From Here To There

Bridges are among the wonders of civilization. But just how do you build one?

In the Chinese city of Zhao Xian, some 40 miles south of Beijing, a bridge called the An Ji curves up from one shore of the Xiache River and down again to reach the opposite shore. One hundred-sixty-four-feet long and 33-feet wide, the bridge, whose name means "safe crossing," has been carrying traffic along its arched back for almost 1,400 years.

The An Ji is not the oldest arched bridge in the world–the Romans were covering Europe with them hundreds of years earlier–but it is the oldest with its particular sweeping design, predating anything like it in the West by some 700 years.

For the question, "How do we get from here to there?" the bridge has often been the answer. Not every river can be crossed with ease by foot or ferry. Wind and weather can make a river's waters tempestuous. A bridge allows people, animals and goods to cross without concern for Mother Nature's roadblocks. Bridges ease isolation and encourage trade. Like the An Ji, they help assure a safe crossing.

But how do you build a bridge? What factors do you have to keep in mind if you want to span a creek, a river or even a bay?

The earliest bridges were probably split logs in a riverbed or vines that grew from shore to shore. These bridges have simple spans. A span is the distance a bridge travels without support. More complex are the so-called clapper bridges that survive in southwest England. Stone slabs balanced on regularly spaced rocks in the river may date back to the Stone Age.

But this is the stuff of children's building blocks. How are longer, more complex and more ornate bridges built?

By David Holzel

How Bridges Stay Up

Consider the beam bridge. We see them everywhere in the form of concrete overpasses, with short spans supported by vertical posts and multiple spans supported by piers. But in its simplest form, a beam bridge is merely a long, rigid piece of wood or other material (the beam) laid horizontally.

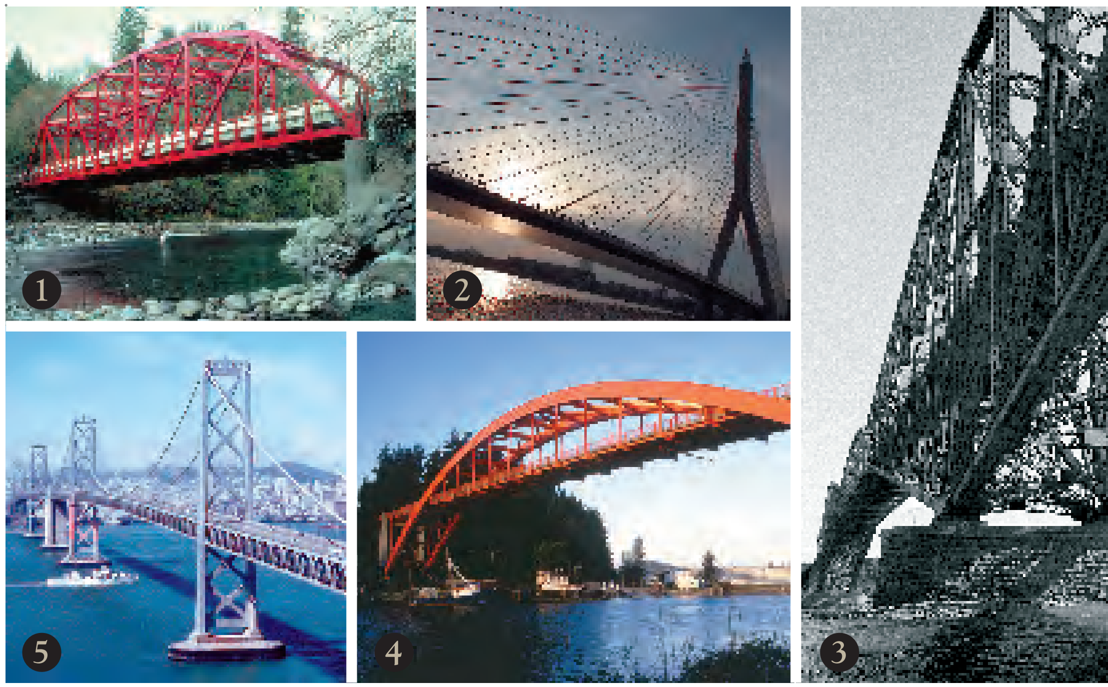
A thick piece of wood over a creek may stand up to a few people crossing at one time. But keep adding weight to the bridge and it may begin to sag, then buckle and eventually snap. Making sure this doesn't happen requires accounting for the two forces that act on a bridge:

- **Compression**–the bending of the beam under a load
- **Tension**–the stretching of the bottom of a beam under a load

Too much compression and a bridge will buckle. Too much tension and it will snap.

