Manual Construction of a Suspension Bridge in a Developing Country: Nicaragua

Helena Turner, Ksenia Ivanova, Mike Green
CH2M Hill, UK

Contact: helena.turner@ch2m.com

Abstract

This paper discusses the technical and logistical challenges of construction of a bridge structure in a remote part of a developing country. Such challenges included delivering to a tight programme with limited use of tools and materials with the requirement to improvise and develop innovative solutions, whilst ensuring safety. Decisions are far more critical in this situation, as the cost and time for acquiring replacement tools and materials were inflated due to the poor transportation.

As well as constructability constraints, the need to have a long-life sustainable bridge was paramount. Much of the local community lacked the knowledge and skills to maintain the bridge prior to our arrival. Hence, in order for the bridge to withstand its 30-year design life with minimal intervention, team members collaborated with the local community; integrating them during construction and educating them about maintenance techniques.

Keywords: low-intrusive construction, low-intrusive maintenance, pedestrian bridge, sustainable, developing country, sustainable construction, manual construction, Nicaragua, Central America
1 Introduction

1.1 Background

It is easy to take for granted our infrastructure when living in developed countries. We have the luxury of choosing to travel by road, rail, boat or air. Unfortunately, over 900 million [1] people worldwide don’t have this basic right of uninterrupted transit routes.

This project was to construct a suspension bridge, with a span of 53m, over the river Campasagua, in Rancheria, Nicaragua. This was over a 12-day duration with a team of just 10 Engineers from one organisation, plus the assistance of the local community and technical advisors from the charity leading this initiative.

During the rainy season, the community of Rancheria was cut off from essential facilities. An example of the disruption caused is school attendance; not only were the children unable to cross the river, but additionally the teacher whom already travelled hours to the community, was also unable to cross. Alternatively if people chose to cross the high-torrent river, such as when transporting their main commodity (milk), their lives were put at risk; see Figure 1.

The bridge connected a community of 350 people to vital amenities such as schools and healthcare.

1.2 Nicaragua

Nicaragua is the largest country in Central America, with a population of nearly 6 million [2], located between Honduras and Costa Rica. It is known as the “Land of Lakes and Volcanoes”, having over 50 volcanoes [3].

With its dramatic landscape; transportation to and from rural communities can be difficult, where a significant amount of time can be spent travelling to fulfil basic needs. The World Bank States that “Physical isolation is a strong contributor to poverty. Populations without reliable access to social and economic services are poorer than those with reliable access” [4].

To illustrate this, Nicaragua has a Rural Access Index (RAI) of 28% compared to the UK which has an RAI OF 96%; see Figure 2. This means that there are over 1.6 million people in Nicaragua without access to reliable transport routes. Although there are other recognised contributory factors, for simplicity, comparing this with the Gross Net Income (GNI); in Nicaragua it is $1,870 per capita, whereas in the UK it is $43,430 per capita [5].

Of the nearly billion people worldwide that don’t have access to at least a reliable road network, approximately 300 million are without motorised access [1]. For this reason, pedestrian footbridges are a key facilitator to rural connectivity.

1.3 The Project

CH2M is a global programme management and engineering organisation with over 25,000 staff worldwide. They are fanatical about ethics and community involvement, so have a corporate funding scheme called CH2M Foundation which makes charitable donations. The CH2M Foundation works in partnership with Bridges to Prosperity (B2P), donating large sums per annum which funds two bridge construction projects.

Pedestrian footbridges are a vital catalyst for growth in areas where the main mode of transport is by foot, bike or horse; such as Rancheria. B2P have determined that through their programmes school attendance has increased by 12%, visits to healthcare facilities have increased by 18% and pedestrian/livestock traffic has increased by 100-500%. Economic benefits include an increase in the number of retail business by 15%, the number of women employed within the community increasing by 15% and a capita increase of 10-20% in just 2 years [1].

