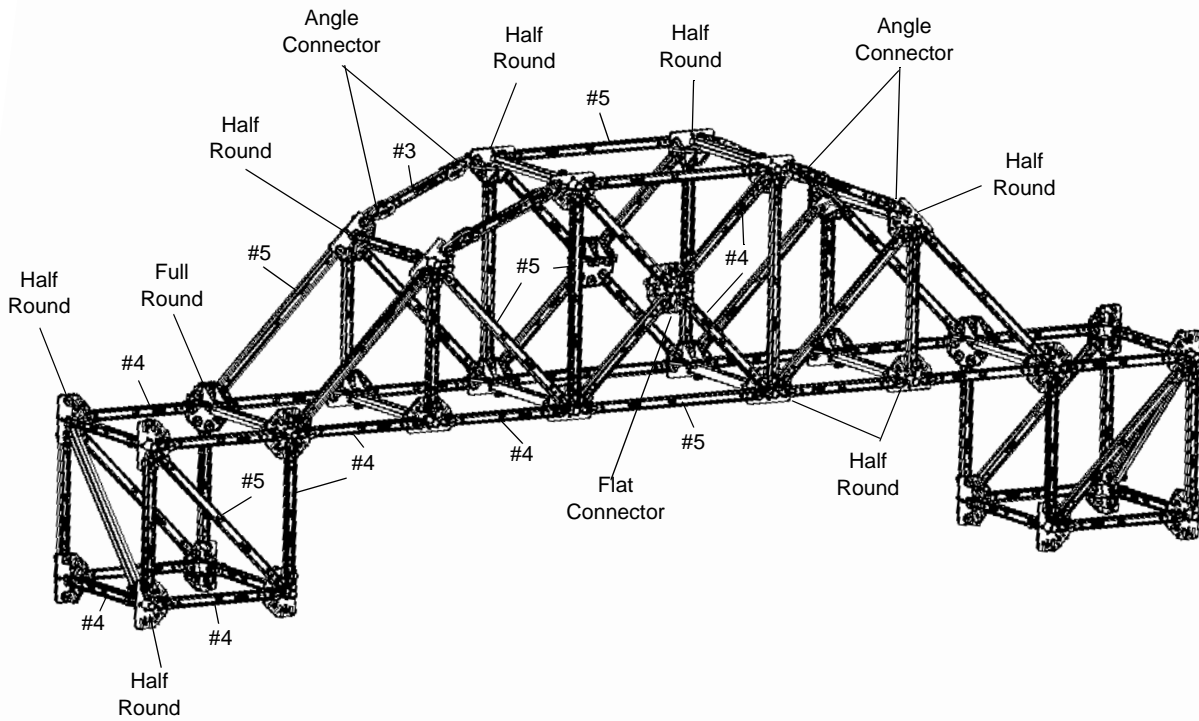
Release the catapult arm to send the pulley/projectile on its way.



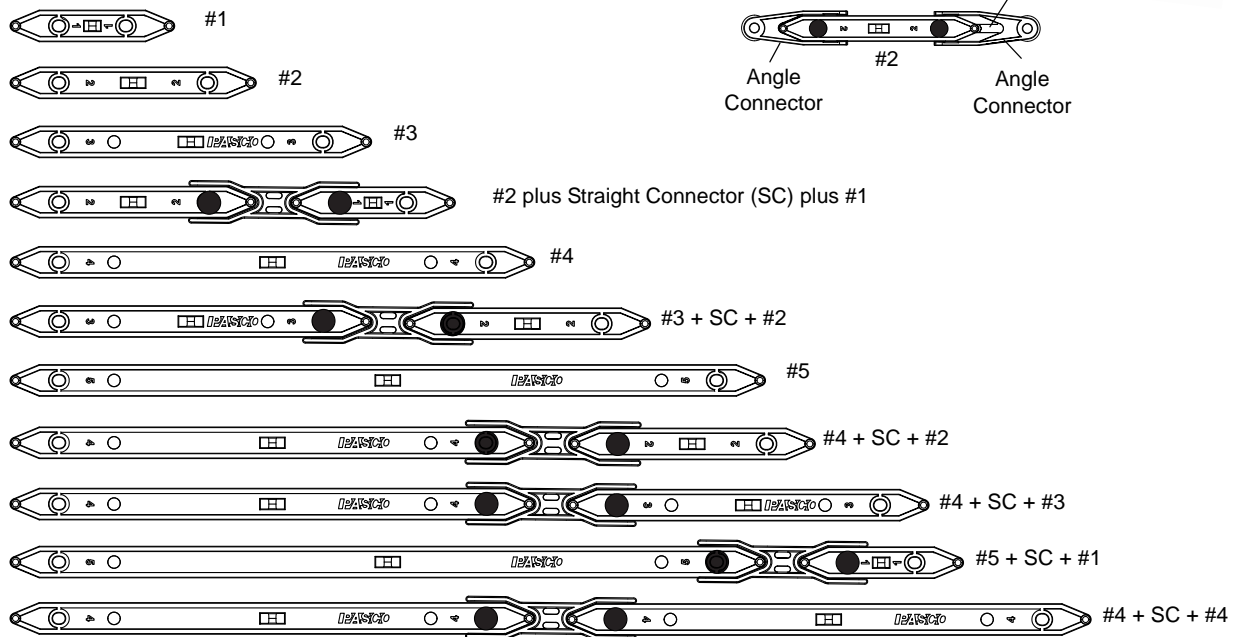
### Question

What happens to the motion of the catapult as the 1-kg mass is allowed to drop?

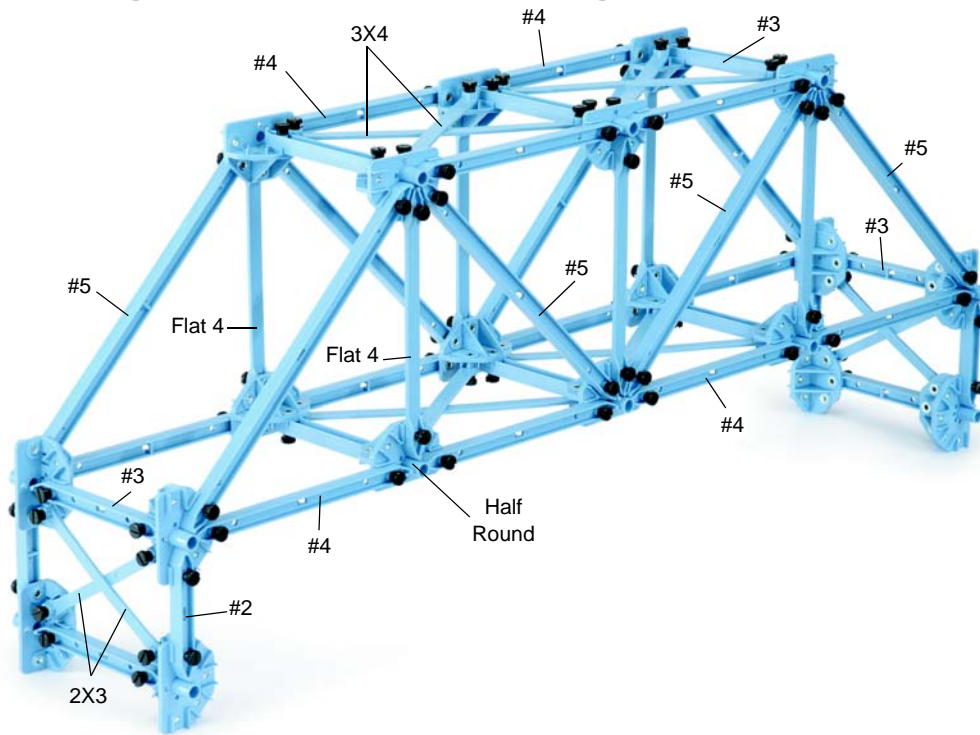
# Camelback Truss Bridge



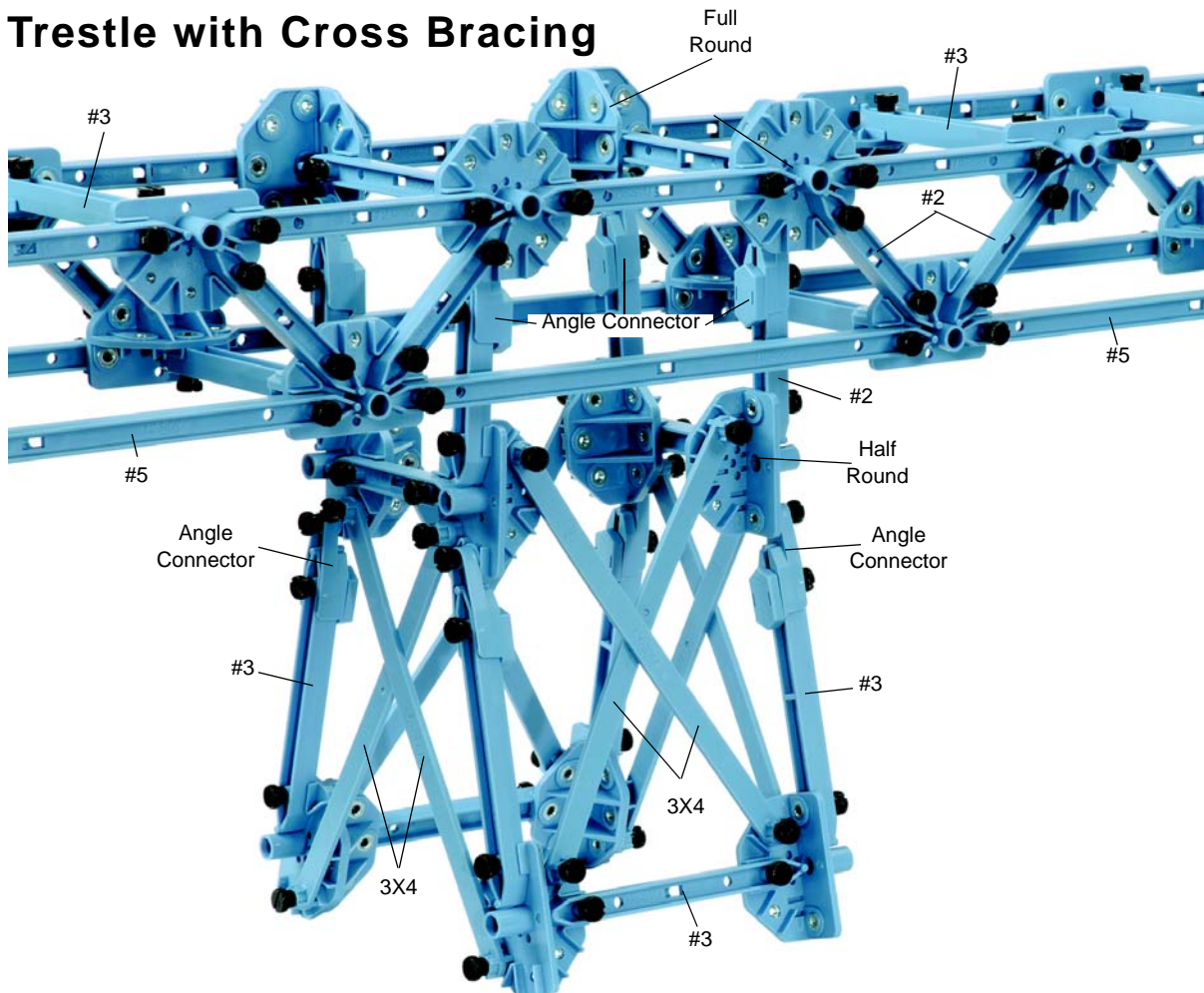
## Multilength Combinations



# Truss Bridge with Cross Bracing

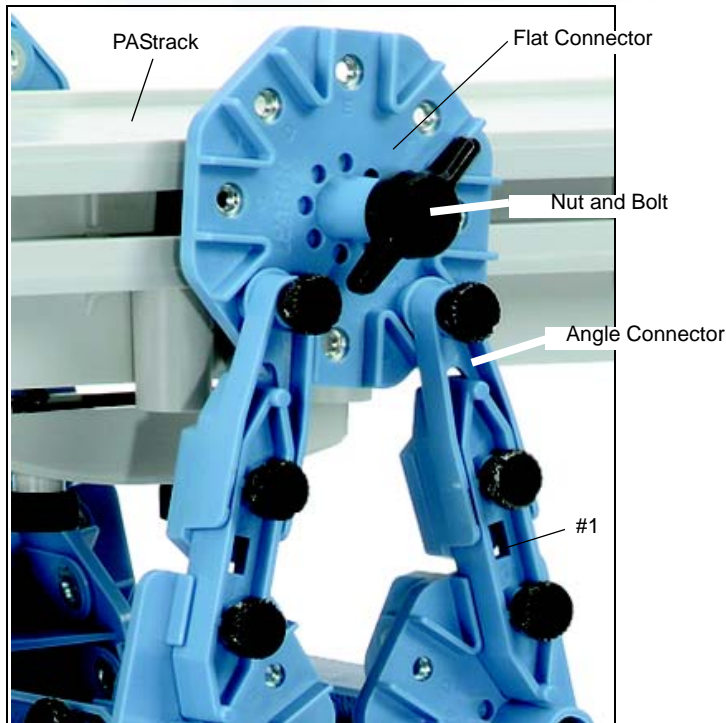
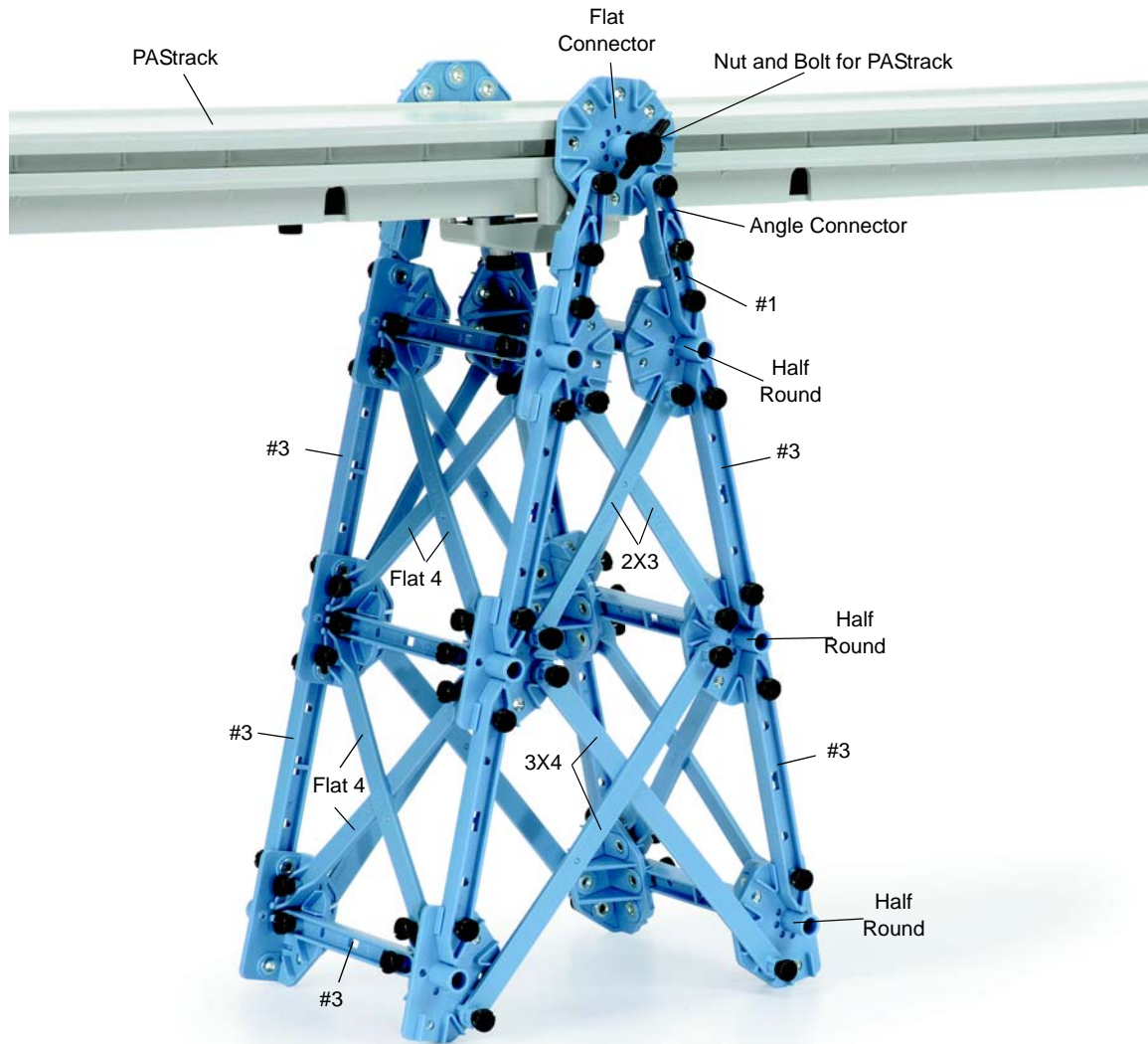


