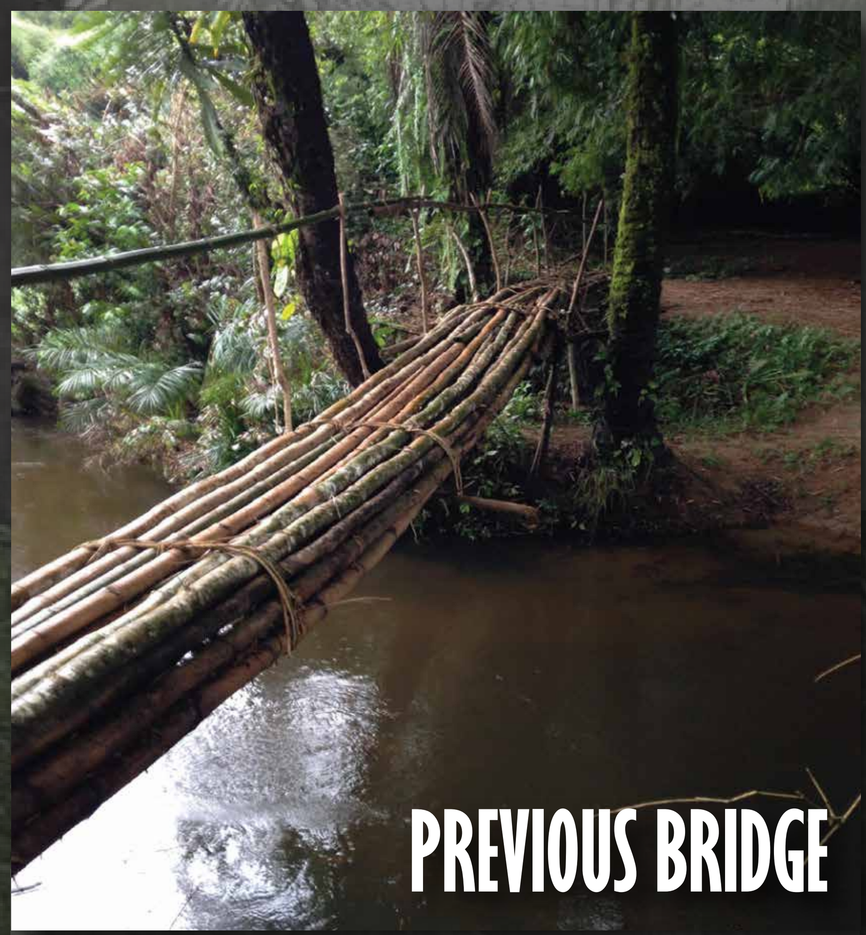
LIBERIA FARM BRIDGE

CONNECTING FARMS, COMMUNITIES, AND BUILDING ECONOMIES



PREVIOUS BRIDGE

"This project not only bridged the gap between villages and society, but between communities and cultures around the world through engineering."

"This was the first time that's been done --connecting these communities- access to medical care, taking children to school, food security- all of that stuff. Before the farm these were isolated communities we didn't even know about."

"They didn't even know they weren't supposed to be able to pull something off of this scale"

Project Description

The Liberia Farm Bridge is a bridge located 45 miles outside of Monrovia, Libera. The bridge was designed by four civil engineering students, and spans 53 feet, with a 30 ton capacity. The engineering project drew together a community in the U.S. Many people donated materials, time, and finances to make the project happen. The Bridge connects a farm and a few villages to the rest of society, providing opportunities for growth and economic developement.

Before the bridge was in place, crossing the water either happened on the bridge shown, or by wading through the water. During times of heavy rain, the locations were completely isolated from all healthcare, food, and outside resources. The engineering students used engineering practicies such as surveying, steel constrcution design, concrete construction design, and soil design.

The students also learned about clear communication with engineers and ethical design. The farm is currently in the process of developing 150 acres of farmland to grow rice, cocoa, and palm, providing jobs as well. It is now one of the largest developing farms in Liberia. Therefore the bridge is aiding in the development of many jobs.

