

Building Bridges: Understanding Forces and Materials

*Eric Laurensen
Allerdice High School*

Overview

Rationale

Objectives

Strategies

Classroom Activities

Annotated Bibliography/Resources

Appendices-Standards

Overview

Living in Pittsburgh we are surrounded by a veritable cornucopia of bridges. There are 446 catalogued bridges in Pittsburgh. They vary dramatically in size, function, design, materials and age. The wealth of bridges we have makes them a subject that is ripe for studying because they are pervasive, accessible, indispensable and diverse. As they say, "form follows function," but in terms of bridges the function is often similar, although varied in scale, while the forms are extremely variable. As a physicist it is my contention that the diversity of solutions for solving similar problems is invaluable for student interest, learning and development of creativity. In my unit, I want to address the problem solving aspects of building bridges and I want this study to culminate in the actual hands-on building and testing of a model bridge.

There are many aspects of bridges that I find compelling and that I believe will translate to my students. This unit is intended for physics students who have been introduced to Newton's Laws and Forces. An understanding of equilibrium and force diagrams would be extremely helpful. However, this unit is intended to be able to be used at a variety of mathematical and conceptual levels. I teach three levels of mathematically advanced physics. One class is a Pittsburgh Scholars Program physics I (PSP) that is slightly more mathematically advanced than a typical main stream physics I course, but which is equally as applicable. I also teach Gifted Physics I, which utilizes a college textbook and is more mathematically advanced. In addition, I will utilize the unit with my second year AP (Advanced Placement) B Physics II students. These students vary in mathematical ability but they are taking physics for a second year and have already completed one of the

previously listed classes. Although this unit is written specifically for physics students, it is my intention to present the concepts required and to provide scaffolding for the mathematics so that the unit could also be utilized by pre-engineering courses, technology classes with an emphasis on construction or any class, such as math, that follows the eighth grade physical science unit and wishes to provide a hands-on, constructivist learning opportunity on bridge building in a conducive learning environment.

The topography of Pittsburgh is trisected by the well-known Three Rivers (Monongahela, Allegheny, and Ohio) and is further sub-divided by many ravines leading from the surrounding bluffs and hills to the riverbanks. Because of this, there are a multitude of bridges throughout the city to allow people to get from one place to another. The presence of so many bridges is ripe for the imagination of our students. Why are there so many different designs? How do these designs relate to the structure of bridges? How did these bridge designs evolve? Why are so many different materials utilized in the construction of bridges? What are the relative properties and benefits of the various materials? How do the economics of bridge building affect the choice of materials? When did architects and engineers begin designing bridges and how did they create structures that are significantly different from those bridges built by craftsmen previously? How are bridges related to physical principles and specifically physics? How does geometry and geometric shapes relate to the strengths of different designs? How are the forces of gravity and load transferred by a bridge for it to fulfill its function? How are structures and function related? What can we learn from drawing force diagrams of bridges? What is the goal of a bridge? What does it mean when bridges are in equilibrium? How should varying materials affect the design of bridges? How do we utilize the knowledge of materials and design to create our own bridge? How do we design experiments to enhance our design? These are some of the questions that will be stimulated by considering the “Bridges of Pittsburgh.”

The main focus of my unit will be on the mechanics of bridges. What is the purpose of a bridge, what are the load requirements, how does form follow function, what is the role of aesthetics, how do the various solutions inform our study of physics, what are the basic principles of forces and stress in bridge design, how do these stresses elegantly display themselves in the forms of bridges, what do the various solutions demonstrate about the inclinations and technological advancements of the builders, how do materials affect the design of bridges and how does this information become relevant in the construction of our own model bridges? These are the major questions that this unit will address. At first this may seem very broad, but I intend to approach it from the physics perspective of decomposing the problem.

First, what is the purpose of a bridge, structurally? The function is to allow a gap to be spanned that can carry a certain load. So the first part of the unit will address the nature in which this is accomplished. I will have the students construct spans with their preconceived notions to test how their concepts match their experimental experience.

The second aspect will be to equate what we have learned in mechanics and particularly in diagramming forces to make some educated analysis of how bridges achieve their function. I will indicate that bridges are a wonderful means of studying forces because they can often be looked at linearly. The forces that act are often along the material members (at least this can be illustrated in the simplest cases). We will study the relative strength of different geometric shapes and discuss the reason that certain structural designs dominate most bridges.

