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Historic Bridge Restoration

Puerto Rico Project Center

An Interdisciplinary Qualifying Project
Submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
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Degree of Bachelor Science

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Abstract

This proposal, prepared for Para La Naturaleza in Puerto Rico, describes the design recommendations for their historic bridge structures. These historic bridges are located at Hacienda La Esperanza in Manatí, Puerto Rico. The WPI project team utilized literature reviews, on-site assessments, and SolidWorks to create new bridge designs, develop a cost-benefit analysis with differing choices in materials for each of the historic bridges, and designed informational signs that would be placed around the bridges.

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Executive Summary

Background

In 1968, Puerto Rico began to undergo an industrialization period that would modernize the economy. This movement posed a threat of urbanization, which meant that many of Puerto Rico's ecosystems would be destroyed (*Conservation Trust of Puerto Rico*, 2016). This growing concern to protect the island's lands led to the formation of numerous conservation groups throughout Puerto Rico. These groups include the Departamento de Recursos Naturales y Ambientales (DRNA), Fideicomiso de Conservacion de Puerto Rico (Conservation Trust of Puerto Rico), and Para La Naturaleza. In addition to the imposing threat of deforestation, the environment was already lacking preservation. As of 2015, only 16% of Puerto Rico's lands were conserved (Para La Naturaleza, n.d.). Para La Naturaleza acts as a subsidiary of the Conservation Trust of Puerto Rico and puts an emphasis on preserving the island's natural environment. Their objective from the Conservation Trust is to protect 33% of the island's land by 2033 (*Who are we?*, 2016).

Hacienda La Esperanza is an area located in Manatí, Puerto Rico and is protected by Para La Naturaleza. This land was bought in 1975 by the Conservation Trust of Puerto Rico to protect the land (Gwenn, 2016). Through their numerous conservation efforts throughout the years, Para La Naturaleza has successfully restored the steam sugar mill, the drying house, and the Marquez manor house. Their next move is to conserve two of the historic bridges that are located on-site. In order to create designs for the bridges we created a restoration plan.

Methodology

In order to successfully create a full restoration plan for Para La Naturaleza our team carried out the following objectives:

- Gained an understanding of the current state of the bridges
- Determined potential designs for the bridges
- Determined the cost of the bridge designs and the different possible materials
- Developed informational signs for the community and tourists

To achieve these objectives our methods consisted of conducting an initial assessment of the structural integrity of the bridges through observation and field measurements. We then utilized a computer-aided design (CAD) program to create and run simulations on potential designs. We also created Excel spreadsheets to conduct a cost-benefit analysis of potential materials for construction. Finally, we designed informational signs to go on site to educate the community.

We needed to gain a clear understanding of the current state of the bridges, which was done by conducting visual assessments. Our assessments included measurements of all parts of the pre-existing structures; for example, the height of the abutments off of the water and the span of each individual part.

Once the assessments were finished, we were able to research different bridge design options. Based on our research, we were able to develop two different bridge concepts for the María Hernández Bridge and four for La Boquilla Bridge. Utilizing CAD software, we designed bridges that included the proper materials and dimensions. To ensure that our designs were realistic, we conducted interviews with Para La Naturaleza employees, force simulations, and a material cost analysis. These methods allowed us to create the best restoration plan for Para La Naturaleza to utilize our proposal recommendations.

Finally, we conducted research on how to present information in order to educate the community and tourists on the history of the bridges. We analyzed educational signs throughout popular historic sites in Puerto Rico to determine the most effective way to convey information. We coupled our research with interviews with Para La Naturaleza to ensure that our sign designs fit well within the company's desired aesthetics.

Solutions and Recommendations:

María Hernández Final Bridge Design:

The Final Bridge Design consists of a flat slab connected by two ramps that go directly over the pre-existing bridge. Four flagpoles were strategically placed at each corner of the concrete slab. These flagpoles were placed where the slabs connected to each ramp to assist tractor operators with their line of sight. The materials used for the construction of the new bridge include steel rebar and concrete.

María Hernández Final Restoration Plan:

The Restoration Plan was split between going through a company named Cintec or another local restoration professional. Cintec’s method of restoring bridges fit the needs of Para La Naturaleza by keeping the original bridge structurally sound. Our investigation showed that the cost of this type of restoration would most likely outweigh the cost of having a local company come in to assess the bridge.

María Hernández Recommendation:

Our final recommendation for the María Hernández Bridge is to build over the pre-existing structure using the Final Bridge Design proposed. This eliminates all forces from acting upon the older bridge and still allows restoration of the historic bridge if need be. This option is also less expensive than the restoration method.

La Boquilla Bridge Design 1:

This design involved constructing the bridge with steel plates on top of resurfaced abutments. These plates serve as protection between the bridge and the abutments in order to improve the bridge's longevity. Furthermore, 4"x4" pylons would be connected to the bridge and extend to the bottom of La Boquilla River. These serve as points to connect handrails and provide increased strength for the bridge.

La Boquilla Bridge Design 2:

This bridge design also utilized steel plates to create separation between the bridge and the abutments, but it does not utilize pylons that go into the ground. Instead, the pylons on this design solely extend upwards to allow the handrails to connect to them.

La Boquilla Bridge Design 3:

Unlike the first two designs, this design would utilize steel H-beams instead of steel plates which would raise the bridge up higher and further from the water. This would decrease any potential water damage done to the bridge. This design also included the 4"x4" pylons that extend into the ground for added support.

La Boquilla Bridge Design 4:

This design did not include the 4"x4" pylons that go into the ground, but did include the steel H-beams on the resurfaced abutments. This design is the cheapest of the four, but was not as structurally stable as Design 3.

La Boquilla Bridge Recommendation:

For our recommendation, we suggest using Design 3. This design has the best balance of both price and structural stability. It also satisfies all of Para La Naturaleza's requirements and will be able to withstand numerous uses and large loads.

Material Recommendation:

While designing our bridges we conducted research on different types of materials and how they would perform in the locations of each bridge. During this research, we looked for a balance of durability, cost, and feasibility.

María Hernández

For the María Hernández Bridge, our design utilized construction grade concrete and ½ inch steel rebar. The concrete was chosen because of its large supply on the island and cheap production cost. The steel rebar was chosen due to its low cost and ability to improve the strength of concrete.

La Boquilla

Our recommendation of building materials for La Boquilla Bridge is to use Pine or Cedar. Pine was recommended because it is inexpensive and can be strengthened with pressure treatment. Cedar was included because it is durable in wet environments and is long lasting. Another material we presented as an option was a combination of conventional wood for the structural parts of the bridge and composite wood (Trex Decking) for the decking. This composite wood is extremely long lasting and needs little maintenance.

Another building material we had to pick for La Boquilla Bridge was the specific type of spacer to be used. We recommend the use of steel H-beams since it is the most cost effective option and did not compromise structural integrity.

Authorship Pages

Contribution Page

Harry Chartoff was responsible for making all models, simulations, professional drawings, videos, and step by step builds for La Boquilla Bridge. He was able to accomplish this by utilizing SolidWorks.

Steven D'Agostino was responsible for making all models, simulations, professional drawings, videos, and step by step builds for the María Hernández Bridge. He was able to accomplish this by utilizing SolidWorks.

Margaret LaRoche was responsible for all informational sign research and design. She accomplished this by compiling and analyzing all informational signs. She developed the potential informational sign models for both the María Hernández and Boquilla Bridge.

Travis Rossen utilized Microsoft Excel to create the material cost spreadsheet. He developed a video to further explain the interactive spreadsheet and created step-by-step instructions for future use of the spreadsheet.

Table of Contents

Table of Figures

Table of Tables

1.0 Introduction

A community is more than just “a group of people who live in the same place” (Merriam-Webster, 2016). A community is composed of the public, their surrounding environment, and the history that they share. It is the responsibility of the community members to maintain the historic aspects of the area in which they live. Hacienda La Esperanza, a nature reserve in Puerto Rico, is visited by numerous people and workers on a daily basis. The historic bridges on site remain unsafe and in disrepair, despite the constant traffic of people that travel throughout the area. This impedance detracts from the overall experience and enjoyment that the plantation has to offer.

To solve this issue, Para La Naturaleza, a conservation-focused organization located in Puerto Rico, plans to improve accessibility throughout Hacienda La Esperanza. Due to the recent urbanization of Puerto Rico, a movement has developed to conserve the environment, protect any original and historical structures, and create a greater appreciation for historic sites (*Conservation Trust of Puerto Rico,* 2016).

In 2013, crews in Puerto Rico restored a 108 year old bridge in Manatí. The bridge linked Manatí to the rest of the island, but had been closed due to unsafe conditions. Once fully restored, the bridge reconnected the community and provided a safe and efficient route into Manatí (Staff, 2013). The restoration of this bridge reveals that enhancing accessibility within a community can create a relationship between the public and the environment.

At Hacienda La Esperanza, Para La Naturaleza already showed a commitment to improve the knowledge of the community in regards to the history of the land. A project conducted by a team from Worcester Polytechnic Institute demonstrated the need for educational exhibits to enhance this relationship. They worked to restore the sugar mill, one of the more prominent structures of Hacienda La Esperanza (Bumila, Gifford, Lovett, & Portera, 2013). Informational signs created by the team were suggested in order to create a greater appreciation and understanding for the history of the site and mill.

The history of Hacienda La Esperanza and the presence of the deteriorated bridges established the purpose for our project. One of the bridges, which is used by both agricultural and official vehicles, is known as the María Hernández Bridge and is currently in disrepair. The other bridge, commonly used by pedestrians and cyclists, is known as La Boquilla Bridge. It is currently pieced together by wooden planks that have been placed over the old concrete pillars on which the bridge was originally constructed. Both bridges required analysis of their structural integrity before any designs could be initiated. New designs were created for both structures while keeping in mind environmental and safety concerns.

The goal of this project was to develop designs for both the María Hernández and La Boquilla Bridge, while utilizing the pre-existing historic structures to ensure public safety and minimize ecological impact. An evaluation of the sites where the bridges are located was conducted to develop different designs for the two bridges. A secondary goal of this project was to provide Para La Naturaleza with plans for informational signs for the bridges and conduct a cost-benefit analysis. From these efforts, Para La Naturaleza will have cost effective designs that, if built, will allow visitors and locals of Hacienda La Esperanza to access the estate and its rich cultural history with ease.

2.0 Background

In this chapter, the importance and history of conservation will be addressed. Next, the codes and regulations that Puerto Rico has set forth for construction will be explained to ensure that the plan fits within necessary building guidelines. Once the regulations have been explained, organizations that are typically involved in restorations will be discussed to allow this project to reflect on their past achievements. This will include a description of Para La Naturaleza, the sponsor of this project. Lastly, the current state of the bridges and any historical facts that may be relevant to the project will be described.

2.1 Importance of Historic Conservation

Throughout history, and especially in recent decades, historical preservation and restoration have been something of importance to many people. Both preservation and restoration represent periods of struggle and want, as well as periods of excess and prosperity. From buildings to monuments to bridges, these structures all hold stories from the time of their construction and use. According to The Washington Trust for Historic Conservation, "Historic preservation is the visual and tangible conservation of cultural identity" (Staff, W. 2016). They also make the point that there are economic advantages to preservation as well as emotional. These advantages include: tourism, art, festivals, and other activities which in turn draw investment, revenue, and economic growth. Conservationists have realized this and for years have set out to save these structures and ensure their future (Archivolti, 2014). An example of this can be seen with the Hacienda La Esperanza sugar mill. This sugar mill had been left to rust, but with the efforts of Para La Naturaleza and WPI students, they were able to create a plan to fully restore the mill and create educational exhibits to surround it. This allowed ordinary people who wished to know more about the island's history to get a better understanding of the sugar mill and the sugar making process (Bumila et al., 2013). It also brought more revenue to the organization through increased tourism. More information about the history of the sugar mill can be found in Section 2.4.1.

2.1.1 History of Historic Conservation

Until recent decades, restoration efforts in the U.S. failed to do much for the historic structures our country once cherished. When the government could not fund facilities anymore, or when large companies and businesses shut their doors, structures were left to rust, decay, and break apart. The buildings and structures would often remain abandoned until another company would come along and knock down what was left rather than work with the existing historic structures. However, small efforts started to be made in 1933. Programs, such as the Historic American Buildings Survey, began to map out important historic structures dating to pre-Columbian times (Historic American Buildings Survey, 2016). The next big push for preservation came in 1949 with the U.S. National Trust for Historic Preservation. Their mission statement declares that they will provide "leadership, education, advocacy, and resources to save America's diverse historic places and revitalize our communities" (National Trust 2, 2016). As preservation became a more prevalent issue to the people, the government itself took a stronger interest in the saving of historic buildings and structures.

In 1966, the Department of the Interior acquired a number of preservation projects to save multiple historic buildings that were set for demolition (Services 1, 2016). To address this growing issue, the department created specialized treatments for different historic structures and their uses. These methods include preservation, rehabilitation, restoration, and reconstruction. Since then, there have been a number of other laws that have gone into effect which include, The Archaeological and Historic Preservation Act of 1974, Archaeological Resources Protection Act of 1979, as well as numerous other state-enforced laws (Historic Preservation Laws & Codes, 2015).

2.1.2 Types of Historic Conservation

Preservation focuses most efforts on maintaining and repairing existing historic structures to save their current state, showing its changes throughout time (Services 1, 2016). This tactic is often used to preserve ruins or other places where modifications were made throughout different eras. One example of preservation is the Vida Shaw Swing Bridge in Iberia Parish, Louisiana. The bridge was petitioned and successfully added to the National Register of Historic Places which was added to receive funds for its maintenance and prevent its imminent destruction (Henderson, 2016).

Subsequently, rehabilitation takes place to reuse pre-existing historic structures. With rehabilitation, modifications or additions are allowed; however, the main historical features of the original structure must remain. This method is generally used in settings, such as industrial buildings, where they are renovated for apartments or office spaces. An example of rehabilitation is the Bridge of Flowers in Shelburne Falls, Massachusetts which was built originally in 1901 as a trolley bridge. In 1927 the bridge became abandoned after the trolley company went bankrupt, and in 1928 the idea to create a garden on the bridge was presented. By 1929 there was a fully functioning garden on the structure that survives to this day (Parmett, 2016).

Restoration is the act of taking a worn down building or structure and bringing it back to its original state (Services 1, 2016). To properly restore a structure with historical accuracy, there is often a need to obtain similar materials that were used in the initial construction. For buildings of greater importance, restoration is the ideal method for historic conservation. An example of this is The Longfellow Bridge in Boston. This bridge has been under restoration for years to bring it back to its original state (Roush, 2016).

In addition to restoration, when a structure has been removed or completely destroyed and people wish to see it again, reconstruction is utilized. With reconstruction, a historically accurate structure is built at a location where the previous structure has vanished or diminished throughout time. Generally, this is the chosen method when evidence of the lost structure is found and the construction will not affect the other aspects of the property. The Turkish Bridge Stari Most is a good example of reconstruction. In 1993, the 427 year old bridge was destroyed in the Croat–Bosniak War, and through efforts of The United Nations Educational, Scientific, and Cultural Organization, was completely rebuilt to exact historical specifications in the same location (Staff, U, 2016).

2.1.3 Ecological Conservation

Often times with conservation efforts, the surrounding environment is a very serious concern. This concern usually arises when the area surrounding a job site is protected as a wildlife preserve or watershed. These areas are often threatened when work is done near them.

Throughout the decades, they have been destroyed with inappropriate fire regimes, invasive species, climate change, water diversion, pollution, and urban development (Staff. D, 2016). This is why when doing conservation work, it is extremely important to follow all rules and regulations that apply to the specific area. These regulations may impact the alteration or removal of certain trees, the types of construction equipment that may be used, or the type of materials that are planned to be used in the build (Staff. EPA, 1996). For each of the conservation types, it is important to understand what factors pertain to each specific project. For instance, with rehabilitation there may be hazardous materials in the structure you are removing, such as lead or asbestos, and it's crucial to inhibit the release of these materials into the ecosystem (Staff. EPA, 2015). With reconstruction there may be certain equipment that cannot reach the worksite without alterations to certain roads or existing paths. Issues that must be dealt with include possible leaks in equipment and any emissions that the equipment puts out (Plataforma 2009). An example of what happens when regulations are not followed can be seen with the Gulf Oil Spill of 2010. In this instance, the right materials were not used in the initial construction of the oil rig, which led to its explosion, sinking, and the resulting ecological damage (Pallardy, R. 2016).

2.1.4 Timeline and Cost of Conservation

Timelines to complete projects can often become elongated due to the strict guidelines that conservation organizations enforce. Generally, specialists are brought in to assess the current status due to lack of knowledge by modern contractors (Jacobson, 2001). There are many factors to consider when establishing a timeline for conservation. For example, with bridge reconstruction, the current condition of the materials originally used must be considered. The primary assessment of the materials' condition will determine the next steps taken in the reconstruction process. If the condition of the materials are lacking, the existing structure may be difficult to strengthen without removal of the pieces. Other factors to consider before creating a timeline for the project include bridge dimensions, weather and environmental conditions in the area, and the accessibility of equipment and materials (Lewis 2016).

Restorations can take anywhere from a few weeks to a number of years. The construction of the Longfellow Bridge in Boston compared to the restoration of two bridges by Wisconsin Central Railroad exemplifies this variation. The Longfellow Bridge required the replacement of thousands of original rivets. The restoration that started in 2008 has yet to be completed because the rivets are being replaced in the same manner as they were in the original construction (Roush, 2016). While this project has taken over 8 years, the restoration of the railroad bridges in Wisconsin took only three weeks. The concrete bridges were on an abandoned service line and were restored to their original state ahead of schedule (*Railway track and structures: RT & S*., 1953).

While there are multiple factors affecting the timeline of these restoration projects, they also have direct impact on the costs. An example of this can be seen in the restoration of the Mata de Platano Bridge in Ciales. The restoration of this metal bridge required the removal of all the original paint, which resulted in an estimated cost of $3.3 million (Staff, C., 2016). Another example of bridge restoration can be seen in the proposal to keep the "iconic span" of the George Washington Bridge intact. The project will consist of replacing over 590 vertical cables, while also replacing 26,000 wires in each of the main support cables in the suspender ropes. The project is expected to be completed by 2024 and is estimated to cost nearly $2 billion (Bridge Restoration, 2016).

2.2 Puerto Rico's Construction Codes and Regulations

In order to undergo a construction project in Puerto Rico, there are certain rules and regulations that one must follow. It is necessary to obtain the proper construction permits, which are regulated by the Commonwealth of Puerto Rico Administration of Permits and Regulations (ARPE) (*National Pollutant Discharge Elimination System (NPDES) phase II, regulated small municipal separate storm sewer systems (MS4)*, 2008, pg. 8*)*. In order to obtain these permits, it is necessary to file applications that do the following:

1. Identify and describe the work to be covered by the permit for which [the] application is made.
2. Describe the land on which the proposed work is to be done.
3. Indicate the use for which the proposed work is intended.
4. Be accompanied by construction documents.
5. State the valuation of the proposed work.
6. Be signed by the applicant, or the applicant's authorized agent.
7. Give such other data and information as required by the "*Reglamento Conjunto de Puerto Rico*." (Faneytt, Rivera, & Fortuño, 2010, pg. 22)

In addition, there are evaluations that will have to be performed by a representative of certain agencies. The agencies that need to be contacted depends upon the type of construction job. For example, a representative from the Puerto Rico Department of Natural and

Environmental Resources might need to evaluate the construction area in order to determine it will not suffer any permanent ecological damage. These agencies can all be contacted through the Office of Permits Management (OGPe) (*Dealing with construction permits in Puerto Rico (U.S.)*, 2016). It is also necessary to hire an Authorized Professional and Inspector for fire recommendations & prevention and environmental health certificates (*Dealing with construction permits in Puerto Rico (U.S.)*, 2016).

There are certain regulations that pertain specifically to footbridges. These include the need for handrails "unless an analysis (design warrant) shows that the risk of falling off the bridge is minimal or the trail itself presents a higher risk" (Hesselbarth, Vachowski, & Fortuño, pg. 96). These handrails are required to be "at least 42 inches high for pedestrian traffic and at least 54 inches high for bicycle or equestrian traffic" (Groenier, pg. 5). In addition, all trail bridges require there to be a curb on the edges of the bridge for safety precautions (Hesselbarth et Al., pg. 96). It is important that footbridges must also be able to withstand a minimum live load of 90 pounds-force per square feet unless otherwise specified in the construction plans (*Standard specifications for construction of trails and trail bridges on Forest Service projects*, pg. 128). These design properties are all very important in order to ensure the safety of the individuals who use the bridges.

Once all required officials have properly examined the site and all of the applications have been filled out, it will be possible to obtain a construction permit from the ARPE. Finally, after the building is complete, the OGPe needs to inspect the final structure, and a licensed engineer or architect needs to ensure that the building meets all of the proper regulations and specified permit outlines (*Dealing with construction permits in Puerto Rico (U.S.)*, 2016).

2.3 Restoration Groups in Puerto Rico

In Puerto Rico, many groups exist to preserve the natural beauty of the island as well as any structures that hold historical significance. Together, these groups work to maintain the current state of these structures to create an increased appreciation and understanding for the preservation of historic structures and land.

