The Construction of Suspension Bridges in Colombia during the Nineteenth Century: Between Tradition and Innovation

Jorge Galindo Díaz
Universidad Nacional de Colombia, Bogotá, Colombia

ABSTRACT: In this presentation, we explore how the construction of bridges in Colombia during the second half of the 19th century was conducted using a mix of artisan tradition and systems from the era of industrialization. The first of these date back to Pre-Hispanic times and involve the braiding of vegetable fibers used in the construction of hanging bridges; at the same time, standardized systems were established by foreign manufacturing entities, which sold their metallic structures around the world through catalogs seeking to adapt to the most complex local conditions. Through the study of a Colombian engineer from the period and his construction work, we aim to demonstrate this condition.

INTRODUCTION

It is a known fact that the figure of the engineer as we know it today appeared with modern science during the 17th and 18th centuries. Several authors (Vérin 1993 and Picon 1988, primarily) have explained very well the way that this profession arose in Europe from the social needs of new states, which demanded the regularization of artisan practices and a search for a sort of mathematical legitimacy on which many traditional activities could be founded.

In Colombia, a similar phenomenon took place during the second half of the 19th century, characterized by the institutionalization of technology, as well as by the professional ascent of the engineer, who was placed midway between the state apparatus and private enterprise: on one side, he was subjected to the forces of the need for standardization; on the other, he faced the pressures of economic profit. The engineer’s genesis as a member of the intellectual elite and as a trade-union operative has already been studied in the local context (Safford 1976 and Obregón 1992), emphasizing the effort carried out by these new professionals within the multiple spheres of their activities.

Nevertheless, in Colombia, as in other American nations, civil engineering had some important precedents developed inside Pre-Colombian civilizations, which undoubtedly forged a tradition of artisans that would be extinguished with the passage of time, and especially given the disdain that European practices manifested toward almost everything that was not part of their civilizing mission.

The first part of this presentation will highlight some achievements related to the construction of hanging bridges on American soil by indigenous labor. The second part will address the construction of suspension bridges during the second half of the 19th century under the direction of local and foreign engineers, who were able to mix some artisan practices with innovations produced by the industrialized world.
HANGING BRIDGES IN PRE-HISPANIC AMERICA

In the vast American territories, the construction of primitive hanging bridges had an uncertain origin, making it impossible to establish its initial date. The lack of writings among Pre-Hispanic peoples and the difficulty of establishing a date for their ruins make us resort to numerous documents written by the Spanish during their conquest. The Spanish were surprised by the construction techniques and dimensions used in the development of these types of structures. For example, Jesuit priest Francisco Clavigero testifies to the existence of hanging bridges in Mexico during the 18th century:

The most peculiar bridge, among the ones used in those countries, was the one called hammock by the Spanish. It was woven with natural strands from a sort of tree that was more flexible than wicker [...] whose extremities hung from two trees from opposite banks [...] Said bridges can still be seen over rivers (Clavigero 1826, p. 352).

Another seventeenth-century author, referring to one hanging bridge built in Peru, evidenced the fear present among the Spanish when they crossed these bridges called hammocks:

The Apurímac [bridge], the longest of all, will be two hundred strides long. I did not measure it, but talking about it in Spain with a lot of people who have crossed it, many give it this length, and on some occasions they say it is longer than shorter. Many Spaniards crossed by galloping on horseback to reveal less fear (Garcilaso de La Vega 1984, p. 108).

Cases like the Apurímac Bridge are registered, even until the mid 19th century, through illustrations that have been preserved as an accompaniment to chronicles of foreign expeditions into the depths of the Andean territories, as seen in Fig. 1.

Figure 1: Vegetable-fiber bridge over the Pampas River in a chronicle from 1865; (Squier 1974)

It is easy to deduce that, on these bridges, as on bridges built centuries later, the choice of an appropriate place constituted the first step in the building process: due to the bridges’ geometric form, they had to be protected from river surges and were thus located, in most cases, where the river flow became narrow; hence, the free distance between opposite extremes was shorter.

There is proof, thanks to many stories similar to those quoted above, that the materials used in the fabrication of catenary cables were composed of braided vegetable fibers, which could make up very thick cables that were resistant to tension. These were accompanied by pieces of wood tied up together to create the floor, or used merely as anchoring wedges to increase the forces of friction that secured the stability of the extremes. It was also usual for the extremes of these ropes to be tied to large natural stone blocks.

Recent studies (González 1992) have estimated that on a hanging bridge—like those built in South America during Pre-Colombian times—turning the rope around wooden beams (as when a vessel is tied to the moorings at pier) produced a 28% reduction in the tension of the thick cable after the first turn, while turning the second beam would reduce the tension to merely 7.8%.