Student, Faculty, and Professional Collaboration

Fields: Construction management, professional contracting, manufacturing, marketing, international logistics, drafting, estimating, scheduling, surveying

Construction team: 4 civil engineers, 1 mechanical engineer, 1 business professor, 1 business major, 1 social work major, and dozens of liberians

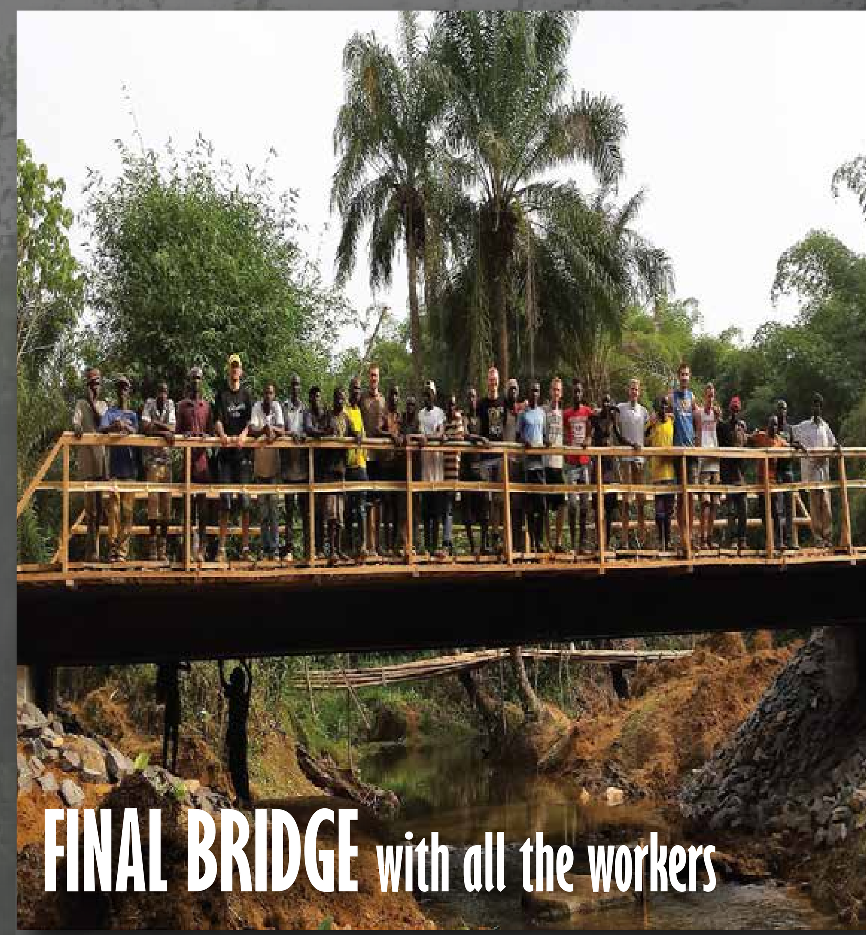
Professional support: Geotechnical, structural, mechanical, and civil engineers, including review by a board of multidisciplinary PE's.

Volunteer support: 27 U.S. companies- general contractors, manufacturers, an agricultural startup, equipment dealers, electrical contractors, coatings and paints specialists, maintenance departments, parts suppliers, logistics companies, and a hospital.

Public Health, Safety, and Welfare

This vehicle bridge provides safety to all local peoples. It protects them from wading in the river and potentially getting water borne diseases and from injury. The bridge gives them access to healthcare quicker than before because of the vehicle access. It also promotes the welfare of the people through stimulating agriculture and economic development.

The bridge was constructed by paid local workers. This prompted the growth of the local community through people joining the existing community because of the work being done. This bridge also aided in the creation of farmland, thus creating jobs and opportunity that the local communities never recieved prior to the bridge.



