Bridges and Natural Forces

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The true sign of intelligence is not knowledge but imagination.
~ Albert Einstein, physicist

INTRODUCTION

Since I started teaching at Jane Long Middle School, I have realized the importance and the need to teach my students a subject that relates math with something meaningful in their lives. Many of students at Jane Long MS predominantly come from economically disadvantaged families that do not always get involved in their children's education. With almost no parental involvement at home, most of our kids come to school unmotivated and with no desire to learn about the world around them.

My undergraduate education in Electrical Engineering has driven my passion for engineering. My education inspired me to promote classroom learning by engaging students with real-world engineering problems that are attractive and fun to study. The topic of structural engineering with an emphasis on bridges is the focus of this curriculum unit.

UNIT OBJECTIVES

The curriculum unit targets the impact of natural forces on the design and construction of bridges. This is a cross-curriculum unit primarily focusing on math and science applications; students will have the opportunity to learn and discover the bridges (design and construction) and the natural forces that affect bridge structures. These natural forces include gravity (weight of structure and objects), soil conditions, temperature effects, earthquakes, as well as wind and vibrations.

A study of these effects will be made through cooperative hands-on bridge building projects. Students will benefit from this topic through real life applications ranging from a variety of areas such as the use of geometry (math) to the design and building of bridges to the discovery and analysis of the natural forces (science), such as heat, winds and their effects on the bridges' structure.

Texas Essential Knowledge Objectives

The Texas Essential Knowledge Objectives (TEKS) objectives covered in this curriculum unit are organized as follows:

Objective ID	Description
MATH.6.11.A	Identify and apply mathematics to everyday experiences, to activities in and outside of school, with other disciplines, and with other mathematical topics.
MATH.6.11.B.	Use a problem-solving model that incorporates understanding the problem, making a plan, carrying out the plan, and evaluating the solution for reasonableness.
MATH.6.12.A	Communicate mathematical ideas using language, efficient tools, appropriate units, and graphical, numerical, physical, or algebraic mathematical models.
MATH.6.06.A	Use angle measurements to classify angles as acute, obtuse, or right.
MATH.6.06.B.	Identify relationships involving angles in triangles and quadrilaterals.
MATH.6.07.A	Locate and name points on a coordinate plane using ordered pairs of non-negative rational numbers.
MATH.6.08.A	Estimate measurements and evaluate reasonableness of results.
MATH.6.08.B.	Select and use appropriate units, tools, or formulas to measure and to solve problems involving length (including perimeter and circumference), area, time, temperature, capacity, and weight.
MATH.6.08.C.	Measure angles.

Vocabulary

To fully understand and get involved with this curriculum unit, students will have to learn certain vocabulary words needed for each lesson. Therefore, a vocabulary review will be delivered to the students to familiarize them with the unit lesson. The following is an incomplete list of vocabulary words that students will learn:

> Girder Bridges, Arch Bridges, Truss Bridges, Rigid Frame Bridges, Suspension Bridges, Compression, Tension, Bending, Sliding, and Twisting.

To better prepare the students with these vocabulary words, students will work on vocabulary definitions before the start of the unit content. The vocabulary instruction will be delivered with a variety of examples with the use of these keywords. Students will have to answer a set of questions related to these keywords as well as to write some examples.

UNIT BACKGROUND

Although bridges often go unnoticed, one of their primary functions has usually been essential to promote the economic development within the location surrounding the bridge. Without bridges, the time necessary to cross a river would increase substantially. In addition, the way people, goods, and services are transported are greatly hindered without bridges. The entire world economy as we know it would be stifled.

The earliest bridges consisted mainly of logs that had fallen or were placed across rivers. While inexpensive, they were less than reliable. Moving heavy loads across them was often impossible. Primitive bridges were nothing more than two or three cables of rope stretched across a river. People could cross, but the rope was not practical for moving heavy loads. These rope bridges can be considered the fore-runners of modern suspension bridges.

