Implementing a Historically Constrained Student Design-Build Project in an Austere Environment

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Abstract

This paper describes a one-semester design-build capstone project in which three senior civil engineering (CE) students designed and built two timber pedestrian bridges at an extremely challenging, remote site. Design and construction was completed as part of a course within the ABET-accredited CE program at the U.S. Military Academy (USMA). The client was the custodian for the historic site under the oversight of the Director of Housing and Public Works (DHPW) at West Point, New York. The team addressed public accessibility to an American Revolutionary War outpost through construction of timber bridges to carry a trail across an intermittent stream and a particularly steep, rocky slope. The site is located on the island directly across from West Point.

A detailed description of the bridge project sets the stage for presentation of the key educational benefits gained by the students who completed it. Student assessment data demonstrates that such projects contribute much, not only to students' learning, but to student's motivation and self-awareness as well. A design-build project in an austere environment forces the students to develop resourcefulness, perseverance, adaptability, and creativity. This project was within the capabilities of senior civil engineering students and represented a unique opportunity for a culminating design experience incorporating real-world considerations of health and safety, constructability, usability/sustainability, historical and environmental sensitivity, economics, political, social, ethical, and aesthetics.

I. Introduction

As long ago as the Revolutionary War, West Point, New York (Figure 1) has been critical to our nation's defense. In the late Eighteenth Century, the high ground flanking the Hudson River

Figure 1: Constitution Island (left) and West Point (right)

at West Point and Constitution Island were key terrain in our forefathers' struggle for independence against Britain. Constitution Island sits on the eastern shore of the Hudson River, directly across from West Point. During the Revolutionary War, American forces occupied both of these critical outposts and denied British advance up the river. Today, West Point is home to the United States Military Academy and still maintains a vital role in our nation's defense by training the Army's future leaders. For these reasons, West Point and Constitution Island are venerated national historic treasures.

The winding trail that leads up to Redoubt Seven on Constitution Island is steep and treacherous. For this reason, one of the best-preserved historic redoubts, or small outpost, that was used by American Revolutionary soldiers is currently off-limits to visitors to the island. These redoubts provided protection and early warning to the main gun batteries and the "Great Chain" that stretched across the Hudson River to prevent unimpeded travel for the primarily ship bound British Army. The British envisioned using the river to mass their efforts as they tried to split the fledgling colonies in half and defeat each pocket of resistance in turn. The "S" shape of the river at West Point made it an ideal location to develop sufficient defenses to prevent unabated travel of the British Navy along the Hudson River. Ships must tack multiple times to negotiate the successive bends in the river – the primary motivation for a steel chain to stop ships dead in the water. It was believed that few sailing ships could ever develop the speed necessary to theoretically break through the chain. Of course, the "Great Chain" was never tested and a discussion on its strength and practicality will be left for another forum. The historic significance and availability of these redoubts are critical in remembrance and reflection on our country's struggle for independence.

Since Redoubt 7 is the most impressive and largest of the outposts and commands an utterly breathtaking view (Arrow, Figure 2) of historic West Point and the Hudson River Valley,