FINAL BRIDGE with all the workers

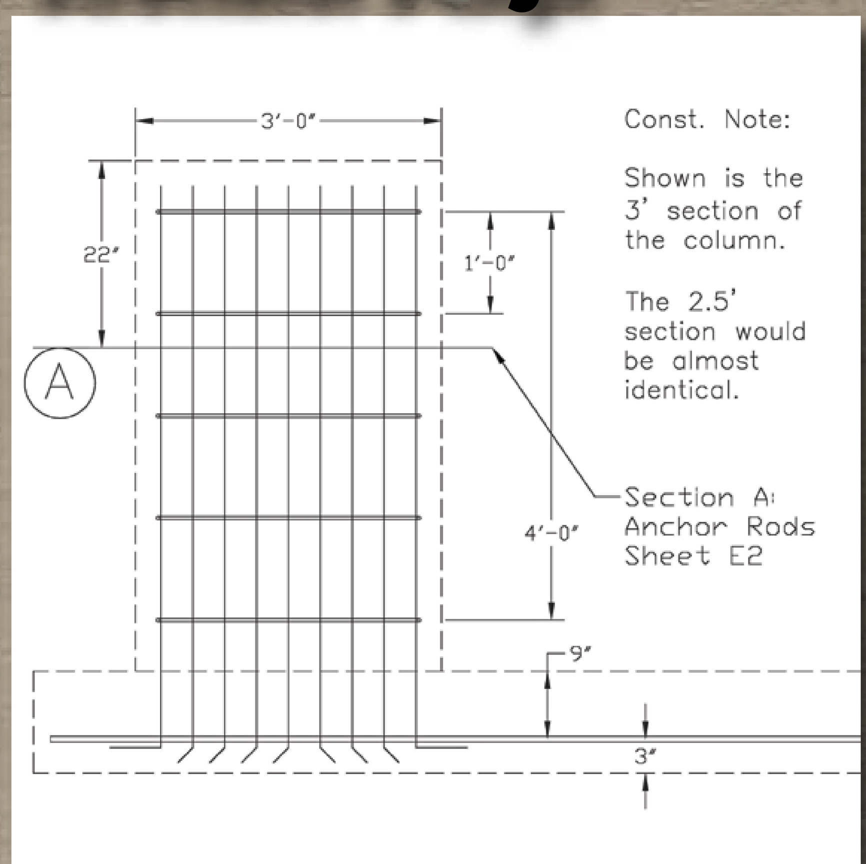
Knowledge and Skills Gained

- Ethics
- Design Codes
- Quality Control
- Time management
- Teamwork
- Software
- Construction management
- Construction practices
- Safety
- Logistics
- Cross culture relations

The engineering students learned how important engineering and infrastructure are to progress in the developing world. They each continue to use the lessons they learned.