# Trestle with Cross Bracing

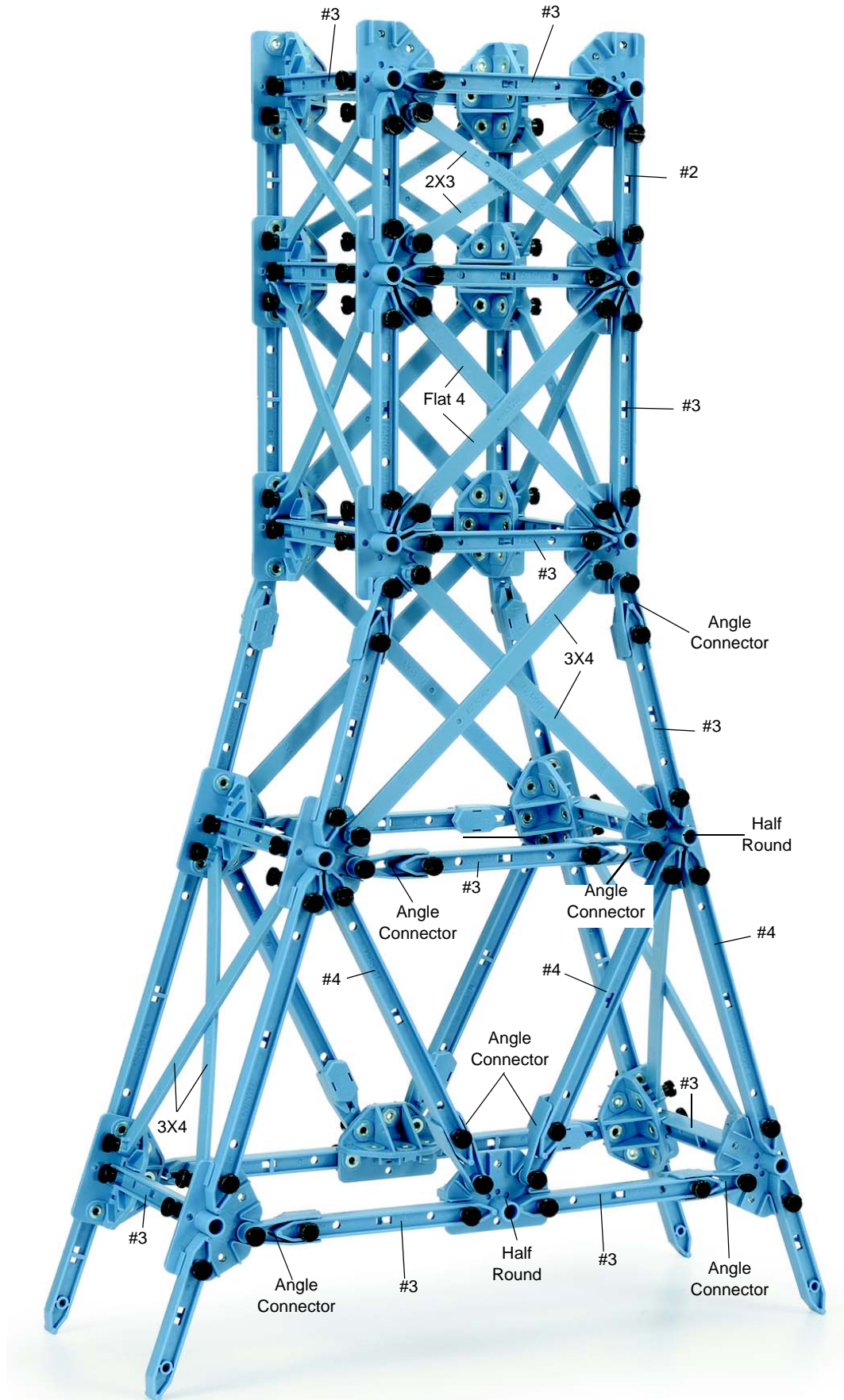




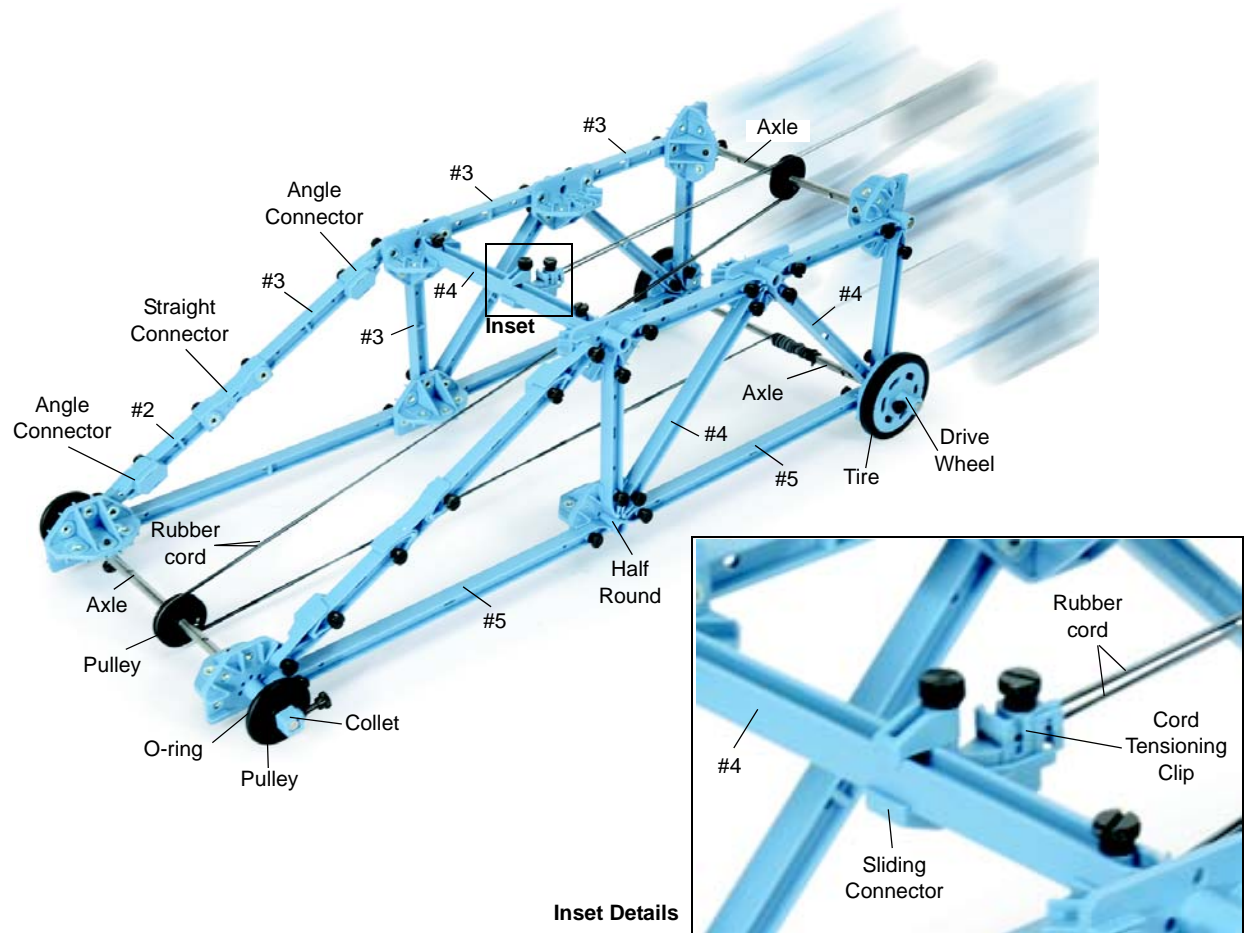
# PAStack Trestle with Cross Bracing



# Tower with Cross Bracing



## Rubber Band Powered "Car"



The rubber band powered "car" uses a piece of rubber cord (sold separately, ME-8986 Rubber Cord) that stores elastic potential energy when the cord is stretched. When the car is released, the elastic potential energy becomes kinetic energy as the car moves.

Assemble the pieces of the car except for the Cord Tensioning Clip.

Get a piece of rubber cord about 2.5 m long and thread it through the Cord Tensioning Clip.

Pull the cord through the clip so that there are two ends of the same length.

Thread the two ends of the cord through a hole in the lower rear axle.

Loop the two rubber cords around the pulley on the front axle and then loop the cords around the pulley on the upper rear axle.

Finally, attach the Cord Tensioning Clip to the Sliding Connector.

Turn the Drive Wheel by hand to wind the rubber cord around the lower rear axle, or place the car on the floor and push it backwards so that the rubber cord winds around the lower rear axle.

Release the car in a clear area. The two ends of the rubber cord should come loose from the lower rear axle after the cord is unwound so the car can continue to roll.

## Spares Part Numbers.

### ME-6985 Flexible I-Beam Set

#5 Flexible Beam (24 cm) - 16

#4 Flexible Beam (17 cm) - 16

#3 Flexible Beam (11.5 cm) - 16

### ME-6986 Structures Rod Clamp - 2

### ME-6987 Flat Structures Members

Flat 3 x 4 Beam (19 cm) - 16

Flat #4 Beam (17 cm) - 16

Flat 2 x 3 Beam (12.5 cm) - 16

### ME-6993 Truss Set Members

#5 Beam (24 cm long) - 24

#4 Beam (17 cm long) - 54

#3 Beam (11.5 cm long) - 54

#2 Beam (8 cm long) - 24

#1 Beam (5.5 cm long) - 24

Half Round Connector - 42

### ME-6994 Truss Set Screws

Screw (6 - 32) - 300

### ME-6996 Cord Lock Spares

Cord Tensioning Clip - 32

Cord, Braided, #18 Yellow - 1 roll

\*Nut and Bolt for PAStack

### ME-6997 Full Round (XYZ) Connectors

Full Round Connector - 6

Flat Connector - 6

1/4 - 20 Thumbscrew and Square Nut\* - 6

### ME-6998A Axle Spares

1/2 by 1/4 by 1/4 Spacer - 12

"O" Ring - 12

Axle, Short (10.4 cm) - 2

Axle, Medium (21.3 cm) - 2

Axle, Long (26.6 cm) - 2

Collet - 24

Pulley - 12

### Wheel - 4

### Tire - 4

### ME-6999A Angle Connector Spares

Angle Connector - 24

Straight Connector - 24

Sliding Connector - 12

## Summary of Extra Equipment

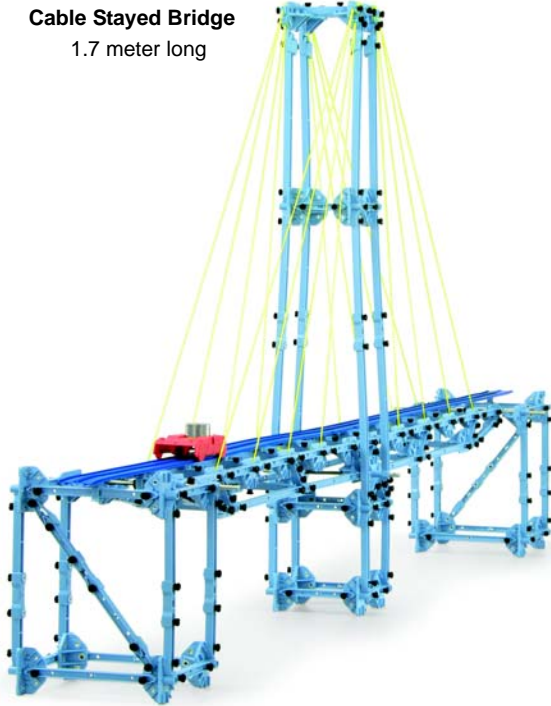
Extra Equipment (Model)	Where Used
Hooked Mass Set (SE-8759)	Boom, Teeter Totter, Back, Tower Crane, Arm, Angle Crane
Large Slotted Mass Set (ME-7566 or ME-7589)	Boom, Leg, Back, Arm, Angle Crane
Angle Indicator (ME-9495A)	Boom
Load Cells & Amplifier Set (PS-2199)	Boom, Leg, Back, Arm
Large Table Clamp (ME-9472)	Leg
Mass and Hanger Set (ME-8979)	Teeter Totter
Force Platform (PS-2141 or CI-6461)	Tower Crane



## Bridges That Require an Advanced Set and a Bridge Set

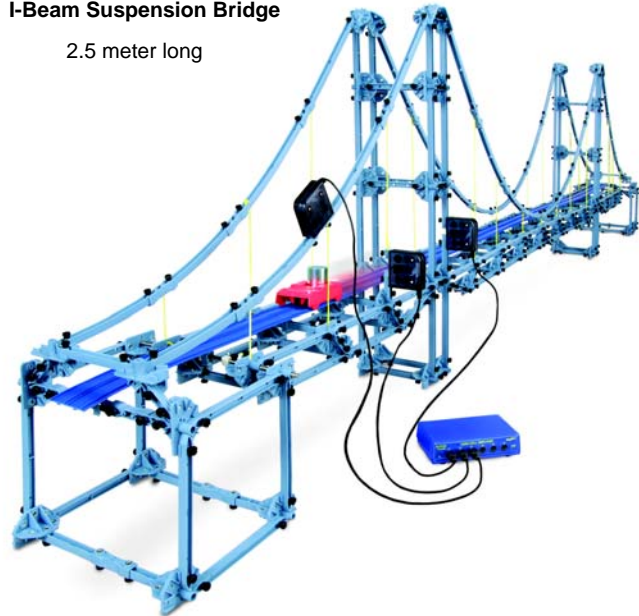
Note that the I-Beam Suspension Bridge and Arched Causeway Bridge can use the I-Beams sideways for the arched part of the bridge, or the Flexible I-Beams. (Since the I-Beams bend more in this orientation they form a curve. The I-Beams used in this manner will take a set and be permanently bent.)

**Cable Stayed Bridge**  
1.7 meter long



**I-Beam Suspension Bridge**

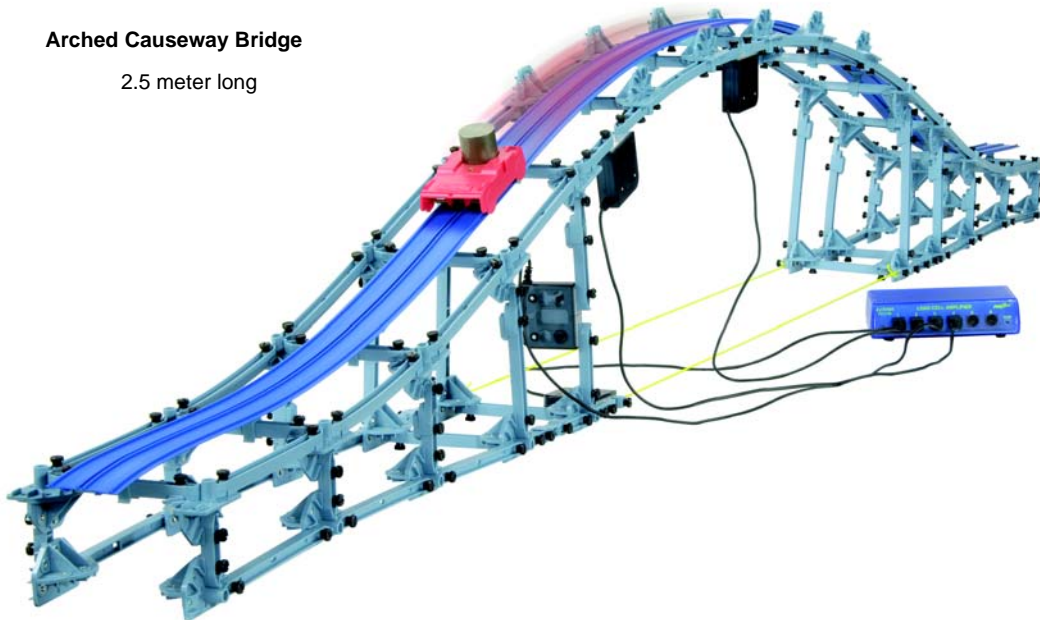
2.5 meter long



The bridge models on this page feature a road bed and mini-car. These items are included in the ME-6991 Bridge Set and the ME-6995 Road Spares Set. (See the PASCO catalog or web site at [www.pasco.com](http://www.pasco.com) for more information.)

