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2008 Volume IV: Bridges: The Art and Science for Creating Community Connections

The Use of Bridge Design in Teaching Mechanics

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Introduction

The School District of Philadelphia traditionally offers physics to students in their senior year of high school as an elective science course. At Robert E. Lamberton High School which is one of the smaller neighborhood high schools within the city of Philadelphia only one class of physics is generally taught. As a result, no more than thirty-three students would be able to take physics during any academic year at Lamberton High School. Although it is an advanced science course, it is not calculus based. It is, however, dependent upon a proficient knowledge of algebra and trigonometry. Even though these students constitute our better students, they tend to have significant deficiencies in both reading and math skills making physics quite a challenge. As a means of addressing these deficiencies, a variety of pedagogical strategies will be used. Initially, the students will be given sufficient time to review the appropriate mathematical and operational skills required to succeed in a traditional high school physics course. In addition to cooperative learning techniques, students will be taught the Cornell Method of note-taking as a means of improving their reading and comprehension skills. The students will also participate in a hands-on activity designed to improve their inquiry and math skills.

Rationale

This unit has been divided into three main sections: the history of bridges, the types of bridges, and the forces associated with each type of bridge. For the first two sections, one day will be devoted to each topic. The majority of time, approximately eight days, will be devoted to examining bridge design and the forces associated with each type of bridge.

With regard to part one, the history of bridges, the development of bridge design as a function of advances in civilization will be presented. More specifically, bridges from the following periods throughout history will be studied: the ancient world up to and including the fall of the Roman Empire in the 5th century, the Middle Ages from between the 5th and 15th centuries, the Renaissance which lasted from the14th to the16th centuries, the Age of Enlightenment in the18th century, the modern era including the Industrial Revolution from the18th to the 20th centuries, and the post modern era from1949 to the present (1). This portion of the unit is intended to examine the structural design of notable bridges throughout history with an emphasis on those currently in use.

Bridges have been classified into six fundamental types: beam, truss, arch, cantilever, cable-stayed, and suspension. With this in mind, the second major section of this curriculum unit will focus on the relationship between the form and function of each type of bridge. One area of interest in this section involves the following two part question: "Which type of bridge would be best suited for a given function or situation?", and "What underlining factors would determine its use?"

The final section, which is the primary focus of the unit, will center on the different forces associated with bridges, such as: compression, tension, stress, strain, and elasticity. The physics of each will be examined in detail especially in relation to static equilibrium.

History of Bridges

Bridges represent architectural structures that are capable of spanning both natural and manmade obstacles. They have been used throughout history to promote commerce, travel, and communication. They have also been used during times of peaceful coexistence as well as in times of conflict. Ancient and current primitive civilizations have relied on bridges constructed from natural materials. As civilizations and technology advanced, so did the architectural design of bridges due to the advances in construction methods and materials. In ancient or primitive civilizations merely placing a log on either side of a river, stream, or creek would have created the simplest of all bridges, the beam bridge. The use of ropes made out of vines has been used by primitive civilizations throughout history to construct basic suspension bridges.

It was the ancient Romans who were credited with truly advancing the architectural design and construction of bridges, as well as other structures. This was due to their ability to implement the use of the semi-circular stone arch with a type of cement called pozzolana. The use of the two in combination allowed the Romans to build longer and stronger bridges. An example of a Roman bridge which is still being used is the Alcántara Bridge which spans the Tagus River in Alcántara, Spain. Having six stone arches, the entire length of the bridge is 194 meters. It is 8 meters wide and 71 meters high (2). Designed by Gaius Julius Lacer and completed in 106, this bridge has been in use for nearly 2000 years. What is just as amazing is the fact that the Alcántara Bridge was constructed without the aid of any mortar. This ancillary bit of information was mentioned in the article entitled "Bridges" which appeared in the fifteenth edition of *The New Encyclopedia Britannica*.