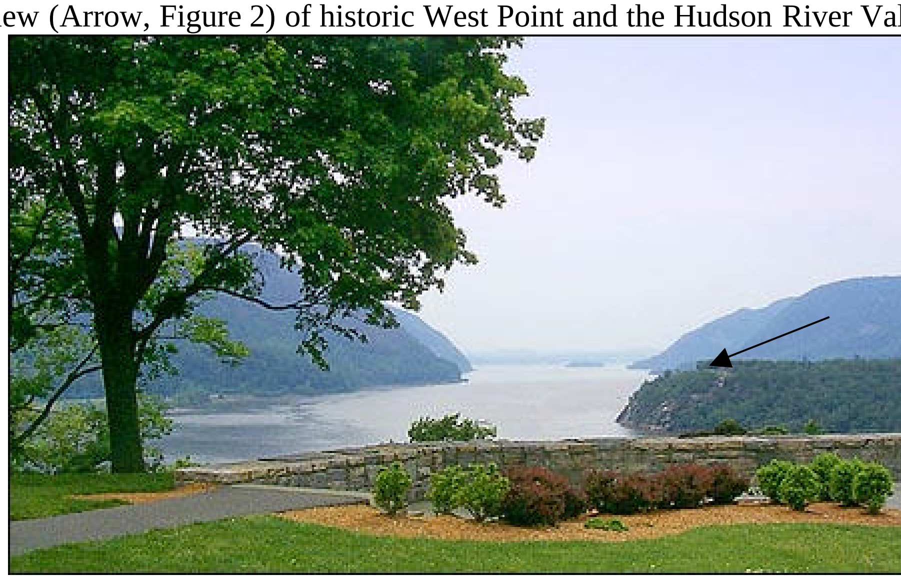

Figure 2: View of Redoubt 7 from West Point's Trophy Point

the Constitution Island caretaker began in earnest to restore a less direct, but much more gradual trail discovered upon review of an old map of the island when it was privately owned by the Warner sisters. A Boy Scout, as part of his Eagle Scout Project, greatly assisted the effort of opening the trial by clearing this old trail of brush and dead branches. Unfortunately, one section of this restored trail was still too steep and often underwater since the swamp that lies up-hill from the trail occasionally overflows. Not to be deterred, the caretaker contacted the Department of Civil and Mechanical Engineering at USMA to request assistance in designing and possibly building a structure that would make this section of the trail accessible to visitors. Designing and building this structure became the one-semester design-build capstone project for three senior CE students.

II. Bridging the Gap

Spring capstone projects are presented to the seniors early each fall to allow timely member selection and to ensure students are prepared to start the project on the first day of the spring semester. There are three basic flavors of projects: research-based, competition-based, and service-based. This project fell into the most sought after form of project in the department - the service-based project. The three seniors expressed a strong desire to fulfill a community need and produce a physical product. The project required coordination with West Point's Director of Housing and Public Works (DHPW) to request resources and initial project approval. There they discovered that they had to send project proposals to two state agencies to obtain formal approval to build the two pedestrian bridges on the island. After project approval, they acquired the necessary materials to complete their design for two timber bridges capable of supporting foot traffic and an ATV loaded with equipment to maintain the historic redoubt.

In order to make this project a reality, the students had to both employ practices and utilize resources that are valuable to engineers. Specifically, they:

- conducted a reconnaissance,
- surveyed the work area,
- developed a three-dimensional map of the area of interest using a computer based terrain analysis program,
- coordinated with outside agencies to gain support for the project,
- lobbied DHPW to provide skilled technical support and funding to support the work,
- constructed a combined 23 feet of timber bridges capable of supporting over 1,500 pounds of traffic,
- assessed the finished product and the steps they took to get there, and,
- performed a dedication ceremony prior to their graduation.

The team's real effort began near the end of the fall semester when the students made a few trips to the island to conduct a reconnaissance of the site and to start visualizing how to address the presented problem. They quickly decided to each develop an alternative solution to the problem and then decide after further research and reflection which alternative best met the client's needs and would be the most cost and fabrication efficient. After Christmas they conducted a site survey using a Total Station Surveying device. After surveying approximately 260 points, they were able to computer-generate a topographic map with a one-foot contour interval using Golden Software's SURFER® for Windows. They used this large scale map to develop and compare their alternatives. The best option was a combination of all three involving the building of two timber bridges that would carry the trail across the wet areas and would use the natural topography of the area to more gradually overcome this steep section of the trail leading up to the redoubt.

Once coordination with DHPW began – the first step for any construction on West Point, the team discovered that the toughest hurdle would be getting approval from the State Historical Preservation Office (SHPO) and the Coastal Zone Management Office (CZM). This approval process would be on the critical path. By the time this hurdle was discovered and proposals submitted, the middle of April would be the earliest response time; and therefore, start point for any construction. As part of the proposal, the team coordinated with a DHPW design supervisor to conduct an in-depth environmental and archeology survey with his lead environmental engineer and archeologist working the students through the process on site. The actual completion of the key documents by the students greatly increased the speed of obtaining DHPW approval and getting the required proposals out to SHPO and CZM.

The time lag between proposal submission and approval by SHPO and CZM was spent completing the detailed design of the two bridges, the Bill of Materials (BOM) and the construction schedule. The first of the two spans is about sixteen feet in length, while the second span is only seven feet long. SHPO has the requirement that authentic reproductions can only be authorized if there is corroborating information detailing the exact look of the original design. Timber and masonry rock arch bridges were prevalent during the time period. Either would have been acceptable as the construction material, while a steel bridge would not have been proper. Timber was chosen as the material of choice since design/building a masonry rock arch bridge appeared to be outside the capability of the team to complete in one semester. Given the fact that timber design is not a course presently available at USMA, the students taught themselves (this is an independent study course) the rudiments of timber design from Timber Bridges: Design, Construction, Inspection, and Maintenance (1). The abutment design also required an extension of the basic knowledge developed in their concrete design class.