According to WordNet®, bridges are structures that allow people, vehicles or ducts to cross an obstacle such as a river, canal, or railway. In designing a lesson to fit the topic of bridges, we have to look at the constituency of the students we are teaching. "At-risk" students often need a “hook” to motivate them. In this case, the actual building of a bridge will show the student a real item that they are building and how they can use math to accomplish this.

TYPES OF BRIDGES

The main types of bridges that will be discussed are girder, arch, truss, rigid frame, suspension, and cable-stayed bridges.

Girder Bridges

A girder bridge is perhaps the most common and most basic bridge. In the simplest form, a log across a creek is an example of a girder bridge. In modern steel girder bridges, the two most common girders are I-beam girders and box-girders.

If we look at the cross section of an I-beam girder we can immediately understand why it is called an I-beam. The cross section of the girder takes the shape of the capital letter “I”. The vertical plate in the middle is known as the *web*, and the top and bottom plates are referred to as *flanges*. To explain why the “I” shape is an efficient shape for a girder is a long and difficult task, so we won't attempt that here, however, it might be possible to develop some simple models to help demonstrate the efficiency.

A box girder is much the same as an I-beam girder except that, obviously, it takes the shape of a box. The typical box girder has two webs and two flanges. However, in some cases there are more than two webs, creating a multiple-celled box girder.

Arch Bridges

After girders, arches are the second oldest bridge type and a classic structure. Unlike simple girder bridges, arches are well suited to the use of stone. Many ancient and well know examples of stone arches still stand to this day. Arches are good choices for crossing valleys and rivers since the arch doesn't require piers in the center. Arches can be one of the more beautiful bridge types.

Arches use a curved structure that provides a high resistance to bending forces. Unlike girder and truss bridges, both ends of an arch are fixed in the horizontal direction (no horizontal movement is allowed in the bearing). Thus, when a load is placed on the bridge (e.g. a car passes over it) axial compression forces occur in the arch. These axial forces are unique to the arch and as a result arches can only be used where the ground or foundation is solid and stable. Structurally there are four basic arch types: hinge-less, two-hinged, three-hinged, and tied arches.

Truss Bridges

The truss is a simple skeletal structure. In design theory, the individual members of a simple truss are primarily subjected to tension and compression forces. Thus, for the most part, all members in a truss bridge are typically straight. Trusses are generally comprised of many members that together can support a large amount of weight and span great distances. In most cases the design, fabrication, and erection of trusses is relatively simple.

Rigid Frame Bridges

Rigid frame bridges are sometimes also known as *Rahmen* bridges. In a standard girder bridge, the girder and the piers are separate structures. However, a rigid frame bridge is one in which the piers and girder are one solid structure.

The cross sections of the beams in a rigid frame bridge are usually “I” shaped or box shaped. Design calculations for rigid frame bridges are more difficult than those of simple girder bridges. The junction of the pier and the girder can be difficult to fabricate and requires accuracy and attention to detail. Though there are many possible shapes, the styles used almost exclusively these days are the pi-shaped frame, the batter post frame, and the V-shaped frame.

Suspension Bridges

Of all the bridge types in use today, the suspension bridge generally allows for the longest spans. At first glance, the suspension and cable-stayed bridges may look similar, but they are quite different. Though suspension bridges are leading long span technology today, they are in fact a very old form of bridge. Some primitive examples of suspension bridges use vines and ropes for cables.

GEOMETRY AND BRIDGES

According to Golia, incorporating geometry with bridges serves two purposes: the study of shapes and symmetry and the function of design. The shapes of geometry: squares, triangles, rectangles, and other geometric shapes can work in the designing of a bridge.

The function or use of these geometric designs will show the students that geometry is important. Projects that include working with different three-dimensional shapes will allow the students to explore how and where these shapes are used in bridges. The shapes can be tested to see which designs are the strongest, how much weight they can hold, or what pressure can be applied without a structural failure. This will help the students in their design.

Also the students need to explore how they can build a strong bridge with the use of a minimum amount of material. Sometimes the availability of materials can dictate the design of the bridge. The strength of the bridge is not necessarily determined by the bulk of material. In geometry, the students will need to understand certain geometric terms, such as lines, angles, symmetry, quadrilaterals, polygons and polyhedrons.