Engineers handle these forces in one of two ways:

- **Dissipate**, or spread, the forces over a greater area, or
- **Transfer** the forces from an area of weakness to an area of strength.



THE DIFFERENT KINDS OF BRIDGE CONSTRUCTION

CLOCKWISE FROM UPPER LEFT: TRUSS, CABLE-STAYED, CANTILEVER, ARCH, AND SUSPENSION.

What Are the Different Kinds of Bridge Construction?

Arch bridges (4)– The engineer who built the An Ji bridge knew that an arch will dissipate the weight of a bridge, distributing the forces of compression and tension along the curve of the bridge's mouth and down to the ground.

The design allows small stones to be used in construction, the easier to haul and build with. In addition, the greater load placed on the arch forces the pieces together, making a virtue out of compression and making the bridge stronger. The arch bridge was the dominant design until iron was introduced in the 18th century.

Truss bridges (1)– Arch bridges harness the power of the triangle. So do truss bridges, which distribute their weight through a large beam fitted with connected triangles or A-shaped frames. Railroad companies constructed long wooden truss bridges in the 19th century to carry trains through the American West.

Cantilever bridges (3) are like two arms reaching out to each other from opposite shores—without touching. Each arm, or beam, is balanced on a pier. An abutment at the shore end of each beam holds the beam in place. A small section, called a key, connects the two outstretched arms.

To extend the length of a bridge, a suspended span is built between the two arms.

Suspension bridges (5) have a deck suspended by cables. The design allows them to be the longest bridges in the world. In addition to the deck, which carries traffic, suspension bridges have three other parts: towers, also called pylons; cables, the long arching connections between the towers; and the hangers, or suspenders, which connect the cables vertically to the deck. The ends of the cables are secured with anchors on each bank.

The suspension bridge is an example of transferring the forces of compression and tension from an area of weakness to an area of strength. Traffic on the deck pulls down on the cables, causing the cables to pull down and sideways on the towers. The anchors, held in place by concrete, keep the towers from falling.

Cable-stayed bridges (2) are a variation of suspension bridges. Instead of being supported by cables attached to two massive towers, each section of a cable-stayed bridge is supported by its own cables attached to a tower. The weight on the deck of the bridge pulls on the cables. The pull is then transferred to the towers, which carry the weight to the ground.