Punta Ballena is a region of a protected natural area that is managed by the Departamento de Recursos Naturales y Ambientales (DRNA). The Department operates under a mission statement of "Protecting, conserving and managing natural and environmental resources of Puerto Rico and all islands and islets that surround it" (DRNA, 2016). To carry out this mission, they work collaboratively with other organizations in an attempt to preserve and restore the island. They work with organizations such as Roosevelt Roads, a company that preserves economic and social growth in the eastern region of the island. Recently, the DRNA also partnered with Para La Naturaleza to form a three-way alliance with Roosevelt Roads in an effort to establish a visitor center at Roosevelt Road's Naval Station (Comillas, 2016). The collaboration between the groups created an innovative way to educate society of the natural ecosystems of the island. Through their efforts to educate the community of their surroundings, the groups also created an increased interest in land conservation and environmental protection.

In 2013, the DRNA was contacted by the National Trust of Historic Preservation to assist in their restoration of the Antiguo Acueducto del Río Piedras (*About us,* 2016). The Trust took on this project due to its direct relation to their mission statement to "protect significant places…by taking direct action" (Anonymous, 2016). Due to the Antiguos Aceuducto's status as the last Spanish-period aqueduct in existence on the island, there is a desire to preserve the structure. It is projected that this project will cost at least $10 million by the time of completion (*National Trust for Historic Preservation*, 2016).

2.3.1 Conservation Trust of Puerto Rico

Beginning in 1968, Puerto Rico experienced an economic modernization and industrialization period that posed a threat to the natural environment on the island. The threat of urbanization meant that a large portion of Puerto Rico's ecosystem would be destroyed. The imposing danger of deforestation on the island motivated the formation of the Conservation Trust. Since its creation, the organization has worked with other groups in Puerto Rico to engage tourists and locals in conservation efforts, awareness, and volunteer programs. The Trust has divided the island into five regions as seen in Figure 1. To better carry out these efforts, the Trust placed an operational headquarters within each region (*Conservation Trust of Puerto Rico*, 2016).

Figure 1: Map of five regions

Protected Areas. Digital image. *Para La Naturaleza*. N.p., n.d. Web. 11 Oct. 2016.

Many groups have come together to combat the preservation disagreements that have resulted from the growing land conservation issue in Puerto Rico. The Conservation Trust of Puerto Rico is a non-profit, private organization whose mission is to "secure functional and healthy ecosystems…and to instill a sense of responsibility toward the conservation of [their] natural resources" (*Conservation Trust of Puerto Rico,* 2016). This group acquires natural and historic sites which can be restored and protected with the help of the organization. The Trust uphold three main objectives to help them reach their goal of rehabilitation and restoration. Their first objective is to protect 33% of the island's land by 2033. They plan to do this through the analysis of conserved land, allowing them to maximize the functionality of the space. Secondly, they work to provide diverse programming to tourists and visitors to increase the awareness of natural and historical heritage. The final goal of the Trust is to promote a "conservation culture". To accomplish this, the group is constantly working to support and implement environmental policies that will protect the ecological value of the island (*Conservation Trust of Puerto Rico*, 2016).

2.3.2 Para La Naturaleza

Para La Naturaleza is a subsidiary of the Conservation Trust of Puerto Rico. Para La Naturaleza focuses specifically on the preservation of the island's natural environment and handle all volunteer efforts, fundraising, and oversight of all the natural areas. The formation of Para La Naturaleza allows for a greater focus on restoration projects (*Who are we?*, 2016). Para La Naturaleza works on sites acquired by the Trust to preserve the lands and restore the historical significance of the sites. Some of their more recent sites include Hacienda La Esperanza, Hacienda Buena Vista, and Punta Ballena (*About us,* 2016).

2.4 Hacienda La Esperanza

Hacienda La Esperanza is an extensive protective area located in the municipality of Manatí, which is located on the northern coast of the territory. It is important to note that in Manatí, it rains a fair amount. At the peak of the rainy season, around six inches of rain falls over the span of a month (*Average monthly weather in Manati, Puerto Rico*, 2016). The Manuatabón River runs through Manatí and makes the municipality an ideal place for gold panning and farmland. Hacienda La Esperanza is a 2,265 acre estate that contains numerous valuable ecological resources, which can be seen in Figure 2. Their forests are filled with unique and unusual flora and fauna, while their wetlands serve as homes to a variety of birds. There are even mangrove systems and coastlines that house marine life (*Who are we?*, 2016).

Figure 2: Map of Hacienda La Esperanza and Bridges

Source: Google. (n.d.). [Google Maps view of Hacienda La Esperanza]. Retrieved November 29, 2016 from https://www.google.com.pr/maps/dir//Hacienda+La+Esperanza

2.4.1 History of Hacienda La Esperanza

The farmlands in Hacienda La Esperanza were responsible for a majority of the sugar production in Puerto Rico during the latter part of the 19th century (Rivera, 2016). When Fernando Fernández bought the plantation in the 1830s, he recognized the land's potential. The river that ran through the plantation served as an efficient way to import and export any products the plantation needed or created (Grupo Editorial EPRL, 2014). The sugar mill, located in Hacienda La Esperanza, made it one of the largest sugar plantations in Puerto Rico during the 1870s. The estate was used to raise large amounts of cattle and horses in addition to sugar production. These animals were used as a food source and as draft animals for sugar production. José Ramón Fernández, the son of Fernando Fernández, decided in the early 1860s to enhance the plantation's machinery by installing a new steam engine and mill. In addition to this industrialization, he obtained more land and slaves. Sugar production in Hacienda La Esperanza relied on imported and native-born African slaves. In addition to their role as field and mill workers, they were used on site for a variety of other tasks (Iguina, 2011).

During the late 19th century, the farmlands in Hacienda La Esperanza continued to produce a variety of crops including pineapples, coffee beans, and green bananas, but their main export was still sugarcane (Rivera, 2016). The sugar mill was recently restored and added to a museum that would further educate tourists and community members on the history of the estate as seen in Figures 3 and 4. The acquisition of the estate by Para La Naturaleza ensured that its land would be preserved and maintained for historical reference.

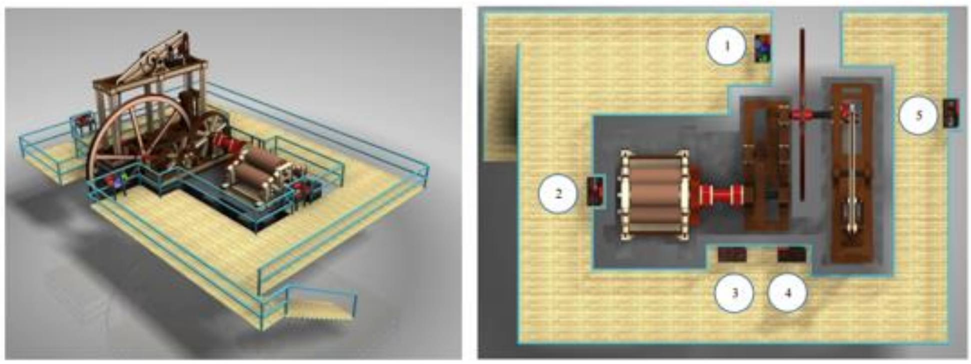
Figure 3: Part of the Steam Engine in the Sugar Mill

Source: Gwenn. (2011).

The plantation's role and impact on Puerto Rico's history made it "an ideal property for The Conservation Trust of Puerto Rico to preserve and restore" (Bumila et al., p.4, 2013). A plan for restoration was recently developed by Worcester Polytechnic Institute students in 2013. The goals of this project were to determine the requirements necessary to power the engine according to historical accuracy, and to create an "educational exhibit" that would surround the mill

(Bumila et al., 2013). Both of their objectives directly fit the mission statement of the Trust by conserving important historical structures while educating the community.

Figure 4: The design of the exhibit for the sugar mill



Source: Bumila et al., 2013

2.4.2 Current Use of Hacienda La Esperanza

Currently the Hacienda is owned by Para La Naturaleza and is utilized as a visitor's center to preserve and educate the community of the plantation's rich history. The old manor house has been restored to follow the layout of the original house and has many exhibits (i.e. a machete collection) to help explain the historic events that occurred at the plantation (S, Ortiz, personal communication, October 26, 2016). The sugar mill, drying house, and boiling pots on site have been restored and allow for a further understanding of the sugar making process. Hacienda La Esperanza serves as Para La Naturaleza's regional headquarters and is utilized by many employees every day. They have a woodshop, a lab, and many tractors and other agricultural equipment on site. Para La Naturaleza utilizes the available nutrient-rich land and also leases some of it to farmers.

2.5 The Two Bridges

The farming lands at Hacienda La Esperanza are rich from limestone deposits and are naturally irrigated due to the plantations unique placement. Because these lands are used frequently, the employees and farmers need to have direct access. The Manuatabón River runs directly through the plantation, requiring the use of an old vehicle bridge to access the other half of the plantation. The river breaks off into smaller streams throughout the estate, inhibiting cyclists' and pedestrians' direct access to other hiking trails. Over time, visitors have resolved this issue by utilizing an old concrete bridge structure that crosses over the stream. Para La Naturaleza is looking to restore both of the bridges due to their current state of disrepair.

Both bridges were linked to the sugar production from the plantation throughout the years, but historical evidence of their origin is lacking. Both bridges have their original concrete and brick columns and trusses intact (Figure 5) (C, Torres, personal communication, September 12, 2016).

The María Hernández Bridge is mostly intact, however there are a significant amount of bricks and concrete falling off the sides as seen in Figure 6. La Boquilla Bridge, which only has its original pillars made of brick and concrete, is very dilapidated. It is currently pieced together with wood and is frequently modified by community members. The addition of new wooden planks temporarily enables access over the bridge, but is by no means safe.

Figure 5 and Figure 6: A Picture of the Current María Hernández Bridge (Top) and A Picture of the Current La Boquilla Bridge (Bottom).

Source: Torres, C. (Photograph). (2016) María Hernández Bridge [photograph].Manatí

Developing a bridge restoration plan aligns with the mission statement of Para La Naturaleza in their attempt to “create public places to protect these resources” (*Who are we?*, 2016). Restoring and preserving these historic bridges will enable more community members to experience the plantation and appreciate the natural beauty and activities the site has to offer.

3.0 Methodology

This chapter focuses on the specific steps we took upon our arrival to San Juan, Puerto Rico. Our mission was to develop designs for both La Boquilla Bridge and the María Hernández Bridge while utilizing the pre-existing historic structures to ensure public safety and minimize environmental impact.

Our methods chapter was designed around the objectives that were developed throughout our preparation for this project as well as during our time in Puerto Rico. These objectives were: to determine which types of bridges best suit the needs of the Hacienda La Esperanza community, to determine the best construction materials to construct these bridges, and to present our findings and recommendations to Para La Naturaleza.

We also completed two secondary goals during our time in Puerto Rico. The secondary goals included the creation of a proposal for informational signs at the entrance to both of the bridges as well as the development of a material cost sheet. The signs were completed through a compilation of facts learned from our tour of the plantation as well as through online research of Hacienda La Esperanza. The material cost sheet was completed using an Excel spreadsheet to determine the cost of each bridge design.

3.1 Restoration Plan

To accomplish our main goal of creating designs for both the María Hernández and La Boquilla Bridges, we needed to first conduct an on-site assessment. The next step was to create design concepts that we could present to Para La Naturaleza before creating detailed designs. Once the ideas were approved, measurements were taken to ensure that the proposed designs were as exact as possible. Another approach to the restoration of the María Hernández Bridge involved researching possible companies that could do a full-scale restoration of the bridge itself. The final step of our restoration plan was to conduct a cost-benefit analysis of the material research.

3.1.1 Initial Assessment

The first task we completed upon our arrival in Puerto Rico was to travel to Hacienda La Esperanza to better understand both the current state and use of the bridges. During our visit, we utilized multiple resources including Para La Naturaleza employees, a historic tour, visual analysis, and actual measurements of the bridges. While assessing the bridges, we discussed Para La Naturaleza's plans for the site and the bridges over the next few years.

We spoke with Carlos Torres and Elizabeth Padilla while doing our on-site assessment of the bridges. The focus of these conversations were to obtain more insight as to how frequently the bridges are used and what type of machinery is driven over them. After speaking with Señor Torres, we felt we had a better understanding of the desires of Para La Naturaleza employees. This enabled us to better develop initial bridge design ideas and concepts for both the María Hernández and La Boquilla Bridges. During the on-site assessment we took pictures and measurements of the bridges using a tape measure that allowed us to create 3D images to scale. All of the pictures taken of the bridges can be seen in Appendices A and B while the checklist we used when collecting measurements can be seen in Appendix C.

The next part of our initial assessment was to make sure that our bridge concepts fit within the limitations that Para La Naturaleza set forth. With the help of Señora Padilla, we were able to organize an interview with Para La Naturaleza's Director of Operations, Rafael Rivera. This interview took place on November 1st and began with a presentation of our initial bridge concepts. Our interview questions accompanies with Señor Rivera and Señora Padilla's responses are shown in Table 1. The questions were given in both Spanish and in English to overcome the language barrier, and the translation of the questions can be seen in Table 2. After this interview, we were able to better understand which bridge types they were looking for and exactly what materials Para La Naturaleza had access to for this specific project.

Table 1: Interview Questions (English)

Interview Responses from Rafael Rivera and Elizabeth Padilla	
Interviewees:	Señora Padilla and Senor Rivera
Date:	11/1/2016
Questions	**Responses**
1. Do you have any knowledge of prior edits to the bridges that may aid us in the design development?	The only changes we know of is about 50 years ago concrete was added to the top of the María Hernández Bridge.
2. What would be your preferred method of building these bridges?	Concrete with minimal steel for the María Hernández and Pine Wood for La Boquilla.
3. Do any of our ideas seem undoable?	No.
4. Which of our ideas do you prefer?	We prefer designs that use minimal steel and preserve the historic structures.
5. Are they any changes you can think of that might improve the currents designs?	No.
6. Are you aware of any permits regarding the construction of these bridges?	No, there are no permits.
7. Are there any other materials that we should consider?	No, concrete and pine wood are what we use.

Table 2: Interview Questions (Español)

Questions for Rafael Rivera and Elizabeth Padilla (Español)
1. ¿Tiene algún conocimiento de ediciones anteriores al puente que nos pueda ayudar en el desarrollo del diseño?
2. ¿Cuál sería su método preferido para construir estos puentes?
3. ¿Alguna de nuestra ideas parecen imposible?
4. ¿Cuál de nuestras ideas prefiere?
5. ¿Hay algún cambio que se puede pensar para ayudar mejorar los diseños actuales?
6. ¿Usted sabe algun permiso para la construcción de los puentes?
7. ¿Hay otros materiales que deberíamos considerar?

After taking our initial measurements, observations, and interviews we decided on three designs for the María Hernández Bridge and four options for La Boquilla Bridge. The initial observations of the María Hernández Bridge showed that the bridge remains in a state of disrepair. The concrete deck is crumbling and many parts have fallen off (Figure 7). The span of the bridge is also uneven and forces the bridge deck to be angled across the two banks. Pictures that we took during our onsite assessment can be seen in Appendix A.

Figure 7: Picture of María Hernández Bridge

From our on-site assessments, we decided to create three different models for this bridge. The first two models would not utilize the pre-existing structure, but instead would involve the creation a new bridge over the existing one. We decided to create bridges that did not rely on the current bridge due to its unknown structural integrity. The third design utilized the pre-existing bridge using concrete arches to reinforce the bridge.

For La Boquilla Bridge, we developed four design options that we felt best fit the area. Our on-site assessment showed that the three pre-existing concrete abutments are intact and appear to be structurally sound (Figure 8). This on-site assessment led us to believe that the abutments could be used in the creation of a footbridge. Appendix B contains all the pictures we took during our on-site assessment.

Figure 8: Picture of La Boquilla Bridge

After speaking with both Señor Rivera and Señora Padilla we decided to create a footbridge that maintains the same width of the abutments. The design may also utilize additional pylons to keep the bridge anchored into the ground and reduce side-to-side movement.

The designs differ in their structural use of either H-beams or steel plates on top of the concrete abutments.

3.1.2 Development of Bridge Models

Once we had developed a full understanding of both bridges, we began to draft SolidWorks models for Señor Rivera and Señora Padilla. These initial drafts were made to show them what our initial thought processes were. After the first drafts were made and discussed with both the Para La Naturaleza employees and our advisors, we began to draft the final design and restoration plan for the María Hernández Bridge.

In designing all of these models, we chose SolidWorks as our preferred platform for creating our models because of its versatility. We considered other relevant programs such as Revit, Auto-CAD, and Bridge Designer 2016. These programs are useful, but most of them do not offer the same capabilities in software that SolidWorks does. SolidWorks can produce a vivid 3D representation of the bridge and its surroundings. Using this software, we were able to run multiple simulations that test the bridge's max load capacity given the specific materials used for construction. Additionally, it showed where deflections occurred when there was a present force on the bridge (Dassault Systèmes SolidWorks, 2010).

SolidWorks can also create an exploded view. An exploded view is a technical drawing that shows the step-by-step process for the full creation of an assembly. We also utilized this feature to further explain our models, as seen in Section 5.1 and 5.3 (Dassault Systèmes SolidWorks, 2010).

In addition, two of our members were comfortable with the SolidWorks software, unlike the other CAD programs. This decreased the time it took to produce the models and increased the accuracy of the designs we made.

3.1.3 Secondary Assessment

Upon initially drafting our models we realized that, in order to accurately convey them, there were additional measurements that had to be collected. Therefore, we went back to Hacienda La Esperanza to obtain the new measurements for both bridges. The documents we used that contained all of the newly obtained measurements can be found in Appendix D. With these new measurements, we were able to correctly portray the bridges as they currently stand and create more accurate designs for the new bridges.

3.1.4 Material Research

While creating the bridge designs we needed to evaluate the type of materials that each bridge could be composed of. Initially, in determining which types of materials to use, we developed multiple parameters for each of the bridges. For the María Hernández Bridge, Señor Torres and Señor Rivera discussed that the bridge should be completely composed of concrete with minimal amounts of reinforced steel. The parameters we looked for when determining which type of concrete to use included the weight of the concrete, the max load, water-to-cement ratio, drying times, and cost.

For La Boquilla Bridge, Señor Torres expressed that Para La Naturaleza wanted to see the bridge made mostly of wood, specifically pine. Keeping this in mind, we decided to investigate different types of wood that could be used during the construction of the footbridge. The parameters to investigate for each wood type were density or specific gravity of the wood, resistance to water, and the ease of importing it to Puerto Rico.

Once the parameters for each type of material were investigated, we conducted a cost-benefit analysis. This included determining which materials could be imported and treated for a low cost, the price of each material, and how long they would last. The cost of each bridge was determined using a material cost spreadsheet that is described more in Section 3.2.

3.1.4.1 Pine

It was expressed to us early on that Para La Naturaleza wanted to use pine as the material to construct La Boquilla Bridge. They felt that the usage of pine, more specifically treated pine, made it the natural choice for this build. There are many varieties of pine that grow in different parts of the United States, however, the type of pine that is most widely used on the Eastern Coast is the Eastern White Pine. We decided to utilize Eastern White Pine in our design due to its low shipping cost. The low cost makes it the ideal pine choice for Para La Naturaleza.

Eastern Pine naturally grows very straight and tall, making in an ideal wood type for cutting long boards. These would be beneficial to Para La Naturaleza when adding “stringers” to the deck’s underside. These long boards run across the width of the stream and serve as supports to the deck of the bridge. Eastern Pine usually has straight, even grains with medium texture that run throughout its length. This means there are a few knots in the wood and the boards can be easily cut. Because it is a softwood, sawmills are able to create cleanly sawn boards with much less waste than other woods at a lower price. This also means that working with this type of pine is fairly easy to do with both hand and machine tools. Its low density and specific gravity make it a lightweight material to work with in comparison to others. However, a large drawback to this material is that is has a low rot resistance and would not be very suitable for use in tropical conditions (Eastern White Pine, 2016). A method to address this issue is to pressure treat the wood. The act of pressure treating wood is when you use pressure to push preserving chemicals into the wood that help prevent decay and destruction from bugs (Hiziroglu 2016). The details of this wood can be found in Appendix E.

3.1.4.2 Spanish Cedar

Spanish Cedar is a unique type of wood that is native to Central America, South America, and the Caribbean. It is more closely related to mahogany wood on account of its low to average density and overall mechanical properties (Spanish Cedar, 2016). The properties of this wood vary greatly depending on the growing conditions and country of origin. These specifics can be seen in Appendix E. Benefits to using Spanish Cedar include it being grown in Puerto Rico, which makes it readily available for use. The wood is also easy to work with due to its soft nature, allowing for easy cuts with saws and other hand tools. Spanish Cedar is also resistant to termite attacks, a valuable asset since the footbridge will be in the middle of the forest of the plantation. Studies show that Spanish Cedar has "excellent weathering conditions" making it an ideal option for any structure constructed in a forest or over a body of water (Spanish Cedar, 2016). Once we had investigated the properties of this material, we looked into the need to pressure treat the wood. Because Spanish Cedar is already extremely rot resistance there is little need to pressure treat it, which therefore saves Para La Naturaleza money.

3.1.4.3 Eastern Hemlock

One type of wood we were told to investigate when we did our initial investigation was Eastern Hemlock. It is a wood that is harvested in a decent quantity on the east coast, so the price for the actual wood and shipping to Puerto Rico would be moderate. This wood normally grows fairly tall. However, it is difficult to cut because of its grain structure which tends to be interlocked and spiraled with an uneven and coarse texture. Also, it can be difficult to work with as the wood tends to splinter. When it is planed (the act of sanding the rough cut lumber to give soft smooth boards), the end result is very poor because it is made up of a mixture of soft and hardwood. The mixture of soft and hardwood creates dips and uneven surfaces when sanded. Another very significant drawback to this wood is that it is known as non-durable when it comes to rot resistance and is very susceptible to insect attacks (Eastern Hemlock, 2016). The mechanical properties of this wood can be found below in Appendix E.

