Guadua bamboo In pedestrian bridges

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Key words

Bamboo; Guadua; pedestrian bridge; ecological engineering; truss beam; arch; compression; tension; traction.

Abstract

When discussing pedestrian bridges, it is always useful to consider the latest work done in Colombia. These innovative constructions not only make it possible to cross rivers and roads, but also show how competitive this material is in ecological engineering. The spread of this type of construction throughout the country indicates that Guadua bamboo is already a part of Colombian culture, and that its fresh style is no longer associated only with poverty and social improvement projects. Furthermore, it shows that this material is a perfectly feasible option for a country such as ours, which is exposed to landslides, flooding and earthquakes.

Although pedestrian bridges were initially built to shorten distances and overcome natural barriers, during the last several decades they have also become necessary to safeguard pedestrians who have to walk in areas of very high urban growth. However, in spite of the existence of alternative solutions to the same problem, almost all such solutions are postponed, in that they normally involve a State investment.

This article addresses a construction technique which originated in South American indigenous populations. Although it was forgotten by several generations, this technique, which has been updated, has multiple benefits. By injecting concrete in bamboo internodes it is possible to build structures that are in harmony with current needs, as well as bridges with more lighting Most importantly, this makes low-impact construction accessible to small communities or private businesses with limited resources.

Figure 1. Bridge in Cúcuta, Colombia. Detail of the braces, Jörg Stamm

Introduction

The use of bamboo as construction material goes back to the times of the Incas, who created hanging bridges with advanced designs. The Páez Indians of Colombia also proved to be true masters in bridge construction, combining false arches made with Guadua bamboo with braces of the same material, kept under tension by tying them to pilings or nearby trees[2].

This indigenous knowledge continues to be available, and is applied when necessary to replace some construction elements. However, times have changed, and a new generation has begun to use it in larger and more innovative construction projects. Use of bamboo with mortar is a technique that extends construction possibilities with broader spans and greater compression loads.

This new start for *Guadua* started in Colombia after the landslide of the Páez River in 1994. This river, located in the Cauca region, destroyed everything in its path, including a bridge in Belalcázar which had been built by natives of the zone.

Damages caused to road and bridge infrastructure were so devastating that it was impossible to provide materials for reconstruction. The loss of human lives and material losses were extensive, comparable to those suffered in Cinchona and Vara Blanca from the earthquake of January 8, 2009. As the community began to face the effects of the tragedy, people started to use Guadua bamboo –still growing abundantly on hillsides in the region– to build pedestrian bridges, also stimulating the local economy.

Farmers were first and most strongly benefited, since they were then able to move on horseback and take their produce to market.

Today, roads with heavy traffic produce an unnatural isolation of nearby communities, leading to loss of access to basic services and interaction among inhabitants within a town. The high priority given to vehicular traffic is crowding citizens into more and more confined and less healthy spaces, where walking is far more dangerous and uncomfortable than moving around in a car. Children often have to walk from home to school. In urban areas they have to get across congested roads, and in rural areas they have to pass through basins and rivers, in both cases being placed at substantial risk.

Guadua bridges

The idea of building bamboo bridges is associated to the use of local materials, low-cost hand tools, few workers, and, primarily, building without environmental pollution or deforestation. In other words, it is a cost-saving ecological option, which is also educational, in that workers who learn to build with bamboo have the ability to later do so with their own resources.

There are no standard recipes for the design of this type of bridge – functional, geological, and topographic characteristics vary in each particular case.

2 Stamm, J. *Guía para la construcción de puentes en Guadua* (*A guide to the construction of Guadua bridges*). Project UTP-GTZ. Pereira, Colombia, 2001.

Figure 2. Load-bearing and railing arches. Bridge in Cúcuta, Jörg Stamm

Since bamboo is a natural material, its canes are not identical. Therefore, the material is selected and separated in groups according to diameter and length. For instance, the thickest and straightest canes are used for pilings and diagonal elements under compression. Intermediate canes are used for diagonal stays and straps. Slightly curved canes are used in arches and railings, and those that have more than two curves are used for footings or for rails of cement floors[3].

In general, Guadua canes used in bridges are long and flexible because they tend to arch upwards, and the convex curvature neutralizes the flexibility of bamboo. At the sides or ends of the bridge, Guadua canes are anchored among rocks, stones, or cement foundations. Usually, the structure consists of a group of 5-8 Guadua canes which are placed so that thick and thin ends alternate at the end of each group of canes[4].

When the design of the bridge has beams that are too long for the length of the Guadua canes, the canes have to be joined stump-to-stump[5] or tail-to-tail[6], using a longitudinal rod at the end of each cane to fasten them. This union is filled with mortar.