Famous (and Infamous) Bridges

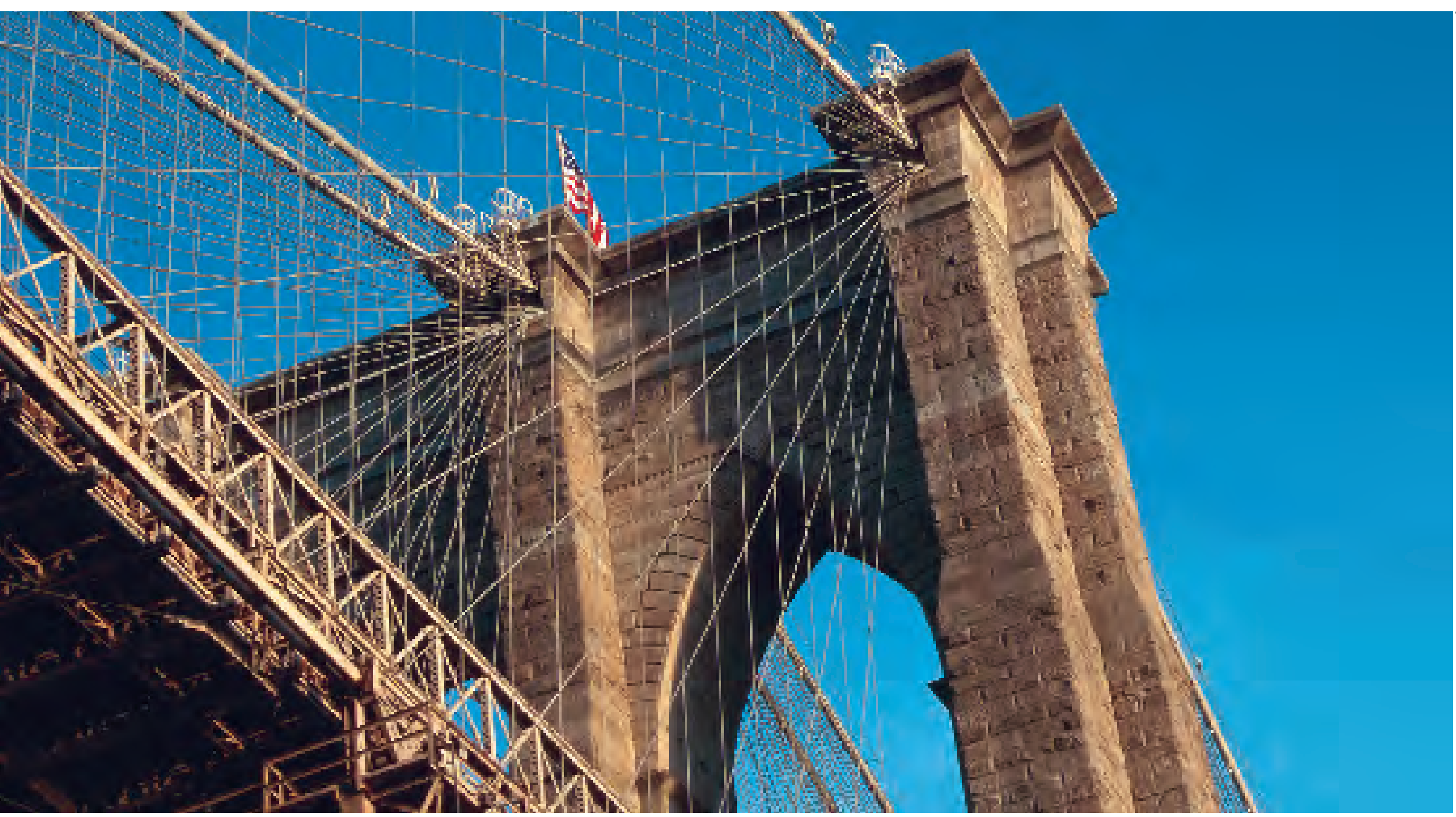
The Eads Bridge over the Mississippi at St. Louis – When it opened in 1874, after seven years of construction, St. Louis residents paid a nickel apiece for the novelty of walking across the Mississippi River.

City business interests saw a bridge as key to compete economically with Chicago to the north. But riverboat companies opposed a bridge, fearing it would hurt their business. The final design was a steel-arch bridge with three spans of more than 500 feet each, which would allow the passage of ships up and down the river.

Construction of the abutments on the east and west banks and the two piers in the river was difficult in the Mississippi's muddy ground. Engineer James Buchanan Eads decided to use a new technology he had seen in France to dig the piers: pneumatic caissons, chambers that allow workers to dig underwater. Water is kept out of the caisson by high-pressure air being pumped in. Eads developed a pump to remove the sand and mud that kept filling the chambers.

The reaction to the bridge was summed up by poet Walt Whitman, who wrote in 1879, "I have haunted the river

The Brooklyn Bridge was the first suspension bridge to use steel cables. Suspension bridge design allows these bridges to be the longest in the world.



every night lately, where I could get a look at the bridge by moonlight. It is indeed a structure of perfection and beauty unsurpassable, and I never tire of it."