Then we will consider the forces of compression and tension that are essential to understanding the application of stresses to bridge design. The desire to minimize the material in bridges often leads to extremely elegant solutions to these concerns. We will specifically look at the beam, the arch, the truss and the suspension design solutions and delve into the nature of each of these solutions. We will consider how the necessary forces are transmitted by stress or pressure (F/A). We will consider the relative strength of different geometric shapes and explore the uses of these forms. In my advanced 2nd year AP course we will consider shear, the moment (torque) and strain, including the mathematical formulations that involve Young's modulus. All of my classes will consider how materials fail including buckling and catastrophic failure.

Currently, I have a material science unit on strength of stone in compression and tension using a 3 point flexure test and a compression test with an armature and a 10 ton press. We demonstrated that black granite catastrophically failed at 49,000 psi of compression but only several hundred pounds of tension! I would like to incorporate this unit into a section on different material choices and how those materials affect the design parameters. Ideally, I would like to consider the relative strength of wood, stone, steel and iron. I will have to make adjustments to my apparatus, but I believe that this will give data to support the variability of materials. In addition, we will test the properties of various geometric shapes. We will experiment on the relative strength of a variety of beam shapes.

All of this will culminate in the students having a limited amount of materials and having to build a model bridge in small groups. I will encourage the classes to pursue all four types of fundamental bridges. I will achieve this by providing the groups with materials that are conducive to different solutions. This will be achieved by providing some groups with different amounts of balsa wood and different dimensions and potentially different types of glues, other groups with string, others with varying supporting column material and lastly different spans to bridge. I will first have the students analyze their materials, assessing their strength under stress. Are those materials good for compression or tension? Then I will have the students perform some mathematical calculations about the necessary anticipated strength required to carry the determined load. This will include force diagrams. The students will proceed to construct their bridges, potentially testing sections of the bridge as they go. The last step will be to

test the bridges under predetermined loads or until they fail comparing their relative strengths. Stressing the bridge structures until failure will provide the most informative assessment of strength while being videotaped at high speed since failure will most dramatically demonstrate the points where the structure is weaker than the forces that were required to maintain the continuity of the structure. We will video this process and utilizing the data collection software LoggerPro we will analyze the video when it failed to explore the forces that existed in the structure and to test whether we were correct in our assumptions of how much force was required and how those forces were transmitted. I am convinced that this will motivate my students to understand the mechanics of forces at a deeper level. As a culminating activity we will analyze local Pittsburgh bridges to determine their relative strengths and rationale for their designs.

Rationale

Considering the “Bridges of Pittsburgh” should initiate the motivation of my students to begin to formulate questions that will lead to the exploration of mechanical concepts that we have learned in physics. One of the first things that students will be encouraged to explore is the relevancy of bridge structure to the physical concepts that we have learned in the mechanical principles of physics. The students should discover that they have a vast toolkit of concepts that will enable them to address many of these questions. Some of the conceptual tools that have been acquired in mechanics are the comprehension of forces which can be either static or dynamic and which can often be readily analyzed by the structural design of many bridges. In addition, our skills at drawing forces are invaluable in analyzing structures because forces often follow structural members. We will look at the concepts of compression as opposed to tensile forces. This will enable us to make simple analysis of bridges that will greatly enhance our ability to understand form and function.

Once we have begun to believe in our ability to visually analyze bridge structures, then we will be prepared to consider the mathematical conceptions that we have developed in our study of Newtonian Mechanics and since they were sufficient to get man to the moon should certainly suffice to help us to comprehend bridge designs. Looking at the mathematical formulations in conjunction with the force diagrams provides us with a powerful combination of tools to view, diagram, and analyze the transfer of forces within a bridge structure. Of course the goal of a bridge is to carry the load of the bridge and its own weight across a span, however, the manner in which this is achieved is extremely variable and can be achieved simply by a beam or by increasing complexity including arch, truss, cantilever and suspension forces! We will discuss these various design options with the eventual goal of incorporating these aspects in our own design of a bridge that will satisfy certain parameters.

Before we begin discussing the various methods of solving these problems of transferring forces across a span to achieve our goal, we will first consider the different types of forces that exist in a typical structure. Secondly, we will look at and explore the properties of some standard materials and their relative strengths, properties and uses. Thirdly, we will endeavor to consider the plethora of solutions that have been attempted and succeeded in Pittsburgh bridges. We will then attempt to put all of this knowledge together in our experimental design and construction of a model bridge. Lastly, we will utilize an engineering technique of testing the models to failure and we will use high speed cameras to preserve the failure of our structures to analyze the places where the forces exceed the capacity of the materials and the bridge structures fail. This will bring us full circle in our appreciation, evaluation, analysis, construction and fulfillment of our design goals using the physics of mechanics and forces.