Preliminary Design

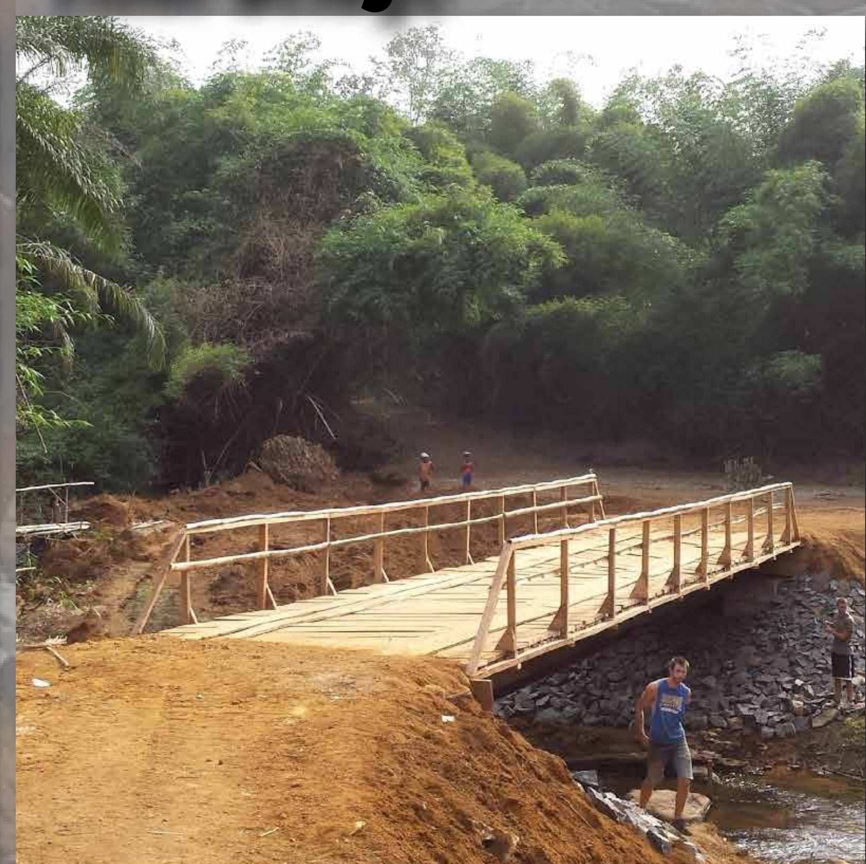
Structural Design



Repurposed Beams

Construction

Final Bridge



Liberian Farm Bridge Abstract

The Liberian Farm Bridge, near Harbel, Liberia, connects a farm and three communities to civilization and the market. Through partnership with a local non-profit organization, four undergraduate engineering students worked closely with three P.E.'s, two construction management professionals, and other consultants to design and construct the bridge. The local church and its members, who operate the farm, have thrived in providing hope and joy in a country leveled by a civil war and an Ebola outbreak within the past 15 years. Recently, church leadership purchased more farmland to take steps toward self-sustainability. However, due to a river crossing between the farmland and market, the farm was without vehicle access. Without a bridge, the farm would not be able to grow and develop as the church needed. The newly constructed bridge and farm are located in the jungle, 45 miles east of Monrovia.

A team of four civil engineering students were challenged to provide a solution to this problem. Conditions required a span large enough (minimum 50 feet) for the river's flood cycle (Liberia receives over 200" of rain/year), and the ability to withstand any loads caused by flooding.

Figure 1: Completed Bridge

The final design used materials from both the United States and Liberia. The 53-foot bridge allows a 30-ton truck to reach the farm. In addition, the farm connects three communities to the modern world. The superstructure is steel beams refurbished from an American hospital. These beams were fabricated by the design team with aid from local businesses and then shipped to Liberia. The footings and piers were made of Liberian concrete materials, and the bridge deck used Liberian wood. Approaches were built using soil around the river.

Construction finished in eight working days in December 2015. The design team also performed the construction, assisted by four others from the school with construction management experience, and about 30 Liberian locals. Liberian help was crucial to the project's success, and also created ownership in the project for the community. To ensure the bridge remained functional long into the future, the design team also created a regular maintenance schedule.

In the year since construction, the farm has grown by 140 acres. More resources have arrived at the farm, such as a rice mill and a shipping container with supplies. One team member now works for the non-profit organization involved, overseeing other engineering projects and following up with the bridge and community. He also assists with inspection and maintenance, while also ensuring the Liberians still have a sense of ownership of the bridge. All of the engineers involved in this project have gone on to take and pass the FE. One is pursuing a master's degree in Structural Engineering and the others are gaining professional experience, working toward a PE license.

This project provided a technical solution, but also made a much larger impact in the lives of many Liberians and shows how engineering can be used to better lives and situations around the world.

Liberian Farm Bridge

I. Project description

The Liberian Farm Bridge is a vehicle bridge located 45 miles outside of the capital city of Monrovia, Liberia, in the middle of the rainforest. It is a 53-foot bridge consisting of concrete, steel, and wood, designed and built by four civil engineering senior design students.

Agriculture in Liberia is a substantial need. The country of Liberia is the 4th poorest nation in the world, and most people there live on less than $1 per day. Their staple food is rice, but 90% of rice in Liberia is imported. The need for growth in agriculture is desperate, and its largest obstacle is infrastructure.

The students were connected to a non-profit with relational ties in Liberia. The Liberians with whom they partner requested help with the bridge, even purchasing 150 acres of land because of the possibility of a bridge. A few communities beyond the bridge also looked forward to the improvement that a bridge could bring.

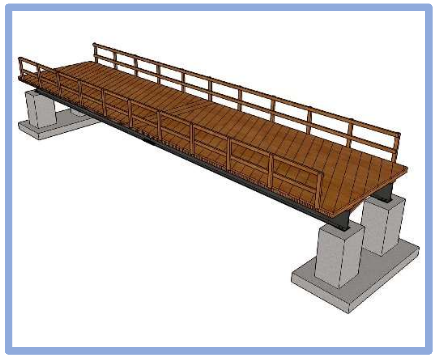


Figure 2: Final Concept Sketch of Bridge

With this vision and purpose, four undergraduate engineering students took up the task of designing and constructing a solution to the problem with the collaboration of faculty members, professional engineers, and mentors. The design included the bridge superstructure, abutments, approaches, decking, safety features, scheduling and estimating. The students submitted many reports to mentors and professional engineers throughout the process. The final design was also reviewed by professional engineers before construction.