3.1.4.4 White Oak

Knowing that we needed a wood that was rot resistant, we investigated White Oak. For years this wood has been used in boat building due to its high durability and resistance to water (White Oak, 2016). The wood has a notably high modulus of rupture, which can be seen in Appendix E. White Oak's mechanical properties highly outweigh many of its competitors because of how easy it is to work with. The wood is also economical and extremely rot resistant, eliminating the need to pressure treat it. White Oak is abundantly available and easy to import in numerous widths and thicknesses (White Oak, 2016).

3.1.4.5 Composite Decking

Per recommendation from Para La Naturaleza, we looked into the option of utilizing composite decking for La Boquilla Bridge. Composite decking is composed of both recycled plastic and wood fibers to create a "dense, heavy, and weather- and stain-resistant deck board" (Truini, 2012). Aside from its great durability composite decking is also maintenance free. Because it is man-made, it does not need to be sanded, refinished, or stained (Truini, 2012). This would mean that the maintenance fees of the bridge would be low, and that the longevity of the bridge would be increased.

3.1.4.6 Plastic Decking

In previous projects, Para La Naturaleza also has utilized plastic decking. Our research into this material showed that the decking is made entirely of plastic, containing no wood fibers or fillers. Due to the decking's unique composition, it does not require finishing or staining and it will not crack, warp, or splinter (Truini, 2012). The low-maintenance of this decking is advantageous from both a cost and time perspective. The disadvantage to using plastic decking is that it is usually designed as one part of an overall system. This means that it must be installed with "strict adherence to the manufacturer's instructions" (Truini, 2012).

3.1.4.7 Concrete

In Puerto Rico, concrete is a very popular building material due to its cheap cost and wide availability. It is able to be made locally due to the abundance of limestone on the island and is therefore very cost-efficient. The concrete is composed of a mixture of cement, water, and aggregates. This mixture is made up of a ratio that is typically around “10 to 15 percent cement, 60 to 75 percent aggregate, 15 to 20 percent water… and 5 to 8 percent [air]” (How Concrete is Made, 2016). Once this mixture hardens, it forms into concrete.

We found that there are two main types of cement that can be used for making concrete: hydraulic and non-hydraulic. The cement is made by heating up limestone with varying amounts of other materials such as “sandstone, marl, shale, iron, clay, and fly ash” depending on the purity of the limestone used. This results in a compound known as clinker, which will then be finely ground with the addition of gypsum in order to create hydraulic cement (The Process for Making Portland Cement, 2016). Hydraulic cement refers to cement that hardens once exposed to water. The hardening time of the hydraulic cement varies based on the amount of gypsum added during the grinding process. Non-hydraulic cement is cheaper than hydraulic cement, but because it doesn’t harden when it gets wet and has long drying times, it is not used as often as its hydraulic counterpart (Scott, 2011).

There are also various types of aggregates (i.e. gravel, crushed stone, or sand) that can be used depending on what the concrete will be used for. Certain characteristics of the aggregates that are taken into consideration include “grading, durability, particle shape and surface texture, abrasion and skid resistance, unit weights and voids, and absorption and surface moisture.” Generally, larger particles with a rough texture require more water than smoother, smaller particles to produce an effective concrete mixture, and therefore need a larger amount of cement in order to maintain the water-cement ratio (Aggregates, 2016). The absorption and surface moisture of the aggregate also affects the amount of water that needs to be added to the mixture. All of these properties need to be taken into account when mixing concrete, because if there is too much water in the concrete mixture, it will reduce its strength (Density of Cement & More Cement FAQs, 2016).

Different combinations of cement and aggregates result in different types of concrete. Some of the types of concrete that we considered for use on the María Hernández Bridge included the following: Normal concrete, high strength concrete, high performance concrete, and lightweight concrete. Normal concrete is the most common form of concrete and can withstand compressive forces between 10 megapascals (MPa) and 40 MPa. In addition, it is made with a water-cement ratio of 0.4. High strength concrete can withstand forces over 41 MPa, and is made by lowering the water-cement ratio to 0.35. Silica fume is also added to the concrete mixture, which reduces its workability, but increases its strength. High performance concrete is made with super plasticizers, which lowers the water-cement ratio needed to 0.25. This allows it to withstand compressive forces between 69 MPa and 103 MPa. Lightweight concrete is much lighter than all the other types of concrete, but it can only withstand compressive forces between 7 MPa and 40 MPa (Types of Concrete, 2014). In addition to these different types of concrete there is reinforced concrete, which utilizes steel rebar frames integrated into the concrete to increase its strength and durability. A more in depth analysis of these expenses can be seen in Section 4.6**.**

3.2 Material and Labor Cost Spreadsheet

After creating our five different models, we decided to conduct a cost-benefit analysis between the different bridges and the materials they could be composed of. We first looked at the average pricing of the four different types of wood and compiled them in an Excel spreadsheet.

The woods we considered were Pine, Cedar, Hemlock, and Oak. We looked at each one in terms of cost per linear foot for 2”x4”, 2”x6”, and 4”x4” pieces of lumber. We also made a separate spreadsheet which involved a combination of traditional wood and composite wood. We then determined which type of spacer we would use for La Boquila Bridge through a cost analysis. The prices for a 4’x4’x1/2” steel plate, a 4”x4”x10’ galvanized steel I-beam, and a 4”x4”x10’ steel H-beam were researched and added to the Excel spreadsheet. For the María Hernández Bridge we also looked at prices of steel rebar and concrete.

After the total material prices were tabulated, we utilized our SolidWorks designs to determine the amount of material needed. The total amount of wood was plugged into the Excel spreadsheet. The next step we took was to include the importation cost of materials that are not readily available in Puerto Rico. Finally, we compiled all of the material costs with the estimated labor cost. This gave us the final cost estimation for each bridge build. The Excel spreadsheet we made is interactive and the costs, amounts, and duration of construction can be changed to fit the needs of the Para La Naturaleza.

3.3 Informational Signs Research

The first step in developing our informational signs for La Boquilla Bridge and the María Hernández Bridge was to conduct research to generate content for the signs. During our on-site assessment we conducted interviews with Señor Torres and Señora Padilla to gather any relevant information that we could include in the sign designs. Since historical data on both bridges was lacking, we decided to interview Señora Padilla on the information that Para La Naturaleza was looking for us to include.

The next step we took in creating our informational sign designs was to visit other historic sites and exhibits in Puerto Rico. Besides our visit to Hacienda La Esperanza we also traveled to Fort San Felipe del Morro and The City Wall in Old San Juan. We chose Hacienda La Esperanza so that we could incorporate their requested theme into our design. The other two sites are located in Old San Juan and were chosen due to the large amount of tourist traffic that passes through the two places. Through analysis of these signs, seen in Section 4.7**,** we were then able to create our own designs that could educate visitors on the important information that Para La Naturaleza wanted us to include.

3.4 Company Contact

The last procedure we executed was contacting a company named Cintec for the restoration of the María Hernández Bridge. This company specializes in a specific type of bridge restoration that could be utilized by Para La Naturaleza. The method they use for restoration stabilizes and strengthens the bridge from within by pumping Presstec™ grout into a hollow steel tube which is surrounded by a fabric sock. “The grout is injected under low pressure, inflating the sock. Milk grout that passes through the expanded sock mesh provides a cementitious and mechanical bond to the in situ materials” (Anchoring & Reinforcement, 2016).

We reached out to this company via email and were referred to Eric Jokinen, who is owner of Jokinen Engineering Svc. He is an independent engineer helping Cintec on a number of projects throughout North America and is familiar with construction in Puerto Rico, particularly with historic bridges and buildings. He even took part in the Conservation Plan for Historic Bridges for Puerto Rican Transportation, State Historic Preservation Office (SHPO), and the

Federal Highway Administration (FHWA) (Eric Jokinen, personal communication, November 23, 2016).

Our team and Mr. Jokinen conversed through email several times over the course of a week. His email is eric.jokinen@jokinen.ca. We sent him pictures and dimensions of the bridge and asked him if Cintec's method of restoring bridges would fit our project. We also asked, if possible, for a general quote if the project could be done.

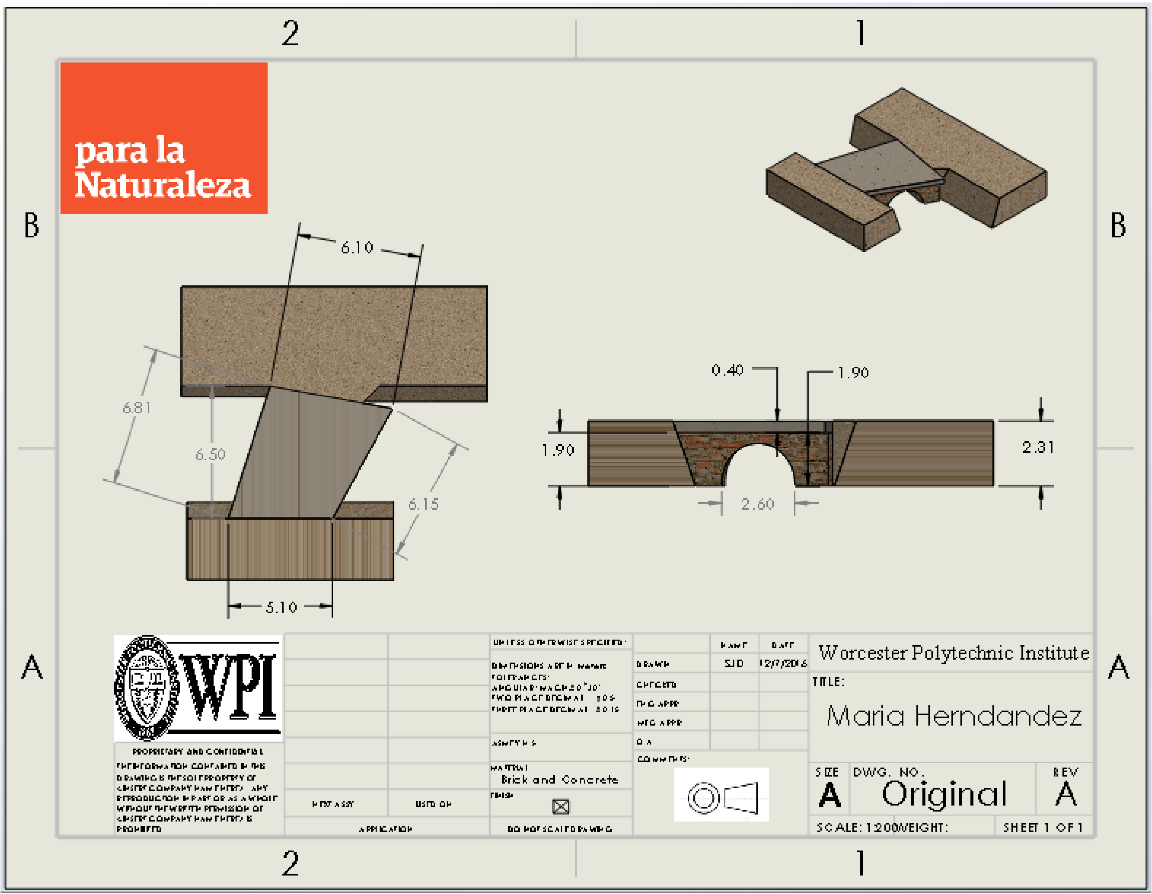
4.0 Results

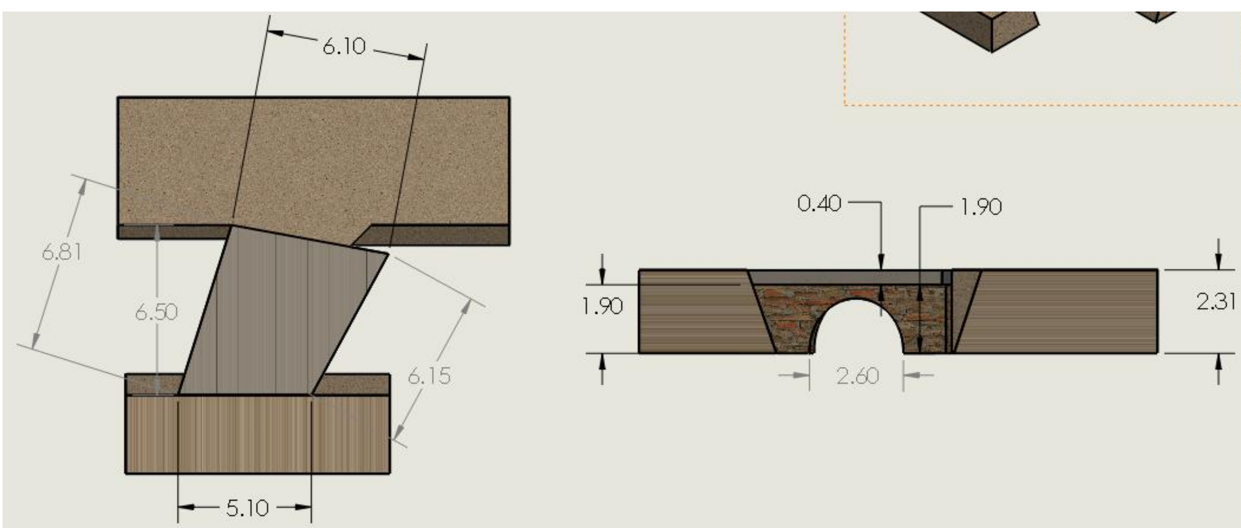
This section was written to discuss all the findings and results of the methodology that is outlined in the above sections. Through our on-site assessments, interviews, and material research, we were able to develop restoration plans and designs for both the historic bridges at Hacienda La Esperanza.

4.1 Initial and Secondary Assessment

From the initial and secondary assessments, we were able to obtain all of the pictures and measurements necessary in order to accurately design models for the María Hernández Bridge and La Boquilla Bridge. The pictures can be found in Appendix A and B and the dimensions can be found in Figures 9 and 10.

Figure 9: Dimensional Drawings of María Hernández Bridge





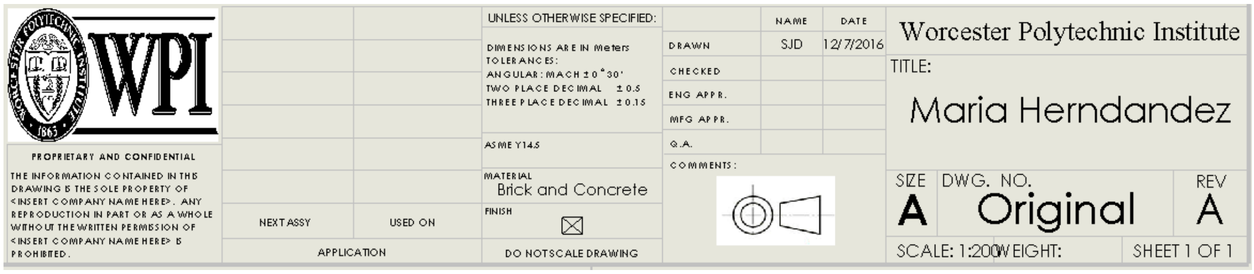
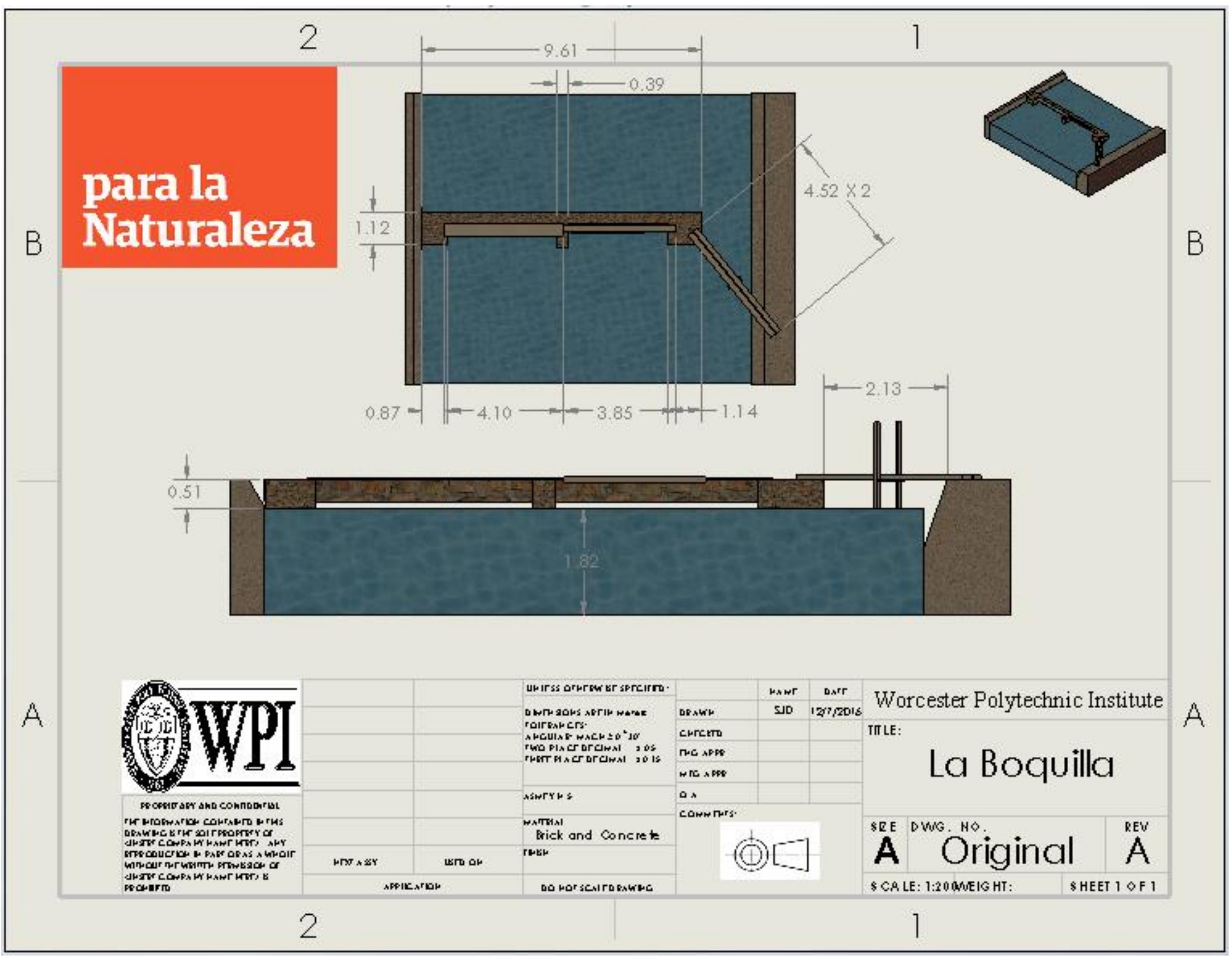


Figure 10: Dimensional Drawing of La Boquilla Bridge



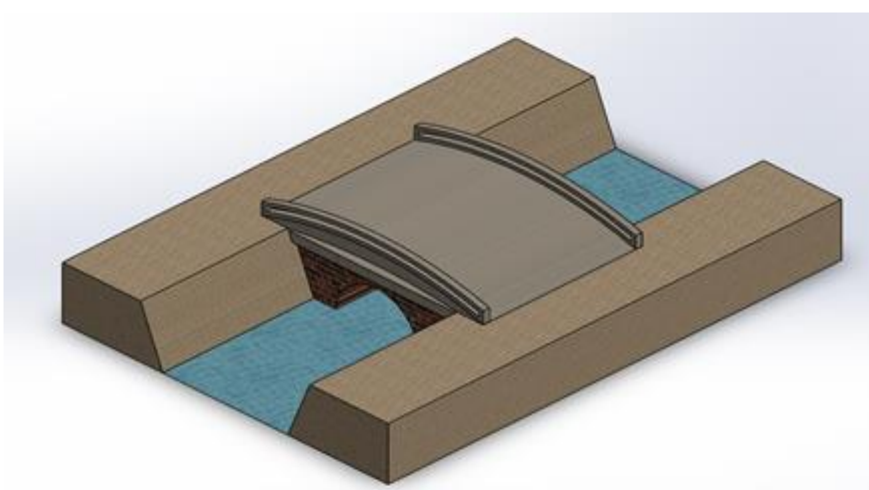
4.2 First Designs of the María Hernández Bridge

The following designs were made to brainstorm multiple ideas on how to solve the issues regarding the María Hernández Bridge. Two of the designs involved building over the pre-existing bridge, while the other was more of a restoration approach.

4.2.1 Design One

Design One (see Figure 11) for the María Hernández Bridge features a slight arch that goes directly over the pre-existing bridge. The reason for the slight arch is to relieve the older bridge of future forces and stresses. The material of the new bridge is made of reinforced concrete. The railings could be made of concrete, steel, or even wood. For this model, they were made of concrete. The design of the railings is also subject to change.