The Purpose of a Bridge

Bridges are structures for spanning a divide. That divide can be geographic as a result of waterways or ravines or a need for man-made convenience in passage ways. The requirement of the bridge is to span the gap. In its simplest design the “bridge” is simple a “beam” that can support its own weight and the weight of the necessary load dispersed across its length. As the complexity of the task increases the weight of the bridge typically increases and the load that must be supported is more complex and eventually dynamic, meaning that the forces that must be supported are not static and simple. As the complexity of the bridge increases, considerations such as spans, supporting towers, distribution of forces, properties of materials, longevity of materials, protecting materials from the elements and the longevity of the bridge under dynamical forces become more significant. Eventually, bridges are designed with economic concerns to maximize their life-span under the significant stresses of industrialized engine power.

The Types of Forces that Exist in Bridge Structures

According to Newton, a force results in the acceleration of a mass. However, in the context of bridges it is not this dynamic definition that concerns us but more significantly the static forces that result in equilibrium. Equilibrium is a state of balance in which forces in all directions are equal. In physics we talk about vectors and by this we mean the components of forces in any direction. In the state of equilibrium the summation of all vectors is zero and the overall motion of the bridge would nullified or static. In reality complex bridge forces must eventually be understood in terms of dynamical forces or failure can be catastrophic, but originally we will consider the forces in the simplest terms of equilibrium.

There are different fundamental forces in bridges that are significant. The first type of force is one that is directed perpendicular into a material. This is known as a force of

compression. Compression forces squeeze a material. The characteristics of a material determine the ability of a material to sustain a force of compression. The opposite force is to pull a material outward and is known as a tensile force. Tension results when a material is pulled outward from itself. A more complex force is the force of torque which is a rotational force. It is a measurement of how much force is applied to twist a material. These are the fundamental forces that we will deal with in analyzing the forces that act on bridges and determine their success or failure. A more complex idea is to calculate the moment (F/A) of the torque.

The masonry arch is a classic example of the use of compression in bridge construction. The sides of an arch transfer the force outward, known as thrust, and must be supported so that they do not move outward. When the arch is constructed it must be supported but the crucial piece of the arch is the angling of each of the curved pieces so that the last piece that is placed is a wedge shape with the top wider than the bottom. This final piece, known as the keystone, supports both sides of the arch and the force is inward at this point, toward the center, thus putting the final wedge in extreme compression. When the last piece of the arch is allowed to “fall” into place the compression forces achieve an incredibly stable equilibrium, as long as the material can support those substantial compression forces.

Tensile forces are witnessed most dramatically in the vertical steel cables of an arch trussed bridge. The steel cables support the roadway. Consequently, the tensile forces are witnessed most dramatically in the vertical steel cables of a suspension bridge that carry all of the load of the bridge spread across the number of vertical cables. The vertical cables must be able to support the load and supporting outward, or tensile, forces.

The most complex forces are when the forces are not linear and result in rotational forces or torque. Rarely are the forces perfectly linear, so torque occurs often, but it is much more difficult to analyze because it requires a significantly more complex mathematical analysis. However, knowing that twisting will result in torque will be particularly useful when we analyze the forces on our models when we test our models to failure. Then it will be clear that many members will fail in a non-linear fashion.

The Properties of Materials as they Relate to Bridges

Materials science is an area of study unto itself. Engineers have characterized materials in an attempt to determine with significant accuracy how much force a given material can sustain. More specifically, engineers have catalogued all types of materials for their various properties under different types of forces. So, if, for example, you want to know within certain safety parameters how thick a wood beam needs to be to span ten meters with a given load, engineering manuals will provide a tested guideline for a particular type of wood. Given that wood is extremely variable, the safety parameters will be significantly larger than for a more significant material like steel. Engineers have amassed incredible

amounts of data on various materials and their reliability and the forces that they can withstand.

In the early history of the United States wood was often used because it was plentiful, and it had sufficient compression and tensile strength as long as it was reinforced by wrought iron. The major downside of wood was that it deteriorated quickly and was subject to damage by fire and insects. Traditionally, stone was used because of its compression strength. However, it was expensive to quarry, face (or shape) and haul. Stone's tensile strength is negligible, so it is only useful for bridges designed under compression forces.

