2009 Bridges and Structures Outline

- Introduction of Project Organizers and Program
  - Overall Concept of the half day
  - Images of Bridges in NH, ME and MA that are examples of the 5 Bridge Designs
    - Beam Bridge
    - Arch Bridge
    - Truss Bridge
    - Suspension Bridge
    - Cable-Stayed Bridge
  - Images of existing bridges other students / groups have done
- Call off participants 1 through 5
  - Creating 5 Groups (1 Group for each Bridge Design which creates 4 individuals per Bridge Design.) If more than 20 individuals, then count 1 thru 7 or 8 to create two or three more groups. There will then be 2 of the same bridge types for some of the 5 Bridge Designs.
- Package of information for Groups
  - Groups to review material (Bridge to be wide enough to accept bricks)
  - Groups to discuss their Bridge
  - Groups to draw out their Bridge Design
  - Groups to divide into two sub-groups
    - Cutting
    - Assembly
- Presentation of Bridges by Groups (short narrative as to-)
  - Type of Bridge
  - Design solution
- Test of Weight that each bridge can handle
  - Groups document their thoughts on their Bridge
- Awards / Overview of how and why bridges worked / did not work

Materials:
Balsa Wood Package for each Bridge Type Group
3’ long sticks maximum
String / rope, Glue (Sobo,) Exacto knives, packing tape

Other:
Bricks or other items for weight
Scale for measuring weight units
Camera to document before, during and after bridge testing
Two sawhorses for bridge weight test
Schedule

- Introduction of Team Members and Program: 10 minutes
  - Overall Concept of the Day: 10 minutes
  - Images of Bridges in NH, ME and MA that are examples of the 5 Bridge Designs 4 minutes
    - Beam Bridge
    - Arch Bridge
    - Truss Bridge
    - Suspension Bridge
    - Cable-Stayed Bridge
  - Images of existing bridges other students / groups have done 4 minutes
- Call off participants 1 through 5 8 minutes
  - Creating 5 Groups (1 Group for each Bridge Design which creates 4 individuals per Bridge Design.) If more than 20 individuals, then count 1 thru 7 or 8 to create two or three more groups. There will then be 2 of the same bridge types for some of the 5 Bridge Designs.
- Package of information for Groups
  - Groups to review material (Bridge to be wide enough to accept bricks) 15 minutes
  - Groups to discuss their Bridge 15 minutes
  - Groups to draw out their Bridge Design 30 minutes
  - Groups to divide into two sub-groups 1 hour
    - Cutting
    - Assembly
- Presentation of Bridges by Groups (short narrative as to-) 3 minutes each group
  - Type of Bridge
  - Design solution
- Test of Weight that each bridge can handle 30 minutes
  - Groups document their thoughts on their Bridge
- Awards / Overview of how and why bridges worked / did not work 15 minutes

Total Time: 3 to 3.5 hour Program

Project Organizers are to help facilitate the schedule and milestone times above and assist with documentation of process, design, testing and results with each Group.

Additional Notes:

1. 
2. 
3.
Introduction to Bridges

Basic Engineering Principles
A bridge is a structure that allows someone or something to cross over an obstacle. As people travel from place to place, they often cross bridges to reach their destination. Whether they are big or small, long or short, bridges are remarkable structures that enable people to cross water, land, and roads more easily and efficiently.

A Bridge’s design is dependent upon many factors, including
- Site and surrounding environment;
- Function;
- Budget and building schedule;
- Bridge engineer’s, architect’s, and/or community’s aesthetic preferences; and
- The community’s needs.

Bridge engineers must also consider
- Needed distance and span;
- Forces, such as compression and tension, acting on the bridge structure;
- Dead and live loads; and
- Building materials

Five Basic Bridge Types
There are five basic bridge types: beam, arch, truss, suspension, and cable-stayed. Each type employs one basic structural element, such as the beam, the arch, the truss, or cables. Many bridges are a combination of one or more of these basic types.

Distance and Span
Distance is the overall length of the bridge, while span is the length of the bridge between supports. A bridge has one distance, but may have multiple spans.

Forces of Compression and Tension
A force is a push or pull on an object. Built structures, such as bridges and buildings, rely on unseen forces that hold them together an enable them to support additional weight, or load. In every structure, two invisible forces are at work; compression and tension. Compression is the act of being pushed or pressed together. Tension is the act of being stretched or pulled apart.