Figure 11: Design One for María Hernández Bridge

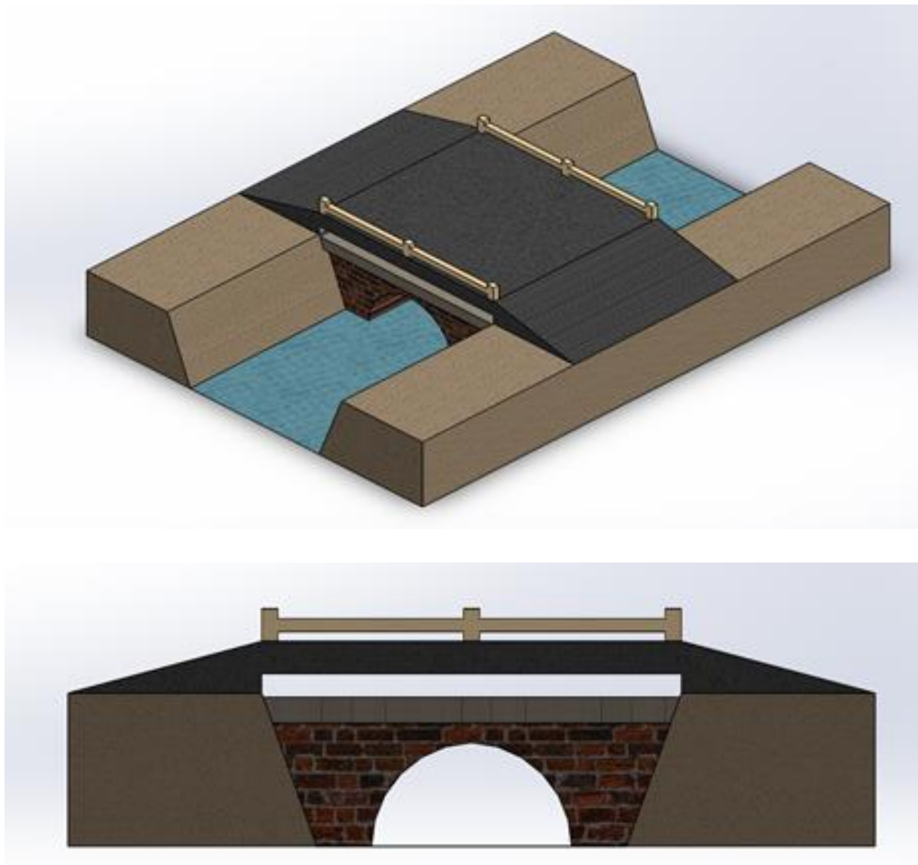


A problem for this design is the arch itself. Señor Torres explained that a bridge design with arches may inhibit the vision of any drivers going over the bridge. This would pose a safety issue to both the drivers and other workers in the area. Additionally, he expressed his concern that the arch may cover the historical bridge and prevent it from being viewed by observers.

4.2.2 Design Two

Design Two (Figure 12) utilized ramps and a flat top to go directly over the bridge, instead of the previous arch. This design would also be used to relieve forces and stresses from the historic bridge and is made of reinforced concrete. The bridge's railings are made of wood in this model, but this is likely to change to either concrete or steel.

Figure 12: Design Two for María Hernández Bridge

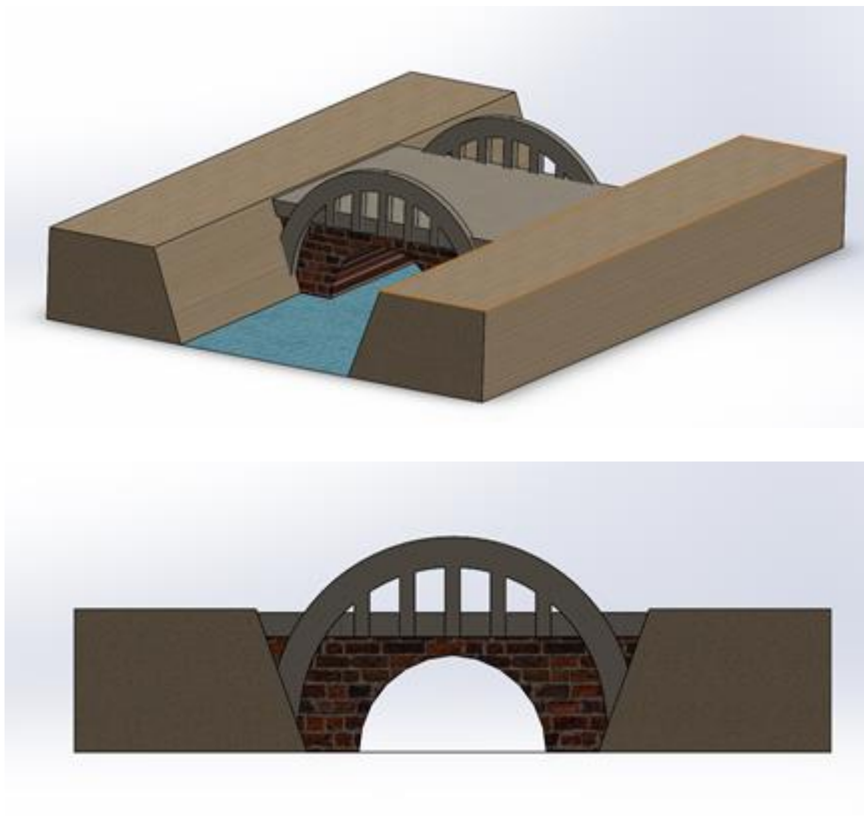


A similar problem arises for this design – the new bridge covers the older historic bridge below. This design is desirable due to the elimination of the arch, which makes the drive over the bridge easier and safer for the workers at Hacienda La Esperanza.

4.2.3 Design Three

Design Three (Figure 13) differs greatly from the previous two models. Rather than creating a whole new bridge, this design reinforces the pre-existing structure, leaning more towards a restoration. The design utilizes an arch that continues into the banks, anchoring the bridge. The hanging supports connect the original bridge to the supporting arch. This arch would help strengthen the bridge by dispersing the loads of the bridge throughout the newly implemented support structure. This design would utilize the arch as a railing as well as a support and would be made of reinforced concrete.

Figure 13: Design Three for María Hernández Bridge

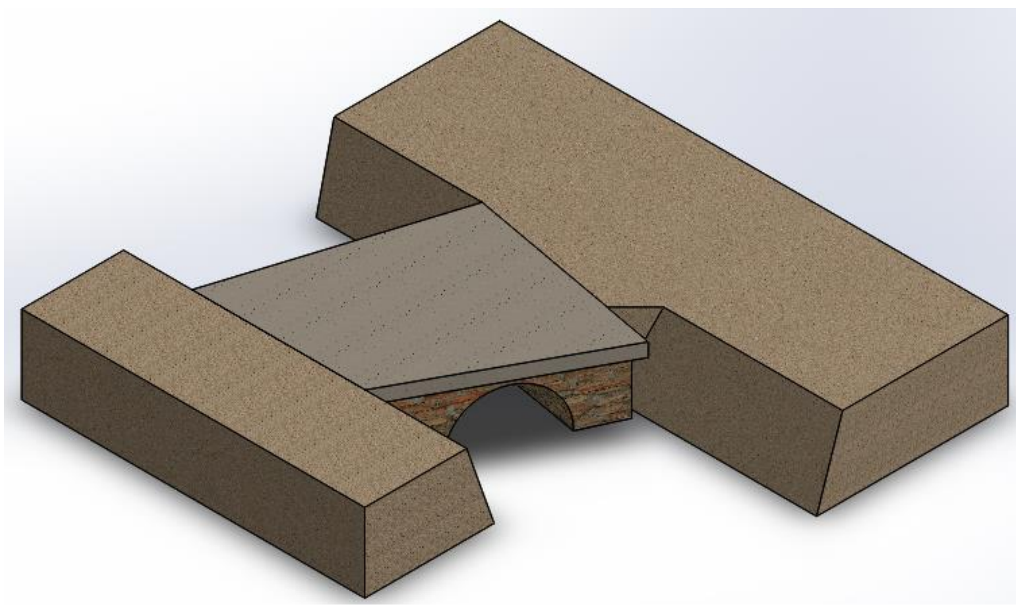


The questionability of the structural stability of the original bridge continues to be a problem with this method. Without subcontracting to a civil or architectural engineer, we cannot accurately determine the bridges max load capacity. A benefit to this design is that the original bridge will still be used and admired.

4.3 Final Design of the María Hernández Bridge

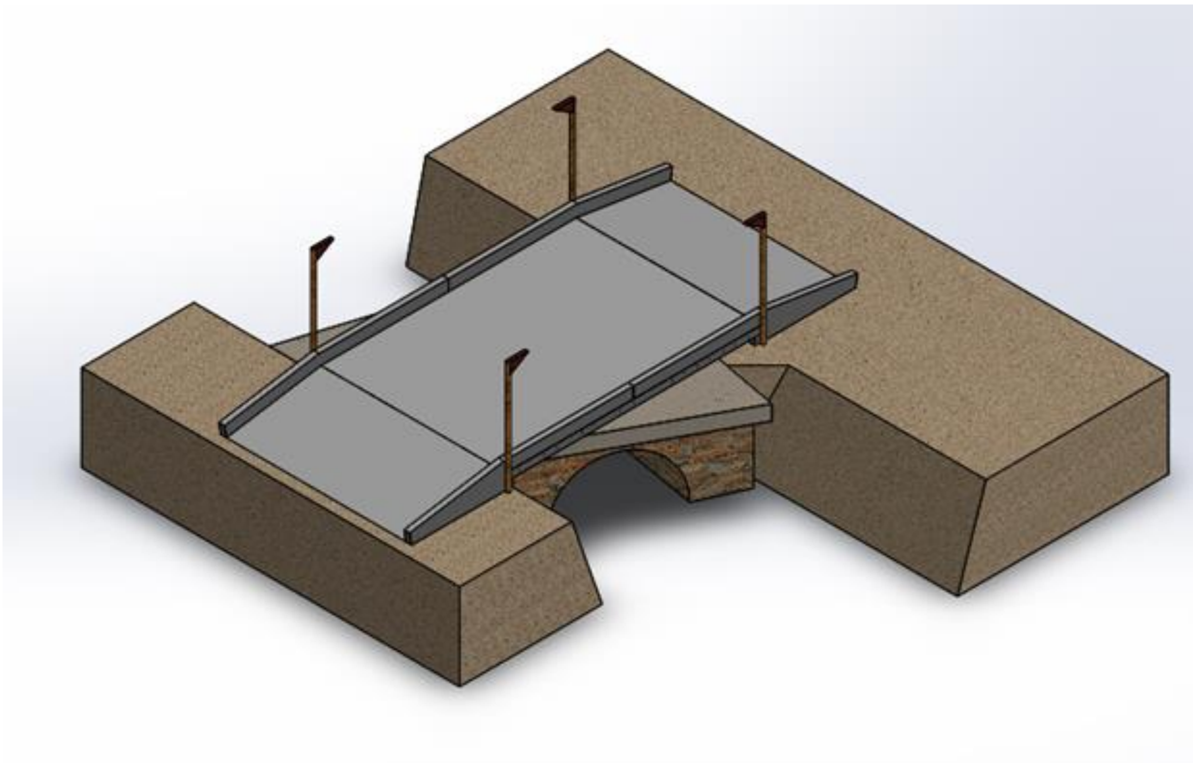
To make the final design, we had to reconstruct the pre-existing bridge, along with the surrounding banks. As you can see in Figure 14, the pre-existing bridge and banks are made to scale. The water was not included in this model because it hindered the ability to see the bridge and also interfered with the simulation running process. The water level when we visited Hacienda La Esperanza was 0.8 meters, but this number is bound to change due to rainfall.

Figure 14: Pre-existing María Hernández Bridge



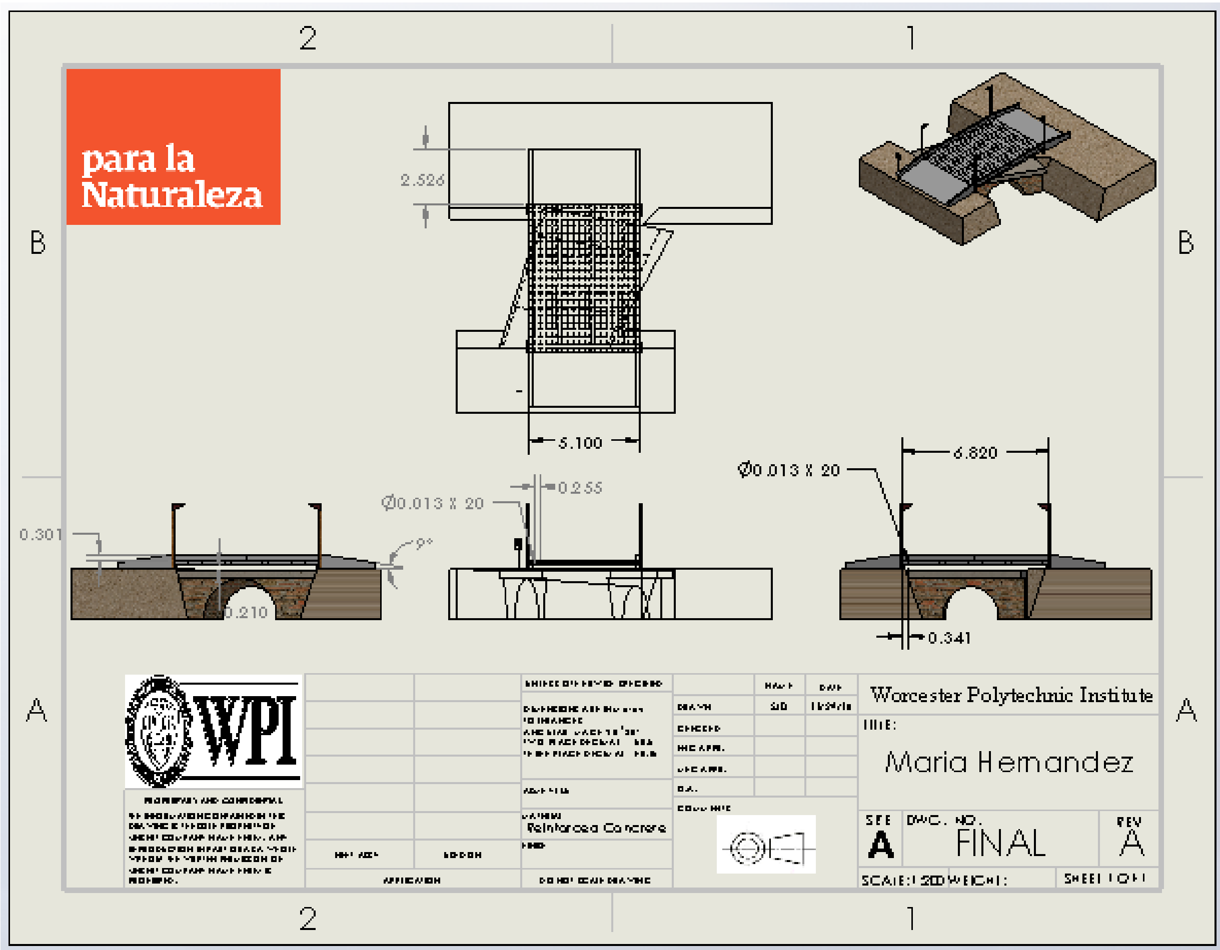
Our Final Design is a further-developed Design 2 as seen in Figure 15. To successfully construct this bridge and make it as realistic as possible, we added rebar to the concrete during the modeling process. We also added square curbs made out of concrete. We chose concrete because it is stronger than wood and a lot cheaper than steel. It is also very easy to work with.

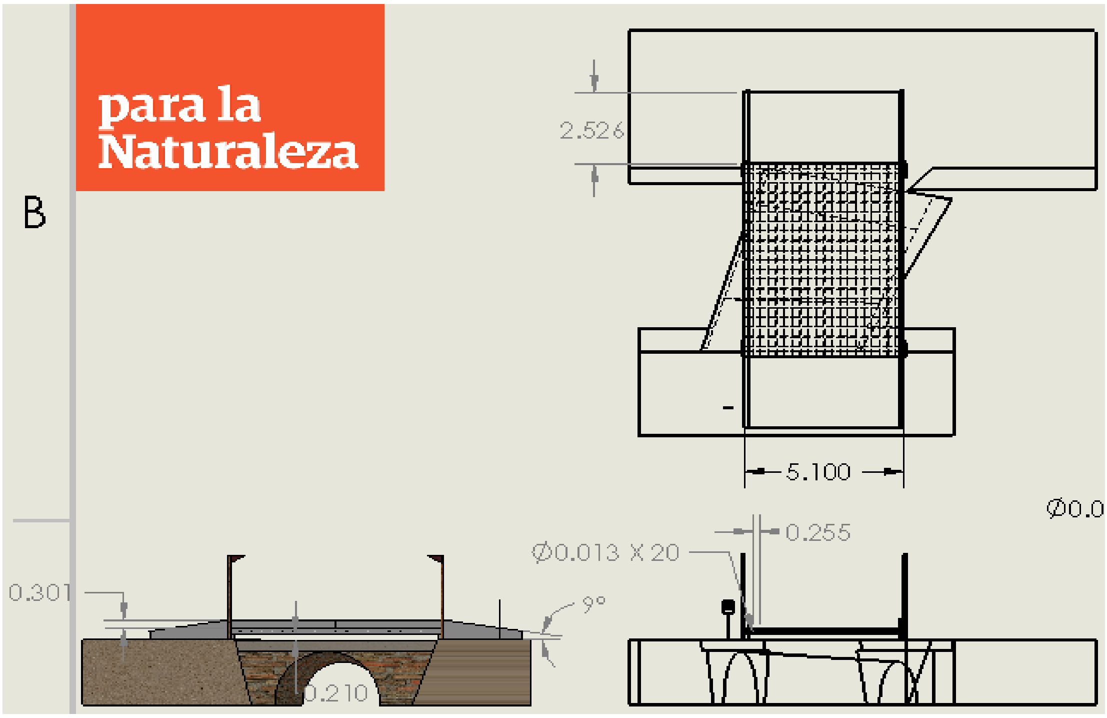
Figure 15: Final María Hernández Bridge Design

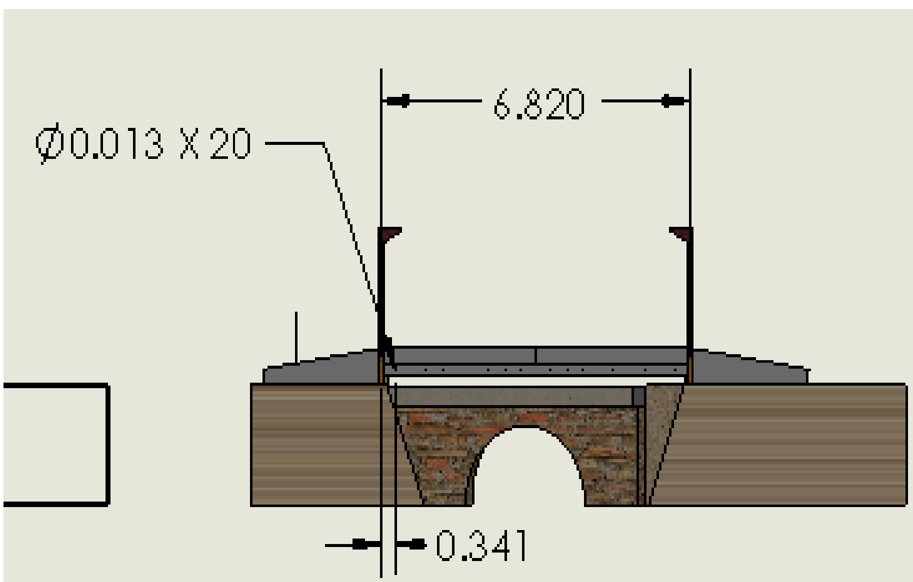


There are also flagpoles added to this design. These were added in after talking with Señora Padilla. Her concern was with the drivers of the tractors not being able to see where the ramps started and ended. These flagpoles are just a suggestion – they could also be lamps, smaller poles, or even reflectors. Additional views of the Final Design can be seen in Appendix F, but dimensions can be seen in Figure 16.

Figure 16: Final Bridge Design Dimensions







4.4 Final Restoration Plan of the María Hernández Bridge

For the restoration plan of this bridge we did research on a company known as Cintec. We also talked to Mr. Jokinen, one of their representatives that works in Puerto Rico, about the possibility of using Cintec's unique restoration methods for the María Hernández Bridge. After sending Mr. Jokinen pictures and dimensions of our bridge he said, "Certainly Cintec's Archtec system could be used to upgrade the bridge, but if they are planning to use it for foot traffic or maybe light agricultural use, then Archtec would be overkill" (Eric Jokinen, personal communication, November 29, 2016). With that being said, the bridge is being used for more than light agricultural equipment (i.e. large tractors with trailers). Since the bridge is being used for more than foot traffic we asked Mr. Jokinen for a quote.

The only way Mr. Jokinen could give us a quote was if he actually visited the bridge. He also said, "The Cintec costs, including advanced engineering analysis, will certainly exceed the replacement cost for a new bridge deck with modern materials on the existing foundations" (Eric Jokinen, personal communication, November 23, 2016). In a way, this validates our Final Design as being a prime recommendation for this bridge. One more thing to address that Mr. Jokinen talked about in our emails is an alternate form of restoration aside from Cintec. He believes that "a good restoration with local labor working under the direction of a heritage mason is what is needed" (Eric Jokinen, personal communication, November 23, 2016). In summary, Mr. Jokinen was inferring that the possibility of working under a professional could be utilized to preserve the natural structure. This would eliminate the need to build a new bridge over the pre-existing structure.