NATURAL FORCES ON BRIDGES

Since bridges are structures, they use internal forces to support loads. There are different names given to forces depending on how they act. The main forces acting on bridges are the compression (squeezing), tension (stretching), bending, sliding (shear), and twisting (torsion). The main natural loads that affect the structural behavior are the bridges' self-weight, the weight of objects, soil properties, temperature, earthquakes, wind, and vibrations.

Compression

Compression is a force that squeezes a material together. When a material is in compression, it tends to become shorter. When a material is under a compression test, its behavior under crushing loads is tested.

The compression test is the method for determining behavior of materials under crushing loads. Compressive stress and strain are calculated and plotted as a stress-strain diagram that is used to determine the elastic limit, proportional limit, yield point, yield strength and (for some materials) compressive strength.

The compressive strength is the maximum stress a material can sustain under crush loading. The compressive strength of a material that fails by shattering fracture can be defined within fairly narrow limits as an independent property. However, the compressive strength of materials that do not shatter in compression must be defined as the amount of stress required to distort the material an arbitrary amount. Compressive strength is calculated by dividing the maximum load by the original cross-sectional area of a specimen in a compression test.

Tension

Tension is a force that stretches a material. When a material is in tension, it tends to become longer. The tensile test is the method for determining the behavior of materials under axial stretch loading. Data from tests are used to determine the elastic limit, elongation, modulus of elasticity, proportional limit, reduction in area, tensile strength, yield point, yield strength, and other tensile properties. Tensile tests at elevated temperatures provide creep data.

The Tensile strength is the ultimate strength of a material subjected to tensile loading. It is the maximum stress developed in a material in a tensile test.

Bending

When a member is subjected to bending, fibers on one side are compressed while fibers on the opposing side experience tension. Bending tests can provide a measure of the ductility of the materials. There are no standardized terms for reporting bend test results for broad classes of materials; rather, terms associated with bend tests apply to specific forms or types of materials. For example, materials specifications sometimes require that a specimen be bent to a specified inside diameter.

The Bending Strength is the alternate term for flexural strength. It is most commonly used to describe flexure properties of cast iron and wood products.

Sliding (Shear*)*

Shear is a force that causes parts of a material to slide past one another in opposite directions. The shear strength is the maximum shear stress that can be sustained by a material before rupture. It is the ultimate strength of a material subjected to shear loading. It can be determined in a torsion test. It is reported in pounds per square inch (*psi)* based on the area of the sheared edge. The shear strength of a structural adhesive is the maximum shear stress in the adhesive prior to failure under torsional loading.

Twisting (Torsion)

Torsion is an action that twists a material. The torsional strength is the measure of the ability of a material to withstand a twisting load. It is the ultimate strength of a material subjected to torsional loading, and is the maximum torsional stress that a material sustains before rupture. Alternate terms are modulus of rupture and shear strength.

The torsion test determines the behavior of materials subjected to twisting loads. Data from a torsion test is used to construct a stress-strain diagram and to determine the elastic limit, torsional modulus of elasticity, modulus of rupture in torsion, and torsional strength. Shear properties are often determined in a torsion test.

BRIDGE MATERIALS

Different shapes resist forces in different ways, so as every material withstands forces differently. To design a good and safe bridge, an engineer must know the forces in every member of the bridge. In turn, he must choose the appropriate material for that member, or for all members. He must know the characteristic of every material under various forces that may occur on the bridge.

For example, should he choose concrete or stone for the pier and abutment? Is it steel instead of concrete that is the best material for a particular bridge? In the ancient times, stone, wood, earth, and brick were used. In the mid 19^{th} century, both cast iron and wrought iron were used. The advent of steel replaced those materials. Nowadays, steel and concrete (reinforced concrete and pre-stressed concrete) are the most popular materials. There are four reasons that lead the choice of materials to be used in a bridge: characteristics, cost, technological level, and availability. The following sections will discuss each of these reasons.