With the fall of the Roman Empire during the 5th century came a decrease in technological advancement. However, it was during the Middle Ages that the Gothic arch was introduced into architectural design. This type of arch is elliptical or pointed in shape. The advantage of the Gothic arch over the semi-circular Roman arch is that the Gothic arch increased the structural support at both the top and base of the arch. A most picturesque example is the Valentré Bridge that spans the Lot River in the city of Cahors, France. Even though it dates back to 1350, it remains fully functional. It is composed of six symmetrical Gothic stone arches in addition to three square towers. The total length of the bridge is 138 meters. It is also 5 meters wide and 40 meters in height (3).

The Renaissance period brought along with it a resurgence of technological advancement in addition to an increased sense of artistic and aesthetic awareness. As a result, bridge design during this period increasingly incorporated both form and function. A prime example is the beautiful Allahverdi Khan Bridge which crosses the Zaandeh River in Esfahan, Iran. It was completed in 1602 and is composed of a double layer of 33 Gothic arches. Its total span length is 298 meters and it is 14 meters wide (4). Another example is the oldest bridge spanning the Seine River in Paris, France. The Pont Neuf Bridge, a stone arch bridge, was completed in 1607. It is composed of two separate and unequal spans. The shorter span of five arches connects the left bank of Paris with the ÃŽle de la Cité. The longer span of seven arches connects the island with the right bank of Paris.

The total length of the bridge is 232 meters and it is 22 meters wide. The last major renovation was competed in time for its 400th anniversary in 2007 (5).

During the 18th century, stone and/or masonry arched bridges continued to be the prevalent type of architectural design for bridges throughout Europe and Asia. One of the most beautiful, the Bolshoy Most or Large Bridge, was built in Tsaritsyno, Russia in 1778 (6). This period in time was marked by enormous strides in the manufacturing of materials, such as iron. As a result, the first cast iron arch bridge was completed near Coalbrookdale, England in 1779. The Iron Bridge is a single arch bridge that spans River Severn. It is 60 meters in length and 18 meters high. The final project required 379 tons of iron (7). In addition, wooden truss bridges with longer spans were constructed during this time. For example, Hans Grubenmann in 1757 built two covered wooden truss bridges over the Rhine River at Schaffhausen in northern Switzerland. One of the bridges had a length of 52 meters while the other was 59 meters long (8).

As the Industrial Revolution progressed into the 19th century, technological advances brought changes in both manufacturing and construction. A noteworthy arched bridge constructed in the 19th century was originally commissioned by Napoleon I. The Pont de Pierre, completed in 1822, was the first bridge to span the Garrone River in Bordeaux, France. Due to the unfavorable conditions of the river, it was necessary to use a diving bell to secure the pillars of the bridge. The Pont de Pierre Bridge is 486 meters long with 17 arches, exactly the same number of letters as in Napoleon Bonaparte's name (9). It was during this period that both wooden and wrought iron truss bridges were being built throughout the world. In the United States, the wooden truss bridges of 1800's were generally the covered bridges that one sees today in the country-side of the Mid-Atlantic and New England states. In comparison, since the wrought iron truss bridges were able to carry heavier loads, they were instrumental in the expansion of the railroads throughout Europe and North America. Suspension bridges began to be constructed, particularly in the United States. The Niagra Falls and Brooklyn Bridges are representative of two suspension bridges that were built toward the middle of the 19th century. Additionally, concrete arch bridges were being constructed as early as the 1860's (10). The development of new materials along with advances in technology, and environmental concerns have influenced the design and construction of bigger and stronger bridges throughout the 20th and 21st centuries.

Types of Bridges

The second portion of this curriculum unit is designed to examine the different types of bridges. In particular, the following two questions will be addressed. The first being, "Which type of bridge is best suited for a given function or situation?", and the remaining question is "What are the underlining factors which would determine its use?" The architectural design of bridges has been classified into six fundamental categories or types. They include: beam, truss, arch, cantilever, cable-stayed and suspension bridges. The distinguishing feature of each is their characteristic geometric shape. Although the physics behind bridge design is the same, the manner in which the compression and tension forces act differs depending upon the bridge design. In knowing the specific function of a bridge will, in part, help determine its type or form. This allows one to examine the relationship between the form and function of a particular structure and for the purposes of this unit bridges. As a general rule, beam, truss, and arch bridges are used for short distances. Longer distances require cantilever, cable-stayed, or suspension bridges. This general rule is certainly dependent upon the specific material used in the construction. A summary of each type of bridge design and the forces they undergo are given in the next few paragraphs. This information was obtained from two articles on bridges. One article was obtained from the eighth edition of the *McGraw-Hill Encyclopedia of Science and Technology* and the other article appeared in the fifteenth edition of *The New Encyclopedia Britannica*.

