Highlights

- **Keshwa Chaca (made from ropes), hand woven , qqoya grass suspension cables, annual replacement honors Inca ancestors**
- **Cable-stayed alternate beats-out modern, suspension bridge base design to become Chile's first.**

SPANS

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LEARNING THE ROPES

FIGURE 1 : Inca decedents test Keshwa Chaca (made from ropes)

The naturally fallen tree trunk that has bridged a stream or ravine since prehistoric times is considered to be the first bridge for man and animal alike. Some millennia later he learned to drape vines across a deep gorge in order to provide access, back and forth, to the opposite side. In all likelihood this first suspension bridge evolved in a place like the west coast of South America (Figure1). This suspension bridge has been used in all parts of the world, down through the centuries, changing little until James Finely of western Pennsylvania invented the modern suspension bridge in 1796.

Prior to Finely, the suspension bridge's profile grade line approached the chasm level and then, across the open space, it fell away to form a catenary curve. Consequently, for thousands of years, people would cross the chasm by walking on the suspended ropes that followed the swooping curve of the catenary. Finely decided to build a tower on either side of the chasm and move the anchor points for the ropes back and away from the edges of the open span then return the ropes from the anchors and lead them up and over the towers with the catenary now positioned between the towers and above the walkway while spanning the chasm. He then hung the walkway from the suspension ropes to carry it level with the approaches. This configuration made it possible for wheeled vehicles to smoothly negotiate the approaches and main span which were now all at the same level (Figure 2).

Curiously, the Ministry of Public Works for the Chilean Government in Santiago de Chile was tasked with building a bridge in a very remote area,

FIGURE 2: Thomas Telford's 1826 Menai Bridge; a modern suspension bridge

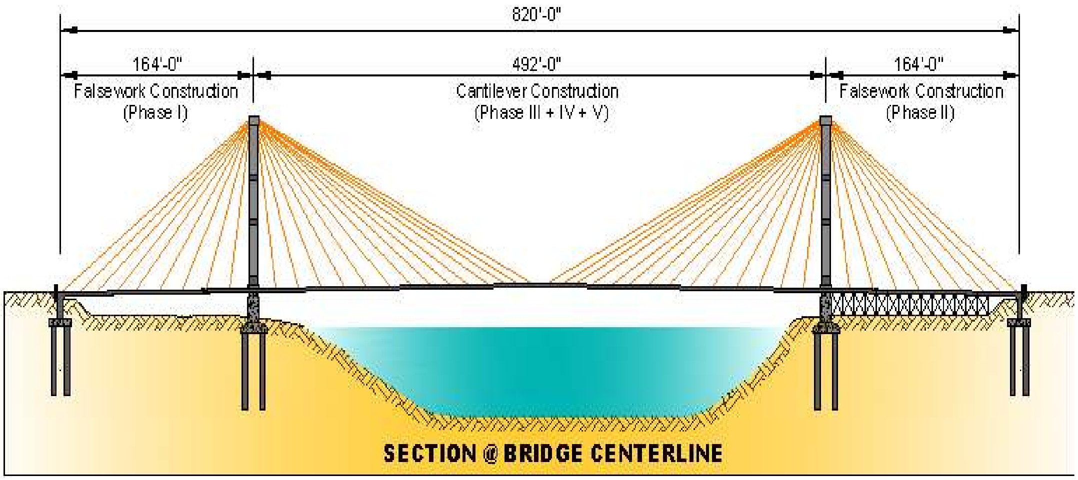

FIGURE 3: Yelcho bridge sidespans on falsework counterbalance mainspan cantilevers

at the base of the Andes Mountains, 360 miles south of the capital. The bridge provides access to the very scenic, glacier fed Lake Yelcho by carrying a one lane road across the Yelcho River to the Lake. The Ministry produced a one lane, suspension bridge design with a main span of 492 feet and two side spans of 164 feet each. A steel stiffening truss was suspended from the cables and steel floor beams carried a cast in place concrete deck. The Ministry produced contract documents that allowed the construction bidders to develop alternate designs that fell within the specified parameters.

Five alternate bids were received, in accordance with the bid documents, and the winning bid was submitted by the Chilean Contractor Sical Ltda. employing the solution developed by Dywidag Systems International GmbH (DSI) and DRC Consultants, Inc, New York, New York. The winning design was for a cable-stayed, cast-in-place, segmental concrete deck girder (Figure 3). The primary factor leading to the success of this design was its constructability. The remote location suggested minimizing off-site fabrication and the need for on-site, heavy equipment.