Positive communication with SHPO and CZM throughout the over 2 month approval process motivated the students to submit a bill of materials to DHPW to prepare for the drawing of lumber, other materials, and tools they would need to construct the bridges. With the generous support of DHPW, they were able to obtain all of the supplies needed for the project. Finally formal approval arrived and the team began moving material to the site the final week of April. With the help of their friends, especially the power lifting team, the students transported supplies by hand up to their remote site. Through the wonderful insight and guidance of one DHPW carpenter who volunteered his time and the extensive and constant help of another student who just wanted to be part of the construction phase, the team was able to take the project from design to completed product in just over two weeks time. Perhaps the most challenging aspects of the entire project was first, waiting patiently for project approval from state agencies since the available time left prior to graduation was less than a month from initiation of the construction, and second, coordination of all the required people, equipment, and supplies to complete the project. Add the burden that very few pieces of equipment could get to and be left at the remote site, it usually took the team at least an hour and a half to begin actual work once they got to the island which was over an half-hour trip from West Point. All construction occurred after normal classroom activities for the day. Some of the material and equipment was stored in the academic building at West Point to support pre-fabrication work and the rest in the island storage shed which was about a half mile from the work site.

During the construction phase, the students modified parts of the design for the sake of constructability and available resources – very similar to any other construction project. For example, they replaced the designed block type concrete abutments on the first span with a treated 6” x 6” lumber cradle placed in two circular column style piers (Figure 3). The change came as an experienced-based recommendation from the carpenter and one of the in-house engineers in a effort to decrease the amount of concrete that had to be hand carried bag-by-bag 30 meters uphill to the site. Using the concrete Sonoform® tubes as pier supports at the one-sixth span points enabled the students to notch the deck into the rock face (Figure 3) on either end of the span, thereby providing the bridge a very customized and professional appearance. Rapid calculations were performed to support the adjustment.

Other construction tasks included:

- clearing soil from existing rock,
- preparing formwork,
- drilling into the rock to anchor the piers with steel anchors,
- mixing the concrete in a gas-powered mixer manually moved up the trail to the bridge site,
- manually moving all material 30 meters up the trail,
- moving concrete around the site in 5 gallon buckets,
- stripping the form-work,
- placing bolt-laminated stringers that were custom fit to the existing terrain features (Figure 3),
- placing concrete ramps at the end of each span,
- always maintaining the site to return to pre-existing conditions, and,
- additionally, the railing system was prefabricated at the department wood shop and hauled to the site for assembly.

Figure 3: 6”x6” lumber cradled placed in two concrete Sonoform® tubes

In the end, the final product exceeded the student's initial expectations in terms of both its quality and its appearance (Figure 4). They are very proud of the work they did and are confident that these two bridges will serve both as a means of preserving a link to Redoubt Seven, which is a part of our nation's history, and as a tribute to the quality engineering West Point was founded on. The site was dedicated one week (Figure 4) after completion of the construction during graduation activities.

III. Key Educational Benefits

In large part, the greatest lesson learned was timely completion of the bridges now carrying the trail across the steep sections to Redoubt Seven. Given the effort put into making sure the bridges were designed to withstand the expected extreme loading (i.e., large factor of safety), the students are confident that the fruit of their labor will last for many years to come and that they are prepared to complete even larger projects in the future. Bottom line: they have a better

Figure 4: Finished 16 foot span

understanding of the constraints associated with historical sites, the difficulty of building what is designed, and to expect the unexpected during construction.

In reference to the design work the students completed for the timber spans and the concrete abutments, they discovered several interesting learning points. First, the most obvious lesson learned was how to design timber structures which is not offered as a course at West Point. They discovered through self-study that timber design is in many ways similar to steel or concrete design though there are significant differences in material properties. As for concrete design, they learned to build on previous course work to learn how to design abutments. More important are the lessons that cannot be taught in the classroom and must be learned on site: how to actually construct timber and reinforced concrete design concepts. Unique designs that cannot be constructed easily are useless and simple designs are sometimes better.

In reference to the interactions with the numerous professionals working at DHPW, the students discovered that many aspects of light construction are determined more through experience and conservative estimations rather than on hard and fast engineering design. They discovered that the scope and cost of a project such as theirs was relatively small, and that it is often times easier to over-design (or overestimate) the structure in favor of being expeditious. The cost difference between an efficiently designed structure of this magnitude and an over-estimated one is fairly insignificant. They learned that this sort of project does not usually require an engineered design and are seldom designed mathematically, but are instead designed from experience – something they do not have yet.

Possibly the most intriguing and educational aspect of this project was the coordination they conducted with DHPW, SHPO, and CZM. The coordination process exposed them to the system that engineers and contractors must go through in order to convert a design into a reality. They interacted with mechanical and structural engineers, supervisors, construction estimators, carpenters, environmental engineers, an archeologist, the island caretaker (the customer of sorts), state agencies, and many others. In the end, they found that each of these people may have a real interest in the project and can contribute much to the success of the project. Similarly, the interaction with each of these individuals had to be on a personal level. The students had to spend time with each person to prove that they cared about what the other was doing. People will do their job because that's what they get paid to do. They will only excel, however, when they like the people they work with and for. Additionally, as soon as this project became job AJ151500R, it became a mission not only for the student team, but also for the professionals at DHPW. They take pride in getting the job done to standard, and it truly was refreshing to interact with so many motivated people.