Characteristics

Every material reacts differently to different forces. For example, concrete is strong in compression but breaks easily when tension force is applied. Another example is brick. It is a good material to support compression force. You can pile a couple feet of bricks without affecting the lowest layer bricks.

However, when you try to break a brick even with your bare hand, it will snap into two. Hence, it is said that brick has weakness in tension. What about the cast iron? This material is strong in compression but is also relatively brittle in tension. For instance, cast iron can break without any warning. It does not show noticeable cracks before starting to rupture. Steel has better characteristics concerning abrupt rupture.

Cost

Bridges are expensive. They are so expensive so that cost is always a major concern. Hence, a designer will not choose a more expensive material if there are cheaper materials available.

Technological Level

The materials to be used depend on the technology we have. When our ancestor did not know how to cast the iron, they used stones, bricks, or wood. At that time, those materials were the best thing they could make. Today people use steel instead of cast iron for structural applications.

The technology used to make steel were devised quite recently. People in the mid 19th century did not know about steel, and iron was the best material. Innovations are always found. Perhaps in the next millennium people will build bridges with plastics.

Availability

Availability of material is another factor in building bridges. Even though you know how to make steel, but if you do not have enough ore, or nobody produces enough steel for your bridge, you cannot design a steel bridge. Another example is that some places do not have good stones for concrete mixture. To import stones from other places is sometimes too expensive. On the other hand, if there is lots of wood instead of stone, a good engineer will adapt to this condition and use woods instead of stones.

Therefore, engineers must have a clear understanding of the characteristics of every material under various forces that may occur on the bridge.

The materials mostly used in bridges are:

- Wood (strong in compression and tension as well, but not good in shear resistance)
- Stone (It has very high capability to receive compression force; however, it is not strong in tension force.)
- Brick (high resistance in compression, but not much tensile strength)
- Concrete (It is a good material to resist compression force, but weak against tension.)
- Reinforced concrete (It is a good material to resist compression force and tension.)
- Pre-stressed concrete (It has basically with the same features of the ordinary concrete; however, the cracking strength of the concrete is delayed.)
- Iron (It is strong against compression, tension, shear, and torsion; however, the material is relatively brittle.)
- Steel (It is the result of improvement in iron production. Some other added mineral are used to satisfy additional characteristics.) and steel cable (very strong in resisting tension).

IMPLEMENTATION STRATEGIES

This curriculum unit will comprise six lessons, divided in two parts (Part I – Lessons 1-3, Part II- Lessons 4-6). Part I will cover the basics, such as bridge types, the basic geometry background involved to build these bridges, the connection made between geometry and architecture, the types of forces and their effect on the structural behavior, as well as the loads (and natural forces) that affect the bridges structure. In this first part, students will have the opportunity to work on small projects involving research papers and oral presentations of the topics mentioned above.

In the following three lessons (Part II), students will work in groups that will each be assigned a specific bridge project involving the basic design and hands-on building. The bridge designs will be based on models and specifications they learned in the first three lessons. They will use a set of hands-on materials available for each experiment. Students also will use available online tools to visualize the effect of those forces and loads acting on the bridges structures through animated computer graphics simulations.

By the end of this six-lesson curriculum unit, students will learn important concepts such as: What are bridges? How is geometry used to design bridges? What are the major types of bridges built? What are the materials and the minimum dimensions used to construct bridges? What are the forces and loads that act on each of the major types of bridges? How do natural forces, such as earthquakes, winds, vibration, temperature, and wind, affect individually (or as a set) the structure of bridges? How does material fatigue happen on bridges and how is it prevented?

EXPERIMENTAL PROCEDURES AND MATERIALS

The experimental procedures and materials needed are described in each lesson.

LESSON PLANS (PART I)

Lesson 1

This lesson will serve as an introduction to the concept of bridges. The purpose of this lesson is to give students a clear idea of what are bridges, their history, types of bridges, and their importance in the past, present, and future.