The Brooklyn Bridge – The same economic ambitions that drove the St. Louis bridge contributed to building its near contemporary, the Brooklyn Bridge. By 1850, the East River had become an impediment to "the growing trade and further advancement" of the competing cities of New York and Brooklyn, Deborah Cadbury writes in *Dreams of Iron and Steel.*

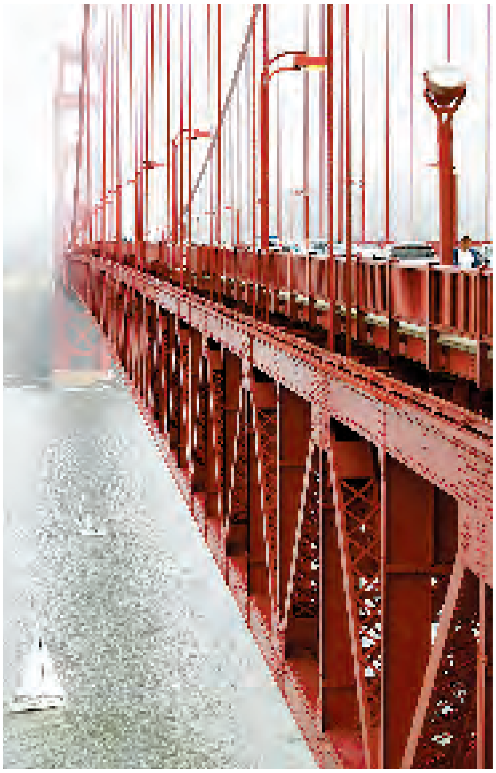
The Brooklyn Bridge, built between 1869 and 1883, was the first suspension bridge to use steel cables. The plan was audacious. Its central span was to be 1,590 feet long. Its cables were composed of nearly 1,250 miles of steel wire. Its gothic granite towers were 276 feet high. There was to be room for a walkway, railway lines and a road.

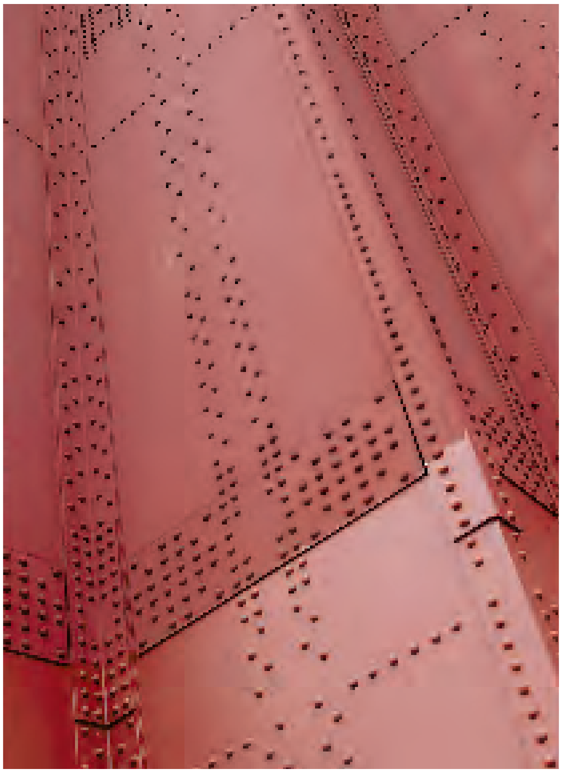
Golden Gate: One of the world's most famous bridges, the Golden Gate is colored orange, reminiscent of the Grand Canyon.

The engineering challenges were enormous. The towers were to stand on foundations that would reach bedrock, 40 feet below water level on the Brooklyn side and more than 70 feet below water level in the deeper water of the New York side.

The building of the Brooklyn Bridge has become part of America's can-do lore. The whole country was "in love with the sheer audacity of the enterprise," Cadbury writes. But there was a price paid. Twenty men lost their lives in its construction, the first being its engineer, Johann August Roebling. Roebling, who already had built bridges at Cincinnati and Niagara Falls, died of injuries he suffered while surveying the site.