4.5 Designs of La Boquilla Bridge Model

After our presentation and interview with Señor Rivera and Señora Padilla, we were able to move forward with multiple bridge designs for La Boquilla Bridge. Initially, we had looked into an expanded deck to allow the footbridge to have more width. This idea was later discarded because Para La Naturaleza does not want all-terrain vehicles to cross over the bridge. They would rather limit the bridge to just cyclist and pedestrian traffic. Señor Rivera and Señora Padilla confirmed our idea of using pylons that would extend into the ground as long as we spaced them out to reduce trash and wildlife debris buildup in the river.

Our four designs include the following: a model with pylons and steel plates (Figures 17 and 18), a model without pylons and steel plates (Figures 18 and 19), a model with pylons and steel H-beams (Figures 20 and 21), and a model without pylons and steel H-beams (Figures 21 and 22). Additional images of the bridge designs can be found in Appendix F.

The steel plates and H-beams are used to separate the wooden stringers from the concrete abutments. The steel plate connection between the concrete abutment and the stringer can be seen in Figure 18.

Another option for connecting the concrete abutment to the stringer would be to utilize steel H-beams. A SolidWorks image of this rendering can be seen in Figure 21.

Figure 17: La Boquilla Model with Pylons and Steel Plates

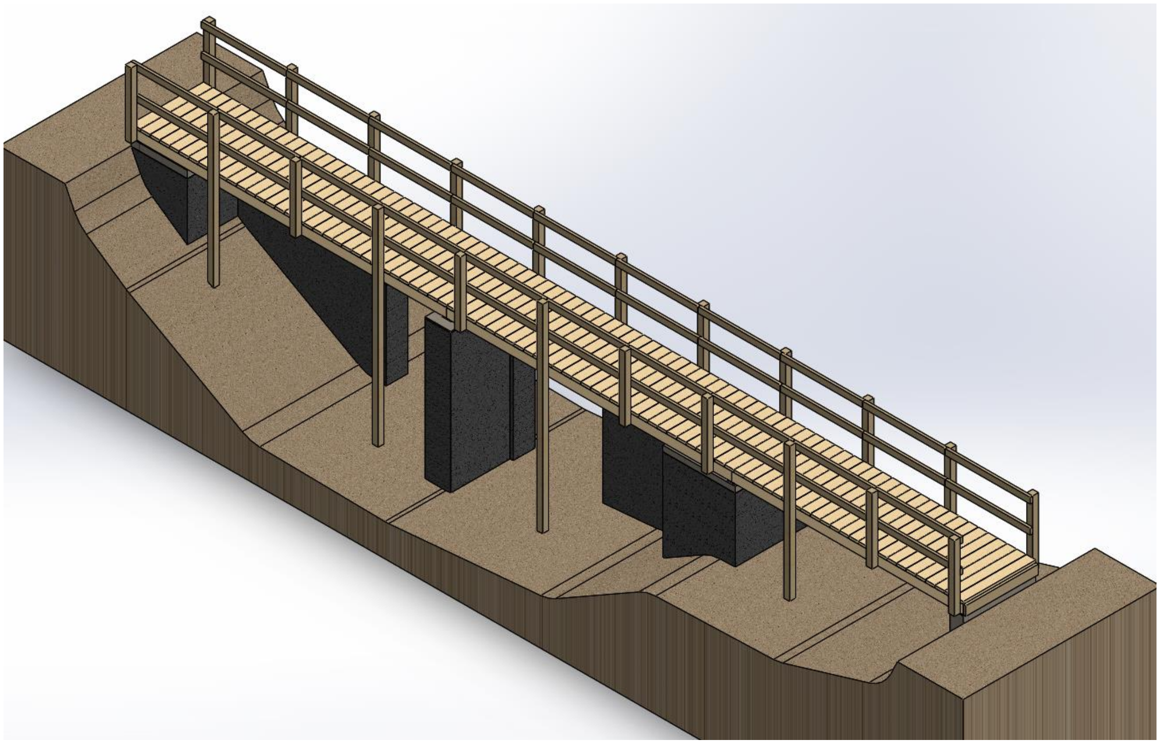


Figure 18: Steel Plate on La Boquilla Bridge

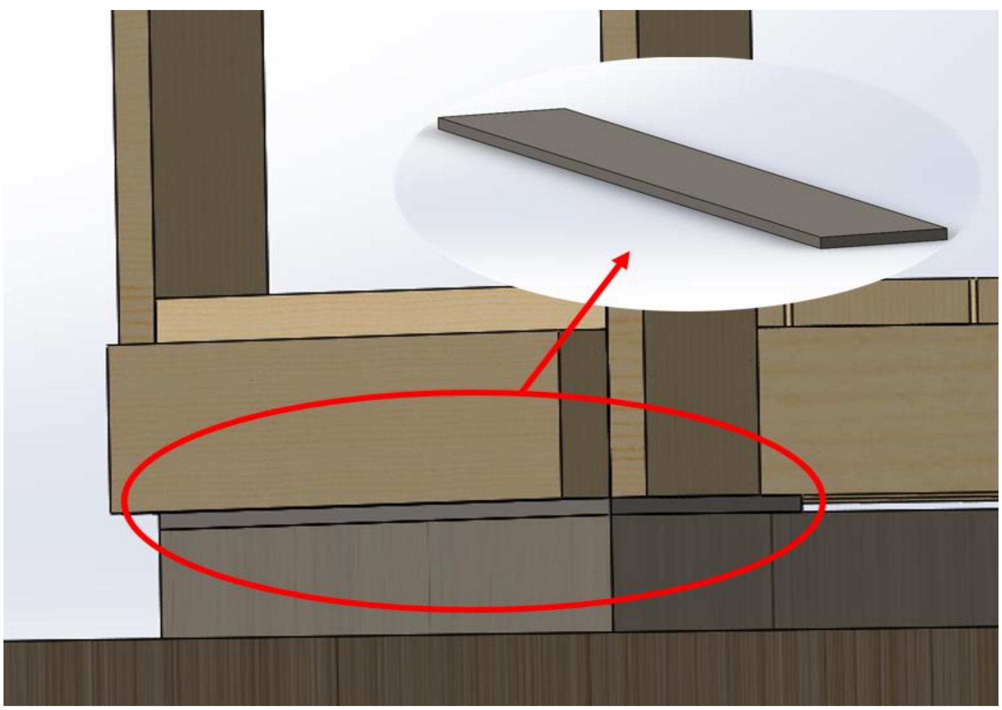


Figure 19: La Boquilla Model without Pylons and with Steel Plates

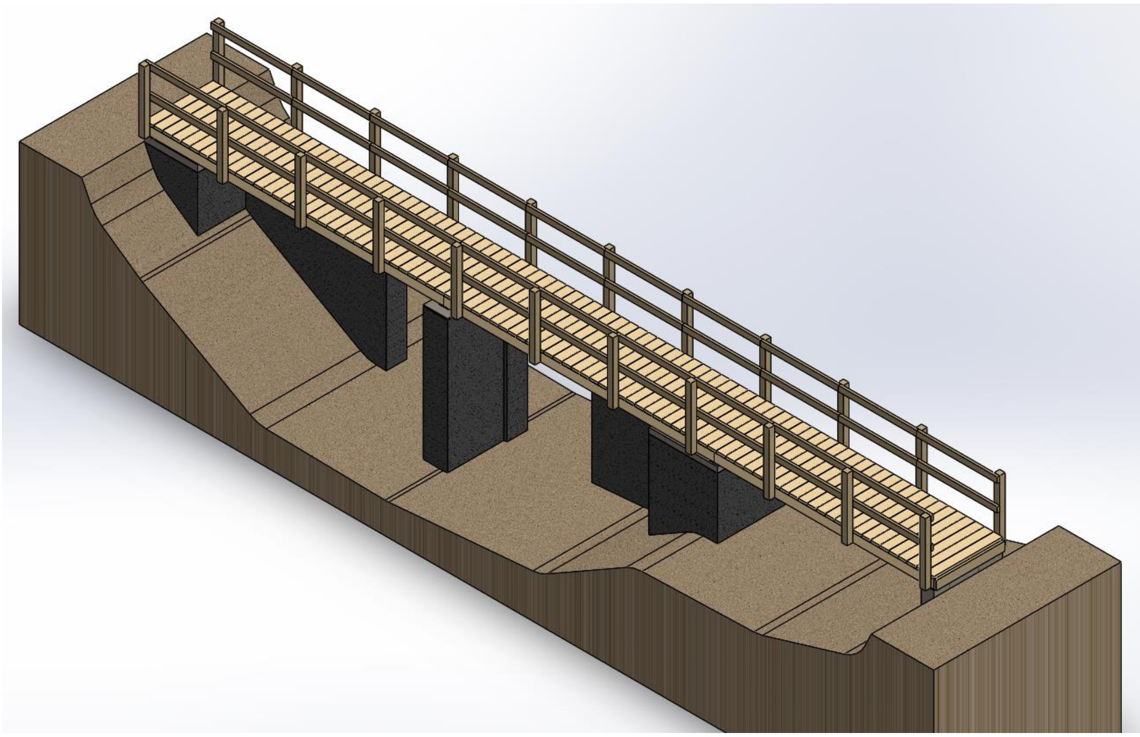


Figure 20: La Boquilla Model with Pylons and H-Beams

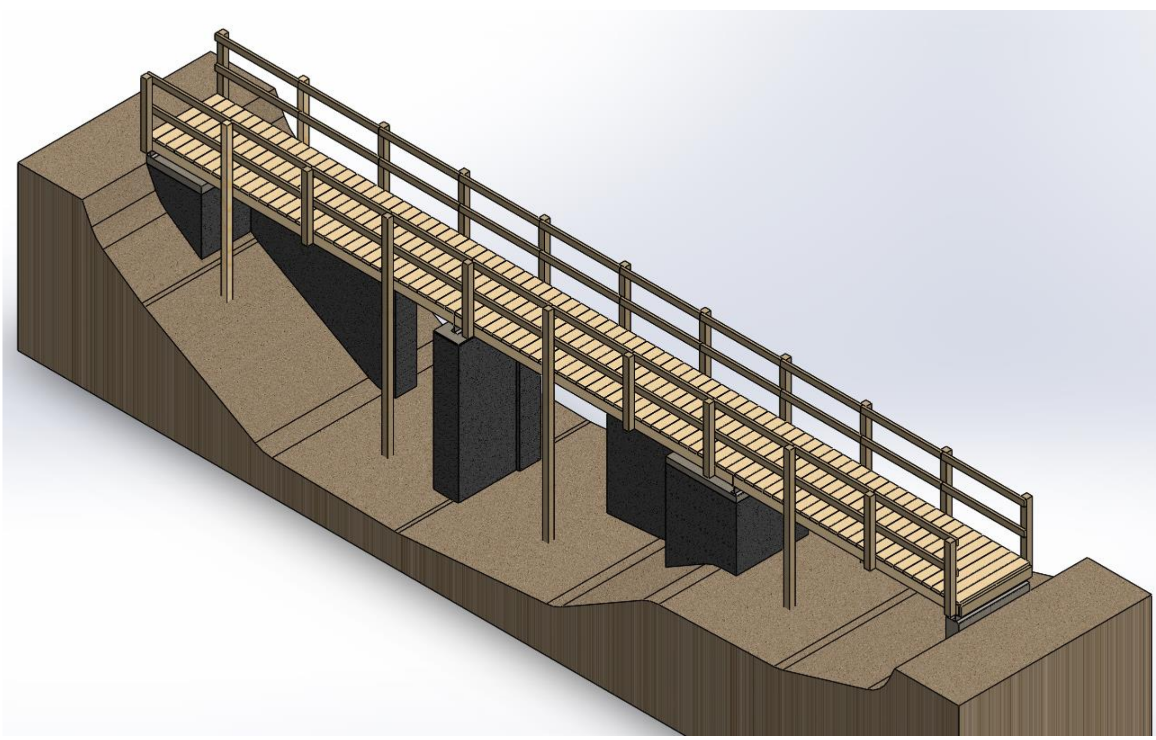


Figure 21: Steel H-Beam on La Boquilla Bridge

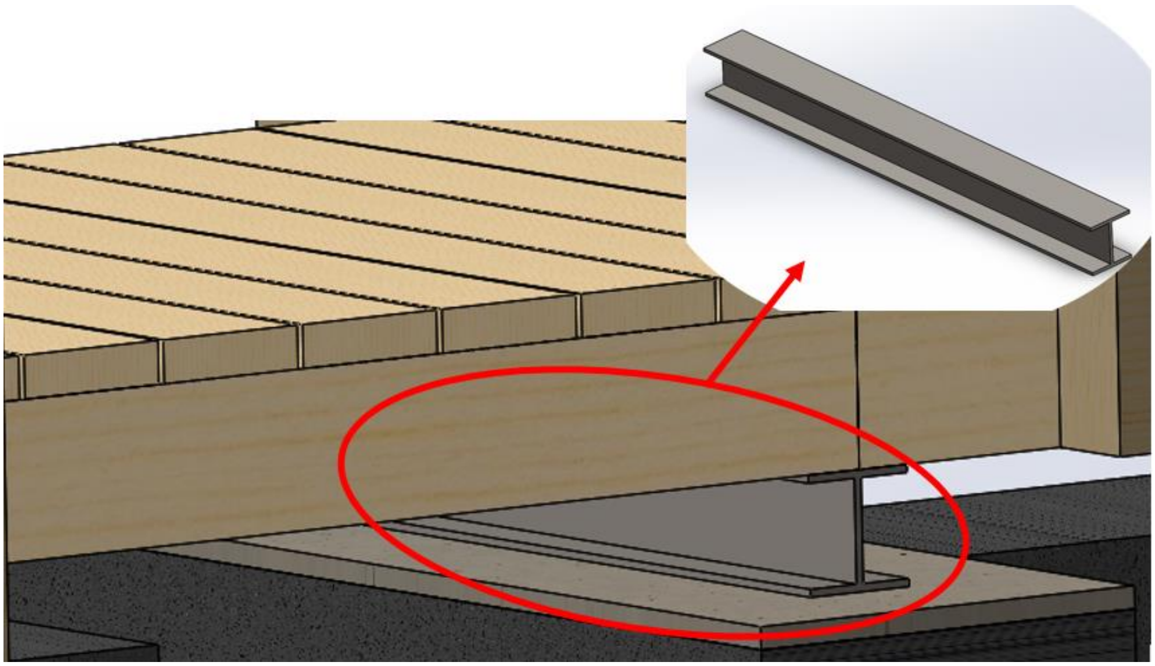
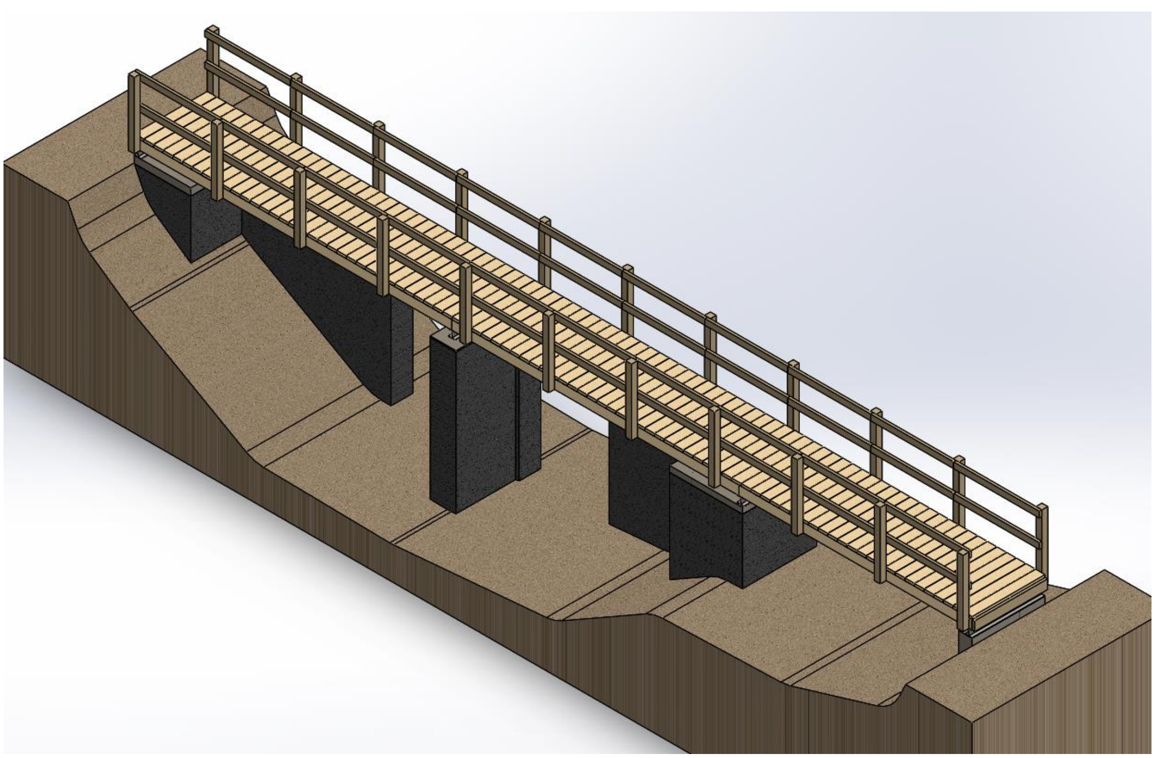
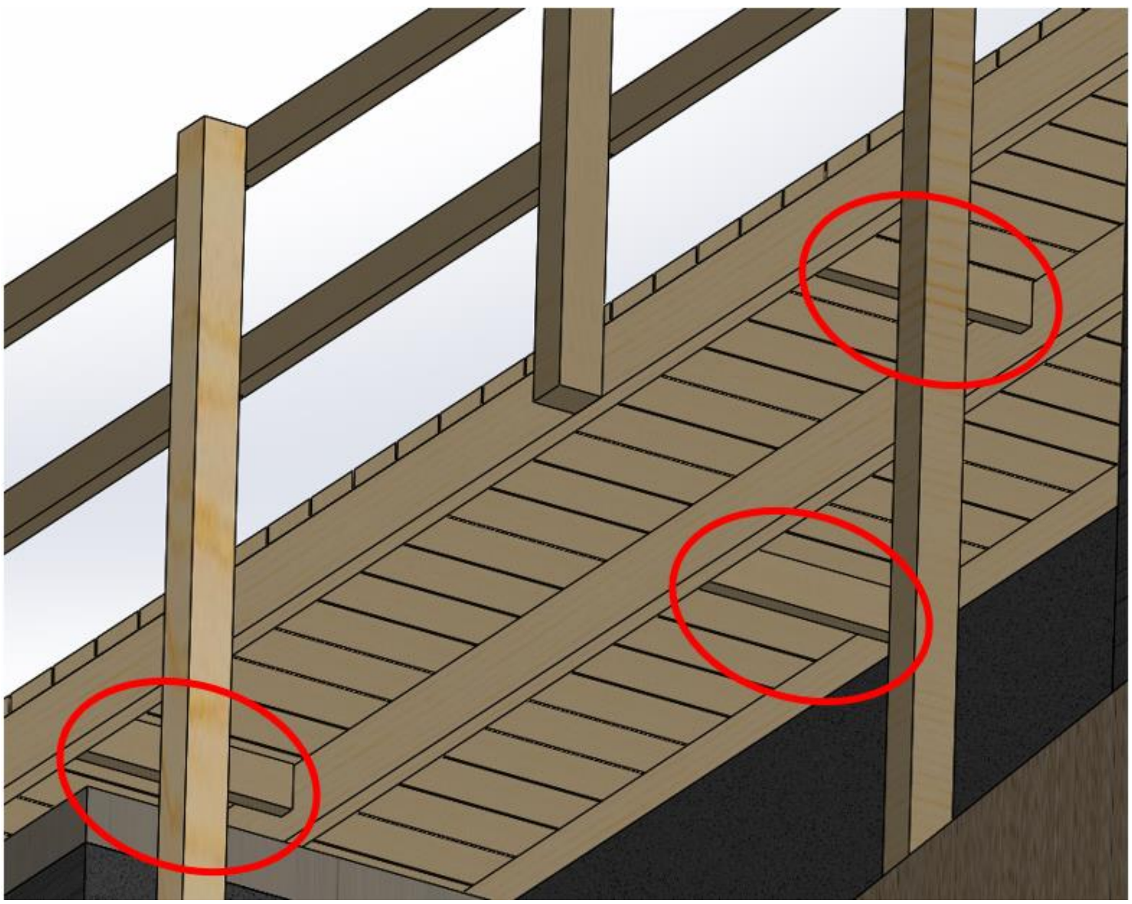


Figure 22: La Boquilla Model without Pylons and with H-Beams



This separation between the bridge and the abutments increases the bridge's longevity, since it prevents the wood from rubbing on the concrete. In addition, the H-beams also raise the bridge up higher, so it will be even more protected from any potential water damage that the river could cause. On top of the steel plates or H-beams are three 2"x6" pieces of lumber (known as stringers) that stretch across each of the bridge's abutments. These stringers are placed on their sides so that they can withstand more downwards forces. Furthermore, there are supports between the stringers that will improve the lateral stability of the bridge (Figure 23).