**Arched Causeway Bridge**

2.5 meter long



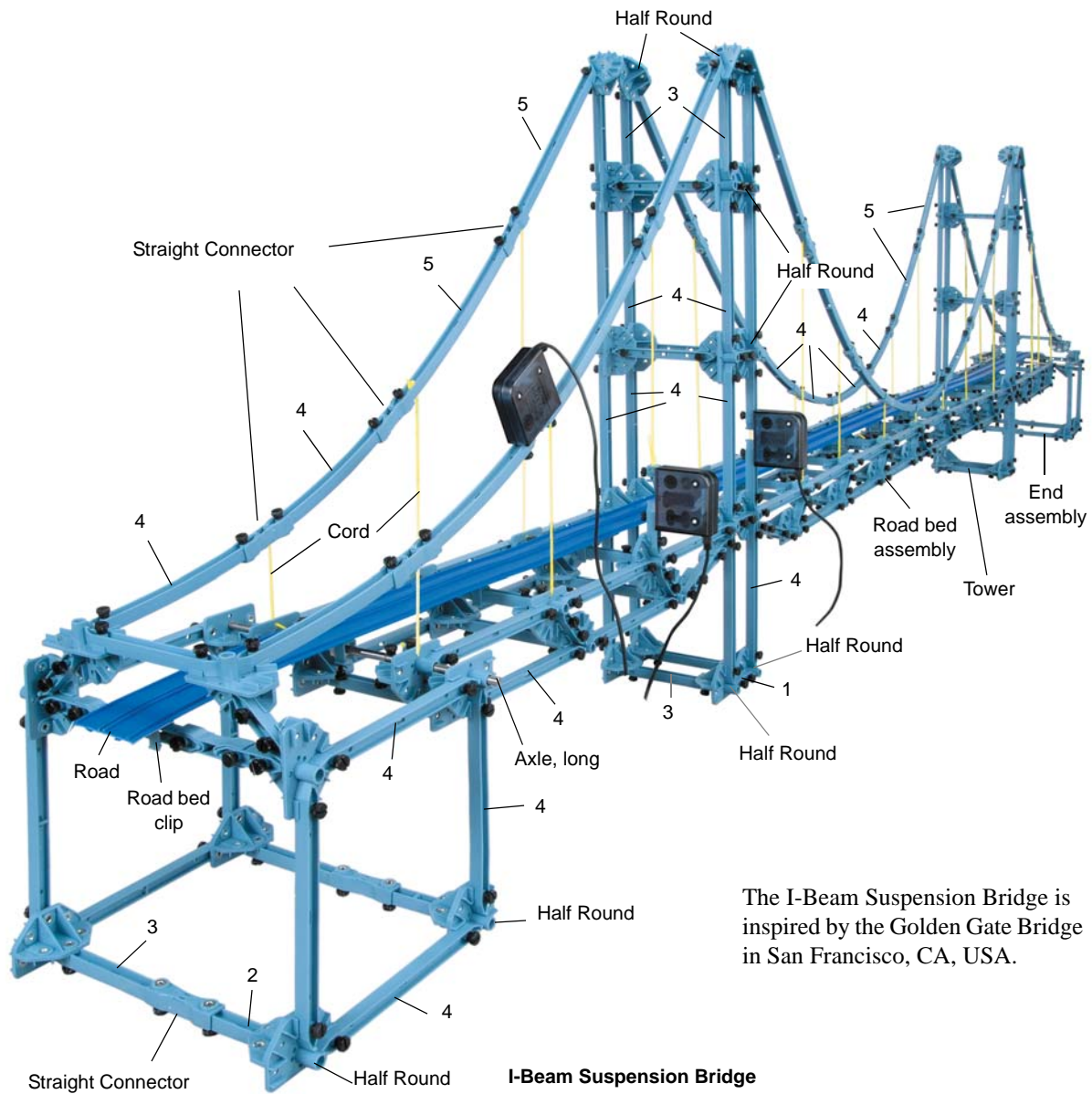
\*Road Bed and Mini-car included in the ME-6991 Bridge Set.

# I-Beam Suspension Bridge Details

The I-Beam suspension bridge requires the following:

1 Bridge Set (ME-6991)	OR
1 Advanced Structures Set (ME-6992A)	1 Bridge Set (ME-6991)
1 Angle Connector Spares (ME-6999)	2 Advanced Structures Sets (ME-6992A)

Note that this suspension bridge is constructed using the I-beams sideways for the arched parts of the bridge. Because the I-beams bend more in this orientation, they form a curve. The beams used in this manner will take a set and be permanently bent.

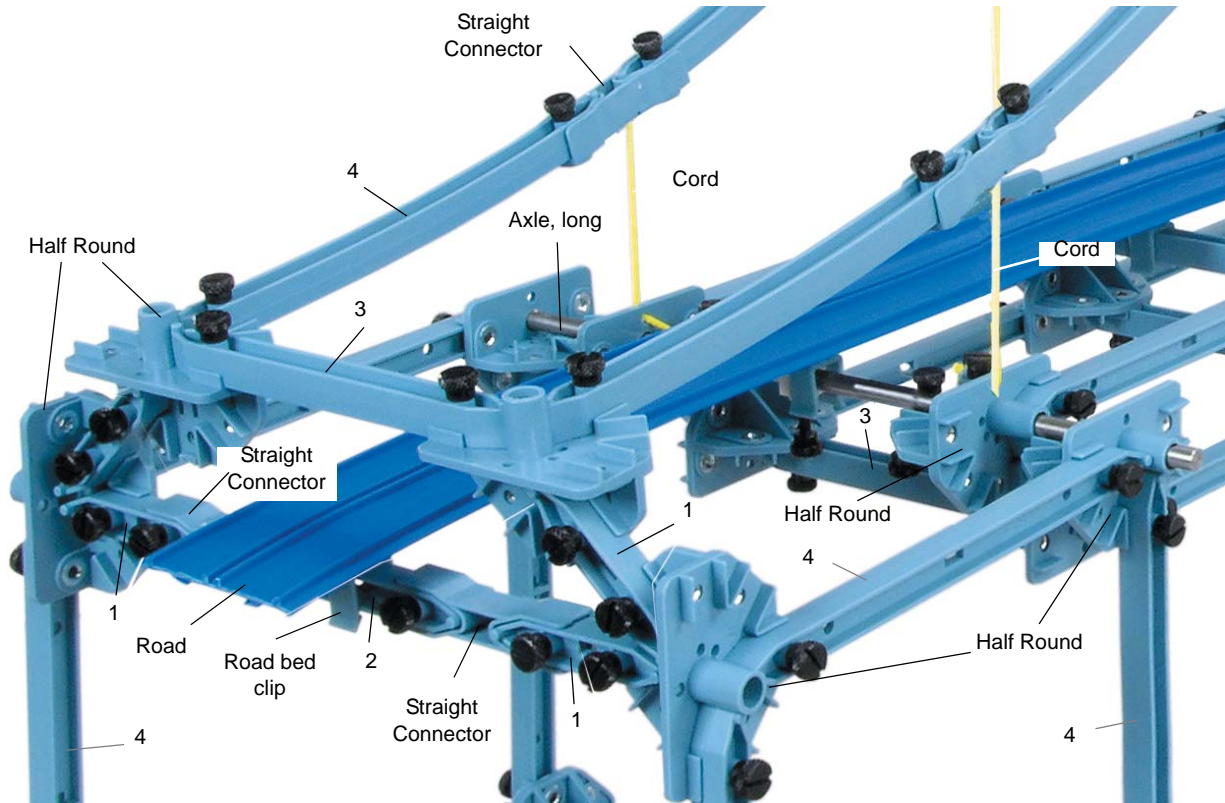


The I-Beam Suspension Bridge is inspired by the Golden Gate Bridge in San Francisco, CA, USA.

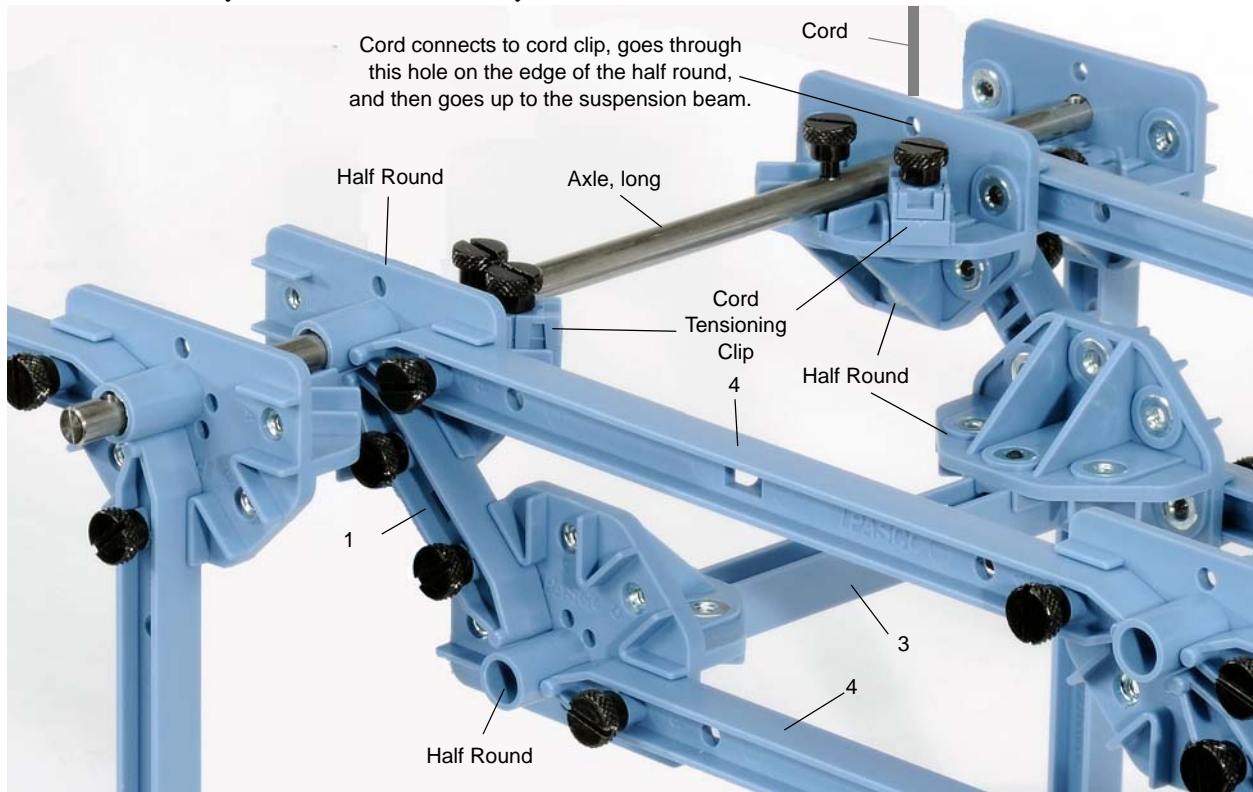
This picture shows the entire bridge structure with three Load Cells attached.

# I-Beam Suspension Bridge End Assembly

The following pages show details of the construction of the suspension bridge using parts from the ME-6992A Advanced Structures Set and the ME-6991 Bridge Set.



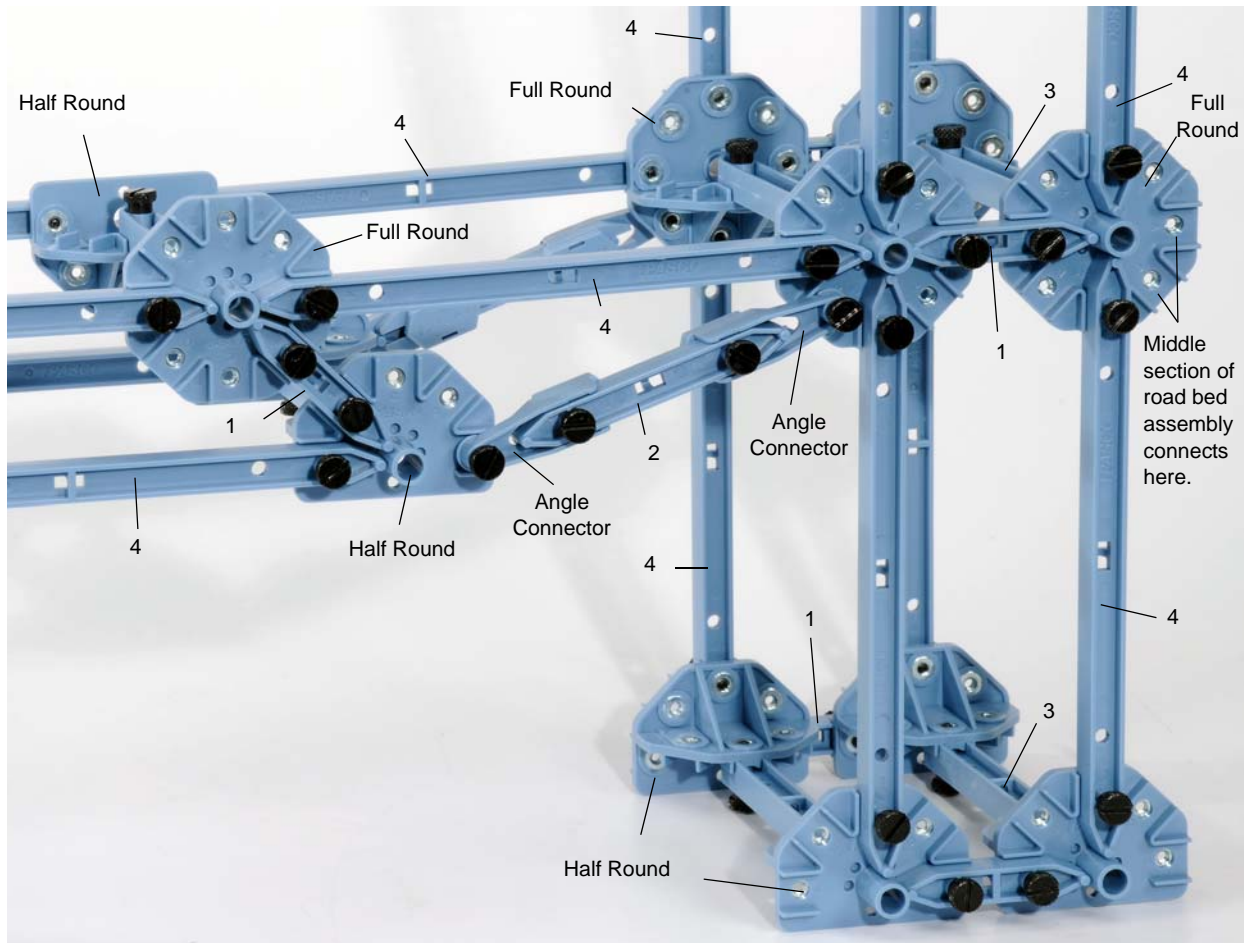
This picture shows details of the end assembly. The next picture shows details of the axle that is the joint between the end assembly and the road bed assembly.



