Bridge Building in the Colorado Rockies: A Mechanical Engineering Major's Perspective

C1C Ryan J. Howe, Dr. Stanley P. Rader, Lt Col Matthew P. Snyder
United States Air Force Academy

Abstract

Select cadets at the United States Air Force Academy (USAFA) were given the unique opportunity to work closely with the U.S. Forest Service to design and construct a pedestrian bridge in the White River National Forest near Breckenridge, CO. The 35-foot long bridge spanned a white water mountain stream at an elevation of 11,200 feet. The cadet-constructed bridge replaced a temporary marina dock ramp, allowing the temporary bridge to be returned to its proper use. This cadet-led project required geotechnical, hydrologic, and structural engineering analyses and design prior to construction of the bridge, as well as the application of construction engineering and management principles and methods throughout the planning and construction process. The cadet team followed Forest Service design parameters, including making the bridge both wide enough and strong enough to accommodate ATVs for search and rescue missions. The bridge was also designed to accommodate the approximately 30,000 annual hikers on the popular McCullough Gulch trail. Cadets designed and analyzed the bridge during the academic year and constructed the bridge during a three-week summer period. This unique "theory to practice" opportunity provided invaluable engineering experience and prepared the team to handle complex challenges facing them as soon-to-be officers and engineers in the United States Air Force. This project also presented an exceptional learning perspective during the construction segment that is often missed in the classroom setting. The paper and presentation will describe the lessons learned and unique perspective of an undergraduate mechanical engineering major throwing himself wholeheartedly into a comprehensive civil engineering experience.

Background

An innovative trail bridge design and construction project was developed by Dr. Stan Rader (USAFA Class of '76) and Col Greg Rosenmerkel (USAFA Class of '88) as a way to benefit both the United States Forest Service and the United States Air Force Academy. The two established a partnership between the U.S. Air Force Academy's Department of Civil and Environmental Engineering and the United States Forest Service to provide a "theory to practice" experience that gave 13 undergraduate engineers the chance to test the concepts learned in class in the context of full-scale construction. The first offering of this course and project was in 2015-16 and featured construction of a trail bridge in the Maroon Bells Wilderness Area of central Colorado. The project featured in this paper took place in the White River National Forest on the McCullough Gulch Trail near Breckenridge, CO. This site was chosen for a variety of reasons; the trail sees traffic of more than 30,000 hikers annually and the existing bridge did not meet Forest Service standards. The existing bridge, in fact, was a marina boat dock ramp borrowed from the local county! These factors, along with the aesthetic preferences of the Forest Service, created a legitimate design and construction challenge for USAFA Civil Engineering Students.

Air Force Academy Civil Engineering cadets all go through initial construction training at the Academy's Field Engineering and Readiness Laboratory (FERL), where cadets practice Civil Engineering principles through a plethora of hands on activities such as soil analysis, concrete construction, wood frame construction, surveying, stream flow analysis, heavy equipment operations, etc. This training is only offered to a select few non-Civil Engineering majors, which is where I began my Civil Engineering and bridge building involvement. The bridge construction project required a two-semester commitment - an academic year in the classroom prior to the construction of the bridge during one of the three, 3 week-long cadet summer periods.

Academics

Traditionally, classes at the Air Force Academy are only one semester long. This class required two semesters; the first to identify controlling parameters, analysis principles, and design methods, while the second focused to complete the actual bridge design, construction plans and specification, and construction scheduling. Thirteen motivated cadets decided to take on this challenge with Dr. Rader as the instructor. The course was modeled similar to an engineering capstone class, rather than a traditional three semester hour course. This was because the timeline was developed jointly by the cadets and Dr. Rader, and the problem statement was not just from a textbook but was much more variable with numerous real-life parameters and constraints.

Site Visit

The primary frame of reference available to the cadets was the previous bridge construction project, two years prior. It provided a template for the project engineering report, which was submitted to the Forest Service for approval prior to the summer construction. After identifying the new bridge location, a site visit was imperative to map out where exactly the new bridge would be placed and catalog potential roadblocks that could hinder project success. Additionally, technical parameters of the site location were collected to provide a baseline for the design process. Early in the first few weeks of the first semester, the cadet team took a three-day visit to Breckenridge, CO, to collect the necessary data for the project. The class was divided into separate subdiscipline teams: Geotechnical, Structural, Surveying, and Hydrology. Each team focused their activities during the site visit according to their subdiscipline. This ensured that each piece needed for the next phase of design would be covered and not overlooked during the site visit – it was not feasible to make repeated visits since Breckenridge is a 2.5-hour drive from the Air Force Academy.

