

BRIDGE IT!

Type of Project: Facilitated Hands-On Exhibit
Target Museum: SciTech and Museum of Science and Industry
Target Audience: Visitors above 7 years old



The Idea

Bridge It! is a hands-on exhibit that invites visitors to experience a design process and to explore the rules of structural engineering through the challenge of building a bridge. Visitors use a collapsible bridge deck, ropes and pieces of wood to build a bridge and test its strength with weights.

On the one hand, the exhibit demonstrates how the three main aspects of structural design – static mechanics laws, material properties and economic considerations can be creatively exploited. On the other hand, the challenge of solving an engineering problem serves three different educational purposes. Firstly, visitors learn to apply the concepts, principles and processes of technological design¹ – they identify a design problem, consider limitations in available materials, build a simulation, test it, assess the results and make improvements. Secondly, through the hands-on experience visitors gain an applied understanding of pure scientific concepts such as tension, compression and torque forces, and Newton's second law. And thirdly, the modular and open-ended nature of the exhibit develops creative thinking and artistic expression.

¹ As specified in State Goal 11-B for late elementary and middle-school students (Illinois Learning Standards for Science, retrieved from <http://www.isbe.state.il.us/ils/science/standards.htm>)

Description

Bridge It! consists of a base, a collapsible bridge deck, a number of separate rope and wood elements, and weights. The base is about 5' long at a height appropriate for visitors 7 years old and older. It is made of painted MDF with attached hardware and casters. Its inside is covered with carpet to absorb the impact of the collapsing pieces. The collapsible bridge deck is made of 7 blocks of bass wood with embedded magnets so that they snap to each other and to the base. The deck is able to stand by itself but it collapses when one or two weights are put on it. In addition to the 10 1-lb weights (fabric bags filled with marbles), there are two long wood posts, 3 short dowels and a number of pieces of rope provided. Visitors are invited to use the rope and the wood blocks to build a stronger bridge and then to test it with the weights until failure.

The exhibit uses the same rope-to-wood connection system for all elements. The deck blocks, the posts and the dowels have small notches in which the rope can be pushed. A continuous strip of Velcro runs along the sides of the notches in order to increase the friction with the rope. Thus, the length of the rope can be easily adjusted by pulling on it. At the same time, the friction-based connection allows for limited strength and a simple collapse mechanism. Under the critical weight, the rope slides out of the notch.



The exhibit label is a flip-through booklet that poses the challenge, provides the instructions and suggests possible designs. Every design is presented by a schematic drawing, a photograph of the exhibit with the particular design built, a photograph of a bridge that uses the same design and short text explaining the technology and providing interesting information on the real-world example. The bridge designs are ordered according to difficulty of conceptualization and implementation. The last two designs combine ideas from the previous basic typologies and urge the visitor to experiment with what they have learnt. Thus, the booklet allows for different levels of engagement with the exhibit. Visitors can simply obtain the use instructions and experiment by trial and error. Or they can choose a design and replicate it. More engaged or older visitors should realize that there is a multitude of design possibilities to explore and try to come up with their own designs.

The *Bridge It!* exhibit requires minimum facilitation mainly for “resetting” (i.e. taking apart the bridge built by the last visitor). However, the visitors will also benefit from a facilitator who

structures the design process, explains the physics laws at work and provides interesting facts about bridges in general.

Connection to SciTech and MSI Exhibits

Bridge It! is intended as a facilitated exhibit for both SciTech Hands-On Museum and the Museum of Science and Industry.

At SciTech, the exhibit can either be free-standing on the floor or taken to classrooms for demonstrations. On the floor, the exhibit can thematically fit among existing exhibits that relate to the built environment (such as the water tower and the truss-bridge construction set). Furthermore, the exhibit is in essence a more specific and advanced version of the classic construction games with blocks and bricks, which SciTech offers to its youngest visitors. If *Bridge It!* is demonstrated in classrooms, the facilitator can lead students through the design process by a question-and-answer method and use volunteers to implement and test ideas.