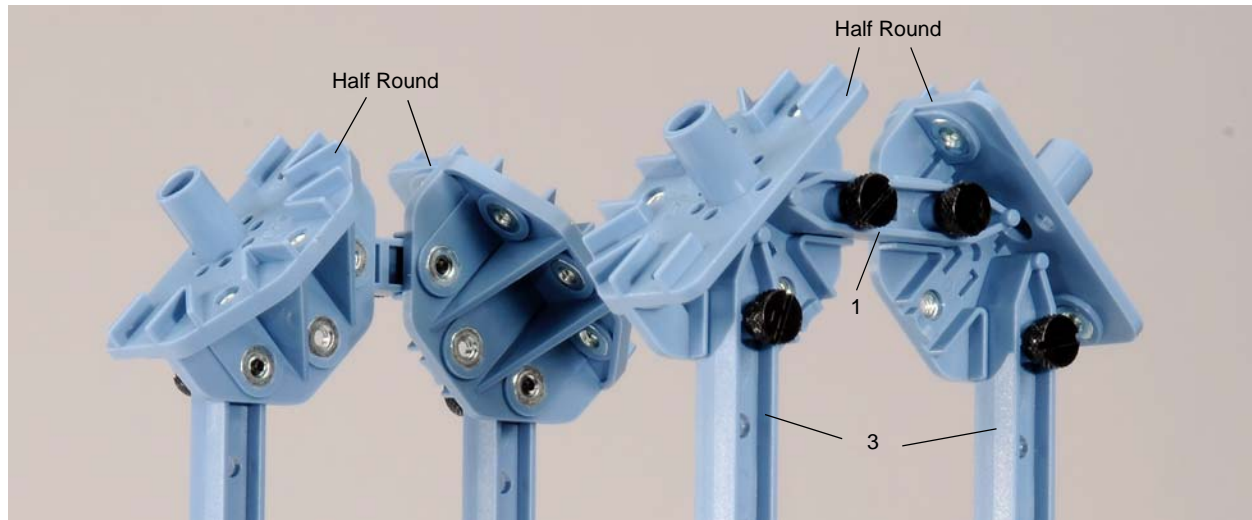


# I-Beam Suspension Bridge Tower

The next picture shows details of the road bed assembly where it joins the first tower.



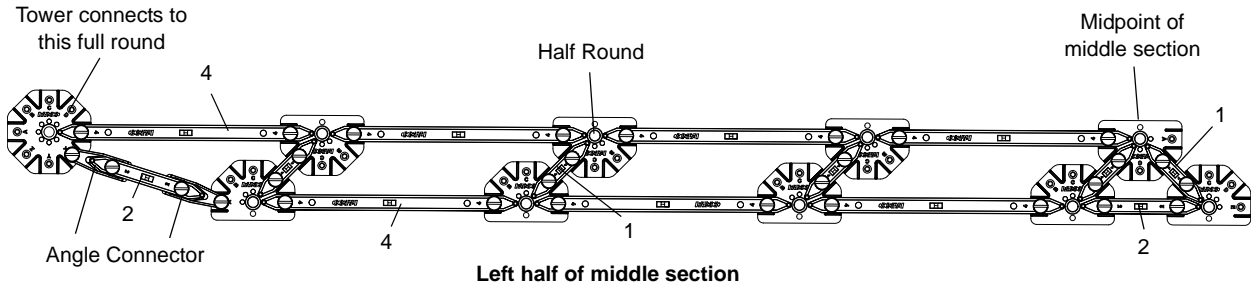
The next picture shows details of the top of the first tower. The suspensions beams are not shown.



## I-Beam Suspension Bridge Road Bed Assembly

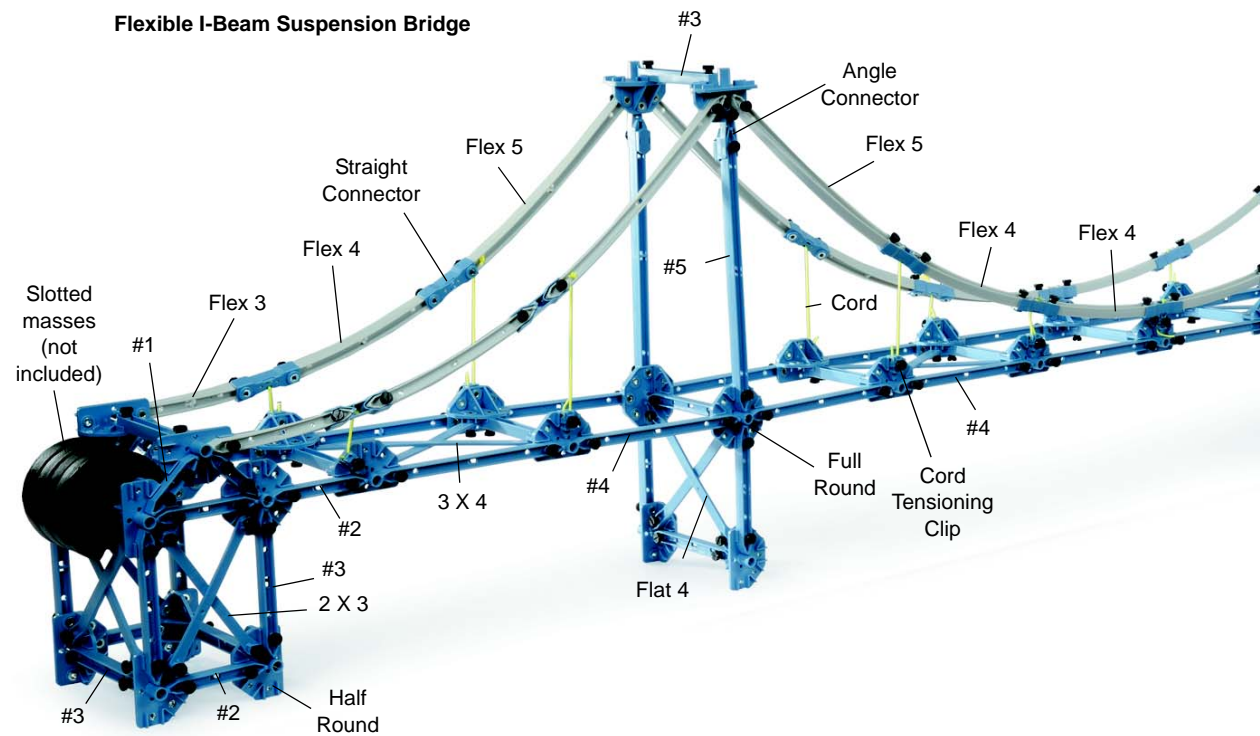
The middle section of the road bed assembly has eight #4 beams on the top of each side, and six #4 beams on the bottom of each side. The middle of the bottom part of the structure is joined by a #2 beam on both sides. The two

sides are joined by #3 beams. The next picture shows details of *one half* of the middle section of the road bed assembly.



## Flexible I-Beam Suspension Bridge

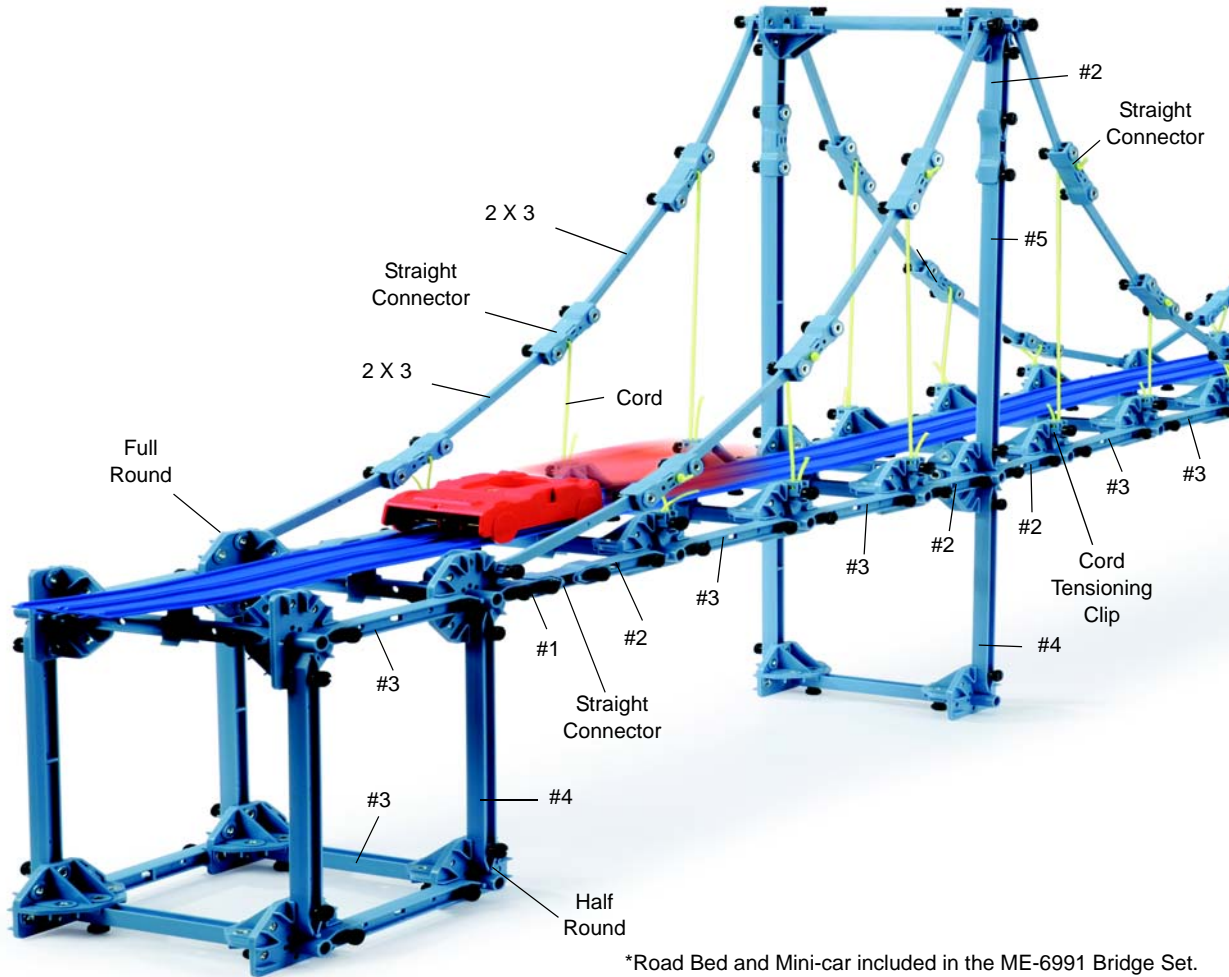
The following shows a suspension bridge model using Flexible I-Beams for the suspension beams instead of the hard plastic I-Beams.



# Flat Beam Suspension Bridge

The following shows a suspension bridge model using Flat Members for the suspension beams instead of I-Beams.