Figure 1. Photo of residents assessing swollen river
1.4 The Team

The team comprised of 10 members of CH2M from various offices around the world, including England, Scotland, United Arab Emirates, Canada and America, with additional nationalities including Spanish and Estonian. All team members were from various transportation backgrounds; from Bridge, Maritime and Pavement Engineers to Construction, Project and Safety Managers. On site, this team was supported by a Bridge Corps Fellow and Programme Manager for B2P, with construction managers and multiple members of the local community.

This is an important contributory factor to the success and challenges of the project; from understanding the same units (metric vs. imperial) to the names of tools and indeed translating work plans from English to Spanish. Understanding different cultures was important and led to many other benefits beyond that of engineering design. The CH2M team was divided into pairs who took ownership of the 5 tasks in order to instruct and guide the local community. These were:

1. Scaffolding and towers erection
2. Setting the suspension cables
3. Fabrication of the hangers and crossbeams
4. Laying the decking
5. Attaching the handrail with safety mesh

2 Design Overview

To reduce costs as well as the programme of works, standard bridge designs are used and modified for each new location based on several factors. The two key factors are:

- Height of river during a flood event (maximum bridge span)
- Topography of land (minimum freeboard)

B2P use either a suspended bridge design or a suspension bridge design. The difference between the designs in this context is that a suspended bridge is not as technically challenging to construct because it utilises a high elevation and masonry abutments (tier heights vary). The cables and decking are able to hang from this elevation; so that the bridge is in a sagging shape. This design is generally used to span a longer distance due to its relatively shorter construction duration (compared to an equivalent suspension bridge span), and can be completed by more junior teams (such as University students rather than experienced engineers). The suspension bridge is more technically challenging due to hoisting of the towers, and is used when the natural elevation is lower; it creates more lift and the decking is a hogging shape (which increases freeboard between the decking and high water level).

The bridge used for crossing the river Campasagua was a suspension bridge. This was chosen because the required span was relatively short at 53m, and
also the 7.5m steel towers were needed to provide additional lift so that the freeboard was a minimum of 3.0m from the high water line during a flood event. Furthermore, during a flood event, due to the low gradient of the river banks, the swollen river would extend to the abutments, hence the hogging deck would provide additional clearance from the high water level.

The bridge dimensions are shown within Figure 3; where the near side of the bridge is the left hand side of the diagram and the far side of the bridge (over the river) is the right hand side of the diagram. In addition to what is shown, the steel towers each weighed 933kg and there were 53 pairs of steel hangers from which the decking hung. The decking consisted of 140 deck boards at a length of 2.2m and 53 cross beams at a length of 1.2m, both with a width of 200mm and thickness of 50mm. There were a total of 6 no. suspension cables used, each with a diameter of 15mm and length of over 100m.

3 Key Challenges

Despite its shorter span, there were various challenges to successful construction. Each day presented a new challenge which the team of engineers with the help of the community had to overcome, using ingenuity to improvise and develop innovative solutions whilst ensuring there was no compromise to everyone’s safety and overall longevity of the bridge.

3.1 Safety Challenges

Like all construction projects, whilst the main goal is to create something, this can be a hollow victory if workers are injured during the process. Working in a country that is less developed posed additional safety risks. Not only were medical facilities less advanced than in our native countries, but it took 30 minutes to get to the main road via pick-up, and then an additional hour to reach the nearest hospital. This meant that injuries on this project could incur higher risk categories and consequences than if it were to be constructed where emergency medical services were available. Before the team arrived in country, they underwent safety training to anticipate hazards and mitigate the risks.

The most critical danger anticipated prior to arrival on site may have been considered to be working at a height on the scaffolding. All team members completed fall protection training as an additional health and safety course. Since community members had not undergone this training, they were restricted from working at height. During construction there were two additional hazards from working at height; the scaffolding was secure, and safe, but not as stable as desired; reaching a total of 5 levels in height. This meant that all team members had to be extra vigilant when moving on and around the scaffolding. On one occasion a thunderstorm developed, but due to the tropical climate it became heavy very quickly, so team members had to dismount from the scaffolding rapidly, and safely so as not to slip.