The beam bridge is the most basic of the six fundamental types of bridges. Simply put, it consists of a horizontal beam supported at each end. As the weight or load is added to the beam it bends and undergoes compression at its surface while at the same time the bottom of the beam undergoes tension. The materials used in the construction of the beam and the load it is intended to support will in turn dictate the length of the beam.

Truss bridges are similar to beam bridges in that they consist of supported horizontal beams. They differ from each other in that truss bridges have two horizontal beams which are connected by a series of triangular supports. As the bridge is subjected to a load, the top beam bends thereby undergoing compression while the bottom beam experiences tension. The alignment of the triangular supports within the truss will determine whether they are in compression or tension. In order to achieve a stable truss system, a series of lateral braces must be included. The arrangement of the triangular supports has led to a variety of different truss systems. Three of the more conventional ones include: Pratt, Warren, and Howe trusses. A major advantage of truss bridges over beam bridges is because of the distribution of forces, truss bridges can withstand greater loads while using less material.

An arch bridge relies on a curved structural element such as one with a circular cross section or with a square I section that is rigidly supported at its base. The compression forces being directed toward the base of the structure. The shape of the curve is an important factor in determining the distribution of the compression forces. A comparative example would involve the differences between the semi-circular Roman arch and the elliptical or pointed Gothic arch. Another essential consideration is the height of the arch. As the height of the arch increases, the direction of the compression forces at the base becomes increasingly vertical.

Cantilever bridges are segmental bridges in that they generally involve three sections. At either end of the bridge is a beam supported in such a way that one side of the supported beam is longer than the other piece. The two cantilevered sections are then connected by means of a shorter section which is placed between the two. The distribution of the compression and tension forces in the shorter connecting span is similar to the beam bridge. The upper beam or chord member is in compression whereas the bottom beam is in tension. As for the cantilevered sections, the opposite is the case. The upper beam is in tension whereas the lower member is in compression.

The cable-stayed bridges utilize a modified cantilever structure. The cantilevered ends are joined together without the aid of the center connecting span. They are supported by a series of cables which emanate from different heights of each tower to each side of the cantilevered beam at varying lengths. The cantilevered beams are in compression, as are the towers, whereas the supporting cables are in tension. Cable-stayed bridge design is relatively recent dating back to the early 1950's.

Like the cable-stayed bridge design, suspension bridges rely on the use of cables to support the bridge beam. In the case of suspension bridges, however, a series of vertical cables along the beam are attached directly to the support cable from the tower. For added stability, the beam may be connected to a truss system. The distribution of the forces in the suspension bridge is the same as those for a cable-stayed bridge. The towers are in compression whereas the cables are in tension.

The Physics of Bridges

The branch of physics which governs the behavior of all bridges is rooted in classical Newtonian mechanics. More specifically, the salient areas of interest are: Newton's laws of motion, static and dynamic equilibrium, compression forces, tension forces, stress, strain, and the elasticity of materials. Therefore, the bulk of this curriculum unit is devoted to teaching high school students in a traditional physics class the aforementioned concepts. One of the major problems students have with science, and physics in particular, is an inability to understand the conceptual vocabulary or terminology. It is incumbent upon the teacher to be able to explain these concepts in a manner in which all students can understand. Hopefully, the following will serve as a refresher or review in achieving that outcome.