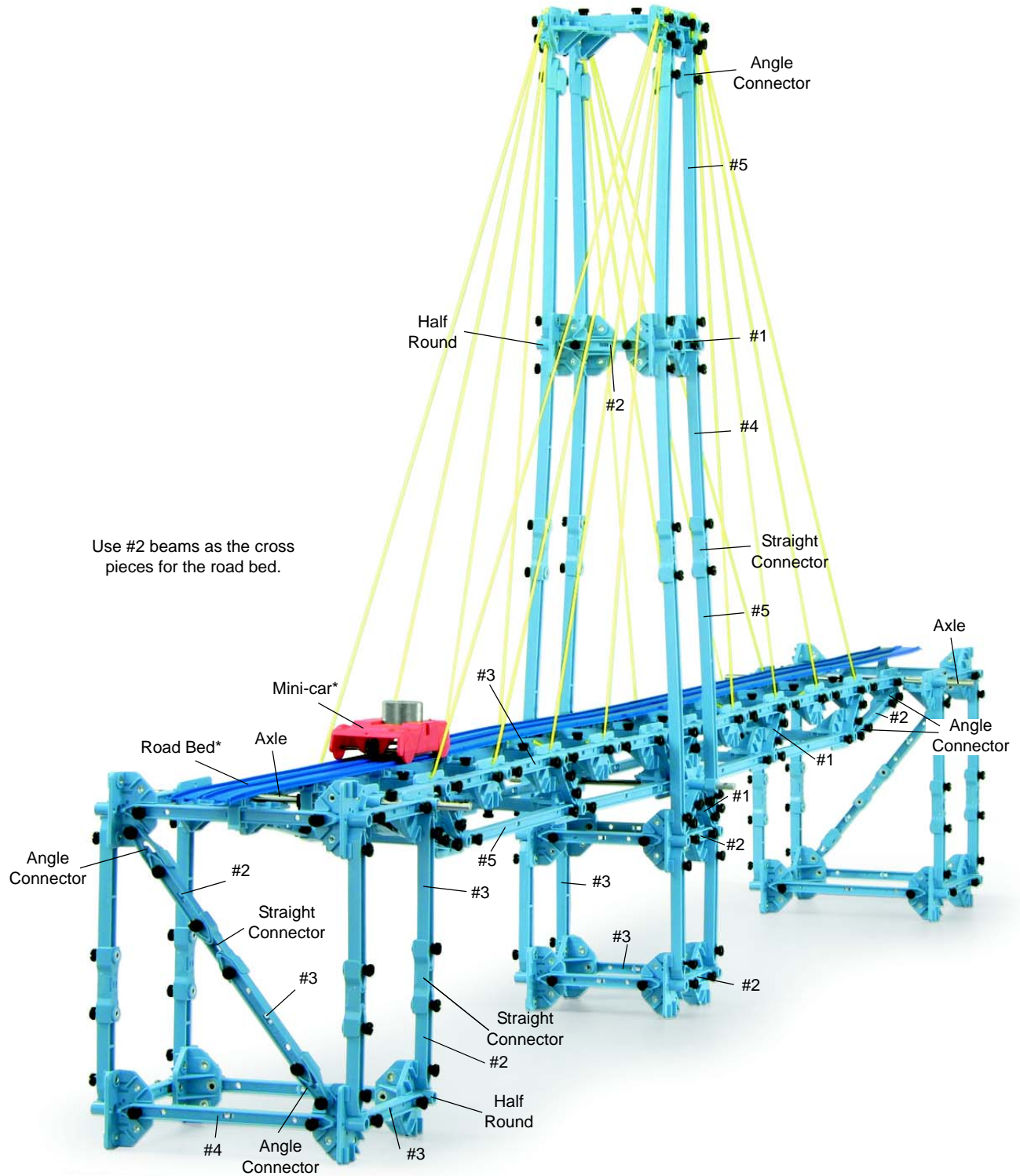
## Flat Members Suspension Bridge





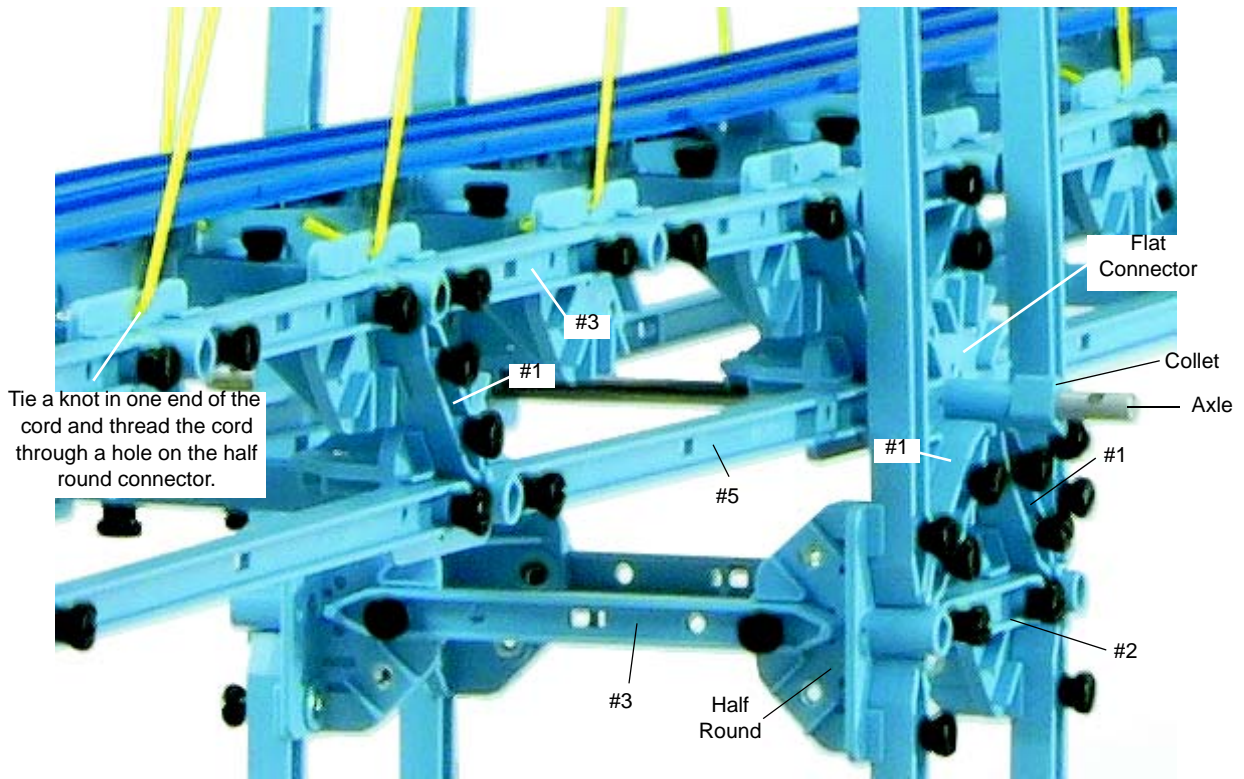
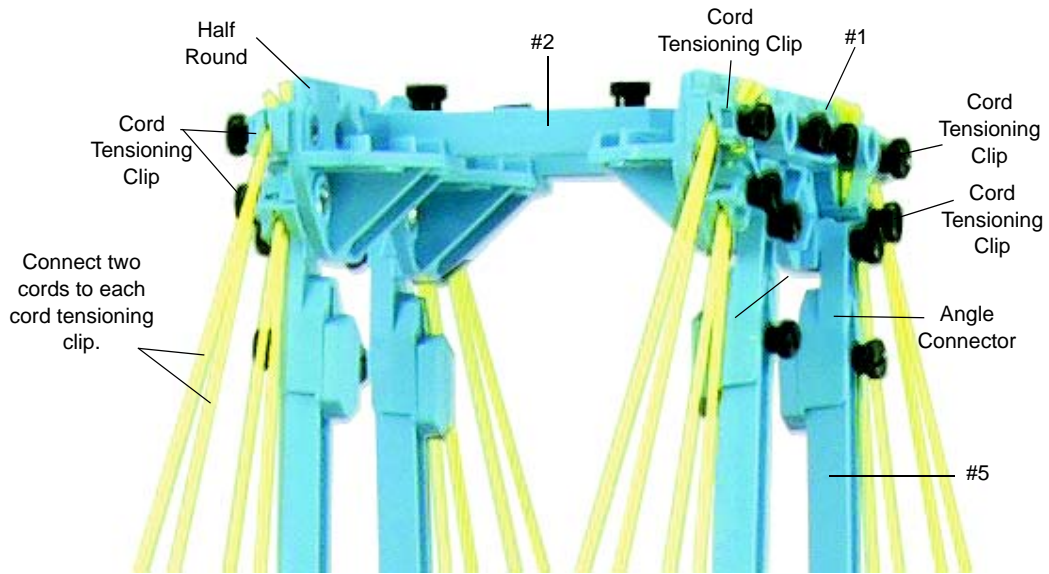
# Cable Stayed Bridge

The following pages show details of the Cable Stayed Bridge.



\*Road Bed and Mini-car not included.

### Cable Stayed Bridge Details



Tie a knot in one end of the cord and thread the cord through a hole on the half round connector.