At MSI, *Bridge It!* Relates directly to *The Transportation Zone* and in particular, to *The Great Train Story*. The model railroad exhibit shows how bridges, together with tunnels and switchbacks, are used to provide continuous travel across diverse terrain. *Bride It!* zooms into one of these instances and lets visitors engineer the solution. The hands-on and creative aspects of *Bridge It!* are intended to elaborate on and enhance the experience of transpiration technology that existing MSI exhibits offer.

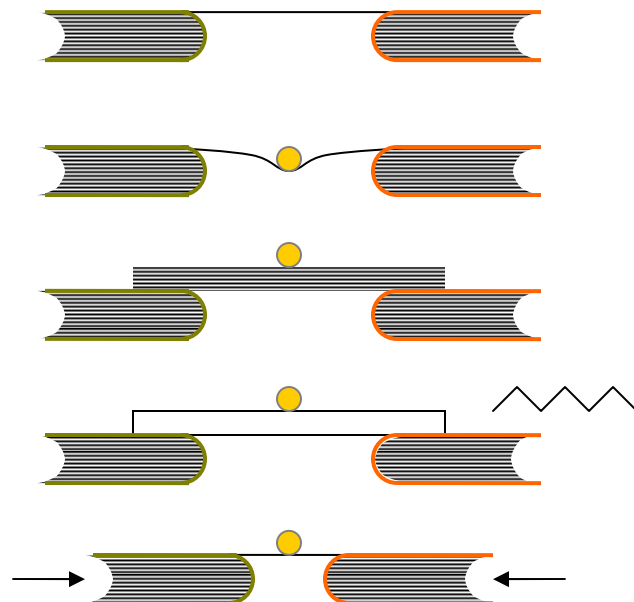
Science and Technology behind the Concept

Building technology combines physics, material science and economic considerations. For example, structural engineers have to design bridges that most efficiently carry loads across long spans.

1. Bridges act as beams. When spanning long distances, the bridge deck bends under load and can eventually fail. The maximum displacement that a beam can undergo before it fails depends on the load, the beam span between supports (the length of the beam), the properties of the material the beam is made of and the geometry of the beam's cross section.

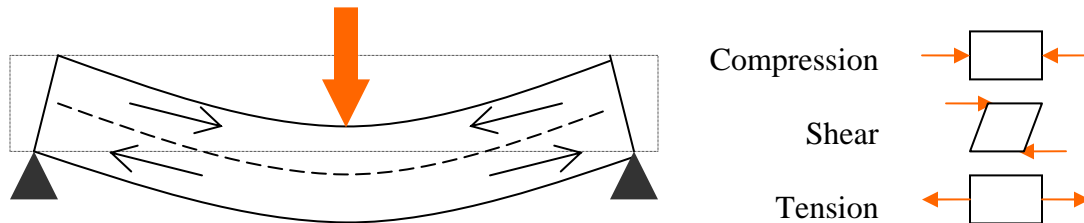
For example, take a sheet of paper and span it across two books. If you put a small pencil on top, the paper will sag and fall. How can you have the paper support the pencil? You can put more paper (increase the amount of material). You can plait the sheet of paper (change the geometry of the beam). Or you can push the two books together (decrease the beam span).

Going back to bridges, when one is given the load requirements and is limited in the use of deck material, in order to prevent failure, one should decrease the spanning distance or strengthen the deck itself. Inserting intermediate columns



may be very costly (for bridges over rivers or great heights) or inappropriate (if the space under the bridge needs to be kept clear for ships or cars in the case of highway intersections). Engineers need to use other tricks to cheat gravity.

2. Beams break when they bend because of shear stress. Beams are problematic because the combination of compression and tension forces produces shear stresses in the material that cause it to break.



Bending happens when the load is perpendicular to the length of the structural member. If we pull or push along the length of the member, we will only have compression or tension stresses. This is what happens in arches and cables. Engineers prefer members with pure compression or tension stresses because they are more predictable and efficient i.e. they require easier mathematical equations to solve and less material to make.