In the middle of the 17th century, Sir Isaac Newton formulated three laws of motion which remain valid to the present day. The First Law of Motion involves objects which are either at rest, that is not moving, or that are already in motion. If an object is not moving, it would take a force from somewhere to cause it to move. Conversely, if an object is presently in motion, it would take a force from somewhere to change its motion, that is to say, either its speed or its direction. Newton's First Law of Motion can be stated as saying that an object at rest will remain at rest, or motionless, unless acted upon by some outside force. For objects which are already in motion, it can be said that objects that are in motion will remain moving in a straight line unless acted upon by some outside force. That force can cause the object to either change its speed or direction. Newton's First Law of Motion has been referred to as the Law of Inertia. Students might then ask "So, what is inertia?" All objects in the universe exhibit inertia. Simply put, inertia is the tendency of an object to resist a change in its current state of motion.

Newton's Second Law of Motion involves the mass, force, and acceleration of an object. In order to understand this law, one must understand the previously mentioned variables. First and foremost, mass and weight are not the same. Whereas the mass of an object is directly proportional to the quantity of matter it possesses, weight is related to the response an object exhibits relative to the force of gravity. With this in mind, it is important to remember that although the weight of an object can change due to the gravity it encounters, the mass of an object does not. Consequently, mass is independent of the influence of gravity. Since gravity is a force, it is important to understand the meaning of force. A force is simply the result of a push or pull. Acceleration is the last variable that needs clarification at this point. It can be defined as a change in the object's velocity relative to a given period of time. Since velocity is a vector quantity, a change in velocity can refer to either a change in the speed or its direction or both. With an understanding of the three variables listed above, one can better understand Newton's Second Law of Motion. One way of stating this law is as follows, the force exerted by an object is equal to the product of its mass and acceleration. Another common method of expressing this law is the acceleration produced by an object is equal to its force divided by its mass. In equation form it can written as:

$F = ma$ or $a = F/m$

Newton's Third Law of Motion involves action-reaction forces. This is an extremely important concept in understanding static and dynamic equilibrium. Newton's Third Law of Motion can be stated as an object that is subjected to a force will respond with an equal but opposite force. A simple example explains why one does not fall through the floor on which they are standing. If the floor is unable to exert an equal but opposite force, the individual would fall through the floor. On the other hand, if the floor exerted a greater force than the person, that individual would be catapulted upward.

Static equilibrium differs from dynamic equilibrium in that static equilibrium involves objects that are not in motion such as structures. In contrast, dynamic equilibrium deals with moving objects. For the purposes of this unit, emphasis will be placed on static equilibrium. Two conditions must be met in order for static equilibrium to occur. Since static equilibrium refers to objects which are not in motion, the first condition for equilibrium states that the sum of all of the external forces that act on the object must equal zero. The two equations listed below on the left hand side and in the middle satisfy the first condition of equilibrium. Whereas the equation on the left states that the sum of all of the external horizontal forces is equal to zero, the equation in the middle states that the sum of all the external vertical forces is equal to zero. In order for the second condition for equilibrium to be satisfied the sum of all of the external torques that acts on the object must equal zero. The second condition involves rotational motion or torque. The term torque is also referred to as moment of force. The equation on the right hand side states that the sum of all of the external moments is equal to zero where M is the symbol for moment. Therefore, the following three equations must be met in order for static equilibrium to occur.

$SF_{H} = 0$

$SF_{V} = 0$

$SM = 0$

It should be noted at this point that the sum of all of the external vertical forces would also include gravity and consequently weight. As stated above, weight is the result of gravity acting on the mass of an object. This can be represented by the following equation:

$W = mg$

By extension, since weight is a force, any force can be represented as follows:

$W = F = mg$

In order to satisfy the second condition of static equilibrium one must understand the basics of torque or moment of force. Since torque involves rotational movement around a point, it will produce angular acceleration simply by a change in the direction of motion. The moment of an object can be determined by using the following equation:

$M = Fr$

M is the moment of the object

F is the external applied force

r is the distance from the applied force to the axis of rotation

If given the mass of an external load rather than the force, the equation for moment becomes:

$M =(mg)\ r$

According to Newton's Third Law of Motion, for every external force applied to an object there will be an equal but opposite reaction force. With that in mind, when a rigid object or structure like a bridge is subjected to a force a portion of that structure will be deformed or bent. A portion of that object will undergo compression. This is where the molecules within that object are pushed together. Conversely, a portion of that object will be in tension. When that occurs, those molecules will be pulled away from each other and the object will stretch or get longer. As a result, two important forces to consider when dealing with the physics of bridges are compression and tension.