Tower Base Detail

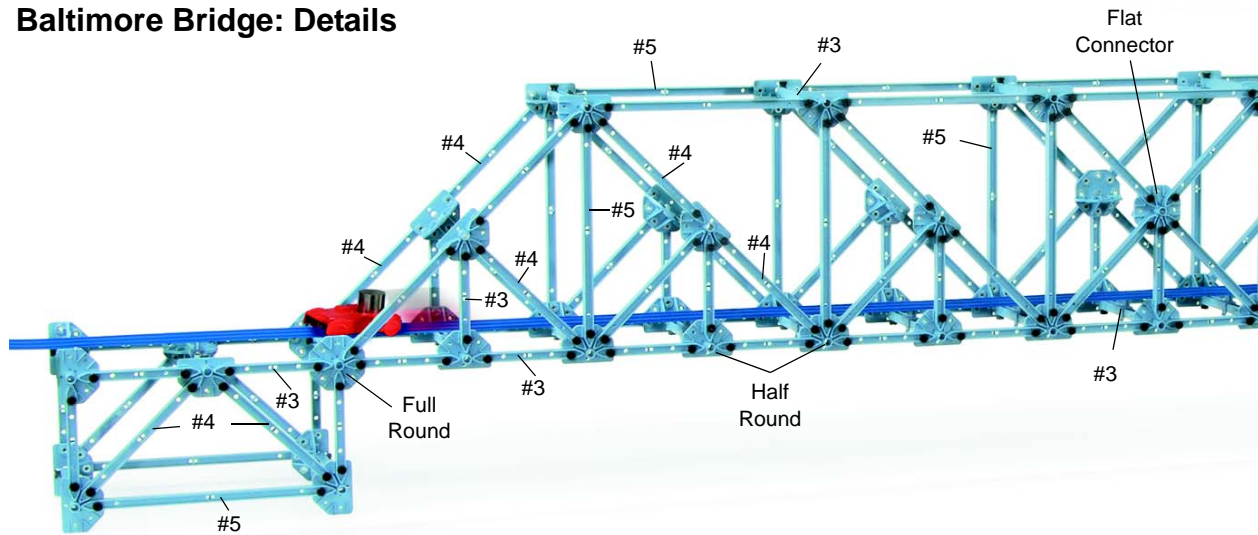
# Baltimore Bridge

Baltimore Bridge

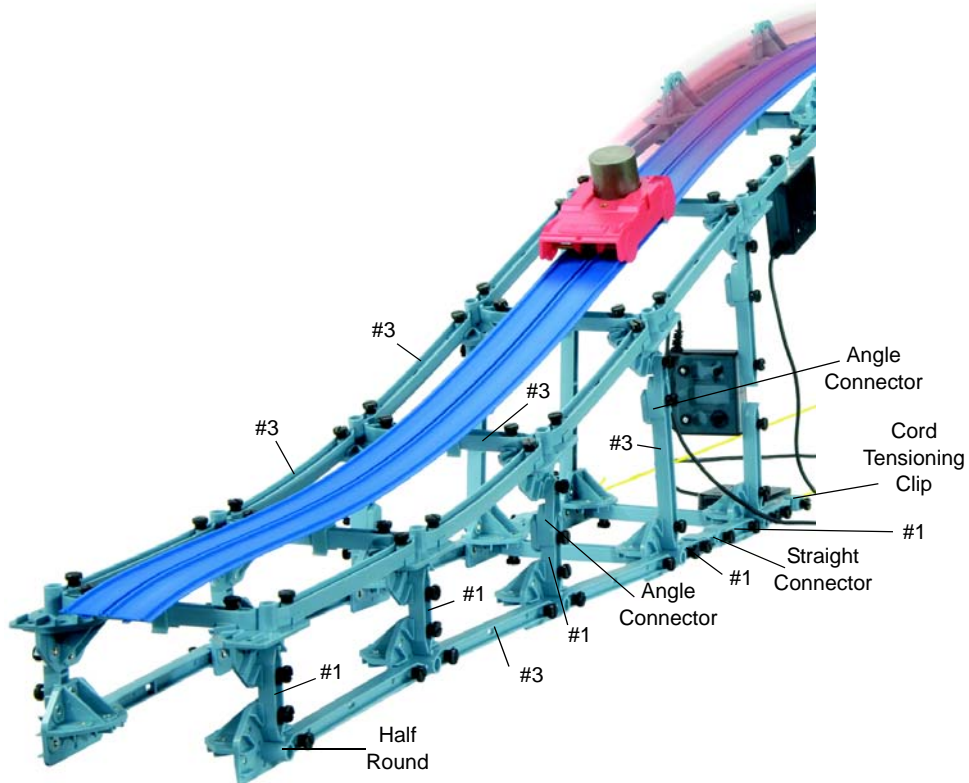
2.3 meter long



## Baltimore Bridge: Details

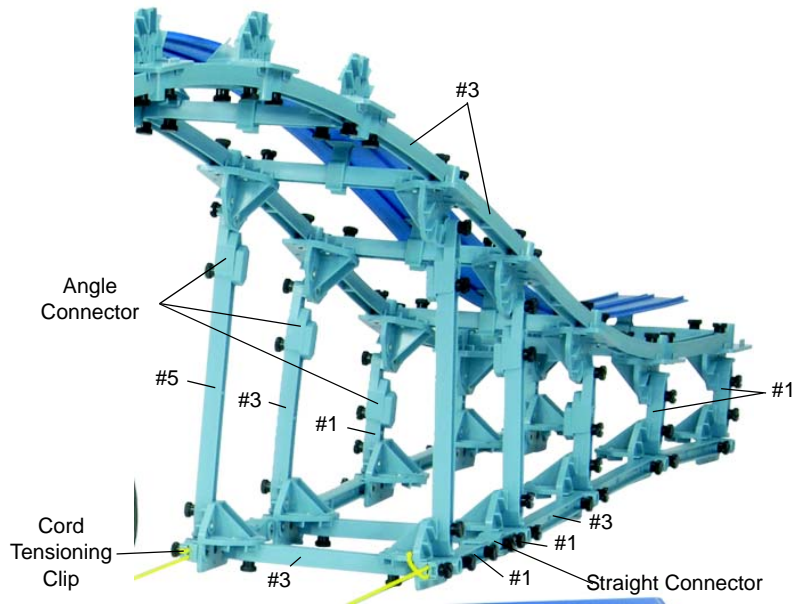


## Arched Causeway Bridge Detail 1

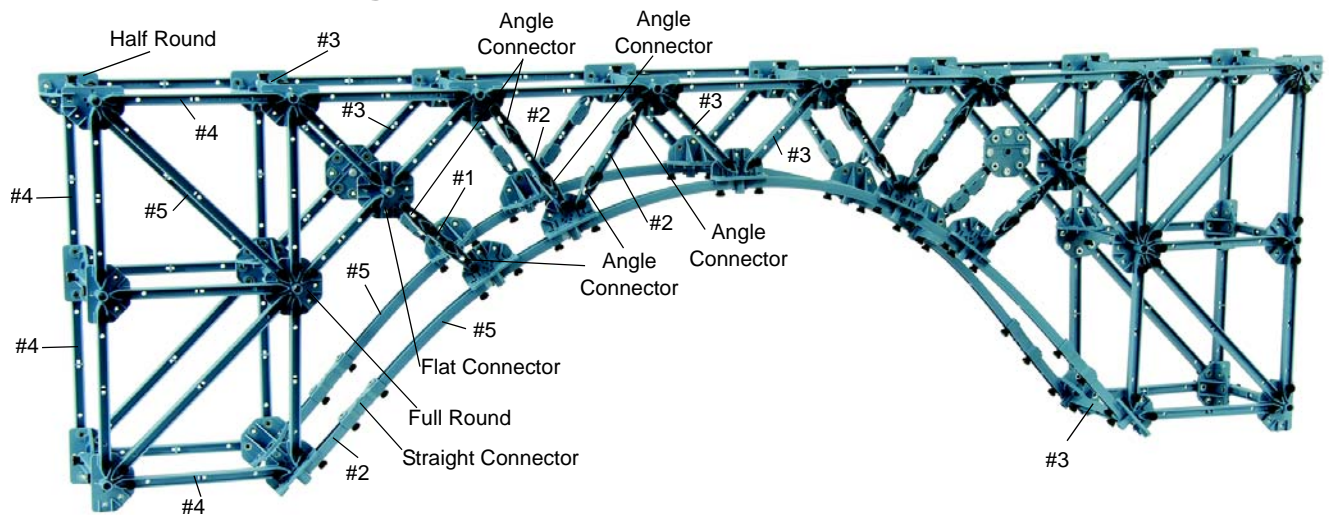




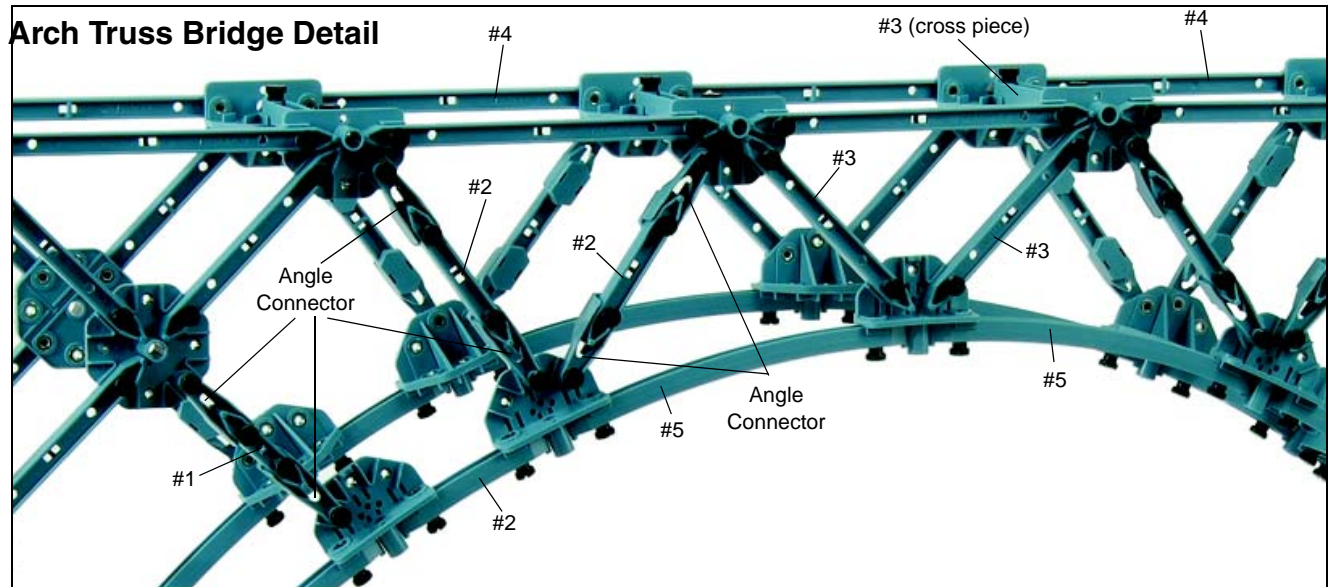
### Arched Causeway Bridge Detail 2



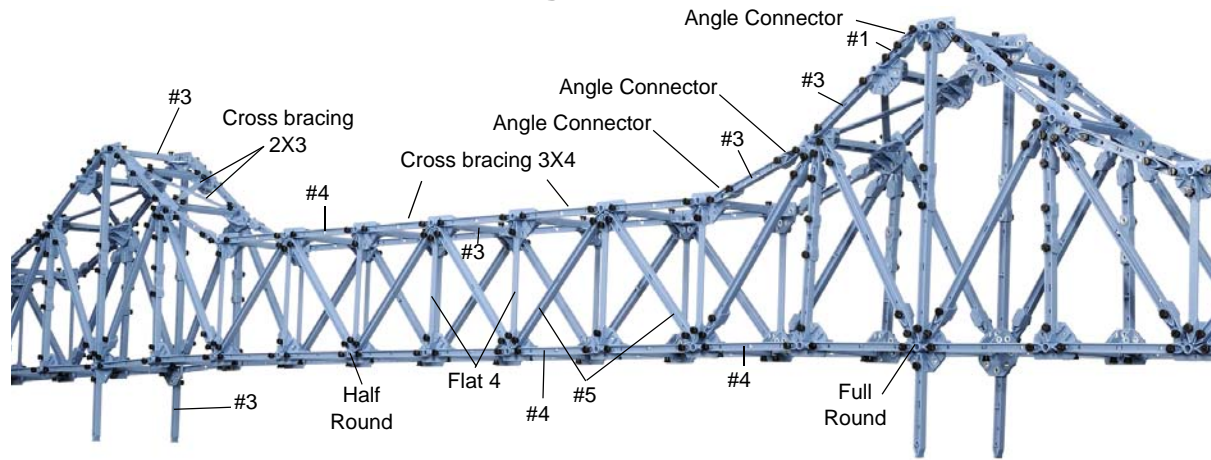
### Arch Truss Bridge



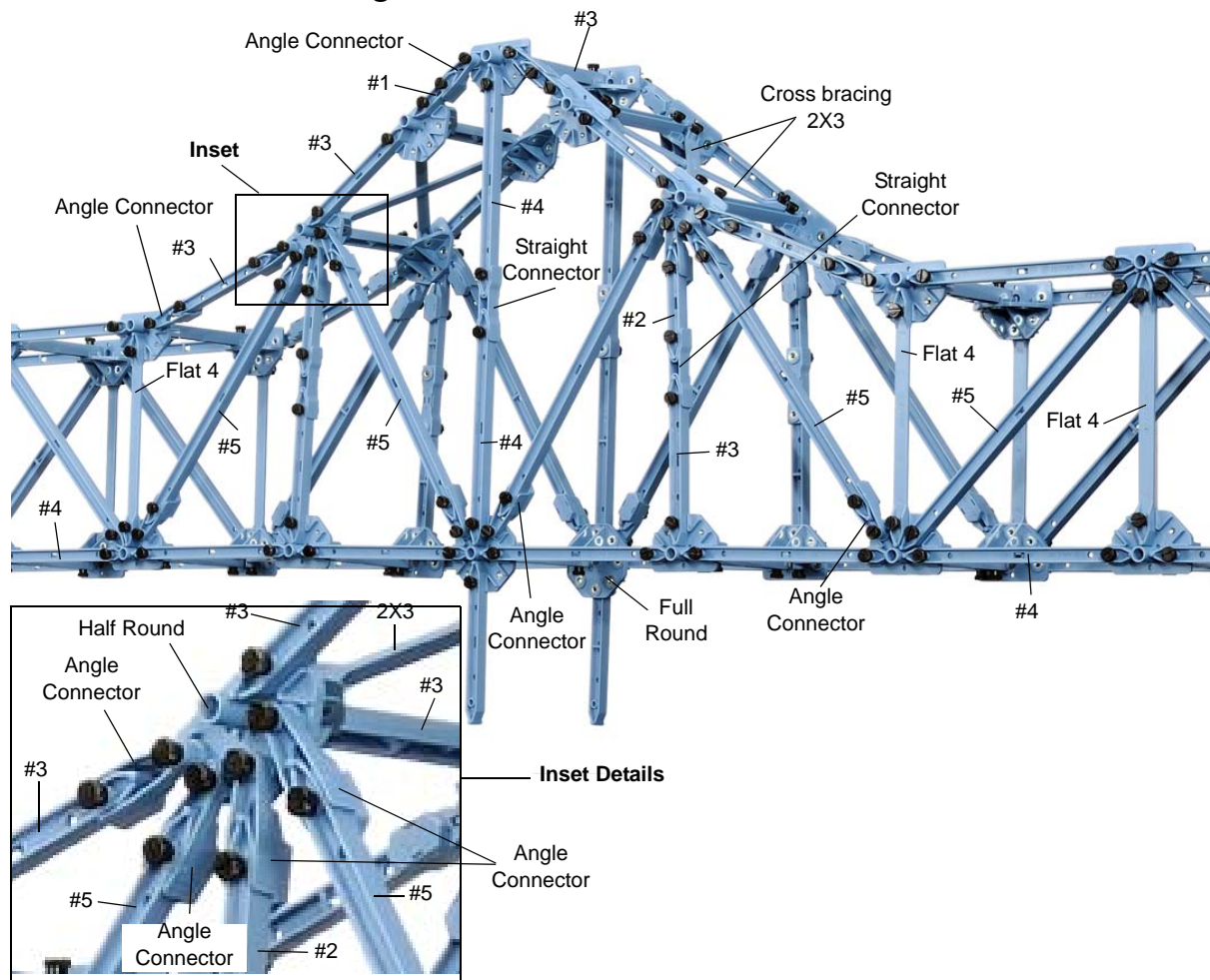
### Arch Truss Bridge Detail



# Cantilevered Truss Bridge



## Cantilevered Truss Bridge Details



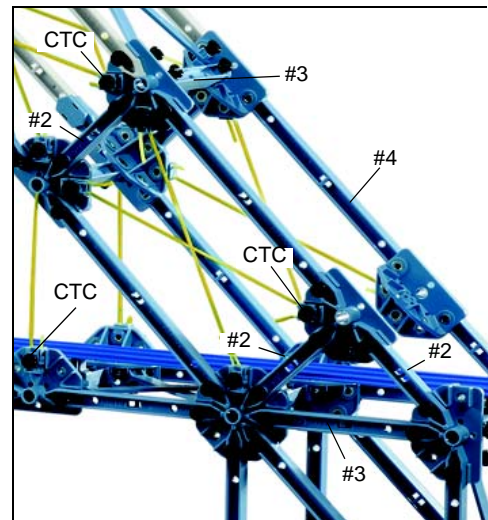
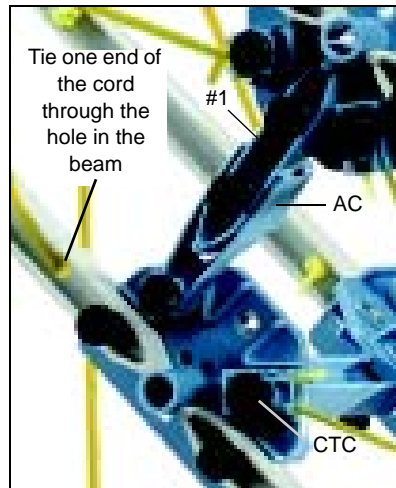
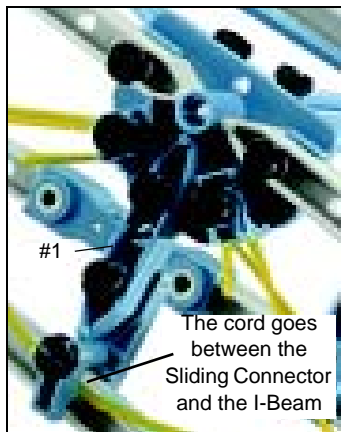
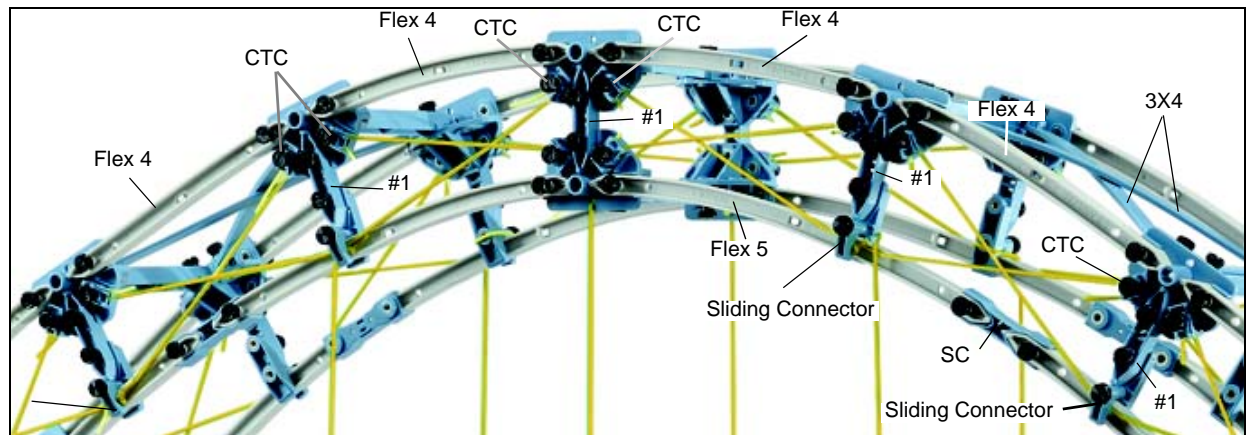
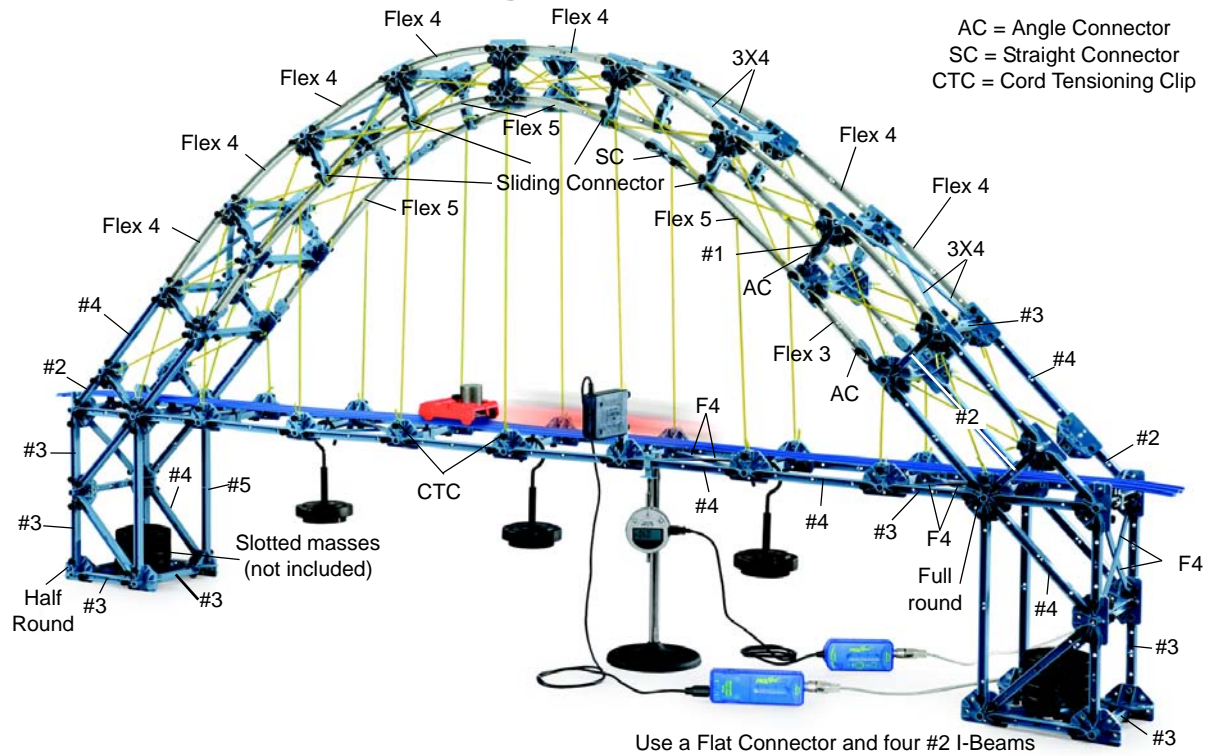
Use a Nut and Bolt for PAStack to attach the PAStack and PAStack Curved sections to the members of the Advanced Structures Set. Slide the square nut into the “T-slot” on the side of the PAStack and PAStack Curved sections.

The PAStack Cable Stayed Bridge shown on this page was constructed using components from two ME-6992A Advanced Structures Sets, four sets of PAStack (ME-6960), and four sets of PAStack Curved Sections (ME-6841).





# Double Tied Arch Bridge with Flexible I-Beams



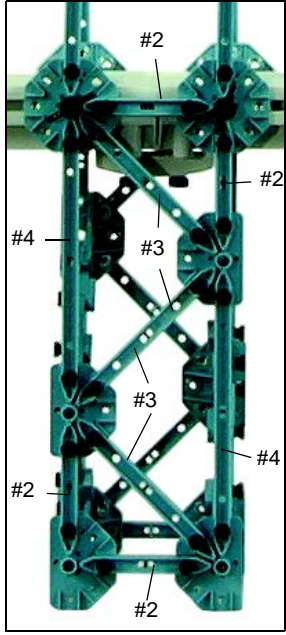
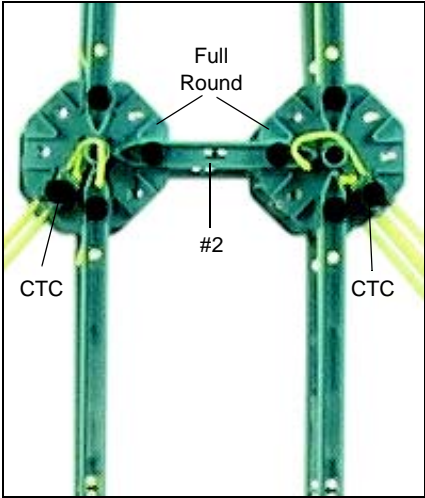
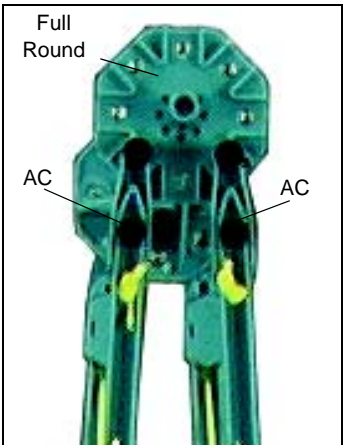
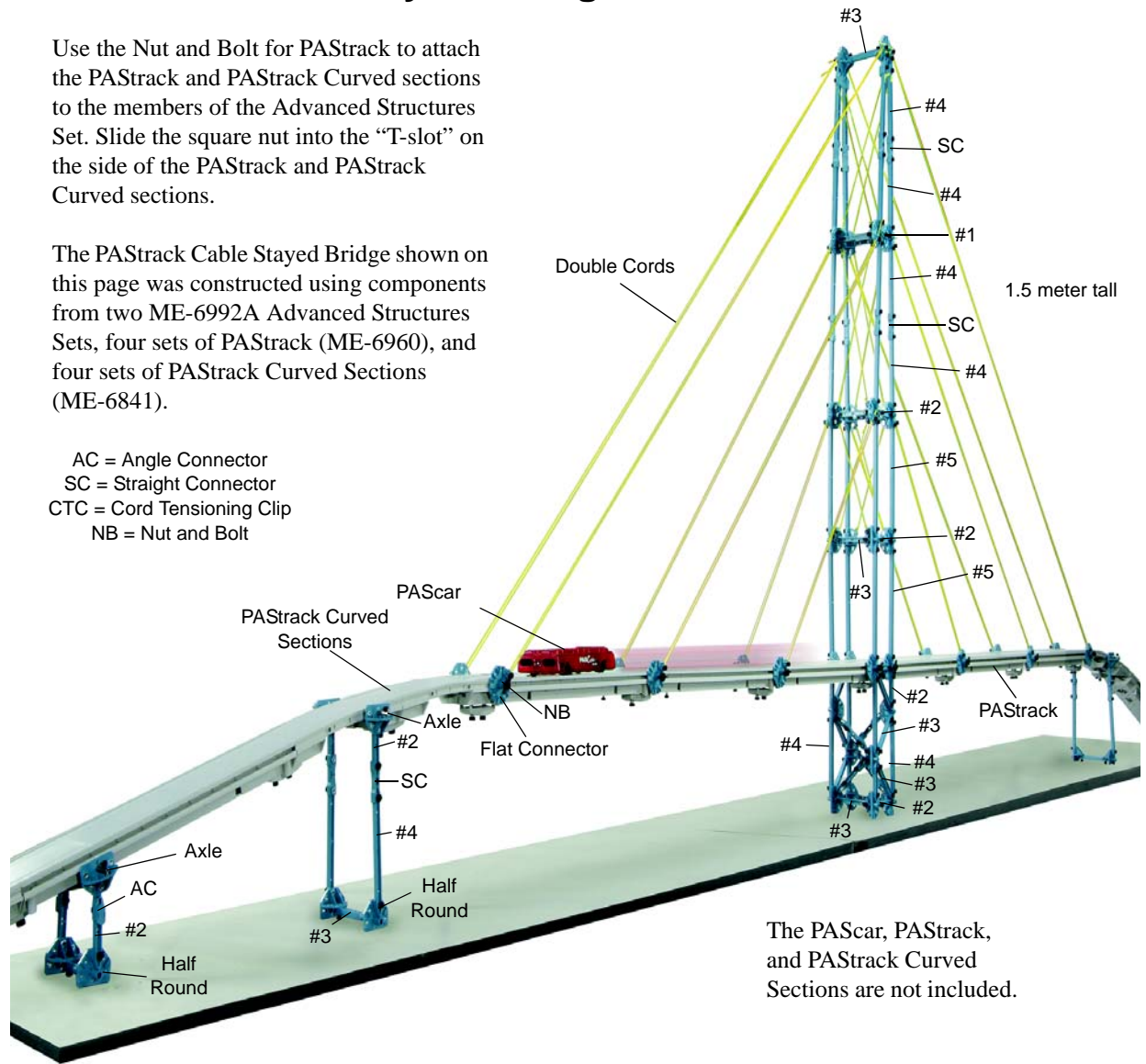