Some materials deal better with compression forces (such as stone and concrete), while others are more suited for tension (such as wood and steel). This is why, for example, concrete beams always use steel rebar inside. As we now know, beams have to deal with both compression and tension so when we combine concrete and steel, we make a stronger beam.

3. Members in compression or tension only are more efficient. This is why engineers prefer to make bridges with trusses (multiple small members in compression or in tension only), cables (members in tension only) and arches (members in compression only).

Common Bridge Designs²



Cable-stayed bridge



Cantilever spar cable-stayed bridge



Side-spar cable-stayed bridge



Tilt bridge



Arch bridge



Compression arch suspended-deck bridge



Tied arch bridge (Bowstring bridge)



Truss arch bridge

² Images and classification from <http://en.wikipedia.org/wiki/Bridge>.



Cantilever bridge



Truss bridge



Brunel Truss bridge or lenticular truss



Viereendeel bridge



Suspension bridge



Self-anchored suspension bridge



Simple suspension bridge



Stressed ribbon bridge

4. In addition to carrying traffic across, bridges also have to withstand wind. So far, we have considered only how bridges counteract vertical load due to traffic. However, bridges are also always exposed to horizontal load due to the strong winds in canyons, across rivers and in the sea. In certain places, bridges also have to be designed to withstand earthquakes. Winds and earthquakes cause torsion forces that require much more complex analysis and methods to solve for.

Random Facts about Bridges

- The earliest bridges used logs and wooden planks in simple support-and-crossbeam arrangements. However, they could not support heavy weights. The Romans were the first to use stone arches for bridges and aqueducts. Some of these structures are still standing today, more than 2000 years later.
- In the 1500s, the Incas used simple suspension bridges made of woven ichu grass reinforced with plaited branches. These bridges were very strong and reliable because local villagers replaced the cables annually.
- The first engineering book on building bridges was written in 1716 by a French engineer.
- With the advent of the Industrial revolution in 19th century, wrought iron started to be used for bridges. However, it does not have the tensile strength to support heavy loads. Today, large bridges are built with steel.
- The bridge with **longest span** is the Akashi-Kaikyo suspension bridge in Japan, finished in 1998. It spans 6532 ft (1991 meters).
- The **longest bridge** in the world is the Causeway across Lake Pontchartrain in southern Louisiana. The bridge actually consists of two parallel bridges, the longer of which is 23.87 miles long.
- The **tallest bridge** in the world is the Millau Viaduct in southern France. One of its piers is 1,125 ft tall, slightly taller than the Eiffel Tower and only 125 ft shorter than the Empire State Building.