Throughout the construction, the team members were able to practice construction management, resolution of unforeseen difficulties in the field, and recalculating design requirements, all while keeping the project on a rigorous schedule.

The construction was completed with the help of thirty paid local Liberian workers and four additional students and faculty of the college in the span of eight working days.

Figure 3: All of the construction workers standing on the complete bridge

This bridge now provides communities access to health care, food and goods markets. It also equips the farm with the access to equipment, markets, machinery, and many other resources.

II. Collaboration of faculty, students, and licensed professional engineers

Were licensed professional engineers (P.E.s) involved?
Two P.E's helped oversee the project through weekly and sometimes bi-weekly meetings. They provided scheduling guidance, design supervision, and other professional contacts when necessary. The team reported to the P.E's both during and following the project, and presented the project to a board of 8 engineers from 4 disciplines in the school's engineering department. A third P.E. with extensive bridge experience provided suggestions or recommendations to challenges the team ran into. Assistance was also given by two bridge engineers that are about to take their P.E. licensing exam.

How did the students, faculty, and P.E.s interact?
The project idea itself formed from a conversation between an engineering student and campus chaplain. After a project goal became more defined, this student and the chaplain traveled to Liberia with a team from the non-profit organization to assess the feasibility of the project.

Following the trip, the students immediately began design work and reaching out to other faculty and P.E.s. A faculty member mentored the group throughout the process, giving project advice and setting scheduling goals. This taught the students about the importance of collaboration with P.E.s; the students were ultimately in charge, but the advising P.E.'s had the experience necessary to keep the project professional.

One of the most important things for the team was to complete construction in a 25-day window over Christmas break. The biggest potential setback to the construction timeline was properly surveying the site to determine bridge abutment locations. Improperly placed, aligning the abutment anchor bolts with the steel beams would be nearly impossible. To mitigate this risk, students worked closely with faculty and P.E.s in a nearby manufacturing company to form a solution: create a temporary structure to support the steel beams. This way, the abutments could be poured directly under the beams with anchor bolts cast in place, eliminating the possibility for error.

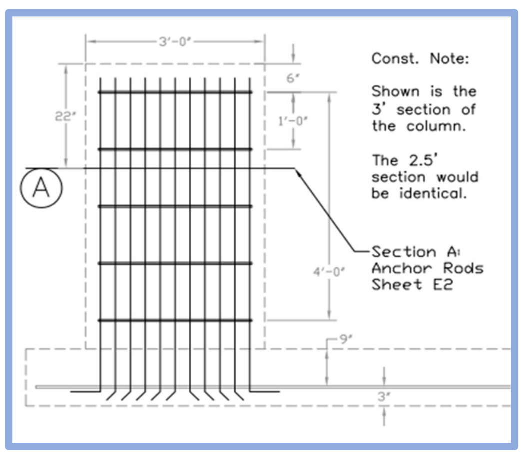


Figure 4: Construction drawing for rebar layout in concrete piers

What was learned through collaboration that would not have been learned in the classroom?
Even though classrooms train students to follow deadlines, late assignments are of irrelevant importance next to missed project milestones. The students had a strict timeline that not only needed to be kept, but also communicated 5,640 miles away to those in Liberia who were helping prepare the site and equipment for the construction.

The students also learned about the importance of clear communication with the public and professional contractors and companies involved. In order for this project to succeed, the team needed outside help and approached local businesses for assistance with services and material. Many local businesses helped with providing recycled steel beams, sandblasting, resizing, and powder-coating. The local community also joined together to donate to the project, making it financially possible. Proper and clear communication of the status and purpose of the project to the public and to businesses was also vitally important; this area is seldom dealt with and could not have been properly learned in the classroom.

Figure 5: Photos of the steel beams before and after cleanup

Volunteer work became incredibly important to this project, especially in the four volunteers who traveled to Liberia with the project leaders for construction. The team of 8 altogether met multiple times before leaving for training in both construction and culture. The team practiced mixing concrete, surveying, and trained each other in the areas each individual was best at: formwork, concrete mix design, tool procurement, and Liberian culture. For those not on the design team, a binder was prepared containing all the construction drawings and a daily schedule including goals and material budgets. Each of the 8 team members received several tasks to prepare for in advance to divide the leadership on site. The team was led in learning about Liberian culture by the two team members who had been there before, reading several books and watching 3 documentaries along the way.