When a beam is made from with several rows of Guadua canes, it is necessary to align the joints between them in an overlapping manner, just as different rows of bricks are aligned in construction. To make a group of Guadua canes behave as a composite beam or arch, all the pieces must be tied together through perpendicular screws (transversally to the fiber), every 1.5-2.0 meters. This reinforcement is independent from the one made when the joint between

3 Stamm, *Guía para la construcción de puentes en Guadua* (*A guide to the construction of Guadua bridges*) Project UTP-GTZ. Pereira, Colombia, 2001

4 Available at: http://www.luguiva.net/documentos/detalle.aspx?id=72&d=6 [January 17, 2009]

5 The lowest part of a bamboo cane

6 The middle section of a bamboo cane

Guadua canes is longitudinal, but in general all internodes containing screws are filled with mortar to avoid crushing. However, this construction detail adds extra weight to the structure, and although this is the only option commonly implemented, it does not seem to be an optimal solution[7].

Figure 3. Bridges over Avenida Libertadores and Rotonda Arnulfo Briceño, Jörg Stamm

Structural design

The structural design may increase or reduce a bridge's bending. For instance, two Guadua canes placed horizontally one next to the other can bend half as much as a single cane, but if two Guadua canes are joined vertically that flexibility is reduced by half. These simple but efficiently logical concepts are the basis of the estimations to be considered in structural design.

The truss beams are the most commonly used structures in bridge construction, but their design must be carefully planned, since a great deal of the forces that produce compression and tension originate in their elements.

Overall, these structures are built with a pre-camber which generates a kind of arch which to some extent compensates for the unavoidable settling of the ribbing (Fig. 4.) It should be noted that the structure is designed to achieve a balance of forces. For instance, a crown post deflects less than a simple beam, and under the same spanning conditions such deflection may be minimized even more with a blind-type beam (simple or double) or with an arch- and blind-type beam[8].

7 Available at: http://puentemedellinregionalquindio.blogspot.com/2008/09/los-puentes-en-guadua-construidos-en.html [March 24, 2009]

8 Stamm, J. *Guía para la construcción de puentes en Guadua (A guide to the construction of Guadua bridges)* Project UTP-GTZ. Pereira, Colombia, 2001

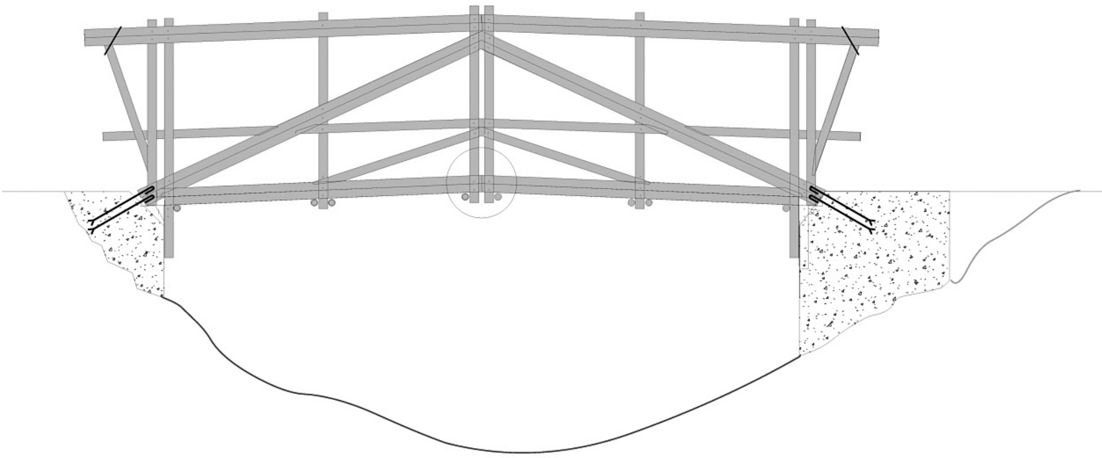

Figure 4. Front view of the Pre-camber in a Jörg Stamm bridge

A crown post is used in a simple way in small bridges and for spans of up to 20 meters which may use the crossed crown post or “Howe” truss. However, for longer bridges such as the one of the Universidad Tecnológica de Pereira (40 m) it is recommended to combine the Howe truss with a loading arch. The advantage of the truss beam is that it can be built with identical modules – for this reason a 20-meter truss beam may be built with 4.5-meter-long modules (Fig. #5)