The bridge configuration of 164' side spans, over the river banks, and the 492' main span, over the river, was to further effect economy by dividing this 820' long, 21' wide (out to out) continuous, prismatic girder into segments (Figure 4). This continuous girder was anchored and restrained in the vertical direction by elastomeric bearing pads at the two abutments and allowed to hang free at the two towers where they were restrained in the vertical and horizontal directions by elastomeric bearing pads. The horizontal tower restraint was for seismic and wind loads. The concrete towers have a hairpin shape standing 136.12' above the mean water level of the river and 111.52' above the roadway deck. The hollow cap-beam for the towers is 7.87' deep and 28.00' out to out in width and houses the stressing end anchors for the deck girder cable stays.

All of the stays were designed to employ the same, single, 1-1/8" diameter, Dywidag, Mono-Bar to minimize the job-site equipment requirements and the light, compact stressing ram for this single bar stay design was to be managed by one man. Further to the constructability issue, the stressing ends of the stays are configured in the transverse direction, 12" on center, to simplify the access to the stressing ends, located in the tower heads, where they all are at nearly the same elevation. Correspondingly, the spacing of the stays along the edge girders is varied in order to keep the tension in the cables within an acceptable, narrow range of stresses, again to maintain the job-site requirements for only a one size stressing ram. This was achieved with the variable spacing of the stay anchors along the edge girders from 19.68' near the towers to 13.12' near mid-span.

The transverse components of the horizontally oriented stressing ends of the stays, at the tower heads, provide additional stiffness by adding horizontal forces that will add resistance to the horizontal loads from the wind and seismic loadings. The short side spans of the bridge provide stiffness for the main span but further require tie-downs at the abutments to react against the inherent tendency of the short spans to introduce up-lift into the side span abutments. All cables (ropes) or high strength bars, in the case of the Yelcho Bridge, were trucked to the jobsite in 40' lengths. These bars have a course, continuous thread that allows them to be cut and assembled to any length with a splice sleeve. The splice sleeve is fully spun onto the leading bar then the trailing bar is matched to the leading piece and then the sleeve's rotation is reversed to engage one half of the added, trailing bar and the length of tension elements are, consequently, increased.

Constructability again becomes a deciding factor as the conforming design, with its very traditional suspension bridge configuration requiring, either a very expensive cable spinning machine for manufacturing the cables in-place or heavy lifting and transportation equipment for delivering and erection of pre-manufactured

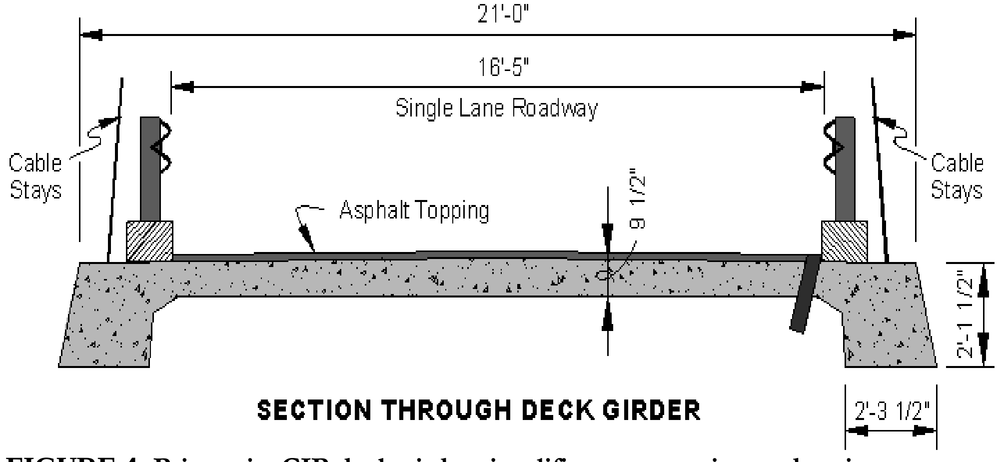

FIGURE 4: Prismatic, CIP deck girder simplifies construction and maintenance

FIGURE 5: Yelcho Bridge carries road over river to edge of Andean glacier

cables. This type of bridge requires distinct, layered, construction phases starting with the building of the foundations; followed by the anchorages; towers; then the suspension cables. The last phase for the suspension bridge involves the hanging of the roadway framing and the casting of the concrete roadway deck.

For relatively short span bridges the cable-stayed configuration will need only two towers, as with the suspension bridge but, unlike the suspension bridge, they do not require the massive anchors and their attendant foundations. Once the cable-stayed towers are in place, the roadway deck is built out in a balanced cantilever fashion about each of the towers then each segment is stayed to the towers before the succeeding segments are added. The evolving, segmental, roadway deck provided the access/work/assembly areas to build the bridge over the spanned obstruction.