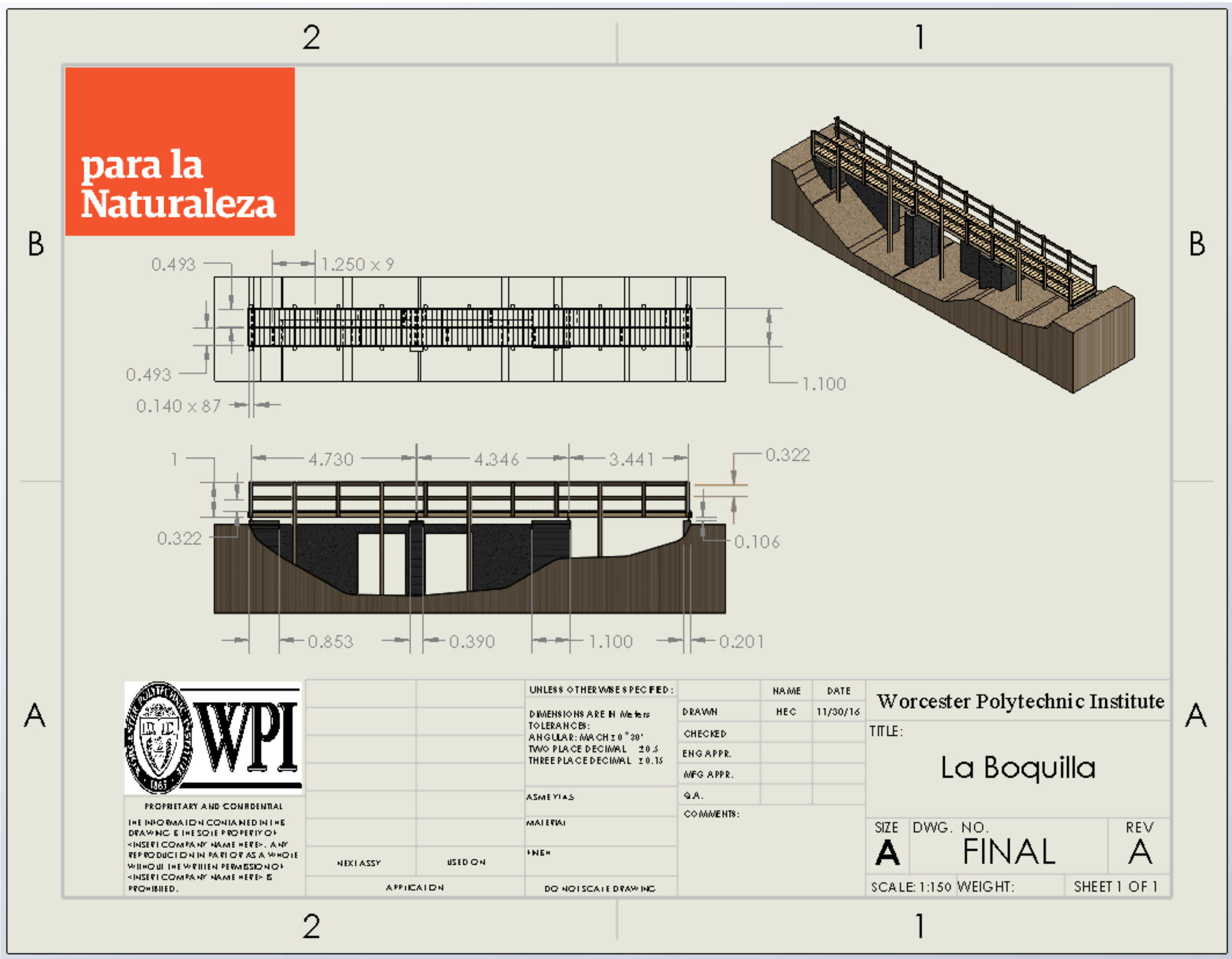
Figure 23: Stringer Supports on La Boquilla Bridge

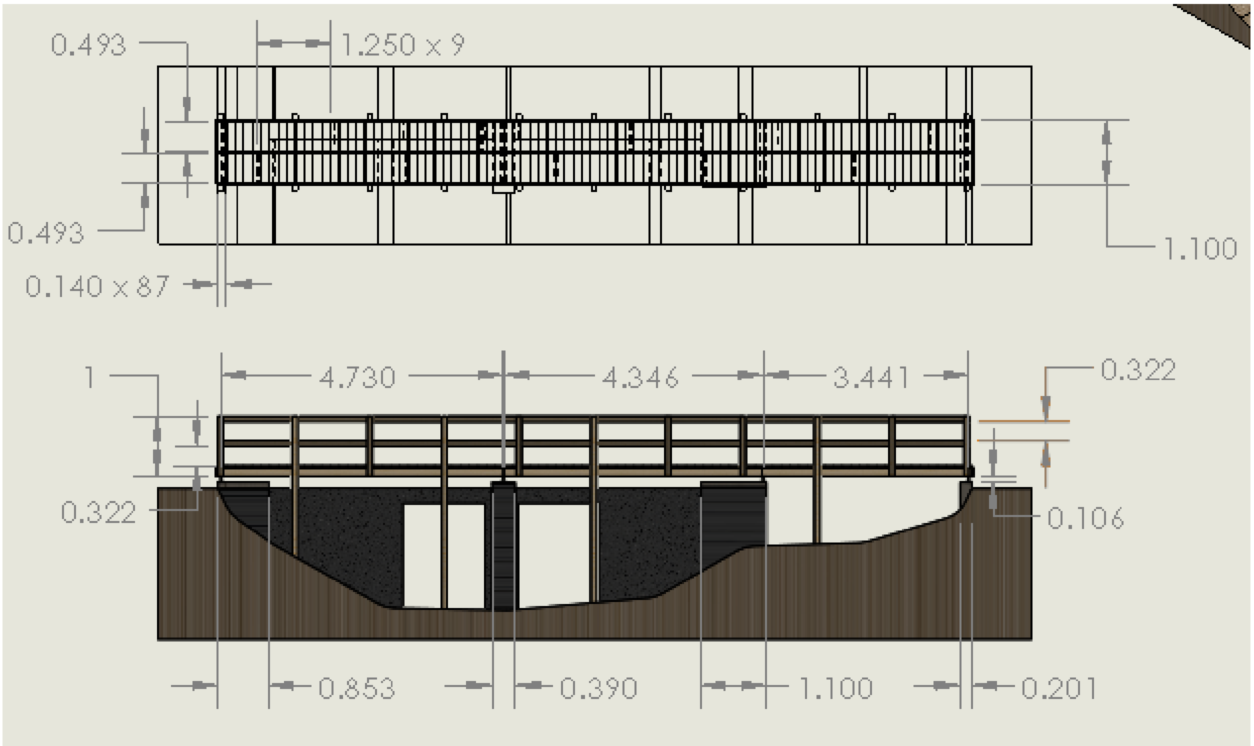


Attached to the sides of the stringers are the pylons for the bridge's railings. Each of the pylons are 4"x4" pieces of wood that are spaced 1.25 meters apart so there is no risk of blocking the flow of the river, which was one of Para La Naturaleza's concerns. These pylons will also increase the structural stability of the bridge, since they increase the number of points of the bridge that touch the ground. On top of the stringers will be a deck made out of 2"x6" pieces of lumber. Originally, the deck was going to be composed of 2"x4" pieces of lumber, but having looked at the costs to make the bridge, it would be cheaper to make the deck out of 2"x6" pieces of wood since it requires fewer individual pieces of wood. The pylons of the bridge will stretch one meter above the deck as per the preference of Para La Naturaleza. Although Groenier stated that the handrails should be at least 54 inches (1.37 meters) tall for bridges that will be used by bicyclists, Para La Naturaleza felt that that the railings would be too tall and would obstruct the view of those who traverse the bridge. Therefore, the railings will be one meter tall.

The bridge will also need dirt placed on either side of it in order to make the approach to the deck a smoother transition. This will ease the transition onto the bridge, eliminating the possibility of going over a bump or having to dismount the bike to walk it over the bridge. Full dimensions and plans for La Boquilla Bridge can be seen in Figure 24.

Figure 24: Dimensions and Plans for La Boquilla Bridge





4.6 Material Cost-Benefit Analysis

During our on-site analysis we noted that the location of the bridges was going to be an issue for the construction materials. The wet environment and climate significantly increases the decay rate of wood and increases the deterioration of metal. To combat this issue, we researched different materials that could maintain a long lifespan in the given conditions. While researching these materials we also tried to stay within a lower price range to be mindful of Para La Naturaleza's budget. Looking at the wood described in Section 3.2 each has its own advantages and disadvantages.

For La Boquilla Bridge we saw that Pine is a very inexpensive wood to purchase and work with, however, it is a softwood and its lifespan is not that long. As described earlier, this lifespan is increased when the wood is pressure treated.

As we looked at the more rot resistant types of wood, we began to see a sharp rise in price. An example of this is Oak. It is a strong, rot resistant hardwood, but the price of a 2”x4” is nearly eight times as expensive as a 2”x4” of Pine. In addition, it is not widely used as a building material and therefore harder to find in large quantities in the size boards we would need. From this, we decided to eliminate Oak as a building material.

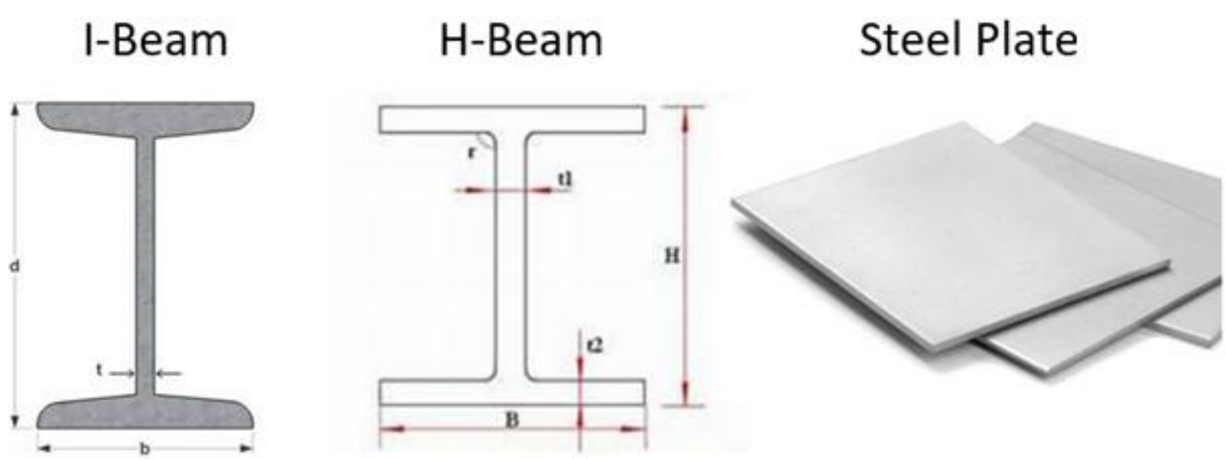
Hemlock was another wood that looked promising, as its price was nearly the same as Pine. However, looking into its properties we found that the wood really was not appropriate for this environment. It is not rot resistant, susceptible to bug infestation, and its grain structure makes cutting the boards difficult. It is because of these facts that we chose to not recommend Hemlock for the build.

Another wood that we felt would be a good candidate is Cedar. Cedar has a long lifespan in hot climates and is termite resistant, making it a good choice for the Hacienda La Esperanza area. One drawback to this wood is that it is five and a half times more expensive than Pine. Regardless of its high price, we recommend this wood as a possible choice because of its properties and ability to withstand environmental factors.

Another option that we investigated was composite wood. Although it is expensive, its longevity makes up for this cost. We also took into account that the composite wood could not be used as the main structural building material because it has a strength that is often uneven. We decided that if composite wood is chosen in the build, it should only be used as decking.

Next we looked at the metal spacers that would be used to separate the concrete abutments from the stringers. When we did our analysis on the galvanized steel I-beam in Section 3.2, we found that it was the strongest choice and the galvanization would fare well in the wet salty air, but it was also very expensive. The steel H-beam was another choice we looked at. Unlike the galvanized choice, the normal steel was a fraction of the cost, however, it is more susceptible to rusting and requires additional maintenance. The final option for the spacers were steel plates. An advantage to using steel plates is that they can easily be attached to the concrete and wood. Disadvantages are that it is an expensive choice and that it will put the wood in closer proximity to the water which may increase rot. Examples of each material for the spacers can be seen below in Figure 25.

Figure 25: The view of each different spacer material



It was easier to determine the materials for the María Hernández Bridge since it will be constructed out of only two materials. The main part of the bridge would be constructed of construction grade concrete and then we chose was ½” steel rebar as it was the common reinforcing rebar used in construction and was the best price for strength given.

4.6.1 Excel Spreadsheet

In order to determine a cost estimate for each bridge, we chose to create an interactive Excel spreadsheet. We created a separate construction cost spreadsheet for each of the two bridges. Column B of the spreadsheet includes the different types of wood and their respective sizes. Step one for using the spreadsheet is to first input into column C the cost per linear foot for each type of wood and size board. Step two is to input the estimated number of linear feet needed to complete the specific design into column D. In turn, your estimated price for each type and size of wood will be automatically calculated and inputted into column E. In addition to this automation, columns G and H show the estimated total cost for each type of wood, if it was chosen to be the building material.

Figure 26: First Section Showing Cost of Wood for Build

B	C	D	E	F	G	H
Wood Boards	COST PER Linear FT	# OF Feet	TOTAL COST		Wood Total	Cost
2"x4" Pine	$0.84	182	$152.33		Total w/Pine	$929.67
2"x4"Oak	$6.62	182	$1,204.84			
2"x4"Cedar	$4.60	182	$837.20		Total w/Oak	$7,528.68
2"x4" Hemlock	$0.89	182	$161.98			
					Total w/Cedar	$5,187.70
2"x6" Pine	$1.26	439	$553.14			
2"x6" Oak	$10.22	439	$4,486.58		Total w/Hemlock	$984.54
2"x6" Cedar	$7.80	439	$3,424.20			
2"x6" Hemlock	$1.32	439	$579.48			
4"x4" Pine	$1.90	118	$224.20			
4"x4" Oak	$15.57	118	$1,837.26			
4"x4" Cedar	$7.85	118	$926.30			
4"x4" Hemlock	$2.06	118	$243.08			

In the next section, the different types of spacers, rebar, and concrete are shown in column B. The directions are the same as for the wood material section. Column C has the cost per section of the material, and column D again has the number of sections. Column E then tabulates the total cost for each material. Columns G through N then give the total cost of the build with each different combination of wood and metal material. This total includes the cost of rebar and concrete. This allows the user to compare the different prices of each possible material. This is shown below in Figure 27.

Figure 27: Costs Associated With the Metal Spacers and Their Combinations with Wood

B	C	D	E
Building Materials	Cost Per Section	# of Units	Total Cost of Material
1/2" A36 Steel Plate (4'x4' Section)	$293.92	2	$587.84
4.16" x .280" x 4.06"(10ft Section) Galvanized Steel I Beam	$429.00	2	$858.00
4.16" x .280" x 4.06"(10ft Section) Steel H Beam	$131.60	2	$263.20
1/2in Rebar (20ft section)	$4.95	0	$0.00
Concrete yd^3	$100.00	0.44	$44.00

G	H	I	J	K	L	M	N
Building Material Totals	Cost	Building Material Totals	Cost	Building Material Totals	Cost	Building Material Totals	Cost
Pine Steel Plate Rebar & Concrete	$1,561.51	Oak Steel Plate Rebar & Concrete	$8,160.52	Cedar Steel Plate Rebar & Concrete	$5,819.54	Hemlock Steel Plate Rebar & Concrete	$1,616.38
Pine Galvanized Steel I Beam Rebar & Concrete	$1,831.67	Oak Galvanized Steel I Beam Rebar & Concrete	$8,430.68	Cedar Galvanized Steel I Beam Rebar & Concrete	$6,089.70	Hemlock Galvanized Steel I Beam Rebar & Concrete	$1,886.54
Pine Steel H Beam Rebar & Concrete	$1,236.87	Oak Steel H Beam Rebar & Concrete	$7,835.88	Cedar Steel H Beam Rebar & Concrete	$5,494.90	Hemlock Steel H Beam Rebar & Concrete	$1,291.74

The next section has the estimated import costs. To calculate this amount, the estimated import cost of a shipping container should be imported into the cell. This value will also be seen in the total cost cell in column G, as no calculation is carried out. The next section calculates the total labor cost. In this section you must first input values for the “Cost Per Day” for each Labor type into column C. For the workers you must also calculate the cost per day based on the number of workers. For example, in our spreadsheet we have three construction workers that each make $200 a day, so therefore our overall cost per day would be $600. The next step is to estimate the number of days the job will take and input that value into column D under the "# of days" heading. This will then calculate your total cost of labor and input that value into column E. All your individual labor costs will then be added up and tabulated into column G.

Figure 28: Costs Associated with Importing Materials and Labor

B	C	D	E	F	G
Item To Be Imported	Cost Of Importing to Puerto Rico				Total Import Cost
Storage Container (W/ Material)	$1,350.00				$1,350.00
Labor Type	Cost Per Day	# of Days	Cost of Labor		Total Labor Cost
Conrete Delivery	$100.00	1	$100.00		$3,413.20
Conrete Mixing	$100.00	1	$100.00		
Concrete Workers (1)	$213.20	1	$213.20		
Construction Workers (3)	$600.00	5	$3,000.00		

The last section then tabulates the entire cost of the build based on the different combinations of each type of wood, each type of metal building material, the concrete and rebar, import costs, and the cost of labor. If one thing gets changed in the spreadsheet, you can see these changes continue throughout the document, which gives an accurate estimate of the overall cost. It is important to note there are no values that have to be inputted into this section.

Figure 29: Total Cost of Construction for La Boquilla

B	C	D	E	F
Materials	Total Cost of Construction Including Importing/ Labor		Materials	Total Cost of Construction Including Importing/ Labor
Pine Steel Plate Rebar & Concrete	$6,324.71		Cedar Steel Plate Rebar & Concrete	$10,582.74
Pine Galvanized Steel I Beam Rebar & Concrete	$6,594.87		Cedar Galvanized Steel I Beam Rebar & Concrete	$10,852.90
Pine Steel H Beam Rebar & Concrete	$6,000.07		Cedar Steel H Beam Rebar & Concrete	$10,258.10
Oak Steel Plate Rebar & Concrete	$12,923.72		Hemlock Steel Plate Rebar & Concrete	$6,379.58
Oak Galvanized Steel I Beam Rebar & Concrete	$13,193.88		Hemlock Galvanized Steel I Beam Rebar & Concrete	$6,649.74
Oak Steel H Beam Rebar & Concrete	$12,599.08		Hemlock Steel H Beam Rebar & Concrete	$6,054.94

For the María Hernández Bridge, the structure had less possibilities for materials so the Excel spreadsheet is much smaller. The first section includes the material costs for the rebar and concrete needed for the build, while the overall material cost tabulated is in cell G4. The next section involves the cost of importation of materials, which is in cell G9. The last section estimates labor costs for the build and is calculated in cell G12. The last section involves the estimated build cost of everything and is tabulated in G17. The picture of the Excel spreadsheet can be seen in Figure 21.