The biggest risk to safety throughout construction was manual handling. All team members were medically fit to participate in the build, all with varying strengths and fitness levels. Upon arrival, one of the first tasks was to lift the nearly 1-tonne

3.1 Safety Challenges

Like all construction projects, whilst the main goal is to create something, this can be a hollow victory if workers are injured during the process. Working in a country that is less developed posed additional safety risks. Not only were medical facilities less advanced than in our native countries, but it took 30 minutes to get to the main road via pick-up, and then an additional hour to reach the nearest hospital. This meant that injuries on this project could incur higher risk categories and consequences than if it were to be constructed where emergency medical services were available. Before the team arrived in country, they underwent safety training to anticipate hazards and mitigate the risks.

The most critical danger anticipated prior to arrival on site may have been considered to be working at a height on the scaffolding. All team members completed fall protection training as an additional health and safety course. Since community members had not undergone this training, they were restricted from working at height. During construction there were two additional hazards from working at height; the scaffolding was secure, and safe, but not as stable as desired; reaching a total of 5 levels in height. This meant that all team members had to be extra vigilant when moving on and around the scaffolding. On one occasion a thunderstorm developed, but due to the tropical climate it became heavy very quickly, so team members had to dismount from the scaffolding rapidly, and safely so as not to slip.

The biggest risk to safety throughout construction was manual handling. All team members were medically fit to participate in the build, all with varying strengths and fitness levels. Upon arrival, one of the first tasks was to lift the nearly 1-tonne

Figure 3. Bridge Dimensions
steel towers up onto the abutments and scaffold bracing by only using ropes; see Figure 4. Injuries can occur from improper bending or twisting. This was apparent with every task; from lifting the heavy deck boards to transporting the generator to carrying the cable drums. This was further exaggerated when working on the towers, as pulley systems were used to winch up materials and tools, but the team were cautious not to over stretch and either injure themselves or loose balance and cause them or something to fall.

The final most critical hazard was the climate; Nicaragua is typically between 22°C and 30°C throughout the year [6]. Since the constriction took place over a 12-day period, both the team and community were fatigued, which combined with high temperatures meant that on several occasions team members had to take time out due to physical exhaustion.

The hangers were each a different length, which meant it was essential that they were labelled robustly in order to be assembled in the correct order. The length of rebar was delivered with a maximum length of 6m (due to manufacturing and transportation methods), so for 12 no. of the hangers (for each side of the bridge), two rebars were required to make up one hanger. Each hanger was bent at the top and bottom in order to slide and remain secure on the cable in order to support the crossbeams. This was repetitive work with a total of 720 bends, as calculated by equation (1), which required the use of a hand-made jig. The steel rebar was skilfully bent by hand. An experienced B2P construction manager solely performed this task, as great strength and accuracy was needed to ensure the angles were correct enabling the decking to hang plumb.

The lack of mechanical aids meant that all construction was completed manually. The towers were erected using a winch, and nearby trees as an anchor. Choices such as using battery power versus generator had to be made. Tools didn’t necessarily have adequate power to perform the

![Figure 4. Photo of steel tower manual lifting](image)
task in hand (such as using a battery powered circular saw to cut the hardwood decking); however only one generator was available on site which needed to be managed effectively.

3.3 Programme Challenges

The team members were only in country for 14-days, which meant that construction had to take place during this time. The community, although mostly unskilled, were incredibly helpful and absolutely vital, and the bridge construction would have been a difficult task with just B2P members. The sequencing of the works was critical to success. For this reason, each task had two leads from CH2M who would understand their role and instruct others (either available other staff or the community). This meant that task owners would drive completion and raise issues to the attention of the Project Manager as early as possible.

An example of effective sequencing was sharing the generator between tasks, which would mean that tasks could progress concurrently with all team and community members utilised, instead of in series.

3.4 Design Challenges

As well as sequencing, flexibility of design was necessary. When securing the decking to the crossbeams, designs stated that there should be a total of 6 no. bolts used to secure the wood; this was modified to 5 no. bolts (with just one in the middle) as otherwise more than 800 bolts would have been needed. To save time with the programme, holes in which to set the bolts flush to the decking was purposely not completed. The correct drill bit was not available and could not be sought in an appropriate timeframe. Additionally, the slightly-raised bolt heads give an additional advantage of traction for the community during rainfall when the decking surface would become slippery. This decision was based on B2P experience from other construction projects.