Equally important are the concepts of stress and strain for when a portion of a structure is subjected to a stress that same portion of that object will undergo strain. Stress, simply put, refers to the amount of force applied in a given area. Strain, however, is reflective of a volumetric change in the size or shape that an object undergoes when it is subjected to a force. The equation below on the left is used to define stress while the equation on the right is the mathematical expression for strain.

$\sigma = F/A$

$E = \Delta L/L_o$

σ is the average stress the object undergoes

E is strain object undergoes

F is the external force applied to the object

ΔL is the change in length

A is the area over which the external force is applied

L_o is the original length

Elasticity is a property of an object that allows it to regain its shape after being subjected to an external force. The relationship between stress and strain will determine the elasticity or stiffness of the material in question. One can determine the degree of elasticity with the following equation:

$E = (F/A)/(\Delta L/L_o) = \text{stress/strain}$

The above equation is used to calculate Young's modulus of elasticity which is denoted as E. As a result, the greater the value for Young's modulus the stiffer is the material. Conversely, the smaller the value of E the more flexible is the material. In designing structures, such as bridges, it is important to know the elasticity of the materials being used in the construction of that structure.

In order for simplification and as an aid in solving mathematical problems in physics the technique of drawing free body diagrams is most useful. This can be done by indicating the object in question and representing it as a box, dot, or simplified drawing. Afterwards, all of the forces acting on that object must be identified and indicated on the drawing as a vector quantity. One can utilize the parallelogram method for resolving vectors either graphically or mathematically. To resolve vectors mathematically the Pythagorean Theorem, trigonometric functions, the law of sines, or the law of cosines might be used. For instance, in order to resolve a given force into its horizontal and vertical components the following equations would be useful. The equation on the left hand side is used to calculate the horizontal force and the equation on the right is for resolving the vertical component.

$F_H = F\cos\Theta$

$F_V = F\sin\Theta$

In this manner free body diagrams help to focus one's attention on factors which are directly related to the problem.

Solving problems dealing with truss systems can be done by using either the method of joints or the method of sections. The former method does not require finding SM = 0, but in order to find a force at a given joint within the truss all of the joints up to the one in question must be considered. This procedure can be laborious and difficult. The later method involves isolating particular sections in question and solving the series of equations $SF_H = 0$, $SF_V = 0$, and SM = 0. This is a more convenient method for high school students.

Objectives

This curriculum unit is intended to complement unit three, "Vectors, Two-Dimensional Motion, and Forces," of the School District of Philadelphia's standardized curriculum for physics. It is also designed to be in alignment with several Pennsylvania Academic Standards for Science and Technology (11). These standards have been taken directly from the pamphlet entitled *School District of Philadelphia Core Curriculum: Curriculum Resource- Science Grade 12 Physics.* They include the following standards: applying the principles of motion and force, analyzing physical technologies of structural design to real-world problems, and applying advanced tools, materials, and techniques to answer complex questions" (12).

As outlined in the pacing schedule for the course, the School District of Philadelphia has allocated seven weeks to cover vectors, two-dimensional motion, and forces (13). As envisioned, this unit will encompass a two week time frame in which the following topics will be examined: the history of bridges, the types of bridges, and the forces associated with bridges. The majority of time, however, will be spent dealing with the third section, the physics of structural forces. The primary goal of this unit, therefore, is to have students examine the architectural design of different types of bridges and understand the forces associated with each type.