Figure 30: María Hernández Cost Of Construction Excel Spreadsheet

Maria Hernandez Ramp Bridge					
Building Materials	Cost Per Section	# of Units	Total Cost of Material		Total Material Cost
1/2in Rebar (20ft section)	$4.95	50	$247.50		$2,017.50
Concrete yd^3	$100.00	17.7	$1,770.00		
Item To Be Imported	Cost Of Importing to Puerto Rico				Total Import Cost
Storage Container (W/ Material)	$1,350.00				$1,350.00
Labor Type	Cost Per Day	# of Days	Cost of Labor		Total Labor Cost
Conrete Delivery	$51.00	1	$51.00		2,869.80
Conrete Mixing	$100.00	1	$100.00		
Concrete Workers (3)	$639.60	3	$1,918.80		
Construction Workers (2)	$400.00	2	$800.00		
					Total Build Cost
					$6,237.30

Figure 31: Cost Breakdown for María Hernández Bridge

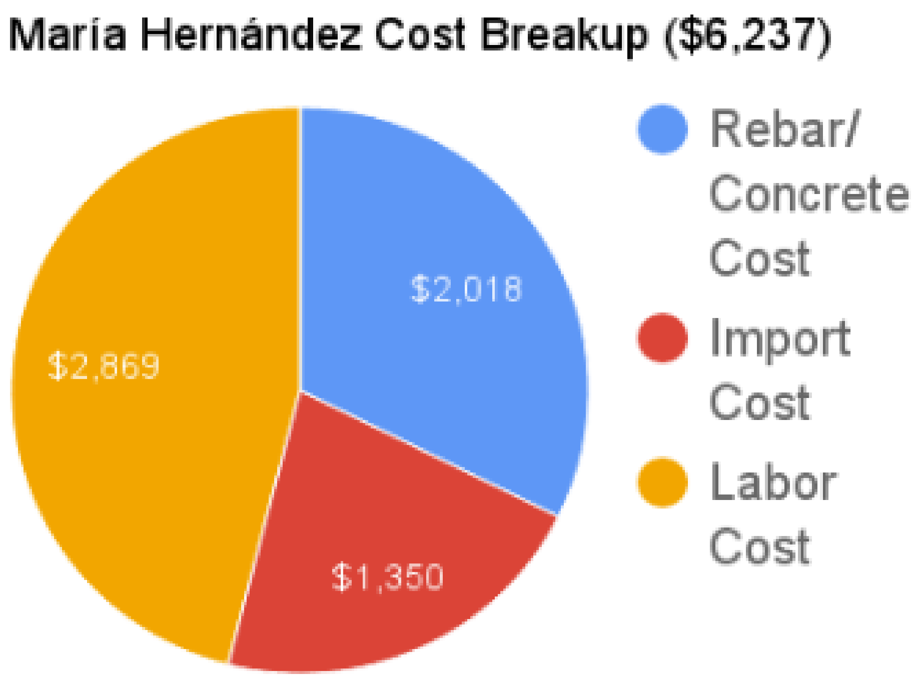
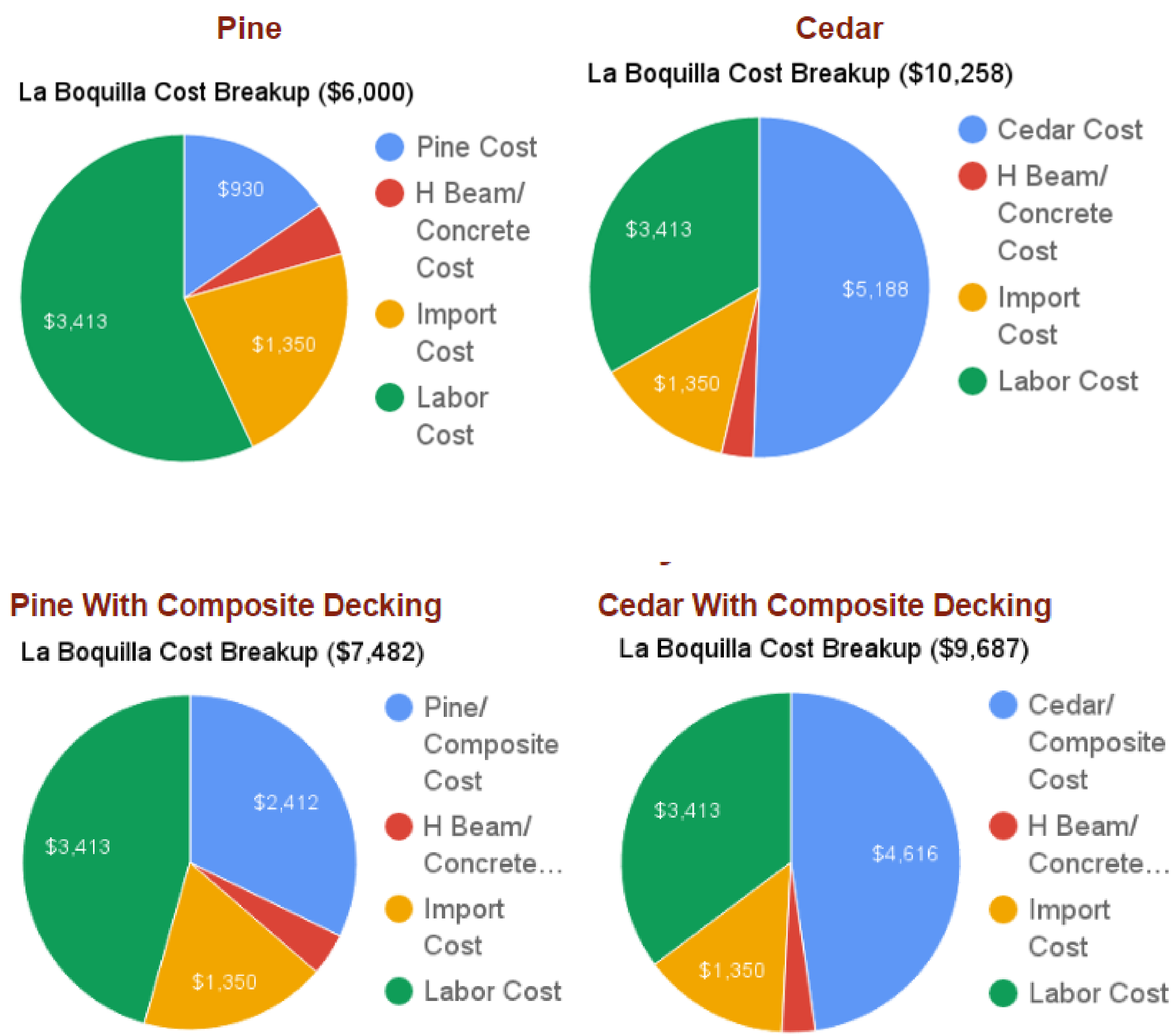


Figure 32: Cost Breakdown for La Boquilla Bridge



4.7 Evaluation of Informational Signs and Interview

This section includes the overview and evaluation of the informational signs located at historic sites throughout Puerto Rico, as well as the interview conducted with Señora Padilla. The historic sites that we visited included The City Wall in Old San Juan, Fort San Felipe Del Morro, and Hacienda La Esperanza. The interview with Señora Padilla was conducted to gain an understanding of the colors, texts, and information that Para La Naturaleza utilizes in their signs at Haceinda La Esperanza in particular.

The first historic site that we visited was The City Wall in Old San Juan. Figure 33 shows a picture of the sign along the wall that borders that tourist walkway past the exhibit. The figure is accompanied with Table 3 that evaluates the exhibit. During our evaluation of each sign we looked at the main purpose of each sign, the location, and any attributes that could assist us in our sign development.

Figure 33: Educational Exhibit 1-The City Wall

Table 3: Evaluation of Exhibit 1

The City Wall	
Main Purpose	To educate the community and tourists about the history of the wall including: original purpose, year of creation, and any renovations that have been carried out.
Location	Old San Juan
Notable Attributes	Translated into both Spanish and English, texture of the sign to contrast against the wall.

The next site that we visited was the Fort San Felipe del Morro in Old San Juan. Fort San Felipe del Morro is managed and maintained by the U.S. National Park Organization and is visited by thousands of tourists every year, which makes the exhibits ideal for observations. Figures 34-37 show pictures of the informational signs that are strategically placed throughout the fort. The accompanying tables analyze the main purpose, location, and notable attributes of each exhibit.

Figure 34: Educational Exhibit 2-Fort San Felipe del Morro-Defending San Juan

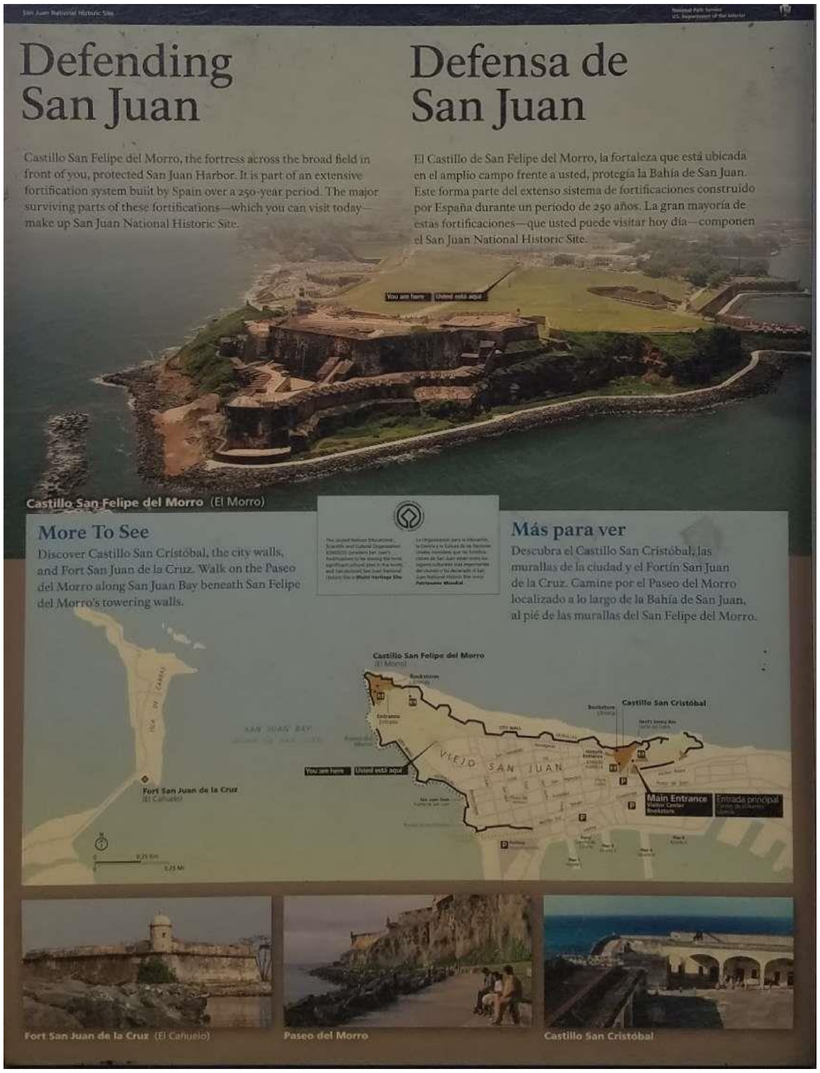


Table 4: Evaluation of Exhibit 2

Fort San Felipe del Morro	
Main Purpose	To educate the community and tourists about the history of the fort and how it acted as a line of defense from the sea for hundreds of years.
Location	Old San Juan, Fort San Felipe del Morro
Notable Attributes	Map of where the fort is located in San Juan, a marker of where the reader is standing in relation to the map, pictures of the current state of the fort, bold headings, translated in both Spanish and English.

Figure 35: Educational Exhibit 3-Fort San Felipe del Morro-The Dry Moat

Table 5: Evaluation of Exhibit 3

Fort San Felipe del Morro	
Main Purpose	To educate the community and tourists about the history of the fort and how they utilized the dry moat to keep attackers away.
Location	Old San Juan, Fort San Felipe del Morro
Notable Attributes	The labels on the picture to teach terminology, a box that answers a commonly asked question, a picture of an attacker in the moat to explain how the moat functioned, translated in both Spanish and English.

Figure 36: Educational Exhibit 4-Fort San Felipe del Morro-The Three Flags

Table 6: Evaluation of Exhibit 4

Fort San Felipe del Morro	
Main Purpose	To educate the community and tourists about the three flags at the fort.
Location	Old San Juan, Fort San Felipe del Morro
Notable Attributes	A picture of each of the flag with their names below, a picture of the flags within the fort, bright colors, translated in both Spanish and English.

Figure 37: Educational Exhibit 5-Fort San Felipe del Morro-Standing Guard

Table 7: Evaluation of Exhibit 5

Fort San Felipe del Morro	
Main Purpose	To educate the community and tourists about one of the gun types used by soldiers in the fort.
Location	Old San Juan, Fort San Felipe del Morro
Notable Attributes	A 3D mock-up of the weapon, a paragraph that described each part of the gun and how they work, a picture of the gun in use, translated in both Spanish and English.

The last site that we visited was Hacienda La Esperanza, the site in which both the bridges are located. Figure 38 shows a picture of the traditional sign that Para La Naturaleza uses throughout the site to help tourists during open houses and tours of the plantation. During our visit, we conducted an interview with Señora Padilla about Para La Naturaleza's vision for the signs for both of the bridges. The interview questions and responses can be seen in Table 9.

Figure 38: Educational Exhibit 6-Hacienda La Esperanza

Table 8: Evaluation of Exhibit 6

Hacienda La Esperanza	
Main Purpose	To advertise Hacienda La Esperanza and the activities available to the public
Location	Hacienda La Esperanza, Manatí
Notable Attributes	Clear contact information, the Para La Naturaleza Logo, contrasting colors, bold text, few words.

Table 9: Interview with Señora Padilla at Hacienda La Esperanza

Interview Responses at Hacienda La Esperanza	
Interviewee:	Señora Padilla
Date:	11/16/2016
Questions	**Responses**
1. What colors does Para La Naturaleza primarily use in their signs?	Usually we use blue, green, red and orange
2. Do the signs needs to be in both Spanish and English?	In public areas, the signs have both Spanish and English words
3. Are there any specific that you want on the signs for the La Boquilla bridge and the María Hernández Bridge?	The top should have the name of the bridge in spanish and in parenthesis, put that "puente" means bridge in english. Maybe the century the bridge was built below and the restoration year below that. Must have the contact information, social media, and logo of Para La Naturaleza.
4. Is there anything else we should know when making the designs?	We use minimal words and usually the logo contrasts with the other color on the sign (ie. blue and orange).

4.8 Informational Sign Designs

The interview we conducted with Señora Padilla paired with the visits to historic sites in Puerto Rico helped us to create our informational signs. Through our analysis of these signs, we determined three aspects that we needed to include to create an informational sign that would benefit the community and tourists. These three main aspects include bright colors that catch the viewer's eye, translation into both Spanish and English, and clear, bold headings.

Our interview with Elizabeth gave us the exact guidelines, template, colors, font, and information we needed to include in our signs, making the development and expectations very clear. Using her responses to our interview questions we were able to develop two signs that could be placed at the opening of both bridges. The signs can be seen in Figure 39 and Figure 40.

Figure 39: Sign Design for María Hernández Bridge

Figure 40: Sign Design for La Boquilla Bridge

Both signs fit the design aesthetic that Para La Naturaleza uses on site at Hacienda La Esperanza. To make the signs visible to tourists, pedestrians, and cyclists we recommend that the signs have a width of 12 inches and a height of 18 inches. The placement of the signs in regards to the bridges can be seen in Figure 41 and 42.

Figure 41: Placement of María Hernández Sign on the Bridge

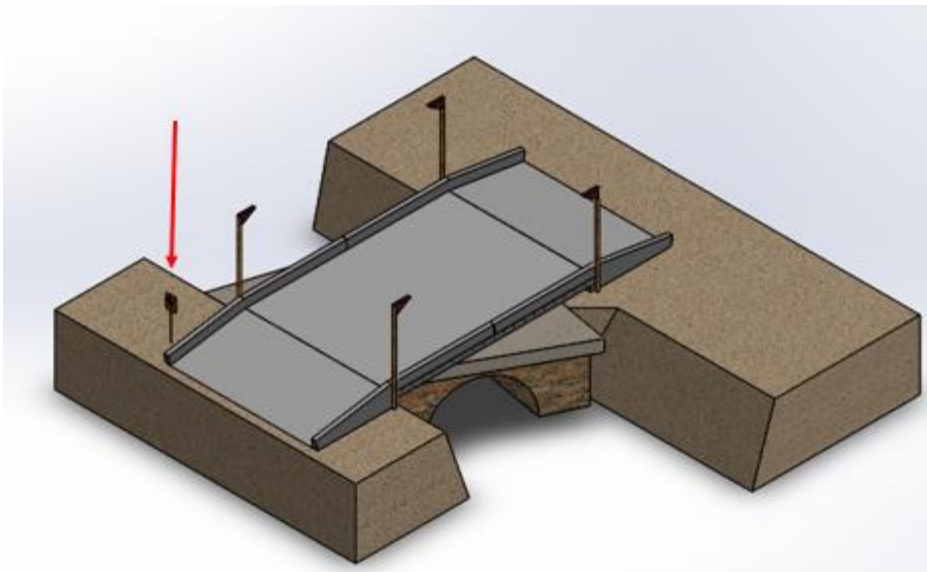
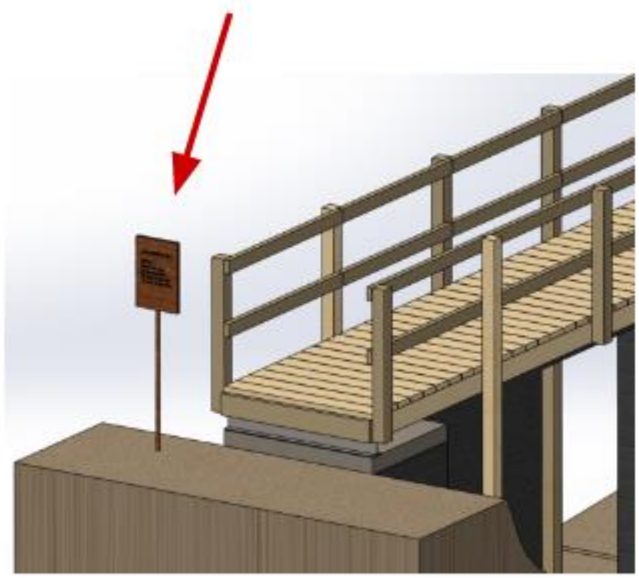


Figure 42: Placement of La Boquilla Sign on the Bridge



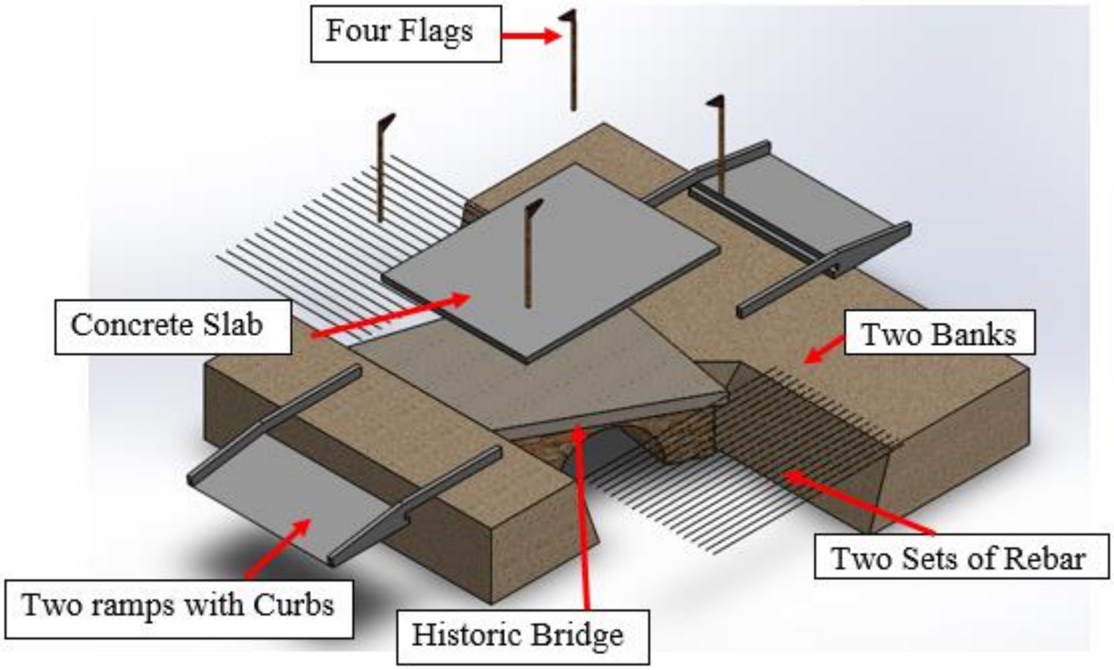
5.0 Analysis

This section will contain a breakdown of each bridge's step-by-step construction. A detailed description of how to construct each part of the bridge is described as well as which materials to use. Proceeding the step-by-step construction description, this section also analyzes the results of the force simulations conducted on each bridge.

5.1 María Hernández Bridge Step-by-Step Construction

Figure 43 shows the María Hernández Bridge broken up into separate parts. This specific arrangement of components is called an Exploded View in SolidWorks. It shows the full assembly of the bridge except for the false frame. A false frame is a support mechanism that would be built underneath where the future bridge would go. It serves as a type of mold for the concrete to settle and harden. After the concrete is hardened, the false frame would be removed. First, the two sets of rebar would come together to form a checkerboard style mesh. Then, the concrete slab is poured so that the rebar resides in the middle. The ramps and curbs are then made coincident to the slab. Finally, the flag poles are put into place and the whole bridge is assembled.

Figure 43: Exploded View of María Hernández Bridge



5.2 María Hernández Bridge Force Simulation

Once we completely finished the model, we ran a few simulations on it to see how much weight it could potentially hold. This is done by specifying in SolidWorks what is to be fixated and what amount of forces should be put where. The orange dots at the bottom of each ramp represent what face on the bridge is fixated when the simulation is ran. The purple lines represent the force acting on the bridge. For this situation, we simulated a 50,000 lb tractor with 50 inch by 20 inch wheels. The 50,000 lbs is split into four groups (12,500 lbs for each 50 inch by 20 inch rectangle shown on the bridge). However, this is not a realistic situation. We did this to add a factor of safety to the bridge. The weight of the largest John Deere 6715 (same model at Hacienda La Esperanza) is around 22,000 lbs without including a trailer or other agricultural equipment (Easterlund, 2016). So instead of just running the simulation with what is actually going to be applying force to the bridge, we more than doubled that number.

The different mesh of colors shown in the legend and throughout the bridge represent stress in Figure 44 and displacement in Figure 45. The stress is in megapascals (MPa) and the displacement is in millimeters (mm). The yield strength for the concrete used in the simulation is 25 MPa, however the flexural strength ranges from 3 to 5 MPa. Flexural strength, also known as modulus of rupture, bend strength, or fracture strength, is defined as a material's ability to resist deformation under a load (Concrete - Properties, 2016). Since we used a moderate strength concrete and the max MPa reached was 2.92, we believe that this bridge could support up to 50,000 lbs. This limit is higher than anything we expect will cross the bridge. The displacement of the bridge says that is will only move 1.87 mm in the weakest part of the bridge. This would be indistinguishable to the naked eye.