# PAStack Cable Stayed Bridge

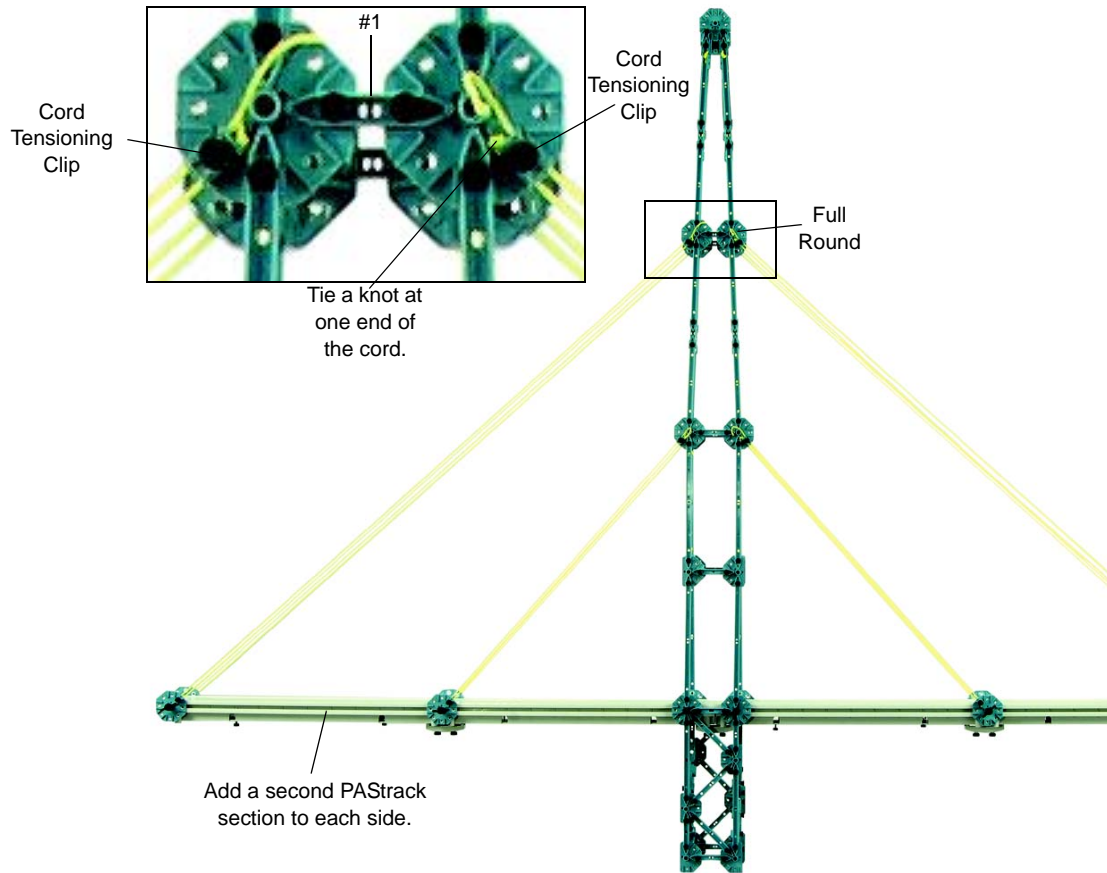
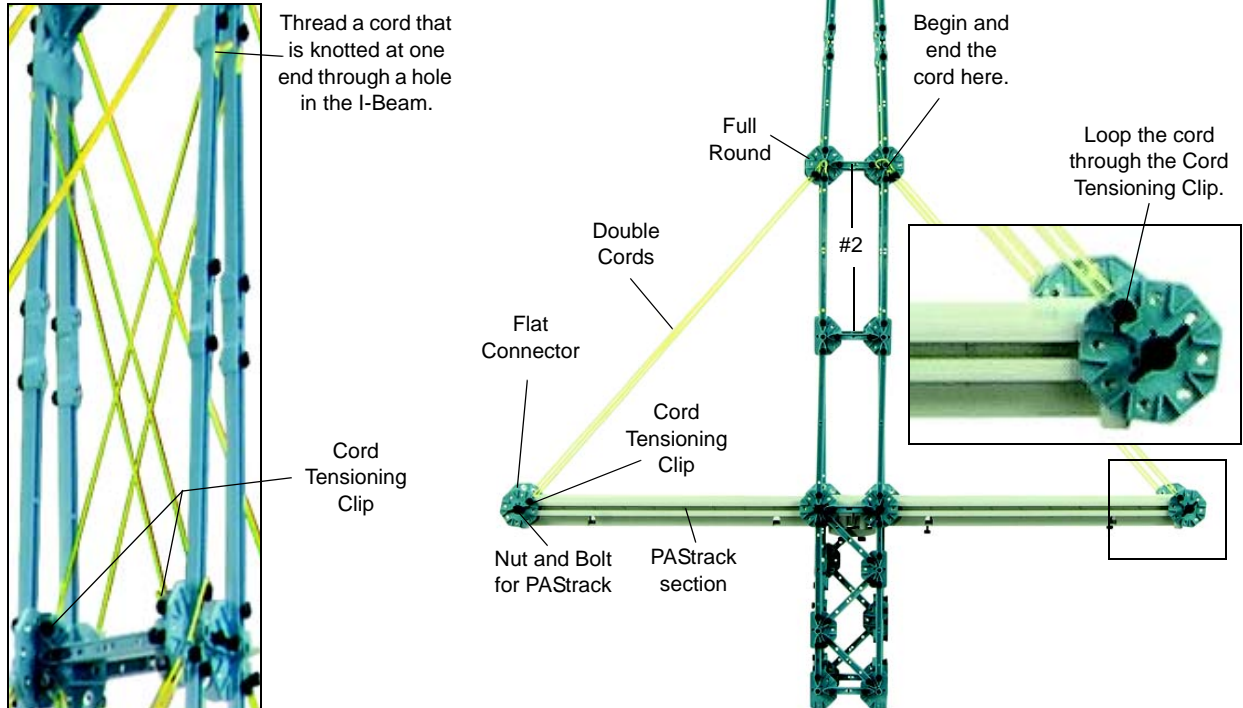
Use the Nut and Bolt for PAStack to attach the PAStack and PAStack Curved sections to the members of the Advanced Structures Set. Slide the square nut into the "T-slot" on the side of the PAStack and PAStack Curved sections.

The PAStack Cable Stayed Bridge shown on this page was constructed using components from two ME-6992A Advanced Structures Sets, four sets of PAStack (ME-6960), and four sets of PAStack Curved Sections (ME-6841).

- AC = Angle Connector
- SC = Straight Connector
- CTC = Cord Tensioning Clip
- NB = Nut and Bolt



# Cable Stayed Bridge Construction Suggestions



## Resonance Structures: Beam and Tower

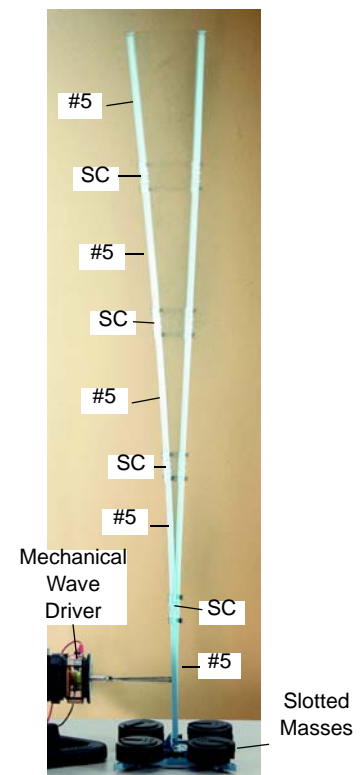
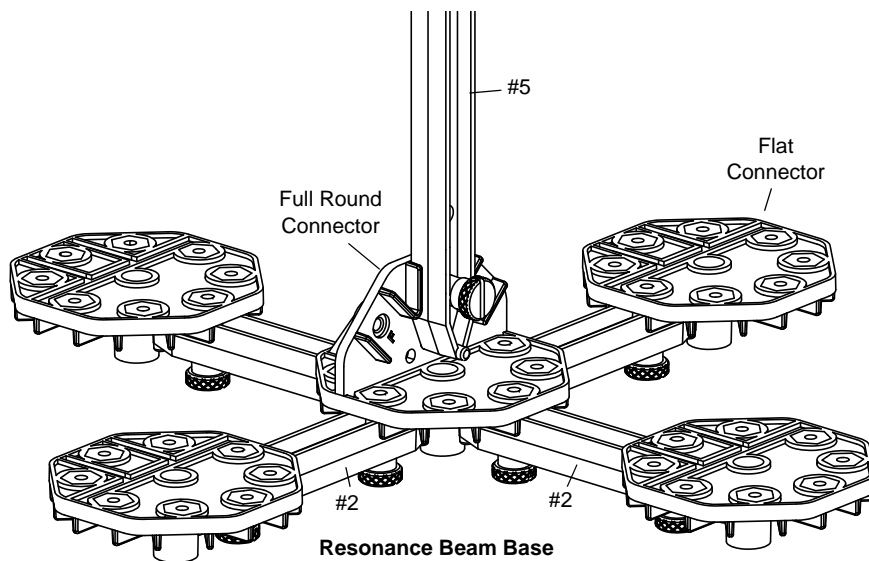
The PASCO Structures System can be used to demonstrate resonance in complex structures. Resonance is the tendency of a structure to oscillate at a greater amplitude at some frequencies than at others. These are known as the structure's resonance frequencies. At these frequencies, even small periodic driving forces can produce large amplitude oscillations.

Resonance occurs when a structure is able to store and transfer energy between two or more different storage modes (such as kinetic energy and potential energy in the case of a pendulum). However, there are some losses from cycle to cycle, called damping. When damping is small, the resonant frequency is approximately equal to the natural frequency of the structure, which is a frequency of unforced vibrations. Some structures have multiple, distinct, resonant frequencies.

Resonance phenomena occur with all types of vibrations or waves. The resonance structures demonstrate mechanical resonance. Unlike a standing wave on a string vibrating between two rods which has nodes at both ends, the resonance beam has a node at one end and an antinode at the other.

### Resonance Beam

Build a resonance beam using five #5 I-beams and four Straight Connectors (SC). Use four Flat Connectors, four #2 I-beams, and a Full Round Connector to build a base for the beam as shown below.



Place slotted masses (such as those from the ME-7566 Large Slotted Mass Set) on top of the Flat Connectors to stabilize the resonance beam.

Mount a Mechanical Wave Driver (SF-9324) on a support rod so that its drive post is horizontal. Align the driver so that you can attach the drive post to the middle of the first #5 I-beam of the resonance beam. One way to attach the drive post to the I-beam is to loop a piece of yellow cord through the hole in the middle of the I-beam and then through the hole on the accessory banana plug of the driver. Another way to attach the drive post is to mount a Sliding Connector to the middle of the I-beam. Loop a piece of yellow cord through the Cord Clip and attach the Cord Clip to the Sliding Connector. Connect the cord to the drive post.

You can control the Mechanical Wave Driver with a PI-8127 Function Generator, or with a PASCO Interface and Power Amplifier.



**Equipment Needed**

**Part Number**

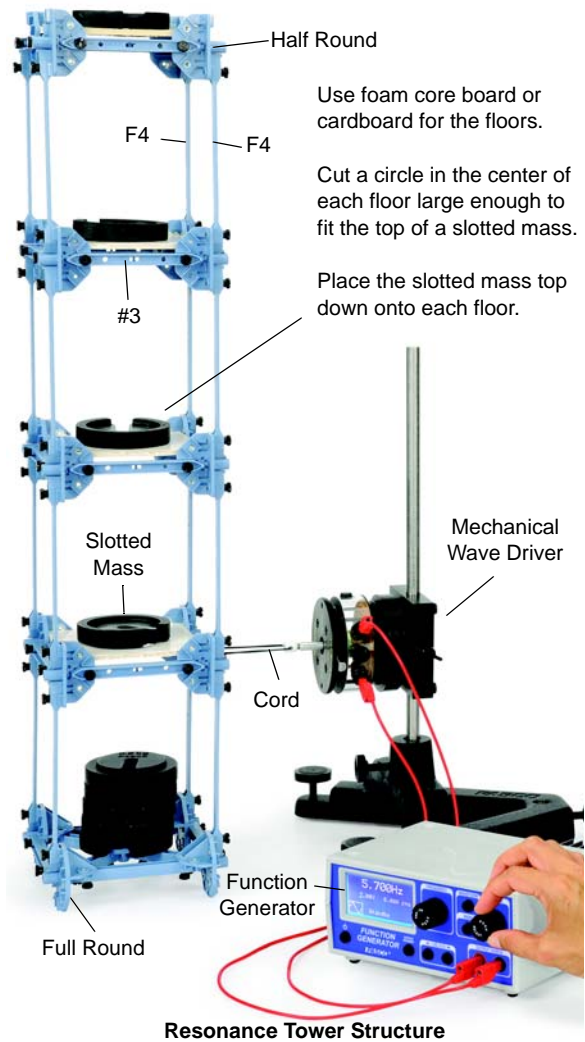
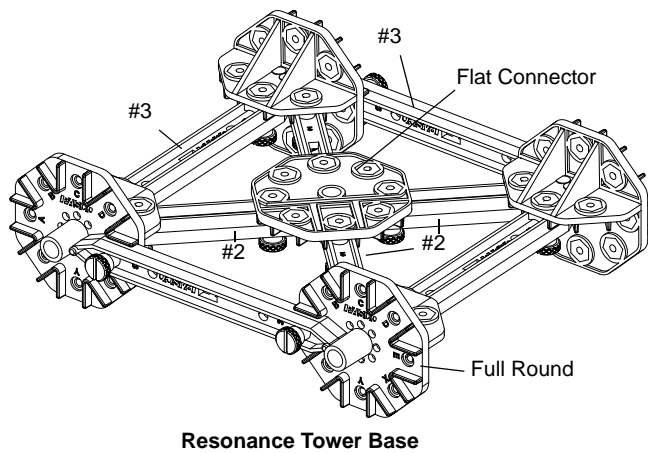
Mechanical Wave Driver	SF-9324
Function Generator	PI-8127
Rod, 25 cm, threaded	ME-8988
Small "A" Base	ME-8976
Banana Plug Patch Cords	SE-9750 or SE-9751

**Resonance Tower**

The Resonance Tower is a model of a building frame constructed with F4 Flat Members, #3 I-beams, #2 I-beams, Full Round Connectors, Half Round Connectors, and a Flat Connector.

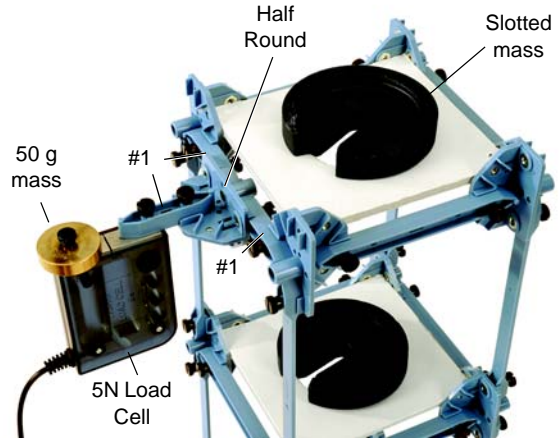
As with the Resonance Beam, you can use the Mechanical Wave Driver controlled by a Function Generator to shake the building. In addition, you can use a 5 N Load Cell PS-2201 to measure the acceleration of the Resonance Tower and use a Motion Sensor to measure the amplitude of its movement.