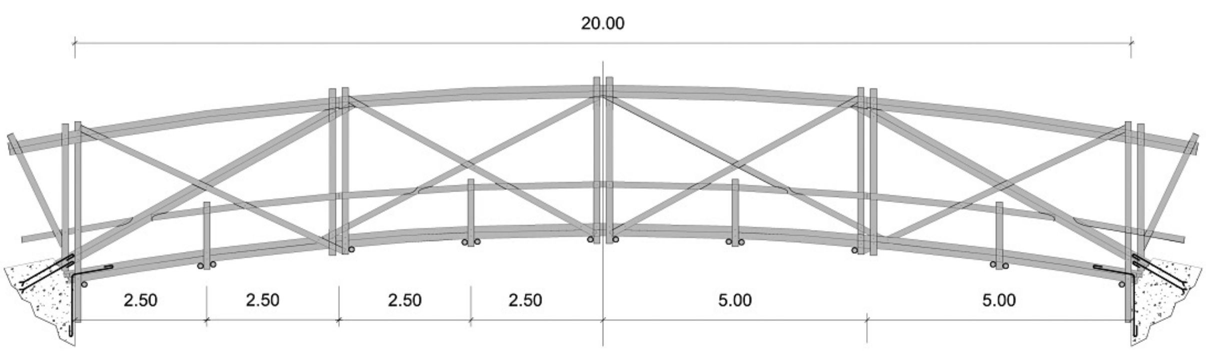

Figure 5. Crossed crown post in a Jörg Stamm bridge

The design used for building longer bridges includes truss beam modules with a load-bearing arch, which is usually made with 4-6 Guadua canes in the form of a cluster. When the arch is the main element of the structure, the compression offered by bamboo should be taken advantage of, based on the latest Colombian research which confirms its usefulness in this situation[9].

In a bamboo bridge it is common to talk about the *load-bearing arch,* the *floor arch* and the *railing arch.* All of them are commonly joined in the chamfer of the buttress. However, construction of a bridge is primarily made on the ground, sketching the heights and axes, and then preparing the composite arches for several Guadua canes. Then the diagonals are fitted into the respective

9 [on line] Available at: http://puentemedellinregionalquindio.blogspot.com/2008/09/los-puentes-en-guadua-construidos-en.html [November 23, 2008]

arches, and finally main posts and auxiliary posts are placed to control lateral sagging of the main arch. To finish, arches are installed in the form of a sandwich.

Figure 6. Exposed structure, Guadua arches and tensors, Jörg Stamm

For structural calculations the different loads interacting in a bridge must be considered, from the dead load (the weight of the structure itself) to the live load (the load of the persons, wind or an eventual earthquake.) In brief, there are live and occasional loads, the latter of which are related to the structure's dead weight, but which may at certain times affect the design of the bridge because they exert a windward (entry of wind) push (compression) and a leeward (exit of wind) suction on the structure. In bamboo bridges the permanent load not only includes the weight of the material, but also that of other elements such as cement, platens and bolts, in addition to the intermediate deck level and the cover. It should be noted that in rural zones pedestrian bridges may be used to move livestock. For this reason, a structural engineer must do the necessary calculations, because a herd may weigh more than a vehicle[10]. Such an engineer should not simply address the limits or extremes the material can stand, but should be able to calculate deformations that maintain acceptable safety – that is, with the value specified by codes for *allowable stress*.

10 Stamm, J. *Guía para la construcción de puentes en Guadua* (*A guide to the construction of Guadua bridges*) Project UTP-GTZ. Pereira, Colombia, 2001

In finishing this section we should mention that Colombia´s Seismic-Resistant Design and Construction Norms consider the design of one- and two-floor bamboo houses, but bridges are not included in any structural design norm. Therefore, research groups have been created to determine the mechanical properties of Guadua *angustifolia*. Studies have been conducted at the National University of Colombia, as well as in the departments of Quindío and Caldas, to determine resistance to the parallel compression of the fiber, its perpendicular tension, the allowable stress under different combinations of loads, and the modulus of elasticity[11].

It must always be remembered that seismically-resistant construction does not necessarily have to be rigid, but it must certainly resist shock waves that may bend it in different directions. Since it is so light, bamboo has the advantage that it moves to the pace of soil, and for this reason in Colombia it is ranked as a seismically-indifferent material –i.e, the same as being anti-seismic.

Figure 7. Arch made with 6 Guadua canes. Jörg Stamm

Cucutá Bridge, Jörg Stamm

To illustrate this article we present the latest work of bridge maker Jörg Stamm. This German, an international expert in bamboo construction who resides in Colombia, combines German woodwork with traditional techniques for building with *Guadua*. Stamm bases his design on the tensile bridges of South American Indians, on Otto Frei's membrane structures, and on Frank Gehry's architecture.