Also, the short life-span of the materials almost certainly demanded constant maintenance, forcing the set of ropes that made up the structure to be periodically renewed without there being a unique formula for the fabrication of the components involved, and with techniques therefore varying from one region to another.
Nevertheless, in all these regions, there was evidence of delicate hand-done work, which spanned from drying the fibers extracted from several kinds of plants to the difficult task of tying them together and, finally, to braiding them so as to achieve high resistance to tension. Given the existence of these bridges, it was possible for many of the American indigenous communities to travel a complex and vast network of pathways that crossed difficult natural obstacles. However, with the arrival of colonists, this network of pathways soon became obsolete. Besides, native inhabitants were exterminated or forced to occupy isolated geographic zones, drastically reducing their artisan and technological capacity.

Between the 16th and 19th centuries, the Spanish in the American territories would build numerous stone and brick bridges with complex and heavy arch structures that were not only costly (given the specialized workforce and the difficult-to-produce materials) but also inefficient in withstanding the strong river surges; they also could not cross distances as wide as those spanned by the Pre-Colombian hanging bridges. It would thus be necessary to wait for the advent of new metallic construction techniques, used in America in the later decades of the 19th century, in order to again see hanging bridges crossing the Andes.

**HANGING BRIDGES IN COLOMBIA (19TH CENTURY)**

From the beginning of Spanish colonization until the end of the first half of the 19th century, the construction of bridges in Colombia was developed around two structural systems: brickwork vaults and wooden lattices. The first system was widely used in the nation’s Southwest, to such a degree that between 1865 and 1895, at least 40 arch bridges were built, several of which were designed and supervised by priests and pseudo-architects from Spain, Italy, and Germany. Their broad acceptance was supported by their well-proven durability; their construction techniques and materials were not foreign to those already being used in all kinds of civil and religious construction projects by foremen and artisans in the region.

Wooden bridges were less desirable than the previous ones, but they were cheaper, and they were made in accordance with the traditions of local carpenters. For example, Colombian artisan Valentín Cadavid claimed to be the most skilled bridge builder; his typical bridge used the so-called “sistema antioqueño” and was merely a rustic wooden structure with a two-sided roof. Such structures were heavy and less durable, requiring permanent and continuous repairs that were difficult given that, at the moment when the paths were uncomfortable, the distances were long and money was scarce.

In spite of the news from Europe and North America about the new goals of engineering with reference to metallic construction, its application was seriously delayed in Colombia by the lack of raw materials; even during the second half of the 19th century, iron was still a scarce and expensive material, and hence, the structures had to be bought almost entirely from manufacturing companies in London, New York, or Bremen, among others.

The need to integrate small local economies with international markets through the construction of new roadways and maritime ports eventually pushed national enterprisers to invest effort and money in the purchase and assembly of bridges capable of crossing open distances previously unimagined in these territories. For example, the Suaza River Bridge in Tolima, conducted by engineer Eugenio Barney, achieved a span of 87.78 m in 1884, which was considered pioneering in this setting. This was followed by the bridge built by José María Villa over the Cauca River in the township of Santafé de Antioquia in 1891, which had a span close to 300 m. Although many cases could summarize the technological experience introduced in Colombia through the construction of hanging bridges throughout its geography, it is worthwhile for the purposes of illustration to explain a reduced set of individual cases that are not too far removed from the general norm experienced by the nation’s early engineers.

**CENÓN CAICEDO: A SELF-TAUGHT ENGINEER**

The role played by Cenón Caicedo (1827-1900) provides an interesting example of the prototypical figure of the Colombian engineer during the second half of the 19th century. Trained as an accountant, Caicedo worked as an administrator and treasurer in private companies; however, his mathematical knowledge helped him to teach himself the mechanical sciences, and his peers even considered him an inventor of artifacts and a “hero of progress”.

His first incursion into the field of the construction of hanging bridges took place in 1883; commissioned by the provincial government, he was to construct a bridge with a span of 34.26 m over the Palo River, which was destined to replace a former wooden structure that had been built only 4 years prior. The soundness of the construction was to be guaranteed for a 20-year period, and metallic pieces were purchased from a manufacturer in England whose name has not been established. The importance this construction had for regional interests is well expressed by the following quotation taken from an official document written at the time, also indicating the difficulties confronting Cenón Caicedo as he sought to finish the bridge within the stipulated time limits:

Bearing in mind that upon erecting an iron bridge over the Palo River, given that this is the first construction of its class in the country, the contractor has encountered some difficulties to finish construction within the due date agreed in the contract ... (ROC a).
Italian Gaspare Mazza was hired as a supervising engineer, and his report finally attested to the good quality of the construction:

The bridge being built over the Palo River is of a good type. It is notable that the details were studied by a person with expertise in the art. The iron materials were worked at the factory with the precision required. The wooden bridges I saw are also of good quality and cut with precision. The bricks are of good quality and well made and the noticeable masonry was also well made [...] By making the resistance calculation on the iron chain that supports the bridge, it was found that the iron is under minimal stress close to 4.50 Kg per square centimeter, when the bridge is without load, and under a load of 130 kilograms per square meter of surface, the stress reaches 9 K per 0.5 cm², which can be tolerable for accidental, non-permanent stress [...] The stress the vertical cables must support is lower in both cases and the bridge will be able to withstand the crossing of common vehicles (ROC b).