Dead and Live Loads
Bridges must be able to support two types of forces, called loads, or they will collapse. Dead load is the weight of the bridge itself, such as columns, beams, nuts, bolts trusses and cables. Live load is the weight or force of temporary external elements acting on the bridge, such as people, vehicles, and wind.

Materials
Engineers must consider the properties of building materials when making choices for bridge design. Steel adds greater strength and durability for a bridge; however, this may not be the best choice for a small footbridge on a hiking trail in the woods. Wood might be a better option when building a small...
Bridge that has limited use and access. When considering building materials for bridges, engineers take into account the cost, proposed use of the bridge, location, environmental forces, aesthetics, and durability.

**Bridge Aesthetics**

What Are Bridge Aesthetics?

Bridge aesthetics are the elements—primarily materials, bridge type, and design details—that, when effectively combined, create what is perceived to be a beautiful bridge design. These elements can be carefully incorporated into a bridge’s structural make-up, such as the Gateway Bridge in Nashville, Tennessee, see Arch Bridges Poster (in the kit), or can be applied in a nonstructural fashion, like the Tower Bridge in London.

**Why Is It Important to Consider Aesthetics When Designing a Bridge?**

Even though the primary function of a bridge is structural, bridge engineers and/or architects are concerned with its appearance because a bridge often expresses the neighboring community’s values. A bridge’s appearance and design reflect the style of the time it was built and the needs and culture of the community where it was built. Bridges, like the Golden Gate Bridge in San Francisco, can also serve as a symbol for a community.

**How Do Aesthetic Considerations Impact Bridge Design?**

Bridge engineers and architects are mindful that users and viewers of a bridge will respond to its visual appearance and thus often design it in ways to evoke certain response. Do a bridge’s sweeping arcs and immense size call to mind a feeling of grandeur and entrance to a major city? Do the simplicity of materials and structure of a bridge built in a beautiful natural setting make it blend into the surroundings?

When conceiving a bridge in its totality, designers first consider the nature of materials, form and pace, proportion, scale, rhythm texture, color and cost. Then they decide how these elements can be combined to evoke feelings or communicate meaning. They must also determine whether the bridge will be a major piece of structural art, such as the Brooklyn Bridge. Finally, bridge engineers plan for a bridge’s decorative features, if any, such as sculpture or special lighting.

**What Are the Aesthetic Objectives for Bridges?**

No absolute and universally-accepted aesthetic criteria exist for bridges. As with any design project, the aesthetic qualities vary, depending upon numerous parameters. Below is a list of commonly accepted criteria that can be used both to design a bridge and judge its visual appeal. Teachers can use this list to instruct their students about possible, but certainly not all, aesthetic considerations for bridge designs.
Bridges and Structures

Introduction
Bridges and Structures is an AIANH Learning by Design program to educate Middle School students and teachers. This innovative program uses bridge engineering to design as vehicles to examine the people, processes and materials that create buildings, places and structures. This program will use the design process as an educational model that will require our New Hampshire Middle School students to identify problems or needs, images solutions, test them before building a suitable design. After engaging in a variety of hands-on activities that stimulate exploration of bridges and the built environment, students will gain a fresh perspective on their surrounding and begin to understand how design decisions can have an impact on the New Hampshire environment.

Educations Objectives
Bridges and Structures meet New Hampshire standards of learning in language arts, math, science, social studies, technology and visual arts through its curriculum-based lessons that use bridge construction as a basis for understanding fundamental structural engineering concepts. Through hands-on, interdisciplinary lessons that address multiple learning styles, this Learning by Design Program will encourage and foster life skills such as critical thinking, decision-making, team work and communication. Skills and concepts from across the NH Curriculum Frameworks that come into play included:

- Mathematics: geometry, estimation and measurement, scale and proportion
- English Language Arts: research, vocabulary, composition and oral presentation
- Social Studies: function, monuments and sites, science and technology in the context of society, history and human affairs.
- Visual Arts: the elements and principles of design, methods, material and techniques, technologies and the arts, interdisciplinary connections.