On site, they learned a lot about what works in theory and what works in practice. They began to see what factors affect the constructability of a project and how to maintain a fluid construction process to facilitate sudden changes. Care must be taken, however, to maintain quality control in what can quickly become an out of control construction site. For example, the abutment design literally changed overnight based on the recommendation of the DHPW engineer and carpenter. Within 24 hours of its conception, the students were drilling rock and setting formwork. The speed of changes is similar to requirements on any job site when structural members do not show up or are the wrong length. The engineer of record is still responsible and must analyze and approve all changes. One of the students had to become the construction foreman. In the absence of a construction foreman, the momentum to just build and get it done can lead a construction crew into making bad decisions. For example in this project, the concrete was initially too stiff. The students did not immediately correct the problem since it was beginning to get dark and ended-up having to later fill air pockets along the edge caused by the stiff concrete and spacing in the formwork for the seven-foot span bridge.

IV. Assessment

Student web-based assessments at the end of the experience were extremely supportive of design-build projects. Students responded to web-based statements using a scale of 1-5 (strongly disagree – strongly agree). The responses (Table 1) for the project were compared to the averages for USMA, the department, and the course depending on what level the statements were generated at.

This design-build project was one of 14 separate capstone projects during the spring. Initially, these type of projects were only for the top 2-3 students within our program. However, the inclusion of competition-based projects (e.g., steel bridge and the concrete canoe) required an increase in students participating and inclusion of students (e.g., welding skills, desire to be part of the competition, etc.) sometimes in the lower performance tiers within the civil engineering program. However, the results clearly show that the experience is extremely valuable for all members of the program and the 14 projects represent the minimum required number of projects for our program to ensure each student has the option of participating in a project similar to the one described in this paper (2).

As can be seen in the table, some of the responses are directed toward the instructor. However, the instructor for most of the projects met with the students only once a week to discuss what they accomplished since the last meeting, what they plan to accomplish by the next meeting, and to provide guidance and ask questions to help direct the teams effort. It is obvious the students thought the conduct of the weekly meetings constituted a plan similar to most instructors during daily classroom sessions. Based on the results, the students felt that the project motivated them to learn on their own, stimulated and increased (creative) thinking, and they feel comfortable solving complex, real world problems.

Table 1: Web-Based Responses

USMA Wide Statement	**Project Average**	**USMA Average**
Instructor encouraged student's responsibility for learning	4.75	4.46
Instructor cared about my learning in this course	4.75	4.38
Motivation to learn increased	4.5	3.88
The instructor stimulated my thinking	4.5	4.19
Critical thinking ability increased	5	4.03
Department Wide Statement	**Project Average**	**Dept Average**
Instructor had a plan for every lesson	4	4.66
Instructor helped me understand the importance and practical significance of this course	5	4.5
Course Wide Statement	**Project Average**	**Course Average**
I can apply the engineering thought process to solve a complex, real world problem	4.75	4.6
I can develop a creative solution	4.75	4.56
I can acquire information and learn new concepts on my own	4.75	4.53

Some of the important things learned:

- Pushing a project through the system.

- Time management – design is easier than construction (at this level).
- Need for creative thinking when resources are low.
- Nothing goes according to plan.

Some strengths of the course:

- Responsible for own learning.
- Forces time management.
- Use most of developed CE skills.
- Hands-on skills are invaluable.
- REAL project.
- Wraps up entire CE experience.

A few of the free-form comments were:

- This project was a great experience for us. I think more students should get the opportunity to actually go from design through construction.
- Someone must take the leaders role even in student group projects. If I had taken an active role as the leader, some of the miscommunications and group dynamics problems could have been prevented.
- We worked hard, but can now actually look back (with pride) at a project we took from concept to a finished product.

V. Conclusion

The true measure of success of the project is now standing on a trail on West Point's Constitution Island. The impact of this project on the three students who completed it will also be lasting. The benefits of grappling with real-world constraints, solving substantial engineering problems, construction on a historical site, dealing with issues of safety and constructability, and coping with construction management difficulties such as an austere environment with no running water, electricity nor established roads, and delayed construction approval are immeasurable. The coordination and effort they put into taking this project from concept to completion in one academic semester, a feat many thought not possible, has prepared them for the future design-build projects they will undertake as engineers.

The detailed description of the bridge project highlighted the educational benefits of design-build projects for any engineering student. Student assessment data demonstrated that such projects contribute much to student's motivation and self-awareness as well. One student's comment sums it all up: "I learned more in this course than any other I have taken in the program." They are proud of the work they did and are confident that these two bridges will serve both as a means of preserving a link to Constitution Island, which is a part of our nation's history, and as a tribute to the quality engineering on which West Point was founded.

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