Beginning in December, 1989 the construction sequence that the winning, cable stayed bridge type employed (Figure 3), for this specific site, was as follows: Construct a tower and abutment first on one side of the river and then on the opposite side to maximize the utilization of forms and equipment. Next, build the falsework for one sidespan, in the dry, on the riverbank then cast the sidespan deckslab in consecutive segments varying in lengths from 32’-10” to 39’- 4”. With the full sidespan deck in place and resting atop the falsework, it is then blocked at the tower against the horizontal thrust induced when the sidespan stays and abutment tie-downs are installed (Phases I and II).

With this asymmetric configuration in place two temporary stays were added to the top of the tower and delivered to the base of the opposite tower foundation to stabilize the tower while it had only back stays in place. At this point the formtraverler was installed for the cantilevered, cable-stayed, segmental construction of the first half of the main span which is composed of 14 segments (Phase III). With the first half of the cantilevered mainspan complete the two temporary stays from the top of the second tower were strung to the base of the opposite tower and anchored.

The form traveler was then relocated to the opposite tower to start the cantilevered construction of the second half of the mainspan’s 14 segments (Phase IV). Once the final, cantilevered segment of the second half of the mainspan was cast the form traveler was positioned to cast the midspan, closure segment and complete the mainspan (Phase V). The typical production for the mainspan, cantilevered segments was one segment per week. The final measure of this very direct construction sequence involved the stressing and grouting of the longitudinal, post-tensioning tendons in the edge girders and the placing of the asphalt wearing surface in December, 1990 to conclude the construction of the Yelcho River Bridge (Figure 6).

This bridge, in remote Palena Province, when completed became the first cable-stayed bridge to be built in Chile.

Hillsborough County Florida

FIGURE 6: The first cable-stayed bridge in Chile spans the Yelcho River

Guest Commentary

By: Scott McAlister

John A. Roebling, A Master Builder

Freemasons have been in the news quite a bit lately. Freemasons have figured prominently in Dan Brown's latest best seller, *The Lost Symbol*, and the movie, *National Treasure*, starring Nicholas cage.

It is believed that modern Freemasons trace their origins to the medieval stone masons who built the gothic cathedrals in Europe. These operative stone masons formed guilds and, over time, began to admit non-operative masons into their membership.

Freemasonry is a fraternity whose members come from all walks of life who share a common belief of the brotherhood of man under the fatherhood of God. Masons not only strive to make themselves better men by using the working tools of the operative mason to teach lessons of social and moral virtue, they also strive to help others.

Many famous men have been Freemasons. Kings, princes, potentates, captains of industry, actors, astronauts and civic leaders have been members of the fraternity. Many of our country's founding fathers were Freemasons, including our first president, George Washington.

One well known Freemason in the engineering field was John Augustus Roebling. Brother Roebling was a German born civil engineer who is perhaps most famous for building the Brooklyn Bridge. Brother Roebling is most noted for pioneering the process of manufacturing wire rope or cable. These stranded wire cables were thinner and stronger than the chain cables and hemp rope they eventually replaced. His wire cables brought about a revolution in the construction of suspension bridges. His bridges made connections which allowed for the transportation of materials and supplies across mountains and rivers that were needed for a growing country.

Brother Roebling was born in Mühlhausen, Prussia (now Germany) in 1806 and immigrated to the United States in 1831. He settled near Pittsburgh, PA, purchased some land and tried his hand at farming. But he soon discovered that he was not cut out to be a farmer and pursued his engineering profession instead, finding employment on state canal projects. He began to design and build bridges using his wire cables. He set up a shop in Saxonburg, PA to produce his wire rope, and then later moved to a bigger factory in Trenton, NJ.

Brother Roebling is also responsible for building several bridges, notably: the suspension bridge across the Niagara River; the suspension bridge across the Ohio River, from Cincinnati, OH to Covington, KY (pictured above); and the suspension wire aqueduct across the Allegheny River at Pittsburgh.

Perhaps his best known accomplishment is the design and construction of the Brooklyn Bridge (pictured to the left) which spans the East River from Brooklyn to Manhattan. It is one of the oldest suspension bridges in the United States and was the longest span in the world when opened to traffic in 1883. Unfortunately, Brother Roebling did not live to see his bridge completed. He died in 1869 after one of his feet was crushed between a barge and some pilings at the construction-site then requiring the amputation of several toes. This led to a tetanus infection (lock jaw) which caused his death. The bridge was completed by his son, Washington Roebling and his wife, Emily. A memorial was erected to his memory in Trenton, NJ near where his factory was located.

Brother Roebling's knowledge, skills and abilities have benefitted his fellow man. Just as Masonry unites men of every country, sect and opinion, so did Brother Roebling's bridges bring people together. Brother Roebling was a fine example of Masonry.

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