It is then clear, in the face of the fear and doubt raised by the new type of construction, that the mathematical analysis apparently backed the construction and its builder. Furthermore, it was common practice for these types of construction projects to be divided into two clearly differentiated activities: the construction of masonry (i.e., foundations, anchorage bases, and all kinds of accessory work), and those dealing with the assembly of the imported metallic structure.

Finally, the bridge was opened in 1884; due to the admiration that it garnered from the inhabitants of the region, engineer Caicedo would almost immediately be commissioned in the delicate task of erecting several more bridges to modernize the roadways of a region that desperately sought to transport its agricultural products (primarily true indigo and tobacco) to the port of Buenaventura on the Colombian Pacific Ocean, an intermediate point on the shipping routes between Panama and Lima.

Between 1888 and 1889, Cenón Caicedo simultaneously directed the construction of the hanging bridge over the Tuluá River, shown in Fig. 2, and the bridge over the Amaime River. Both structures had been purchased from A.S. Hallidic in San Francisco (California, USA) through local merchants who were intermediates between Colombian businessmen and foreign makers.

In 1892, Caicedo began the construction of his third project, a hanging bridge, also over the Amaime River, downstream from where the previous bridge was located. This time, the metallic structures were purchased from John Roebling’s Sons in Trenton (New Jersey, USA). The peculiarities of the construction are as follows:

The pylons, from one extreme to the other, had an extension of 5.54 m and the distance between pylons was of 2.45 m [...] The height of the towers was 5.07m excluding the seat / base of the chains; the wooden extension of the bridge was 38.95 m. The extension of the brick work is 8.44 m with a thickness of 5.55 m. The height of the bridge over the water level was 4.26 m [...] (ROC c).

Nevertheless, of all his bridges (summarized in Fig. 3), the one that crossed the Aganche River, whose construction began in 1892, received the greatest admiration, which was revealed in a special note published by an anonymous author in the Colombian engineering journal Anales de Ingeniería:

Foundation of bases of the brick work [...] The one on the right bank 3 m below the ordinary water level, over incompressible and difficult terrain with large river stones placed in horizontal layers and held together with mortar up to a height of 2 m; from that point up it was built with rocks up to a height of 3 m above the same level [...] Of the brick work: these have been raised over a base 8.40 m long by 5.80 m wide, with their
corresponding pylons, and over which were raised the walls that secured the anchorage that supports the chains up to a height of 4.45 m by 8.23 m long with a thickness of 1.56 m. In the sides facing the river and over the walls described, four towers were raised to support the saddles placed on carved quarry stones. These towers have a 1.56 m square base with a 2 m height. Iron materials: the catenary on each side is formed by thirteen steel slabs to 2.55 m long, 0.90 m wide, and 0.016 m thick, joined at their extremities by steel bolts 0.038 m in diameter, from which paired iron hangers suspend with decreasing lengths, from the brickwork to the center and a thickness diameter of 0.02 m, which support the twelve beams that hold the surface of the bridge. The weight of these materials is 3,581 kilograms (Anonymous).

The bridge was 30.48 m long, and it was located where the river flow only reached 26 m in width. And in spite of the high specifications of the bridge, what caused great interest was that the hanging structure used braided telegraph cables for the construction of the catenaries.

Due to the loss of the original steel cables during the transportation of the pieces from the port of Buenaventura to the interior of the country, only the bars for the anchorage towers and the vertical cables that joined the cables to the flow structure managed to arrive at the assembly site. In light of this situation, Caicedo decided not to request the missing parts from the manufacturers in Trenton again; instead, he opted to use several meters of telegraph cable owned by the provincial government, with the aid of indigenous artisans who manually braided the metallic strands much in the same way that they braided the fibers on their textiles, bracing them with copper rings and using them in the whole structure.

There is no certainty that Caicedo previously applied this same procedure to bridges constructed under his direction. What is clear, due to documentary evidence in this case, is that, during the late 19th century, the millenary artisan tradition partnered with industrialized systems just entering the country. There are, indeed, documents relating similar experiences during the early decades of the 20th century, which without a doubt indicate that this situation was not merely an isolated or anecdotal event.
Engineer Cenón Caicedo died in 1900, leaving at least 6 hanging bridges in operation throughout the region. His figure became a model for generations to come, until he was relegated to oblivion with the introduction of concrete structures in the early decades of the 20th century.

CONCLUSION

The brief case exposed herein allows one to identify a mix of tradition and innovation used by Colombian engineers during the advent of their profession in the second half of the 19th century. Though they desired to be part of the world of industrialized technology, limitations imposed by time and distance obliged them in many cases to make use of the artisan traditions of the inhabitants. Ancestral knowledge, proven in numerous hanging bridges built during the Pre-Colombian period, was rarely, if ever, considered cultural patrimony; generally, it was disregarded and forgotten. Nevertheless, its usefulness and efficiency emerged as necessary. The universe of the technique seemed unaware of any clear frontiers between dominant and dominated knowledge.

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