His eldest son, Washington August Roebling, took over. He, too, fell victim to the bridge, developing "the bends" or "caisson disease" in 1872. Workers on the St. Louis bridge had noticed strange after-effects from working in the high-pressure caissons. The crippling, often fatal condition occurs when nitrogen in the body becomes gaseous and bubbles, damaging body tissue. As the digging of the Brooklyn Bridge's foundations went deeper, incidences of the bends became more common and more severe. Washington Roebling was so incapacitated that he was forced to watch the rest of the bridge's construction through binoculars from his Brooklyn home.





The Golden Gate Bridge – Opened in 1937 after four years of construction, the Golden Gate connects San Francisco and Marin County to the north. Its central span is 1,650 feet long and its Art Deco steel towers are 750 feet high. Each of the bridge's cables weighs more than 7,000 tons.

Engineer Joseph P. Strauss described the Golden Gate's orange color as reminiscent of the Grand Canyon.

Tacoma Narrows Bridge — People weren't dismayed by the peculiar behavior the bridge over Puget Sound exhibited after it opened in July 1940. The world's third longest bridge pitched and tossed and quickly earned the nickname "Galloping Gertie."

That summer and into the fall, the bridge drew a record number of cars, their drivers enjoying the carnival-like ride. But when a gale hit that November, the bridge began to twist ominously from the center. It was cleared of traffic, and before long Galloping Gertie's center section collapsed into Puget Sound.

AKASHI KAIKYO: IN 1988, THE WORLD'S LONGEST SUSPENSION BRIDGE, THE AKASHI KAIKYO WAS DESIGNED TO WITHSTAND EARTHQUAKES AND WIND SPEEDS UP TO 180 MPH.

Longer and Longer

Several factors contributed to Galloping Gertie's demise. One is that it lacked a stiffening truss, a beam harnessing the power of the triangle to handle the forces of tension and compression. Another factor is that the builders had failed to take into consideration the power of wind.

With these lessons learned, longer and longer bridges began to rise all over the world.

In 1988, the world's longest, tallest and most expensive suspension bridge opened in Japan, after 10 years of construction. The Akashi Kaikyo Bridge stretches 12,828 feet to connect the city of Kobe with Awaji-shima Island. The suspension bridge's longest span, its central one, is 6,530 feet. Its two towers rise 928 feet, just 60 feet shorter than the Eiffel Tower.

During construction, the Akashi Kaikyo was in a race with Denmark's East Bridge to become the world's longest. In 1995, it appeared the Japanese bridge might lose the contest when an earthquake measuring 7.2 on the Richter scale hit the country. The earthquake was serious enough to take 5,000 lives. But the bridge, designed to withstand much stronger quakes, as well as winds of up to 180 mph, was undamaged.

In another six years, the Akashi Kaikyo may lose its title as the world's longest suspension bridge to one connecting Italy and Sicily. Construction of the Messina Strait Bridge is expected to begin this year. When completed in 2011, its central span will be two miles long, and the entire bridge will weigh nearly 300,000 tons.

Such bridges are among the wonders of civilization. Yet they all must abide by the same forces of nature, whether the most complex suspension bridge on the planet or a beam that children have placed over a brook.

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A Ride In the Clouds

The photographs are dreamlike: The bridge, its cable-stayed concrete pillars rising like masts, sailing through the clouds over France's southern Tarn River valley. The Millau Viaduct, which opened in December to much fanfare, was built in just three years to ease traffic bottlenecks between Paris and the Cote d'Azur. The Millau Viaduct is both the heaviest and tallest bridge in the world.