There were some critical tasks of construction which would determine the quality or successful outcome of subsequent stages. Cutting the pull-cable (used to secure hanger and crossbeam assembly, which ran along main cable) correctly was a decision which was discussed and agreed with the Project Manager. The length of cable required was calculated using the dimensions as shown in Figure 3 and the Hanger Schedule (an extract is shown in Figure 6), which showed a total length of 54.145m; see Equation (2).

\[
\begin{align*}
nearside\; cable &= 18.309m + 54.145m + x \\
\text{farside}\; cable &= 54.145m + 21.906m + x \\
\text{where } x &= \text{extra length for handling}
\end{align*}
\]

The reason that this decision was made by the group and then approved was because additional cable was required to secure the scaffolding. Even though there was adequate cable for the construction, an “x” value which was too short could make handling difficult, whereas an “x” value too long would mean that more cable would need to be sought for securing the scaffolding. This was not a viable option as the new cable could take several weeks to source and be delivered.

Another crucial moment which would determine the outcome of final quality included setting the cable sag using the level. The hoisting sag must be higher than the design sag to ensure that the height of freeboard is not lower than its minimum

<table>
<thead>
<tr>
<th>No.</th>
<th>Overall H (mm)</th>
<th>Type 2 H (mm)</th>
<th>Type 1 H (mm)</th>
<th>Type 2 Cut Length (mm)</th>
<th>Type 1 Cut Length (mm)</th>
<th>Spacing Along Pull Cable Measured from Left Tower (mm)</th>
<th>Distance from Left Tower (mm)</th>
<th>Spacing Along Pull Cable Measured from Right Tower (mm)</th>
<th>Distance from Right Tower (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>N/A</td>
<td>5320</td>
<td>2343</td>
<td>6000</td>
<td>3123</td>
<td>531</td>
<td>531</td>
<td>1059</td>
<td>531</td>
</tr>
<tr>
<td>2</td>
<td>7715</td>
<td>5320</td>
<td>1855</td>
<td>6000</td>
<td>2035</td>
<td>1059</td>
<td>1591</td>
<td>1055</td>
<td>52554</td>
</tr>
<tr>
<td>3</td>
<td>6707</td>
<td>5320</td>
<td>1387</td>
<td>6000</td>
<td>2157</td>
<td>1055</td>
<td>2646</td>
<td>1051</td>
<td>51499</td>
</tr>
<tr>
<td>4</td>
<td>6256</td>
<td>5258</td>
<td>1000</td>
<td>5938</td>
<td>1780</td>
<td>1051</td>
<td>3697</td>
<td>1047</td>
<td>50449</td>
</tr>
<tr>
<td>5</td>
<td>5828</td>
<td>4928</td>
<td>1000</td>
<td>5096</td>
<td>1780</td>
<td>1047</td>
<td>4743</td>
<td>1043</td>
<td>49402</td>
</tr>
<tr>
<td>6</td>
<td>5417</td>
<td>4417</td>
<td>1000</td>
<td>5097</td>
<td>1780</td>
<td>1043</td>
<td>5786</td>
<td>1039</td>
<td>48390</td>
</tr>
<tr>
<td>7</td>
<td>5026</td>
<td>5026</td>
<td>5026</td>
<td>1039</td>
<td>6625</td>
<td>1035</td>
<td>47221</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>4654</td>
<td>4654</td>
<td>5434</td>
<td>1035</td>
<td>7860</td>
<td>1032</td>
<td>46286</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure 6. Extract of the Hanger Schedule*
value, once loaded. Furthermore, if this wasn’t done correctly, the bridge decking could be laid at an angle if the sag is different for each side of the tower.