Program Description
Bridges and Structures is an AIANH Learning by Design program that will teach Middle School students the fundamental structural engineering concepts involved in building different types of bridges. This program will present bridges as structural solutions to specific problems and will introduce students to basic bridge types: beam, arch, truss, suspension and cable-stayed. Students become engineers and work in teams, using craft material to build model bridges that solve transportation problems, while balancing issues of geography, material, cost and aesthetics. Students participating in this program will explore how technology and design, coupled with human and environmental resources, working concept to meet demands of a mobile society.
Program Details

Learning Standards Assignments
Students work in design-and-build teams. First, the teams define their design problem. Then, they investigate their problem, learning about structures through traditional research and physical hands-on activities.

Developing Ideas and Building Models
Through sketching and diagramming, student teams generate ideas for their structures and choose the best solution. After skill-building activities on side, materials and building techniques, the students describe their solution through a prototype, i.e. they design and build their structural scale models, mini evaluation and group design meetings during the sketching and model building phases give the students chances to redesign their solutions as needed.

The students evaluate the success of their designs by testing their structural integrity. In writing, they consider:
- Does my design solution solve my design problem?
- How well does it solve my Problem?
- Could the design be modified or improved?

Through graphic design boards, media presentation and/or oral presentations the student teams present their final projects.
Bridge Vocabulary

**Abutment**
A support for the end of a bridge

**Anchorage**
A foundation structure that secures suspension bridge cables on land and allows them to bear the weight of the bridge

**Arch**
A semicircular structure

**Arch Bridge**
A bridge in which the roadway is laid across one arch or a series of arches

**Architect**
A professional who designs, plans and coordinated the building of structures

**Beam**
A rigid, usually horizontal, structural element

**Beam Bridge**
A bridge constructed of a horizontal beam supported by vertical piers

**Bridge**
A structure spanning and providing passage over a gap or an obstacle, such as a body of water or roadway

**Bridge Aesthetics**
The elements — primarily materials, bridge type, design details — that, when effectively combined, create what is perceived to be a beautiful bridge design

**Cable**
Formed from steel wire bound in strands; used in modern suspension and cable-stayed bridges

**Cable-Stayed Bridge**
A bridge in which a portion of the roadway is supported by diagonal cables attached to a pylon

**Compression**
The stress resulting from a pushing force on a structure; opposite of tension

**Dead Load**
The weight of any components in a structure; for example, the weight of a the parts of a bridge

**Distance**
The total length of the bridge

**Engineer**
A professional who applies mathematical and scientific principles to the design of structures, equipment, and systems

**Force**
A push or pull on an object; when an object is at rest (not moving), the forces acting on it are balanced

**Keystone**
The slightly larger, wedge-shaped piece of stone or wood placed at the center of the arch to take pressure off both sides of the arch

**Live Load**
The weight of anything that is not a part of the structure, such as vehicles or pedestrians crossing a bridge; includes external environmental forces such as wind or water.

**Pier**
A vertical column holding up a bridge or other structure
**Pylon**
The vertical structural element from which cables radiate in a cable-stayed bridge.

**Roadway**
The part of the bridge that traffic travels across

**Span**
The distance between two supports of a bridge

**Structure**
An object constructed of a number of parts that are put together in a particular way

**Suspension Bridge**
A bridge in which the roadway is hung from strung cables that pass over tow towers.

**Tension**
The stress resulting from a pulling force on a structure: opposite of compression

**Tower**
The vertical element in suspension bridges from which cables are hung.

**Truss Bridge**
A bridge in which the roadway is supported by rigid frames composed of short, straight pieces joined to form a series of triangle
Beam Bridges

Beam bridges are the oldest known bridges and tend to be the simplest to design and build. Roughly half of all bridges in the United States are beam bridges. They consist of vertical piers and horizontal beams. A Beam bridge’s strength depends on the strength of the roadway and can be increased by adding additional piers. While beam bridges can be quite long, the span, or distance between adjacent piers, is usually small.

Pros and Cons of Beam Bridges

- **Pros**: Easy to build; inexpensive relative to other bridges types; used widely in urban and rural settings.
- **Cons**: Limited span; large ships or heavy boat traffic cannot pass underneath; design generally not considered very interesting or eye-catching.