Bridge Facts

Type:
Cable-stayed Bridge

Length:
1.6 miles

Width of the deck:
105.2 feet, carrying two lanes of traffic in each direction

Thickness of the deck:
13.8 feet

Weight of bridge:
266,759 tons

Materials Used:
39,683 tons of steel
227,076 tons of concrete

Number of stays:
154

Built to withstand:
Winds up to 155 mph

Number of construction workers:
500+

Expected time to cross by car:
1 minute

Cost:
$523 million

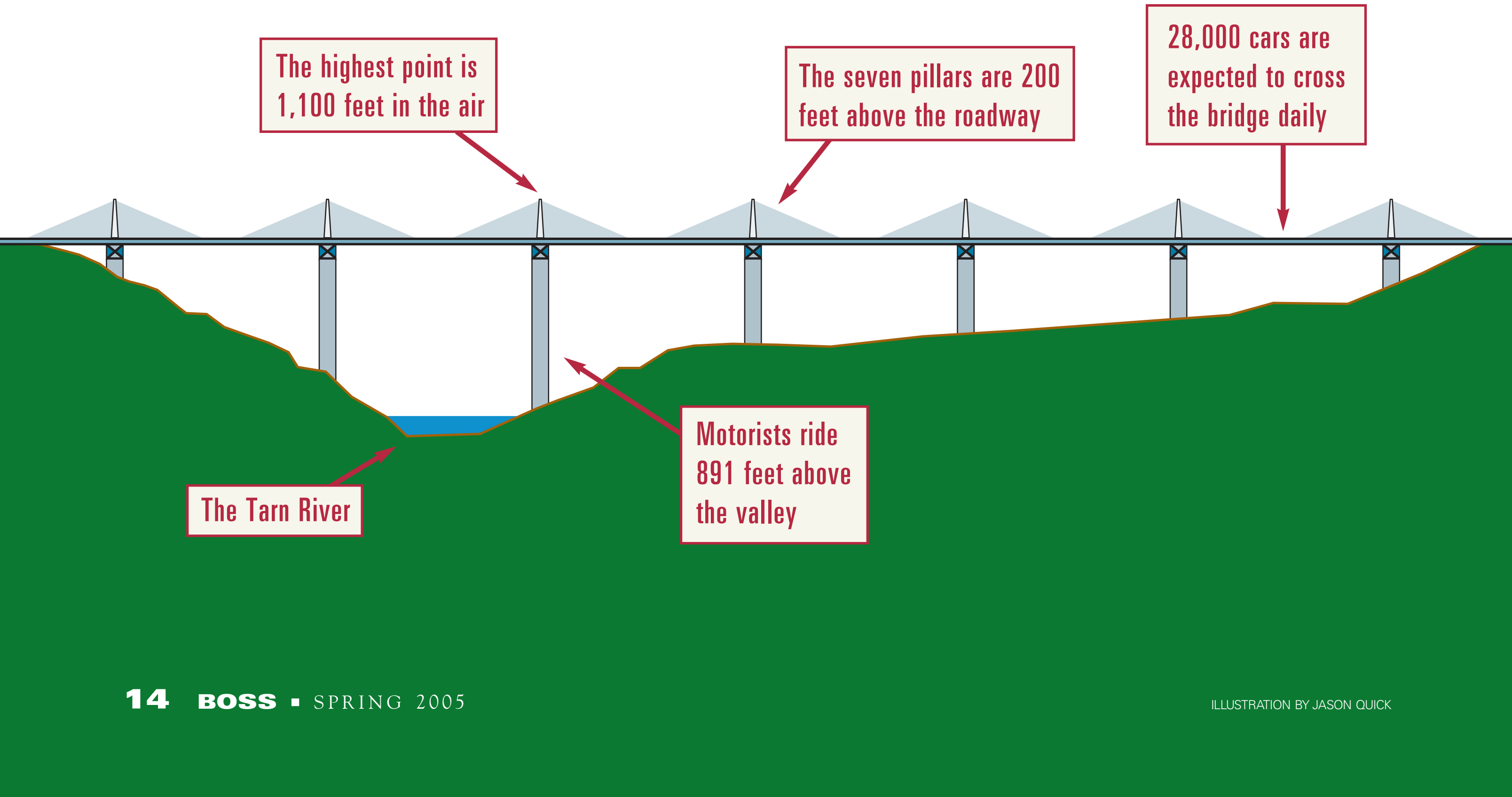

ILLUSTRATION BY JASON QUICK