Strategies

Students in public schools from around the country face many of the same problems. Deficiencies in reading and math skills have impacted the scholastic achievement in many subjects, but in particular math and science. As a means of addressing these problems, this unit will utilize both content specific classroom strategies and pedagogical strategies. In the first case, graphical analysis, mathematical problem solving, and technology will be used. With regard to pedagogical strategies, a series of cooperative learning skills will be addressed in addition to teaching note-taking skills.

The ability to create, read, and understand graphical relationships are essential, not only to math and science, but it is equally applicable to any content area. Many students have difficulties distinguishing a dependent variable from an independent variable. Setting up a graph and establishing an appropriate scale can be very challenging to students. Identifying relationships within a graph and understanding their significance is problematic for many students. In view of the aforementioned problems, time will be allocated for reviewing and applying graphical analysis to a variety of problems associated with the physics of bridges. In particular, there is the option of graphing the following three different ratios: external force per unit area, the change in length of an object verses its original length, and the correlation between stress and strain. Calculating the slope of each graph would give the following values: stress, strain, and degree of elasticity or Young's Modulus.

Difficulty in reading comprehension makes solving word problems that much more complex. The ability to simplify these problems is crucial to solving any physics problem. There are four basic steps that students can follow in simplifying word problems. Initially, students simply need to read the problem. The second step is to write down all of the information that is given. This may involve drawing a diagram, such as a free body diagram. The next step involves finding an equation to solve the problem. The last step requires the student to perform the mathematical operations exactly as indicated in the equation. All units must be included in this last step. Using dimensional analysis and knowing the expected units in the answer, one can determine whether or not the equation is set up properly. Students will be given a series of word problems dealing with truss bridges. They will be expected to solve them using the method of sections, as outlined earlier.

The ability to create power point presentations is an effective skill that high school students should possess in preparing for post-secondary education or careers. The technology piece of this curriculum unit will concentrate efforts on teaching students how to prepare a successful power point presentation. Several points to consider take into account the use of special effects, the size of the font, the background color of the slide, and the number of words on a slide. Students need to remember that each slide signifies a specific point. As a direct result, each slide should summarize a particular point. The formation of a high-quality presentation will enable the student to acquire a variety of important skills, not the least of which is the ability to paraphrase and summarize.

Cooperative learning takes into account a number of different pedagogical techniques which are aimed at improving both scholastic and social skills. Working in small groups provides students the opportunity to interact and exchange ideas that conventional classroom seating arrangements do not. Positive group dynamics can lead to improving student confidence. The objective of reciprocal teaching is to enhance reading comprehension. It consists of small groups and four basic steps that include: questioning, clarifying, summarizing, and predicting. A related activity aimed at improving the ability of students to summarize material is a technique referred to as the Cornell Method of note-taking. Walter Pauk, an education professor at Cornell University, developed this highly successful method over fifty years ago. The essential points involve writing down key words or questions in one section on a sheet of paper, notes and/or phrases in another section, and then putting them all together by writing a short summary at the bottom of the page (14).

Classroom Activities

Activity 1: Power Point Presentation on Bridges

The following culminating activity is designed for the first two sections of this curriculum unit, the history of bridges and the types of bridges. The behavioral objectives incorporate both pedagogical and content specific skills. The pedagogical skills involve: the ability of the students to work cooperatively in groups, the proficiency of the students to summarize material, and their ability to use computer software. The content specific skills are based on an understanding of the development of bridges as an effect of advances in civilization. Working in cooperative learning groups comprised of four students, each group will create a fifteen minute power point presentation on a specific type of bridge. The presentation will focus on the historical development and examples of that specific type of bridge. In addition, the presentation will examine the function and/or situation for which that type of bridge is best suited while considering the underlying factors which would influence its use.

Activity 2: Graphical Analysis of Young's Modulus of Elasticity

The behavioral objectives for this activity involve the students' ability to: distinguish independent variables from dependent variables, create appropriate scales, use data in creating a graph, calculate the slope of a line, and determine its significance. Using the data listed in Table 1, the students will graph stress (P/A) verses the strain (ΔL/L) for a series of metals, calculate the slope for each, and determine the percentage error between the calculated value and the accepted value of Young's Modulus for each metal.