During the industrial revolution iron began to become available. At a certain point it became economical to use for bridges, but its structural characteristics make cast iron better under compression than tension and limited its pragmatic use for building bridges. Eventually, wrought iron was developed in processes that were less labor intensive and was used until a superior material was developed.

The most significant advance occurred with the production of Bessemer steel. Steel has compression, tensile and torsion force given the different chemical make-up. It is so far superior to other materials that it largely supplanted all other materials with the exception of the compression piers. The towers are largely made of concrete and occasionally stone, but the concrete is only viable with rebar reinforcing rods in its interior in the construction of suspension bridges. Steel greatly broadened the variety of solutions available to bridge builders and led to the development of bridge engineering.

Material science has continued to explore and advance the materials that are most useful for construction. Additives have been advanced as have the methods of testing and evaluating materials and improvements are constantly being made.

Pittsburgh Solutions to Bridge Problems

Pittsburgh has 446 bridges. There are a plethora of solutions from which to choose. The most common is the truss bridge, which utilizes the triangle to maximize its strength with alternate members in compression and tension. There are also examples such as stone bridges, arched truss bridges, suspension bridges and cantilevered spans, often within sight of each other.

Designing and Building a Model Bridge

We will utilize what we know about different bridges to construct a model that we will test to failure. I will have different groups design arch, truss, cantilever, and suspension bridges. Each group will first design their bridge and draw force diagrams of the bridge. The materials will be supplied according to the bridge type. The goal is to design and

build the strongest bridge possible. This means to construct a bridge with the provided materials that will support the greatest load.

Testing Models to Failure and Analyzing the failures

It is an engineering approach to test models to failure to discover the weakest aspects of particular designs. By loading an engineering model to its maximum and past it, the hope is to be able to discover the weakest aspect of the design, which would result in its failure.

In this process, we will load the model until it reaches catastrophic failure. We will utilize high speed photography to capture this process so that we can slow it down and analyze which members failed first. This will specifically enable us to analyze the structures that fail. The hope is that this will offer us insight into how to construct stronger bridges in the future.

Objectives

Students will be able to utilize their knowledge of physics concepts to reinforce, strengthen and improve their understanding of Newtonian Mechanics. The students will delve more deeply into the concepts of force and equilibrium and respect the inherent power of analyzing physical systems that are static. Students will improve their mathematical understanding of the relationship between static forces, force diagrams and complex mathematical solutions. The students will learn the value of developing ideas logically, consistently, gradually, methodically and thoroughly before committing their efforts to physical solutions. The students will experiment with materials to explore the physical characteristics of those materials and their relevancy to problem solving. The students will explore technological solutions that have been testing successfully locally and will endeavor to implement those solutions creatively in the construction of their own bridge model. The students will utilize data from experiments to inform their judgments regarding the use of a variety of materials. The students will research engineering tables and learn to read graphs to help to determine the mathematical properties of competing materials. The students will learn that failure is an engineering step that is an essential process in design. The students will be able to clarify the mathematical relationship between form and function.

Strategies

The basis of this unit is a constructivist approach. It is my belief that hands-on learning is the most potent tool towards increased retention, spatial understanding, ownership and motivation. During the year we learn physical and mathematical concepts in physics class, but it is essential to pursue the scientific approach and to actually physically test our mental constructs and assumptions. In this unit it is my goal to explore familiar intellectual territory in a new way so that students approach a significantly deeper

understanding of the first semester of Mechanics.

I am convinced that building models increases student ownership and team building skills, increases significant motivation to learn and provides the commitment to solve extremely challenging problems that require the learner to leave their proximal comfort zone and explore new intellectual, sensory and motivational territory. We may be expanding on previous learning skills but the change in method provides the impetus for substantive growth in long term motivation and learning.

Scaffolding is provided through a number of avenues. Initially, the pace of the unit is determined by the students' ability to relate the acquired physics concepts to diagramming forces of bridge structures. Then when the teams are constructed, it is with the intention of having varied tasks and abilities so that the group can help to reinforce the concepts for the individuals within the team. I have found that constructing models draws on a multitude of skills that are not within the academic skill set.

The ideas of inquiry learning are also incorporated into this unit. The majority of the unit is developed around the testing of materials and concepts in a guided inquiry model. The laboratory experiences and field trip are meant to provide the student with a wealth of experiential learning that the student can apply at their own pace. The experiences are guided by questioning and by continued reinforcement of the physics concepts that have been learned throughout the first semester of Newtonian physics.