The materials needed for this first lesson are the school library's computers and books, papers, construction paper, markers, colored pencils, and erasers. Students will use the school library and its resources (books and the Internet) to collect all necessary information they need for their research on bridges. The students will work in pairs to collect and organize the information on bridges and prepare for a class presentation.

Students will be given clear instructions to properly follow the research activity directions as well as material presentation. As assessment, each group will have to answer some questions about their presentation as well as general questions about the bridges. This activity will be reviewed as a group and as a whole class discussion and participation.

The presentation will be made through the use of posters and panels. Students will be given a week deadline to prepare and organize their work. Each group presentation will cover the information they have collected and how they organized it based upon their research.

Lesson 2

In this second lesson, students will learn the basic geometry needed to understand how bridges are designed and built. The purpose of this lesson is to review and apply important geometrical concepts such as the basic shapes, area and perimeter in the design of the basic bridge types.

Materials needed for this lesson are rulers, protractors, drawing templates, and construction paper. A presentation about the polygons and use of geometry in engineering will be given to students. Students will see different design projects from the world's famous bridges and will identify the main geometric shapes mostly used in a specific bridge design.

For the assessment activity, students will use the geometric materials to draw the main bridge types such as the girder, arch, truss, rigid frame, suspension and cable stayed bridges. Each individual work will contain a table of specific information including which and how many geometrical shapes are used in their bridge design. As a homework activity, students will work on a similar assignment compared to the assessment, by identifying the main geometric shapes used in specific bridge design.

Lesson 3

In this lesson, students will learn about the main types of forces that affect the bridges as well as their effect on bridges' structural behavior. The purpose of this lesson is to expose students to real life examples involving the forces on bridges in order to help them materialize the concept of force.

For this lesson, students will use the following materials: wireless laptops, construction paper, posters, markers, and colored pencils. They will be given clear instructions to properly follow the directions for all classroom activities. Students will be organized in pairs and will use the computers to work on the force simulation computer tool.

The simulation tool will help the students visualize the effect of forces such as compression, tension, bending, sliding (shear) and twisting (torsion) on bridges. Students will take note of their observations and write a summary about what happened to the bridge after each force was applied on it. As the assessment, each group will also use the posters to draw real examples of the above mentioned forces on bridges as well as present the material. The homework will be a set of illustrated questions about the effect of forces on bridges.

LESSON PLANS (PART II)

Lesson 4

In this lesson students will experience a hands-on bridge project involving basic design and hands-on bridges building. The purpose of this lesson is to provide students with the opportunity to apply the knowledge and theory learned in the previous classes.

The materials needed for the bridge project are rulers, construction paper, markers, colored pencils, Play-Doh® containers, tooth picks, Fiori pasta, paper clips and line cords. Students will be organized in groups of three, and each group will be assigned a task to design and build a specific bridge type (girder, arch, truss, rigid-frame, suspension or cable stayed-bridge). They will use the materials mentioned above to build their bridge models.

The project specifications will be given for each group, including instructions, materials needed, and project safety procedures. During their group activities, students will be asked to answer questions about the main features of the bridges that they are building. The assessment will be done after the bridge models are ready. Each group will be responsible to document in a poster the groups' work progress, the model bridge's main features as well as the materials needed to build the model.

In the homework activity, students will bring pictures, newspapers, or magazines containing pictures of the same type of bridge that each group built to prepare a poster for a classroom presentation.

Lessons 5 and 6

In these two lessons students will work on a written report based on their project presentation and data acquisition. The purpose of these two lessons is to provide students with the ability to write and document summary reports, according to their level and limits of writing, about their previous work.

For these two lessons, students will use wireless laptops and plain white paper. They will use the computers to type their reports. They will use the entire class time to work on their reports as well as to clarify some possible unanswered questions during the project presentation and preparation.

CONCLUSION

This curriculum unit is a unique opportunity to engage students in a meaningful and significant learning. The art of engineering brings students to new world of discovery, curiosity, fascination and exposure to the real world. This helps students to be more self-directed and motivated to learn. The benefits of this curriculum unit can naturally change the lives these students. By discovering and appreciating the art of engineering, students will be taken to an edge. This edge is called sky.

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