Table 1: Values are listed below for the stress (P/A), strain (ΔL/L), and Young's Modulus for a number of selected metals.

Aluminum

Sample 1	Sample 2	Sample 3	Sample 4
$P/A = 7.30\times10^{7}$	$P/A = 14.6\times10^{7}$	$P/A = 21.9\times10^{7}$	$P/A = 29.0\times10^{7}$
$\Delta L/L = 1.00\times10^{-3}$	$\Delta L/L = 2.00\times10^{-3}$	$\Delta L/L = 3.00\times10^{-3}$	$\Delta L/L = 3.97\times10^{-3}$

(The units for P/A are N/m^2)

Young's Modulus for aluminum = 7.3×10^{10} N/m^2

Brass

Sample 1	Sample 2	Sample 3	Sample 4
$P/A = 2.1\times10^{7}$	$P/A = 5.7\times10^{7}$	$P/A = 7.2\times10^{7}$	$P/A = 10.3\times10^{7}$
$\Delta L/L = 0.29\times10^{-3}$	$\Delta L/L = 0.55\times10^{-3}$	$\Delta L/L = 0.70\times10^{-3}$	$\Delta L/L = 1.00\times10^{-3}$

Young's Modulus for brass = 10.3×10^{10} N/m^2

Magnesium

Sample 1	Sample 2	Sample 3	Sample 4
$P/A = 4.5\times10^{7}$	$P/A = 7.2\times10^{7}$	$P/A = 9.9\times10^{7}$	$P/A = 13.5\times10^{7}$
$\Delta L/L = 1.0\times10^{-3}$	$\Delta L/L = 1.6\times10^{-3}$	$\Delta L/L = 2.2\times10^{-3}$	$\Delta L/L = 3.0\times10^{-3}$

Young's Modulus for magnesium = 4.5×10^{10} N/m^2

Steel (High Carbon)

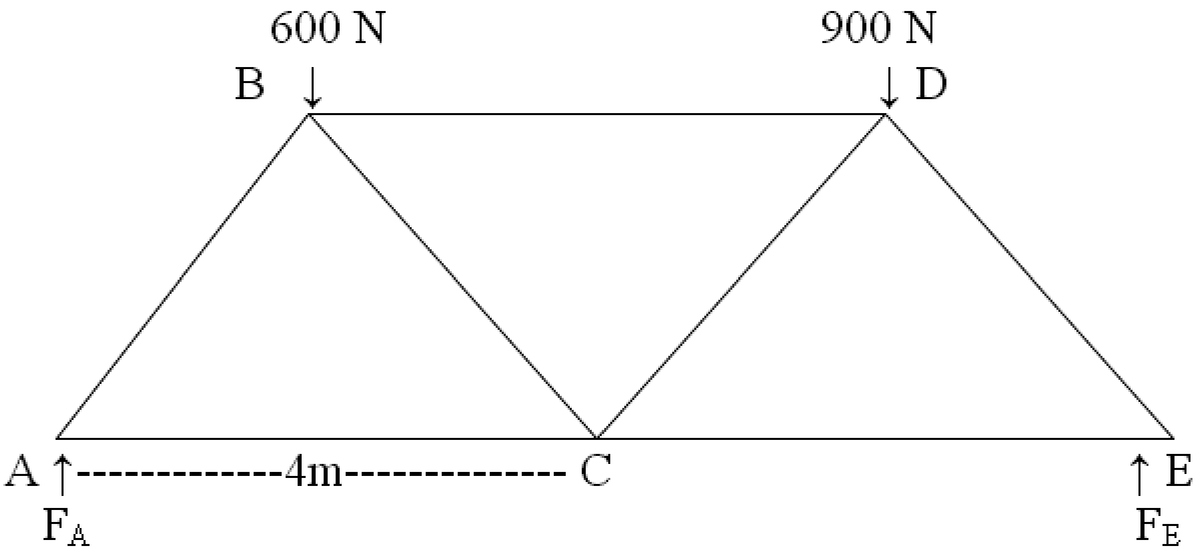
Sample 1	Sample 2	Sample 3	Sample 4
$P/A = 4.1\times10^{7}$	$P/A = 16.5\times10^{7}$	$P/A = 31.0\times10^{7}$	$P/A = 41.4\times10^{7}$
$\Delta L/L = 0.2\times10^{-3}$	$\Delta L/L = 0.8\times10^{-3}$	$\Delta L/L = 1.5\times10^{-3}$	$\Delta L/L = 2.0\times10^{-3}$