Figure 44: Stress Simulation Results for María Hernández Bridge

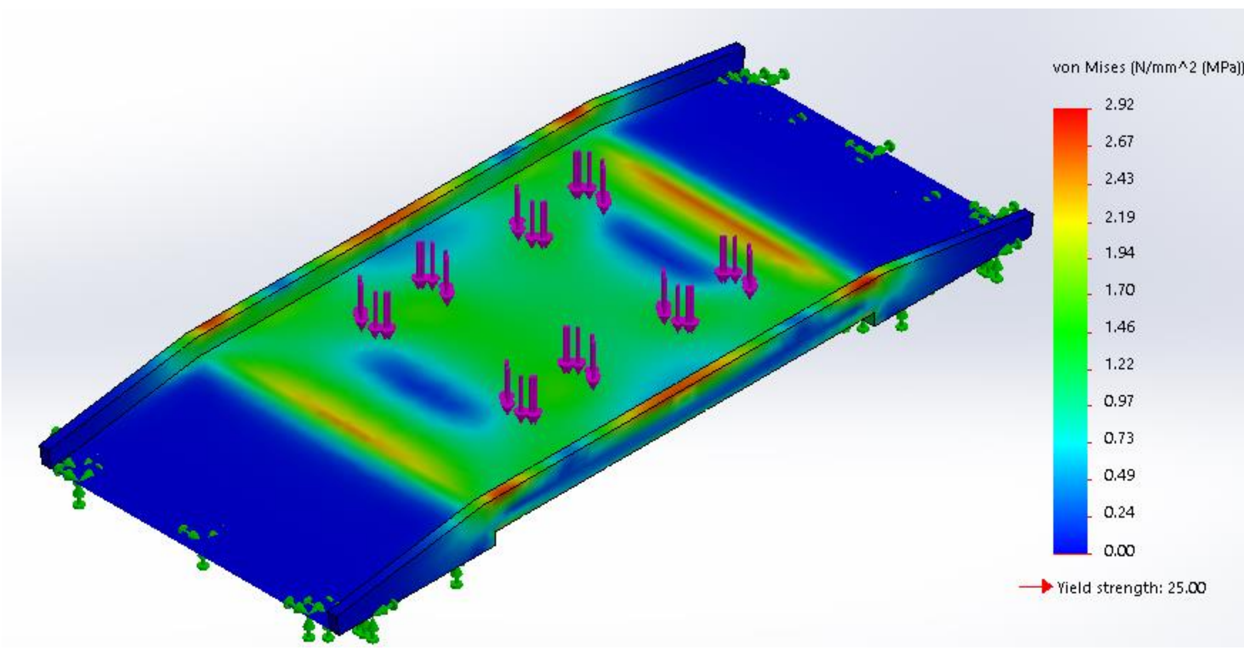
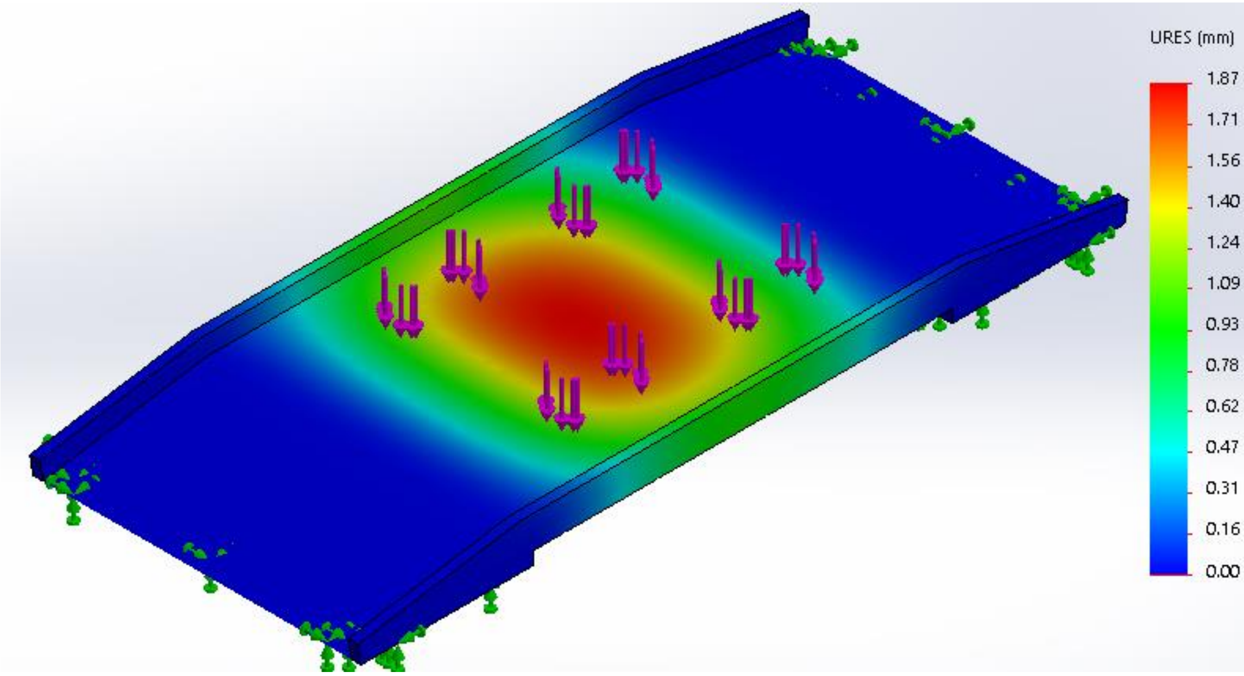


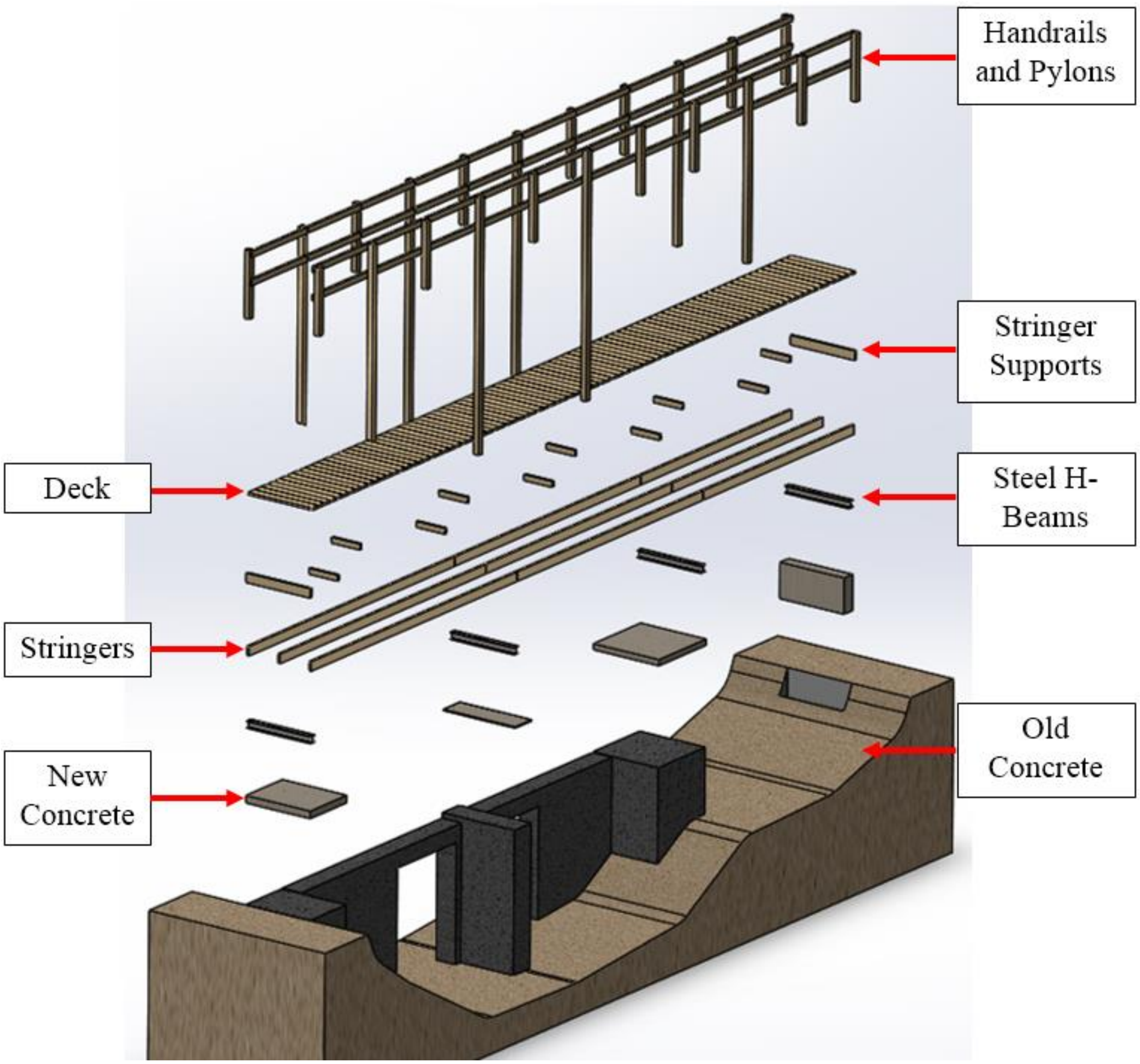
Figure 45: Displacement Simulation Results for María Hernández Bridge



5.3 La Boquilla Bridge Step-by-Step Construction

For the construction of La Boquilla Bridge, the following steps will need to be performed. First, new concrete will be placed on top of the old concrete abutments. This concrete will be a couple of inches thick at the most – just enough to resurface the old concrete abutments so that they are completely flat. Next, steel H-beams will be placed on top of the new concrete and will be attached with concrete screws. The stringers will then be attached to the H-beams and the stringer supports will be bolted in between them. The decking will then be connected to the stringers with screws or nails, and will consist of a total of 87 2”x6” planks of wood. The Pylons will then be bolted to the stringers and hammered into the ground, and the handrails will be screwed or nailed to the insides of these pylons. Once all of this is finished, the bridge will be complete (Figure 46).

Figure 46: Exploded View of La Boquilla Bridge



5.4 La Boquilla Bridge Force Simulation

By putting the model of La Boquilla Bridge in a simulation, we were able to determine that it would be able to withstand more than 1000 pounds of force before breaking. The force was applied to the middle of the bridge, as you can see by the purple arrows in Figures 47 and

48. In addition to calculating the stresses that the bridge underwent, the simulation also calculated how much the bridge would deform under these conditions. Under the 1000 pound load, the bridge deformed four millimeters at the most. The model we used only encompasses a portion of the bridge. However, since the bridge is broken up into essentially three segments, separated by abutments, we figured that this simulation would be satisfactory in displaying accurate results. The bridge was also made out of pine, which was the least expensive wood out of the ones we have chosen to research.

Figure 47: Stress simulation Results for La Boquilla Bridge

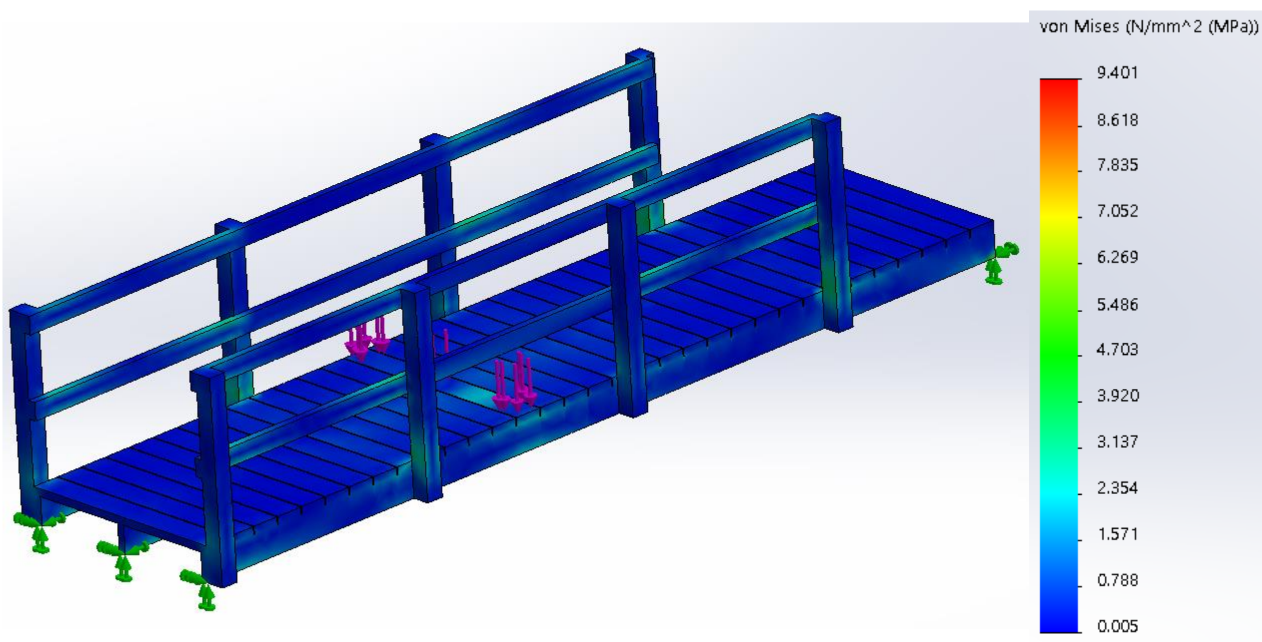
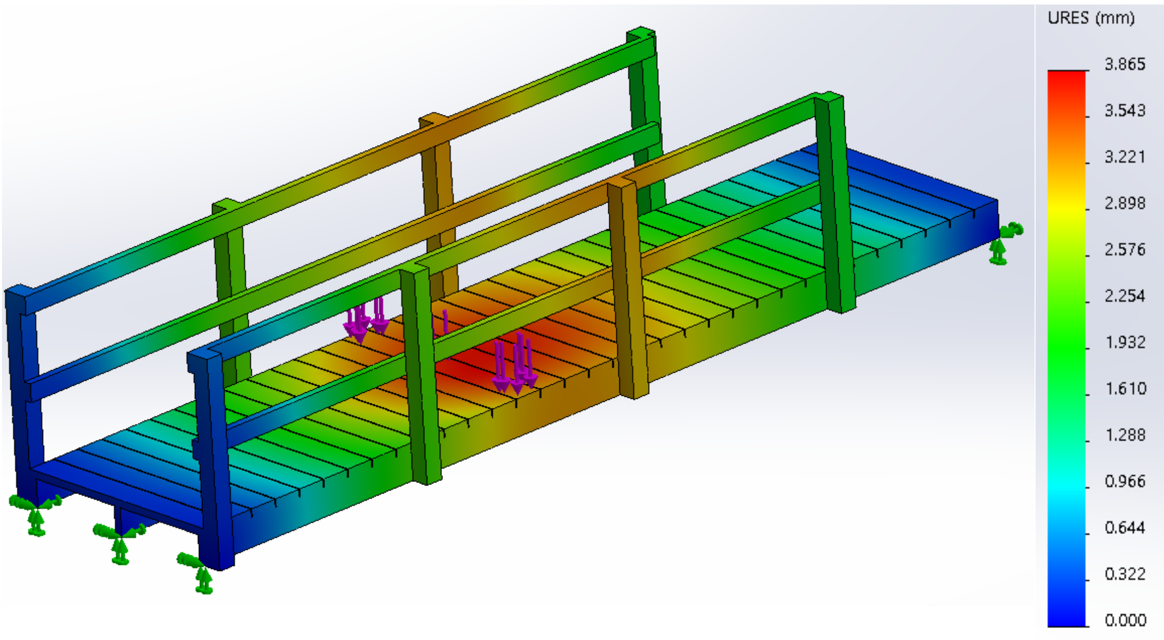


Figure 48: Displacement Simulation Results for La Boquilla Bridge



6.0 Conclusions and Recommendations

The bridge design recommendations our team has developed for Para La Naturaleza are mentioned above. The recommendations we have proposed aim to help Para La Naturaleza preserve and utilize the historic structures while creating safe and structurally sound bridges. For the María Hernández Bridge our team recommends that Para La Naturaleza create a new reinforced concrete bridge that will go over the pre-existing structure. This bridge design will eliminate the use of the historic bridge, preserving the structure as it is. We also recommend that for La Boquilla Bridge, Para La Naturaleza should build either a completely pine or cedar footbridge or a combination of those traditional woods with composite wood for the decking. Each design will utilize the pre-existing structures. The most cost effective design will be to utilize steel H-beams under the stringers to create long lasting stability while also being mindful of the project's budget.

Our final recommendation to Para La Naturaleza is to install informational signs at the entrances to both bridges in an attempt to educate the community. The signs will inform visitors of Hacienda La Esperanza of the history and name of the bridges. We hope that our recommendations will help aid Para La Naturaleza in their pursuit to preserve historic structures while educating the general public.

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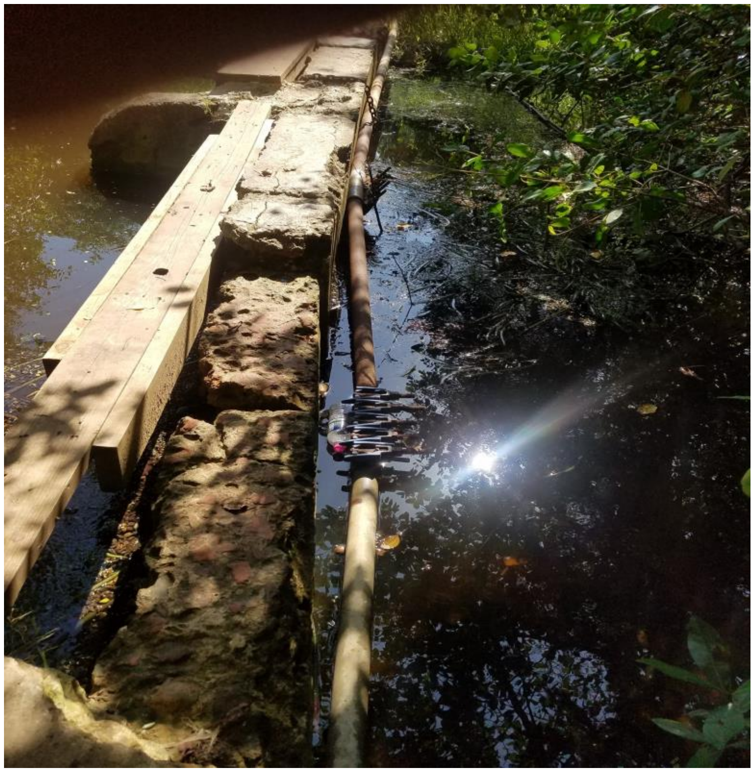
Appendices

Appendix A: María Hernández Bridge Pictures

Appendix B: La Boquilla Bridge Pictures



Appendix C: Initial On-Site Checklist

- Dimensions:
    - Total span of bridge:
    - Height of bridge from water surface:
    - Width of abutment (both sides):
    - Length of abutment (both sides):
    - Height/thickness of abutment (both sides):
    - Distance between pier and abutments (both sides):
    - Thickness of pier:
    - Width of pier:
    - Height of pier:
    - Width of path leading to bridge:
    - Distance from water pipe to bridge:
    - Width of river from the surface of the water:
    - Width of river from the top of the river banks:
    - Depth of the middle of the river (from the surface):
    - Depth of the river ¾ of the way to the edge (both sides) (from the surface):
    - Angle of the river bank from the water's surface (both sides):
    - Angle of the river bank from the ground (both sides):
- Materials:
    - What is the bridge composed of?
    - Is more than one type of material used for any part of the bridge?

- Structural Analysis:
    - Describe any cracks and the location of them.
    - Describe any rust and the location of it.
    - Describe any deterioration/wear and the location of it.
    - Are there any signs of water lines/variations in the height of the river?
    - Any signs of termites or other creatures that have caused damages to the bridge?
- Environmental Concerns:
    - Are there mangroves present? How close to abutment?
    - Are there any habitats present? How close to abutment?
    - Is erosion apparent on the banks of the river?
    - Are there any risks of objects falling on top of the bridge? Will they damage it if they do so?
    - How hard is the ground surrounding the bridge? Is there clay under the surface? Is it very muddy? Is the ground full of rocks?
    - How much does the water level rise and will it affect the bridges?
- Describe any other observations or concerns:

Appendix D: Secondary On-Site Checklist

María Hernández Bridge:

Angle 1 of deck: 107.5 degrees

Angle 2 of deck: 98.2 degrees

Angle 3 of deck: 116.4 degrees

Angle 4 of deck: 89.8 degrees

Abutment length of arch mill side: 6’5”

Abutment length of arch field side: 4’4”

Width of tire tracks: 8’10”

Overhang width: 4’8”

Overhang length of dirt: 8’4”

Vehicles driven over the bridge: tractors, utvs, golf carts, trucks, and cars

La Boquilla Bridge:

Total distance: 44’10”

Length of abutment 1: 3;8”

Width of abutment 1: 2’10.5”

Height off of water of abutment 1: 10.25”

Length of abutment 2: 1’3”

Width of abutment 2: 3’

Height off of water of abutment 2: 11.5”

Length of abutment 3: 4’11”

Width of abutment 3: 3’8”

Height off of water of abutment 3: 1’1.25”

Distance between abutment 1 and 2: 11’1”

Distance between abutment 2 and 3: 10’2”

Distance between abutment 3 and bank: 13’5”

Length of bar: 23’7.5”

Width of bar: 1’3”

Height of bar: 1’4”

Depth of water abutment 1: 1’8.5”

Depth of water middle of abutment 1 and 2: 5’2”

Depth of water abutment 2: 5’3.5”

Depth of water middle of abutment 2 and 3: 4’7”

Depth of water abutment 3: 1’9.5”

Depth of water middle of abutment 3 and bank: 1’7”

Appendix E: Mechanical Properties of Wood

Type of Wood	Average Dried Weight (lbs/ft^3)	Specific Gravity	Hardness (lb_f)	Modulus of Rupture (lb_f/in^2)
Eastern White Pine	25	0.34-0.40	380	8,600
Spanish Cedar	29	0.38-0.47	600	10,260
Eastern Hemlock	28	0.36-0.45	500	8,900
White Oak	47	0.6, 0.75	1,350	14,830

Appendix F: SolidWorks Images of Both Bridges