Pulling the cables to extend the hangers and crossbeams to their design position was also vital. Each crossbeam was a set distance apart from one another, as shown by the Hanger Schedule (see Figure 6). Although a relatively simple task, if measured incorrectly the decking wouldn’t meet properly; it may be too short or overlap at joints. The Hanger Schedule shows that the distances between the crossbeams were measured to the millimetre, however the only available marker was too thick to be this accurate. This was another example of how the design had the ability to flex; it was created accurately but had enough design manoeuvrability to allow for variations in the size of decking (which was a common issue throughout B2P projects, worldwide).

Previous experience had shown that for another similar project, the bridge did not meet in the middle, as the hangers were not spaced to the schedule or initial setting out points were not established correctly. To prevent this happening, an extra location was marked out, but was not intended to be used. There was miscommunication between the team on the ground and team on the towers, and so all the hangers were hung one position out of place. Due to the curvature of the completed decking, the crossbeams were spaced at more than 1m along the cable, however because the difference became minimal towards the centre of the bridge (Figure 6 shows the spacing decreasing as the hanger number increases towards the centre of the bridge), and also because the design allowed for flexibility; there was no impact on the overall construction. To fix this, the cable was pulled to compensate for the extra cable length, and the decking tolerances allowed for adjustment.

4 Discussion
The outcome of the bridge construction was that it was a success; see Figure 7. It was completed on schedule, with no major injuries and there were no design compromises that resulted in reducing the design life or increasing maintenance.

4.1 Evolving Design
The B2P advisors on site feed back lessons learnt to the head office enabling evolution of design. It improves planning so that if certain materials and tools are difficult to source, either an alternative solution is used as a contingency, or the design/task is simplified. Construction efficiency is improved by making tasks leaner in such a way that the risk of error (and thus wastage of materials/time) is diminished. This in turn improves health and safety, as tasks aren’t rushed and advanced planning gives time to visualise the task in hand; possibly determining a better way to transport tools and realising the next stage of construction (e.g. assembling the scaffolding on the ground to ensure it fits before attempting to do so at height).

4.2 Sustainable Construction
The bridge was sourced from sustainable and local materials wherever possible; the cables and steel towers were and donated from a Port Authority in Virginia (repurposing materials that otherwise would have been scrapped), and the wood was cut from a nearby sustainable source.

The completed bridge was designed to be low maintenance; the hand rail safety mesh was expected to require periodic replacement, but the remaining bridge elements were expected to withstand a 30 year design life.

These qualities ensured the entire bridge lifecycle was sustainable and was low-intrusive construction and maintenance.
4.3 Maintenance Legacy

There will also be a lasting legacy for the community. They have been taught, through shadowing the team, how to construct the bridge and how to maintain the bridge. These skills will ensure longevity of the bridge and thus enable it to be used for future generations, as well as add value to the community members by providing them with skills which make them more employable.

5 Conclusion

In many instances, because the community, and indeed the team members, had not been involved in such a project before, understanding the constructability of the design was a constant challenge. Through working together (see Figure 8), and utilising the different skills of the team, innovative solutions were found.

Added benefits to all of those involved was the ability to practise and enhance communication skills; from the community having their first contact with those from abroad, to the team members working on explaining tasks simply ensuring they were understood. In addition, the female engineer’s discovered that they had inspired the female members of the community by showing them new ways of making a living.

The community of 350 people in Rancheria are already realising the benefits of the completed bridge which B2P has observed following the construction of the pedestrian footbridge.

6 Acknowledgements

Thanks to the funding and organisation provided by the CH2M Hill Foundation, led by Tessa Anderson and Ellen Sanderberg. Thanks to B2P for the design and leadership in country; Alex McNeill, Lionel Suárez, Robyn Chaconas, Brandon Johnson Katie Lovvorn and Esteban Palma. The bridge would not have been constructed without the CH2M Volunteer Team; Javier Escandón, Tim McCarthy, Owen Salava, Kenny MacFadyen, Helena Turner, Nathan Murdoch, Ksenia Ivanova, Marlon Smoker, Mohammed Ismail and Candice Hein. Special thanks goes to the entire community of Rancheria and drivers Raoul and Ramone.

7 References

[1] Bang A. Bridges to Prosperity, Pathway to Human Progress. Denver, August 2015