The labs are not constructed with the intention of a single outcome. Instead, the intention is to allow the students to pursue their ideas in an open and unimpeded manner. The process is intended to create enthusiasm about the scientific method and to engage the students in a scientific discourse about the relevancy of various experiences that the students will have over the three weeks that the unit is in progress.

Classroom Activities

Classroom Activity #1- Bridge Field Trip

We will begin our "Building Bridges" unit by initially exploring the range of solutions that exist for the problem of spanning a distance. This will be achieved by first taking a field trip of local Pittsburgh bridges. We will visit a variety of bridges that demonstrate a range of bridge types indicating the wealth of solutions for spanning a distance. The students will be encouraged to consider what the presented task was for the builders and how it was achieved. The students will be asked to consider the materials that were utilized to realize the bridge and to contemplate why the materials were chosen and whether or not they are appropriate for the task. Why were those materials chosen and how successful have they withstood the elements? My students will explore the solution for a variety of bridge tasks and discuss what some alternative solutions might have been.

The goal of visiting a variety of bridges is to motivate the students to envision a multitude of purposes for bridges, consider how those purposes have changed and what effects that it has on the structures, view a sight and appreciate the challenges that it poses, overcome the unconscious utilization of engineered structures, and generate an enthusiasm about the potentiality involved in designing and constructing bridges in a city that is as geographically diverse as Pittsburgh. We will incorporate our understanding of physics by drawing the bridges and making Force diagrams to the best of our ability.

Upon returning from our field trip we will discuss the force diagrams that we made of the bridges. Obviously the bridges are in equilibrium. So all of the forces in each direction must be equal and we will attempt to account for all of the forces and demonstrate how those forces are transmitted through the structure into the ground. Bridges are a great vehicle for drawing forces because the materials utilized tend to be minimalistic and follow the force lines of the structure. When the materials are not in line with the forces the effect is often dramatic and lends itself to dynamic solutions such as the cantilever bridge. Looking at bridges should be a natural exploration of Newtonian Physics in action.

When the students return to the classroom they will conduct research to discover the different types of bridges that they have diagrammed. The research will enable the students to discover whether or not they correctly diagrammed and labeled all of the forces that are acting on the bridges that they visited.

I will provide some books of bridge design as well as engineering textbooks that diagram the loads on bridges. I will allow the students to explore these books to enable them to experience the value of engineering research materials to the engineering profession.

We will also have a discussion about the change that occurred when bridge builders went from being craftsmen, primarily as wood workers, to trained professionals that carried the title of engineer. As a class we will discuss why this transition might have occurred and how it has affected the types of bridges that were constructed.

Activity #2- Material Testing

Once the students have had the opportunity to stimulate their thinking about the uses for bridges, I want them to look at the physics of materials. The discipline known as material science is dedicated to exploring the properties of materials. I currently test the compression and tensile strength of stone. We do this by utilizing a steel structure with variable apparatus that is attached to a hydraulic press. By altering the apparatus we have been able to test both the compression and the tensile strength of stone.

I intend on expanding this lab activity to encompass the testing of a variety of characteristics of some typical building materials, including wood, stone, cast iron and steel. Initially I will have the students do a compression test to see how much force it takes to deform these materials and to analyze what the differences are among the materials. These materials will react very differently from each other under compression and tension. The students will be asked to compare the variety of materials as much as is possible. I will ask the students to describe what happens as the materials undergo forces and what happens to their shape.

Once the students are familiar with describing the different types of deformations that can occur in these materials, we will then analyze the point at which the materials fail. We will be able to utilize the pressure gauge as well as high speed video to capture the images. The program LoggerPro can be utilized to decipher the visual results and to quantify them. I have a steel armature that will enable us to test materials up to a maximum load of 10 tons which will be sufficient to compromise any materials that we are testing. In my experience as a teacher, the students embrace the opportunity to explode and destroy materials. In the context of a lab, this situation is ideal.

The second part of this lab will be to take one type of material, such as wood, and compare the effect that altering the geometric shape of the “beam” will have on the material’s strength. I envision comparing rectangles, squares, triangles, I beams, and any odd shapes that the students consider as viable options to determine their relative strengths. This will enable the students to make connections between the geometric shapes and their ability to support loads. I am certain that there will be many surprises in this activity but I expect that we will systematically be able to decipher the mathematical relationship between shapes and loads that will empower the students to begin to design their own complex bridge structure.

This lab is designed to test and reinforce the correct ideas that students have about beams and to disentangle misconceptions that the students have about the relationship of shape to strength. The students will gain an experiential basis for comparing materials and will significantly improve their appreciation of bridge design.