Use four #2 I-beams and a Flat Connector (as shown) to build the support for the slotted masses at the ground floor of the structure.



**Measure Acceleration**

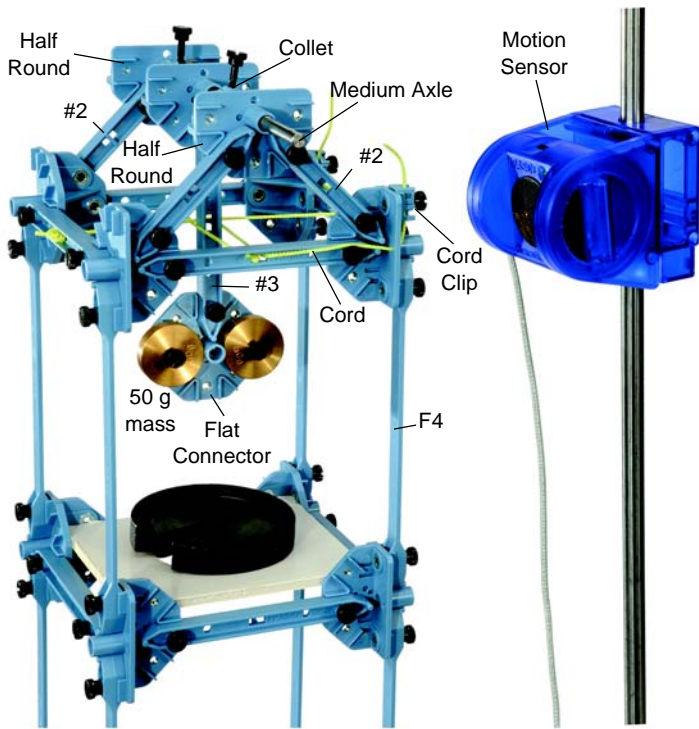
To measure the acceleration of the Resonance Tower, replace one of the #3 I-beams at the top floor of the tower with a Half Round Connector and two #1 I-beams as shown. Connect the 5 N Load Cell to the tower with a #1 I-beam, and mount a 50 g mass on the Load Cell.



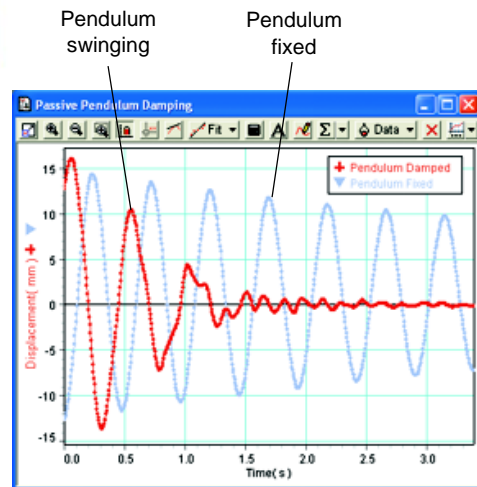
**Measure Acceleration**

**Measure Oscillations**

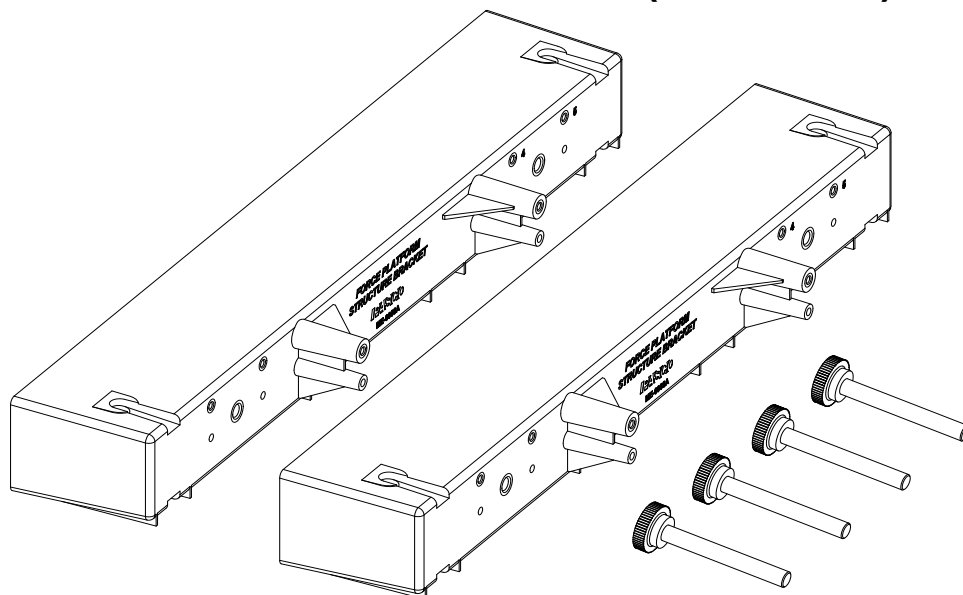
To study damped oscillations, replace the top floor of the tower with a 'pendulum' as shown. When the pendulum is tied in place with cord and cannot swing, the tower's oscillations persist. When the pendulum is allowed to swing, the oscillations are damped. Mount a Motion Sensor on a support rod to measure the oscillations.



**Measure Oscillations**



## Force Platform Structures Bracket (ME-6988A)



### Introduction

The PASCO model ME-6992B Force Platform Structures Bracket includes two brackets and four thumbscrews. The adapter bracket is designed to connect members of the PASCO Structures System to a PASCO Force Platform.

Force Platform	Model Number
PASPORT 1-Axis	PS-2141
PASPORT 2-Axis	PS-2142
ScienceWorkshop 1-Axis	CI-6461
Recommended Equipment	Model Number
PASCO Structures System	see <a href="http://www.pasco.com">www.pasco.com</a>

Each Force Platform Structures Bracket has six positions where members of a PASCO Structure System can be attached, and two thumbscrews for attaching the bracket to a Force Platform. Note that each bracket also has two threaded holes for storing the thumbscrews when they are not in use.

**Advanced Set (ME-6992A)** - The largest set with pulleys, axles, and additional connectors that make possible bridges which have angles other than 45 and 90 degrees. This set can also be used to build suspension bridges, cranes, cars and catapults.

The Force Platform allows the student to measure tension and compression forces in trusses, bridges, roller coasters, or other structures assembled with the PASCO Structures System sets.

See the PASCO catalog or web site ([www.PASCO.com](http://www.PASCO.com)) for more information about the PASCO Structures System.

## Installation

Use two thumbscrews to mount a bracket to one side of a PASCO Force Platform. Note that two brackets will fit on one Force Platform.

Use Truss Set thumbscrews (ME-6994) from one of the PASCO Structures Systems sets to attach I-beams or other members of a structure set to the six attachment positions on the bracket. (See Figure 1.)

## Using Brackets on a Force Platform

If a structure is connected to one or two Force Platform Structure Brackets that are mounted on a Force Platform, the dynamic changes in tension or compression of the members of the structure can be measured.

The different attachment positions along the side of the bracket allow different I-beam members to be used between two Brackets mounted on a Force Platform. Let the *span* of a structure be the distance between its attachment positions on two Brackets. Let the *separation* of the structure be the distance between two vertical members attached to the same Bracket.

The center attachment positions (labeled “3”) allow a span and separation of a #3 I-beam member. The next two attachment positions relative to the center allow a span and separation of a #4 I-beam. (See Figure 2.)

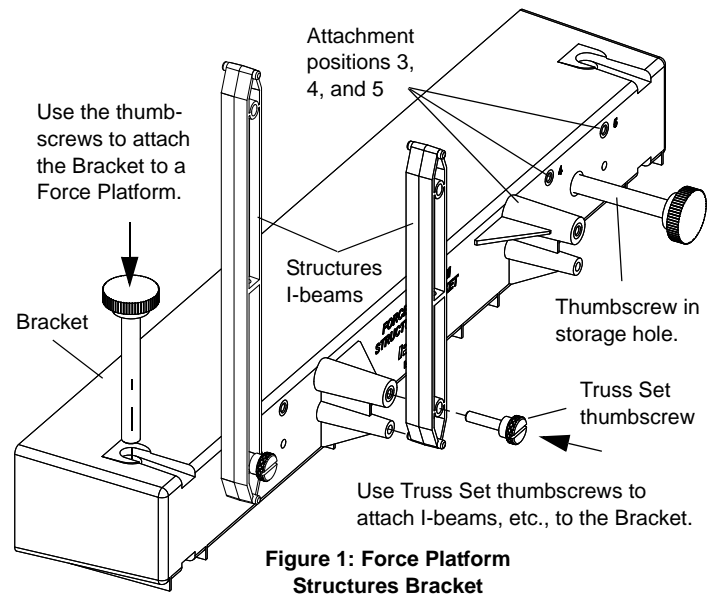


Figure 1: Force Platform Structures Bracket

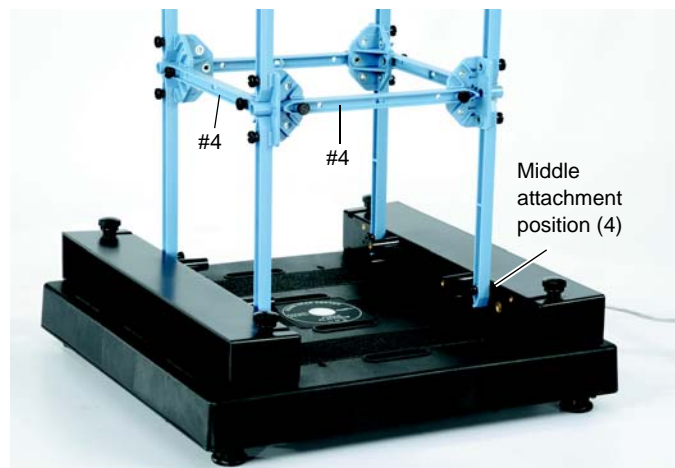
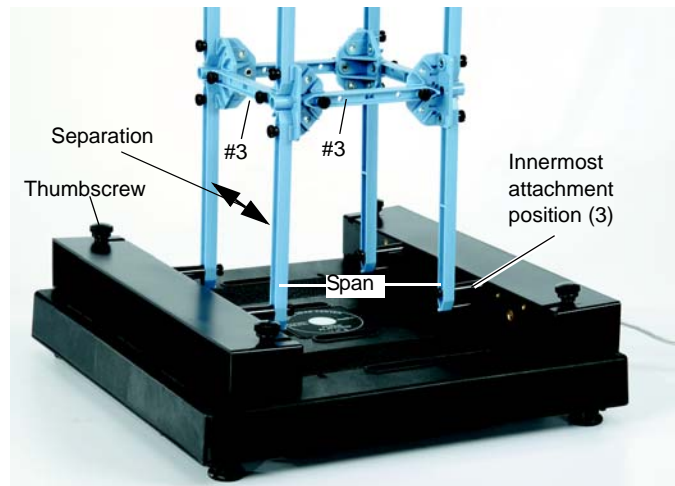
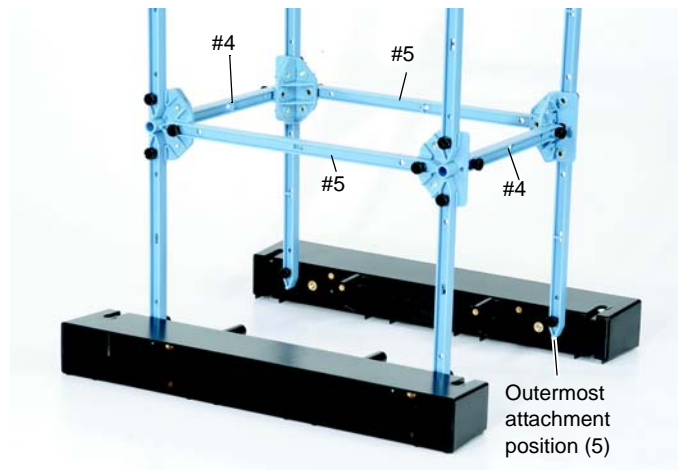


Figure 2: Mount Various Structures on a Force Platform

The outermost attachment positions relative to the center are designed for a span of a #4 I-beam and a separation of a #5 I-beam if the Brackets are mounted on a PASCO Force Platform. However, if the Brackets are mounted on another platform, or no platform as shown in Figure 3, then the span can be longer or shorter than a #4 I-beam.

Please refer to the instruction manuals for the PASCO Structures System Sets for ideas of what structures can be built and attached to the Force Platform Structures Bracket and a Force Platform. Examples include large bridges and a tower crane.



## Other Uses for the Bracket

You can use the Force Platform Structures Bracket on a different force-measurement platform if you have the means to attach the Bracket to your platform.

As shown in Figure 4, it is also possible to attach a structure to just one Force Platform Structures Bracket.

The attachment positions on the Bracket are at the same height as the top attachment position on a “half-round” connector.

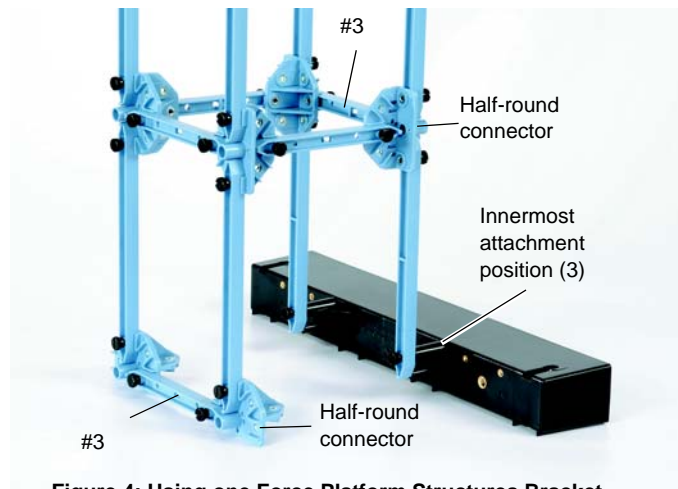


Figure 4: Using one Force Platform Structures Bracket



## Technical Support

For assistance with any PASCO product, contact PASCO at:

Address: PASCO scientific  
10101 Foothills Blvd.  
Roseville, CA 95747-7100

Phone: 916-786-3800 (worldwide)  
800-772-8700 (U.S.)

Fax: (916) 786-7565

Web: [www.pasco.com](http://www.pasco.com)

Email: [support@pasco.com](mailto:support@pasco.com)

For more information about the Advanced Structures Set and the latest revision of this Instruction Manual, visit the PASCO web site at [www.pasco.com](http://www.pasco.com) and enter ME-6992B in the Search window.

**Limited Warranty** For a description of the product warranty, see the PASCO catalog.

**Copyright** The PASCO scientific 012-12179A *Advanced Structures Set Instruction Manual* is copyrighted with all rights reserved. Permission is granted to non-profit educational institutions for reproduction of any part of this manual, providing the reproductions are used only in their laboratories and classrooms, and are not sold for profit. Reproduction under any other circumstances, without the written consent of PASCO scientific, is prohibited.

**Trademarks** PASCO and PASCO scientific are trademarks or registered trademarks of PASCO scientific, in the United States and/or in other countries. All other brands, products, or service names are or may be trademarks or service marks of, and are used to identify, products or services of, their respective owners. For more information visit [www.pasco.com/legal](http://www.pasco.com/legal).

**Patents Pending:** The following PASCO products are some of the products that have patents pending:

### ME-6990 Truss Set

ME-6992A Advanced Structures Set  
ME-6994 Truss Set Screws  
ME-6996 Cord Lock Spares  
ME-6998 Axle Spares

### ME-6991 Bridge Set

ME-6993 Truss Set Members  
ME-6995 Road Bed Spares  
ME-6997 Full Round (XYZ) Connector Spares  
ME-6999A Angle Connector Spares

PS-2198 Load Cell Amplifier

PS-2199 Load Cell and Amplifier Set

PS-2200 100 N Load Cell

PS-2201 5 N Load Cell

PS-2206 Dual Load Cell Amplifier