Compression and Tension

- **Compression**: As live loads, such as cars and trucks, travel across the bridge, the force of compression acts on the top of the roadway and passes down into their piers.
- **Tension**: The force of tension acts on the underside of the roadway, which is pulled apart by the live loads pressing down on the top of the roadway.

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R = \frac{wL}{2}
\]
Arch Bridges

Arch bridges were built by the Romans and have been in use ever since. They are often chosen for their strength and appearance. It is the shape of the arch that gives the bridge its strength, which is reinforced by placing supports, or abutments, at its base. Arch bridges can be built from various materials, including wood, stone, concrete, and steel. The famous Italian artist Leonardo da Vinci once said, “An arch consists of two weaknesses, which, learning on each other becomes a strength.”

Pros and Cons of Arch Bridges
- **Pros**: Wide range of materials can be used; considered attractive; very strong.
- **Cons**: Relatively expensive; typically, designs are limited to certain sites (e.g., where the ground can support the large forces at the base of the arch; where the span-to-depth ratio of the arch is proportional; or where an arch is visually appropriate).

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R_v = \frac{wL^2}{8H} \\
R_v = \frac{wL}{2}
\]

Compression and Tension
- **Compression**: the force of compression is greater at the top of the arch. The abutments press against the bottom of the arch, preventing the bases of the arch from being pushed outward.
- **Tension**: The force of tension is strongest at the bottom of the arch and pulls the sides outward. In general, the larger and shallower the arch, the greater the effects of tension and need for abutment support.
Truss Bridges

Wooden truss bridges were used as early as the 1500s, but the first metal one was completed in 1841. They are very strong and have been used for railroad bridges mainly because of the heavy loads that they can support. A truss, a rigid support structure that is made up of interlocking triangles, holds up the roadbed and is set between two piers. The triangle is used because it is the only shape that is inherently rigid.

Pros and Cons of Truss Bridges

- **Pros**: Very strong; frequently used as a draw bridge or as an overpass for railroad train.

- **Cons**: Difficult to construct; high maintenance; difficult to widen if necessary; generally not considered attractive.

Compression and Tension

- **Compression**: As traffic pushes down on the roadway, compression acts on the upper horizontal members of the truss structure.

- **Tension**: Tension acts on the bottom horizontal members of the truss structure. The forces of tension and compression are shared among the angled members.

\[ R = \frac{wL}{2} \]
Suspension Bridges

Suspension bridges are strong and can span long distances. One early bridge was designed and built in 1801 in Pennsylvania. They are expensive because they take a long time to build and require a large amount of material. They are commonly found across harbors with a lot of boat traffic. The primary elements of a suspension bridge are a pair of main cables stretching over two towers and attached at each end to an anchor. Sampler cables attached to the main cable support the roadway.

Pros and Cons of Suspension Bridges

- **Pros**: Span distance up 7,000 feet; considered attractive; allow large ships and heavy boat traffic to pass underneath.

- **Cons**: Expensive (require a long time and a large amount of material to build).

Compression and Tension

- **Compression**: Traffic pushes down on the roadway, but because it is suspended from the cables, the weight is carried by the bales, which transfer the force of compassion to the two towers.

- **Tension**: The force of tension is constantly acting on the cables, which are stretched because the roadway is suspended from them.
Cable-Stayed Bridges

The first modern cable-stayed bridge was completed in Sweden in 1956. Cable-stayed bridges were created as an economical way to span long distances. This bridge’s design and success were made possible as new materials and construction techniques were developed. Cable-stayed bridges have one or more towers, each of which anchors a set of cables attached to the roadway.

Pros and Cons of Cable-Stayed Bridges

- **Pros:** Span medium distance (500-2,800 feet); less expensive and faster to build than suspension bridges; considered attractive.

- **Cons:** Typically more expensive than other types of bridges, except suspension bridges

Compression and Tension

- **Compression:** As traffic pushes down on the roadway, the cables, to which the roadway is attached, transfer the load to the towers, putting them in compression.

- **Tension:** The force of tension is constantly acting on the cables, which are stretched because they are attached to the roadway.

American Institute of Architects New Hampshire Chapter
Beam Bridge: Rye, NH
Arch Bridge: Keene, NH
Suspension Bridge: Portland, ME
Cable-Stayed Bridge: Boston, MA
Truss Bridge: Berlin, NH