11 Takeuchi, Patricia, González, César E. [on line] Available at: http://dialnet.unirioja.es/servlet/articulo?codigo=2343080 [October 13, 2008]

But we should mostly recognize that his works entail more work than inspiration. It is his extensive experience in building bridges that has taken him so far in his journey. Stamm takes advantage of the physical characteristics of *Guadua* –especially its flexibility for the construction of geometric forms which would be very difficult to achieve with industrial materials. He has thus been able to position *Guadua* at a much more contemporaneous level in harmony with its natural beauty, as may be seen in the bridge located in Cúcuta, a city on the border with Venezuela.

This bridge has come to be considered a symbol for the population, promoting *Guadua* reforestation as a beneficial activity for Colombia.

Before the Cúcuta Bridge, Stamm built many other bridges in different parts of the world. Those at the Universidad de Pereira (40 m)[12], Tierradentro (30 m), Salvajina, the Liceo Francés (52 m), and the Green School in Bali (22 m) stand out.

Eng. Oscar Montoya took part in building the Cúcuta Bridge, while Israel Collazos was the foreman, and eight workers took only three months to finish it. During the first month they built the abutments, while the structure in Guadua was prepared during the second month, and the canvas was installed in the third month. Construction ended in September 2008, but the bridge was only inaugurated in December to allow the completion of landscaping.

The bridge was covered with canvas imported from France, whose useful life is estimated to be approximately 25 years. It is a PVC material known as Ferrari 702 which has UV protection. It is interesting to note that this material is dirt-repellent. Its usefulness goes beyond the purely functional, since its color contrasts with bamboo and provides a blend of the natural and the modern.

The technical details of this membrane were handled by Eng. Gerardo Castro, a recognized expert in the area for his works in South America[13].

Concerning the cement structure, the bridge has two abutments and a retaining wall. As for any other engineering work in conventional materials, the bridge also had to comply with basic norms of resistance and durability – i.e., it must have a useful life of at least 30 years. For this reason Eng. Herman Lehmann, who was in charge of structural calculations, tested the structure during construction with a 12-ton load. Resistance tests were carried out with water filled barrels and the results proved that the arch descended only 3 cm over the 31 meter span of the bridge. The symmetric load of 450kg/ m2 (required for pedestrian bridges) was tested in one-third of the surface, producing a deformation of 9 cm. However, both curves returned to their original form after the tests.

According to data provided by Jörg Stamm, the bridge complied with the Colombian regulation and will have the capacity to withstand a live load equal to 40 persons. Fitting trials were implemented before the test, anticipating the shredding usually produced by screw threads.

It is important to emphasize that on a structural level, the arch is the main element of this bridge. Visually speaking, it seems that bamboo cables are the ones that keep the bridge suspended, but in reality 90% of its load is absorbed by the arch, as shown by the fact that the resistance test was carried out without tension cables on the towers.

Six hundred Guadua canes from 10-14 cm in diameter and from 6-10 m long were used to build this bridge, representing the annual crop of a hectare of Guadua bamboo. The raw material was

12 Seminar-Workshop on design and construction of Guadua bridges. Available at: http://www.utp.edu.co/facultad/ambiental/guadua/html/puente.htm [April 20, 2009]

13 Available at: www.castrorojas.com [December 15, 2008]

carefully selected and protected from insect damage, using methods which are not toxic for human beings.

The approximate cost of the work in US dollars was $50,000 (in 2008) for the cement infrastructure which basically consisted of the buttressing and accesses, in addition to $50,000 for the bamboo structure, and the same amount for the membrane[14].

The bridge weighs 130 tons, and measures 31 meters between its main supports and 29 meters between auxiliary supports. The design process was based on the construction of several models until the final proposal was decided upon.

In conclusion, it is worth stressing that this work is a sample of ecological engineering where the building experience of Jörg Stamm is combined with the competiveness of constructing with *Guadua* bamboo.

Figure 8. Lateral tensor of the cover. Jörg Stamm

Conclusion

Pedestrian bridges built with bamboo not only protect and provide safety to persons that pass through them, but at the same time add the warmth and contact with nature which is so lacking in our cities.

14 Data provided by Jörg Stamm

The issue is not one of competing with other longer lasting materials, but rather with being pro-active and solving problems with the resources we have available. Let us remember that any urban infrastructure requires high investment that may take months or even years to be obtained, while bamboo may be used as a temporary, low-impact material. In times of crisis, when populations are left isolated, when damages are so considerable that Government aid takes a long time to arrive, we should think of low-cost and easy-to-build alternatives.

The information provided in this document clearly shows that over the long history of their use, bamboo bridges have proven to be highly resistant and long-lasting[15].

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