Young's Modulus for steel (high carbon) = 20.7x10 ^{10} N/m

Activity 3: Truss Bridge Problems

The behavioral objectives for this activity include students being able to solve static equilibrium problems, draw free body diagrams, resolve vectors mathematically, and distinguish compression forces from tension forces within a given truss bridge structure. Given the truss structure in Figure 1, the students should be able to calculate the external forces F_A and F_E at points A and E. In addition, they should be able to calculate the internal forces between members A-B, A-C, B-D, and B-C. They should also be able to determine whether those members are in compression or tension.

Figure 1: Truss Bridge Diagram (all angles are 60º)



Activity 4: Build a Bridge

The behavioral objectives for this final activity center on the ability of the students to apply their knowledge of bridge design and physics in constructing a scale model of a bridge. They may choose from any of the following: beam, arch, truss, cantilever, suspension, or cable-stayed design. The bridge is to be constructed from wood with the dimensions not to exceed 24 inches in length, 4 inches in width, and 12 inches in height. Prior to the actual construction of the bridge, a scale drawing of the bridge must be submitted.

Endnotes

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Appendix - Academic Standards

The Pennsylvania Academic Standards for Science and Technology which will be addressed in this curriculum unit were taken directly from the *Pennsylvania Teacher's Desk Reference and Critical Thinking Guide*, and include the following:

3.1.12 Unifying Themes: The unifying themes of science and technology provide big

ideas that integrate with significant concepts. There are only a few fundamental

concepts and processes that form the framework upon which science and

technology is based, which includes: motion and forces.

- D. Analyze scale as a way of relating concepts and ideas to one another by some measure.
- Compare and contrast various forms of dimensional analysis.
- Assess the use of several units of measurement to the same problem.

3.2.12 Inquiry and Design: The nature of science and technology is characterized by

applying process knowledge that enables students to become independent learners.

These skills include observing, classifying, inferring, predicting, measuring,

computing estimating, communicating, using space/time relationships, defining

operationally, raising questions, formulating hypotheses, testing and

experimenting, designing controlled experiments, recognizing variables,

manipulating variables, interpreting data, formulating models, designing models,

and producing solutions.

A. Evaluate the nature of scientific and technological knowledge.
    - Know and use the ongoing scientific processes to continually improve and better understand how things work.
B. Apply the elements of scientific inquiry to solve multi-step problems.
    - Organize experimental information using analytical and descriptive techniques.
C. Analyze and use the technological design process to solve problems.
    - Assess all aspects of the problem, prioritize the necessary
    - information and formulate questions that must be answered.
    - Evaluate and assess the solution, redesign and improve as necessary.

    3.4.12 Physical Science, Chemistry and Physics: Physics and chemistry involve the study of objects and their properties. Physics deepens the understanding of the structure and properties of materials and includes atoms, waves, light, electricity, magnetism and the role of energy, forces and motion.

D. Apply the principles of motion and force.
    - Describe inertia, motion, equilibrium, and action/reaction concepts through words, models and mathematical symbols.

3.6.12 Technology Education: Technology education is the use of accumulated

knowledge to process resources to meet human needs and improve the quality of life. Students develop the ability to select and correctly use materials, tools, techniques and processes to answer questions, understand explanations and solve

problems encountered in real life situations.

C. C. Analyze physical technologies of structural design, analysis and engineering, personal relations, financial affairs, structural production, marketing, research and design to real world problems.
    - Apply knowledge of construction technology by designing, planning and applying all the necessary resources to successfully solve a construction problem.