III. Protection of health, safety, and/or welfare of the public


Figure 6: Footbridge that had been servicing the river previously

Prior to construction of the bridge, the community had been using a footbridge constructed of bamboo stalks tied together, pictured at right. This bridge was a safety hazard- narrow, uneven, and extremely slippery when wet. Because this footbridge was the only way to haul goods to and from the farm, carrying goods across made the situation even more perilous. Those who did not choose to use the footbridge would opt to walk through the river- also a dangerous situation. During flood season, the farm became nearly impossible to reach via the footbridge due to rapidly moving water.

The engineered bridge aimed to solve all of the hazards created by the footbridge. The new bridge is 12 feet wide, wide enough for both pedestrian and vehicle use. The bridge deck was flat and made from locally sawn lumber, giving adequate traction even when wet. Finally, the bridge was constructed to ensure that the highest flood (according to local guidance and recommendation) would not reach the bottom of the steel beams. Except in the case of extreme flooding, where the flood water rises and spreads past the built-up approaches, the bridge is passable even during the rainy season. Hence, travel is still possible to or from the farm for both regular use, and more importantly, in case of emergencies.

Another important design aspect was railings for the bridge. Even though the bridge was built for predominantly vehicle and equipment traffic, the design team knew it would be widely used for pedestrian traffic as well. Thus, including railings was an important construction step. Immediately after the deck was completed, construction of the railings began to minimize the risk of falling off the bridge deck.

Knowing the risks above needed to be mitigated during design was easy. It was clear the farm needed something safer and stronger. However, the *extent* to which the bridge was safer and stronger needed to be determined. Even though Liberia has no building design codes or construction inspections, the design team chose to adhere to the building codes and requirements used in the United States. U.S. codes have been thoroughly tested, and the team concluded that using these provided the highest amount of safety to the Liberians using the bridge. The team used Load and Resistance Factored Design (LRFD), using all applicable factors. The team used ACI 318-14 for concrete design, The AISC Steel Construction Manual for the steel design, and National Design Specification (NDS) for Wood Construction for the timber design. By using these well-established manuals, the bridge's factors of safety are acceptable in the U.S., greatly exceeding any safety requirements from the Liberian government.

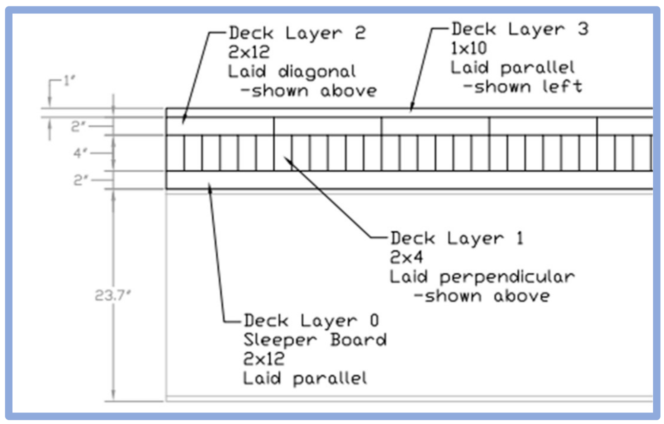


Figure 7: Construction drawings for wood deck layout

Because the bridge project included construction hazards, the team also ensured jobsite safety. Similar to design codes and standards, Liberia has no workplace standards that are enforced as they are in the United States. Again, because these standards have proved to be effective, the design team wanted to adhere to U.S. standards as closely as possible. Equipment such as safety glasses, earplugs, and gloves were used in construction processes that required them. The design team was able to bring various mechanical tools from the United States that the Liberian construction team had no experience with. Given this, the team from the U.S. either worked with these tools or trained Liberians thoroughly before using them.