Classroom Activity #3: Designing and Building a Bridge

The culminating activity for this unit will be to have the students design and build their own model bridge in teams. Having explored bridge designs, materials and relative strengths of various shapes, it is time for the students to test the physics knowledge that they have with what they believe to be true about bridges.

At this point, already having a conception of beams, the students will construct towers. The students’ task will be to designate the responsibilities of the members within their team with the goal of constructing the strongest bridge possible given a restriction of

materials.

The first task will be to design towers for maximal strength. The students will be given a limited amount of balsa wood and glue to build towers to support the bridge that they will eventually build to span a two foot gap. The students will be allowed to have two trial runs before constructing their final tower structures.

The teams will be allowed to choose between a variety of materials such as balsa wood in “sheets” and “beams”, string, straws, and glue before they construct the bridge. The next task, materials having been considered, is for the students to design on paper their bridge. Once diagrams have been completed the students will be asked to create physics sketches of their proposed bridges which will culminate in Force Diagrams of their bridge.

At this point, the building will begin in earnest. The students will utilize everything that they have learned to construct the optimum solution for their bridge. The bridges will be built with the intention of testing them to failure by suspending a bucket from the two foot bridge expanse and filling it with sand until the bridge fails. This testing will be filmed with high speed cameras.

When the bridges have been tested until they fail under their maximum load, the students will analyze the video to decipher the weakest parts of their bridge designs, to determine if their force diagrams were correct, and to propose how each group could improve upon their design. The students are forced in this situation to sacrifice their structures for the “good” of science. I believe that this is an important lesson that the value of models is that they can be tested and if the variables are controlled well enough that the information can be extrapolated. So while it is not feasible to test full scale models, it is very manageable to test models in a lab and the information gained can be invaluable in the construction of full scale structures.

Annotated Bibliography/Resources

American Institute of Steel Construction, Inc. *Manual of Steel Construction: Allowable Stress Design* 9th ed. American Institute of Steel Construction, Inc., 1989.

Includes specifications for steel structures and graphic diagrams of approved loads.

Breyer, Donald E. *Design of Wood Structures*. 3rd ed. McGraw-Hill Inc., 1993.

This text includes engineering tables of nearly every conceivable type of wood and provides the methods for designing and constructing any structure that I can think of out of wood. It includes essential tables for analyzing the wood beam lab results.

McCormac, Jack C. *Structural Analysis*. 4th ed. Harper and row Publishers. 1984.
An Engineering text with structural diagrams indicating how to construct structures and

the expected component forces.

McCormac, Jack C. *Structural Steel Design*. 2nd ed. Intext Educational Publishers, 1971.

An engineering text book that includes information about steel design and diagrams of forces in steel structures.

Structural Engineering Handbook. Ed. Gaylord, Edwin H Jr. and Charles N. Gaylord. 3rd ed. McGraw-Hill Publishing Company, 1990.

An introduction to structural analysis, basic concepts in engineering design with diagrams to illustrate the key concepts.

Seelye, Elwyn E. Design: *Data Book for Civil Engineers*. 2nd ed. John Wiley and Sons, Inc. 1951.

A book that instructs on how to design and build, with specification tables, nearly any structure imaginable. This text demonstrates the continuity of engineering principles over the last half of a decade.

Reading List

Delony, Eric. *Landmark American Bridges*. Bullfinch Press Book, 1993.

This book published in association with the American Society of Civil Engineers is exemplary for its combination of pictures and diagrams of a range of American bridges.

Appendices-Standards

S11.A – The Nature of Science

S11.A.1 Reasoning and Analysis

S11.A.1.1 Analyze and explain the nature of science in the search for understanding the natural world and its connection to technological systems.

S11.A.1.2 Identify and analyze the scientific or technological challenges of societal issues; propose possible solutions and discuss implications.

S11.A.1.3 Describe and interpret patterns of change in natural and human-made systems.

S11.A.1.3.1 Use appropriate quantitative data to describe or interpret change in systems

S11.A.1.3.2 Describe or interpret dynamic changes to stable systems

S11.A.2.2 Evaluate appropriate technologies for a specific purpose, or describe the information the instrument can provide.

S11.A.3.1 Analyze the parts of a simple system, their roles, and their relationships to the system

S11.A.3.2 Compare observations of the real world to observations of a constructed model

S11.C.1 Structure, Properties, and the Interaction of Matter and Energy