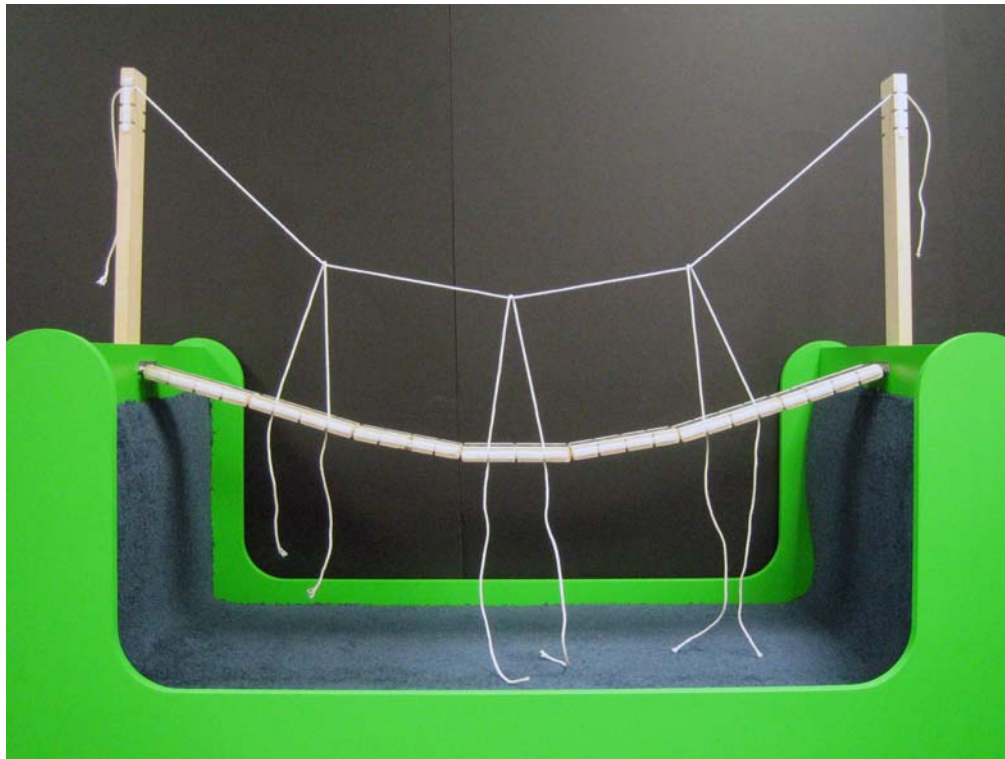
The Process

Prototype

We started by building a small-scale prototype of the exhibit with the intention of testing the construction details. For the connections of the deck blocks we used a system with two

embedded magnets with staggered polarity. For the rope-wood connection we used a button-and-string system. And as a base, we used two poster board stands with clamps. We also provided simple signage but at this stage, we relied on facilitated introduction and instruction.

The first problem that became obvious was that the straight edges of the blocks did not allow for the catenary shape that the deck takes under its own weight. Thus, we rounded the edges. The magnet connections proved strong enough but the staggering of the polarity turned out to be unnecessarily confusing.



Evaluation

We tested the prototype at MSI with 3 groups of children. The first two children were brother and sister at the age of 9 and 7 respectively, the second group were two boys and a girl 10-11 years old, and the third group – 3 boys and 3 girls 6-8 years old. We provided design drawings but at this stage, we relied mainly on facilitation. In general, we were surprised to see how quickly the children understood what they are expected to do and how involved and diligent they became. They all worked together, commenting on and correcting each other. Although the concept proved to be accessible, certain technical problems became evident:

1. The button-and-string connection was not obvious and it was hard to use. What is more, it was too strong and did not allow for incremental weight testing.
2. Since we had the “pylons” always clamped, all kids chose the cable-stayed bridge design which seemed intuitive in such set up.
3. Once the bridge was built, we had to manually “reset” it for the next group.
4. Crowding became a problem due to the fact that we had set up close to a wall and the poster board stands were not sturdy enough.
5. The falling of the deck pieces to the floor was noisy and messy.

We replicated the evaluation at SciTech and the results were similar.



Conclusions

Based on the two evaluations, we set the following goals for the next iteration of the design process:

1. Develop a simpler, more intuitive and better working rope-to-wood connection system.
2. Provide attractive weights that will allow incremental strength testing.
3. Design deck blocks for impact from falling.
4. Develop better signage but also reconsider the exhibit as facilitated.

Modifications

The final exhibit is about twice the size of the prototype. For the rope-wood connection we considered a hook-and-chain design, as well as cleats (V-shaped rope-holders used on sailing boats). The chains appeared clumsy and the hooks caused a safety concern. The cleats were ideal in terms of performance but too big for our exhibit. We decided to approximate them with friction-based notches.

The major challenge was the base. The poster-board stands provided ideal height, mobility and flexible setup but now could not support the weight of the final version of the exhibit. We designed a base that provides the necessary sturdiness and safety but also allows for mobility.

Image Credits

Alamillo Bridge. http://www.turismo.sevilla.org/imagenes/album_fotos/galeria/31_7.jpg.

Golden Gate Bridge. Retrieved from <http://images.arm.gov/armimages.nsf/by+id/TENG-6DKPDH>. Courtesy: U.S. Department of Energy's Atmospheric Radiation Measurement Program.

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Collapsed bridge in Oklahoma. Retrieved from <http://eppsnet.com/2006/08/massive-accountability>.