When it came to the public welfare, the design team aimed to provide a bridge that brought the most blessing to the entire area. To meet the needs of the 8-acre farm prior to construction, any small bridge would be adequate. However, a design that maximized the load capacity would bless the community the most. In the future, the design team wanted to ensure that the farm's limiting factor in growth would not be transportation or equipment access. The design team wanted the bridge to be able to support a farm that could someday work with 800 acres. Besides blessing the farm, the bridge also created a safer way for people in surrounding communities to cross the river. It also allowed more people to travel to and from market. Finally, after the bridge was completed, people from the local communities began to ask the church leaders for another church branch to be established on their side of the river. In summary, the bridge provided new opportunities and luxuries that the people there previously didn't have.

IV. Multidiscipline and/or allied profession participation

This project encompassed the construction management, professional contracting, manufacturing, marketing, international logistics, drafting, estimating, scheduling, and surveying disciplines. The construction team exposed multiple disciplines to engineering as well, including not only four civil engineers and one mechanical engineer, but also a business professor, a business major, and a social work major.

A total of four geotechnical, structural, mechanical, and civil engineers provided insight to the team. The team performed weekly meetings with these professional engineers before construction, consultation during construction, and follow-up after construction, logging 650 hours of design and planning work before construction alone. Design calculations were reviewed by a PE licensed in four states, and following construction, over ten presentations were given to both professional and volunteering parties, including two graded presentations.

Twenty-seven U.S. companies contributed materials, services, or equipment, including three general contractors, three manufacturers, three equipment rental dealers, two electrical contractors, two coatings and paints specialists, two maintenance departments, two parts suppliers, a trucking company, an international shipping company, an agriculture initiative, and a hospital. The team also worked closely with the leadership, agriculture development, fundraising, and accounting divisions of the nonprofit partner, as well as the construction team counterparts in Liberia.

V. Knowledge or skills gained

Ethics: Understanding ethics within a specific cultural context was a key component in design and construction of the bridge. In a developing country like Liberia, there are no legal design guidelines to follow in country. Ethical engineering, however, reaches beyond hitting minimum standards. It required that the design team designed the bridge to be as safe as possible with the available materials. Using the design codes required in the United States and using construction materials from both countries, the team, with the help of many local Liberians, successfully accomplished the task of building a strong, safe bridge, meeting all U.S. code requirements. Ethical thinking also led the design team to make the decision to build the bridge with as many local materials as possible, contributing to the local economy. Finally, the team designed the bridge in such a way that maintenance could be done by local Liberians with basic tools after the team left the country.

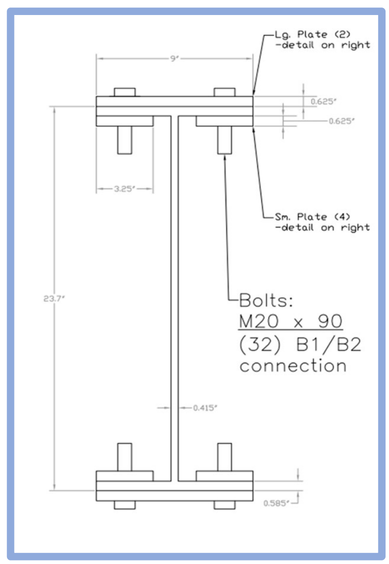


Figure 8: Construction drawings for bolted moment connections

Design codes: The structural elements of the bridge were designed using the AISC Steel Construction Manual, the ACI 318-14 Building Code for Structural Concrete, and the NDS Code for Wood Construction. The design of the bridge stretched the design team, requiring them to dive deeper into the design codes than they had previously done in their coursework.

Quality Control: In order to find an acceptable concrete mix design, the design team experimented with many different concrete test mixes before going to Liberia. Knowing that Liberians tend to add too much water to their concrete, the team closely regulated the amount of water added to each batch of concrete during construction. The team also made cylinders during construction and ran the 28-day test in the US, confirming the 30 ton load capacity of the bridge.

Historical context: Pre-trip research provided the design team with essential information that governed the design of the bridge. One such piece of information was the maximum water level occurring during normal and severe flooding. More preliminary research led the team to discover that in the Liberian market, one cement brand from Germany was substantially stronger than the more readily available Turkish brand of cement. Without understanding the local context and history of the local materials, the bridge may have been substantially weaker.

Aesthetics: While the superstructure of the bridge was built with steel and concrete, the design team desired to use wood on the deck to tie the bridge in with the surrounding jungle, looking less out of place. During construction, the team also used bamboo on the railings as a tribute to the original bamboo bridge.

Time management: This was one of the largest areas of learning for the design team. With one semester to design and three weeks to build, time management was crucial. The design team took advantage of various tools such as Gantt charts to plan a project timeline and ensure all deadlines were met on or even ahead of schedule. The team supplemented Gantt charts by using a task-scheduling application called Trello, enabling them to assign team members to different tasks, while also dividing tasks into the order they needed to be completed by. During construction, the team utilized all non-work time to plan ahead so they stayed on schedule. They had frequent meetings during lunch breaks and at the end of the day to solve unforeseen problems and plan the upcoming days.

Teamwork: One of the most effective ways the team learned about teamwork was through assigning distinct roles to each person. The four-person team consisted of a project manager, a project engineer, a communications liaison, and a construction manager. Although each member wasn't strictly constrained to only work within his role, it was a valuable way to initially divide the workload and then help the others out as needed. While in Liberia, new lessons in teamwork were learned daily. The 8-person construction crew initially planned on spending 2 full weeks building the bridge. With the help of over 30 local Liberians, and proper teamwork and dividing up tasks, the bridge was completed in just 8 working days.

Software: Computer programs that contributed to the planning and design of the project were Mathcad Prime (design calculations), AutoCad Civil 3D (construction drawings), SolidWorks (preliminary modeling), and Risa 2D (load calculations) – all of which are programs which are used by many engineering professionals.

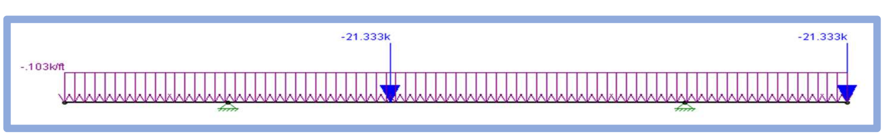


Figure 9: Example RISA 2D analysis used for finding maximum moments

Construction management: One thing the design team heard repeatedly from consultants was: "Things never go as smoothly as planned, so have a good plan, but also prepare for things to deviate from the plan." The design team took the advice seriously and put together a comprehensive construction plan that included a day by day breakdown of tasks and the manpower and equipment required to complete them. The team also put together a contingency plan, so that if anything deviated from the plan during construction, they would have already thought about how to move forward and keep the construction on schedule. One surprise that occurred during construction was when over 30 Liberians showed up to help build the bridge when only 10 were expected. This required the design group to quickly re-think how to best allocate the extra manpower. The extra manpower ultimately led to the bridge being finished in just 8 working days.

Construction: The team gained experience in many construction skills. One example was site layout – using a total station to precisely locate the boundaries of the footings and the height of the forms needed for the pedestals. Other construction skills learned included bending, placing, and tying rebar, excavating foundations, framing, mixing, pouring and vibrating concrete, fabricating steel beams, torqueing bolted connections, constructing the wood deck, and placing rip rap.

Maintenance: Of course, building a bridge is one thing, but keeping it maintained and safe is the only way to make it last. The design team learned what would be required to keep the bridge safe and sturdy, and wrote a maintenance checklist accordingly. This checklist was given to the Liberians that work at the farm, and the team does regular checks with them to confirm the condition of the bridge.

Safety: The team learned that safety was of utmost importance during construction. Safety glasses and gloves were used, and precautions were taken seriously. This especially came into effect with the power tools. Many Liberians were eager to help, but had little or no experience with some of the power tools. It was important to first teach them how to use the tools, and then supervise while they used them, and if necessary, the design team would handle the more difficult or dangerous tasks that required the use of power tools.

Logistics: One major hurdle during the project was for the design team to figure out how to get 4 large steel beams from Sioux Center, Iowa to Liberia, Africa. It was soon decided that they would be shipped overseas on a shipping container. After learning that the container could be used for more than just the beams, the team also sent along many construction tools and supplies in the container that would be useful to have while constructing the bridge. Many other supplies and donations for the organization were also sent to be most stewardly of the money being spent on shipping. All of this had to be completed months in advance to arrive in Liberia on time.

"They didn't even know they weren't supposed to be able to pull something off of this scale." -Lead Mentor