The Geotechnical team was concerned with the soil composition and its overall load bearing capabilities. Pretty quickly, I started to see the discontinuity between me as a Mechanical Engineering major and the rest of the team of Civil Engineering majors. Many of them were in a geotechnical engineering class and other relevant classes to prepare them for a site visit like this. Simply put, they often knew what was going on much more than myself. They used a Dynamic Cone Penetrometer to measure the "give" of soil as depth increased, seen performed in Figure 1. After recording these values, they collected various samples of the soil for use in the lab and further testing. This data would be used to determine if the soil could support the new bridge we planned to build.

Figure 1. Dynamic Cone Penetrometer Tests at the McCullough Gulch Bridge Site

The surveying team worked with one of the technical experts in the Civil Engineering Department, as well as a few members from the structural subdiscipline team. Using a Trimble surveying instrument, they mapped out the topography of the surrounding area, as well as the stream below the bridge site. Sparing the technical details (which are not covered in Mechanical Engineering), the team provided a topographic map to the class, outlining the where the new bridge would be placed and the elevation changes across the site area. This map can be seen below in Figure 2.

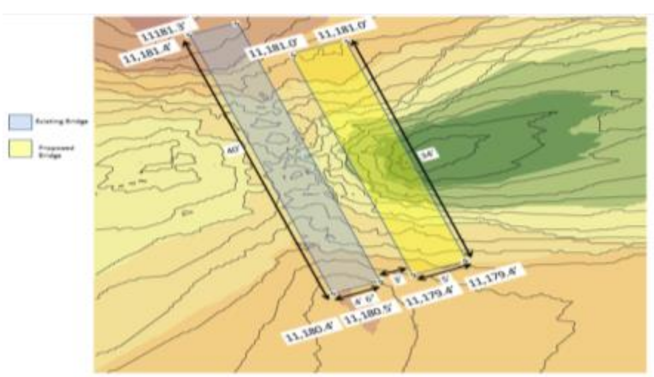

Figure 2. Completed survey map of old and new bridge locations

Figure 3. Stream flow rate tests during the site visit

The hydrology team, of which I was a part, needed to identify the 100-year flood event flow rate and flood boundaries for the stream in order to safely position the bridge. In order to do so, this required taking flow rate measurements at various points along the river. One measurement was taken far upstream and the other was taken just below the existing temporary bridge. This test involved measuring the width of the stream, parsing this width into sections, and measuring the velocity of the propeller that was submerged in the water.

$$Q = 39.5{A_1}^{0.706}S^{1.577}$$

$$Q = \frac{1.486}{n}A_2{R_h}^{2/3}\sqrt{S}$$

$$R_h = \frac{A_2}{W_p}$$

$A_1 =$ *Drainage Area*

$S =$ *Average Drainage Slope*

$A_2 =$ *Area of Cross Section*

$W_p =$ *Wetted Perimeter*

$n =$ *Roughness Coefficient* $= 0.05$

Figure 4. Equations used to calculate relevant flow rates

Additionally, pictures of the stream were taken to get an idea of the stream bed roughness we might use in later calculations. After this site visit, our team was responsible for delivering an accurate 100-year flood flow rate and an associated height of the bridge to clear the 100-year water level. Up until this point, no class had offered a problem without a worked out solution – this was unique in that we had to develop a solution method that would work and provide us with reasonable results. Just as the Civil Engineering majors were ahead of me in soils knowledge, it was no different with hydrology – many of them were also in a hydrology and hydraulics class, and my dynamics and thermodynamics classes became even less applicable than I would have hoped… This problem required a lot of background studying for me in order to get "spun up" to the project. We ended up finding an equation that allowed us to iterate through different heights of the stream that corresponded with different flow rates. The equation used was in terms of the cross sectional area of the stream, which was determined from the survey data gathered earlier. We calculated the flow rate for a 100-year flood, using surrounding drainage basins as a baseline. Once a flow rate corresponding to the 100-year flood was found, the depth of water was identified, allowing us to see how much freeboard, or clearance, was needed for the bridge to be safe. Thankfully, we had sufficient freeboard available to avoid having to raise the bridge abutments above the existing grade at each end of the bridge.

In-Class

The structures subdiscipline team determined the length requirements to span the whitewater stream during the site visit and was kept busy determining loading requirements and general design parameters of the bridge that we were to build. One of these design parameters came from the Forest Service, which required that the bridge support ATVs for search and rescue operations upstream from the bridge. The previous bridge was not wide enough and may not have been strong enough to support this type of load. But, since we were designing this from scratch, we could accommodate such requirements in the design. The team investigated what a reasonable ATV design load might be and also determined the controlling load for the bridge. Because this bridge would be placed at 11,200 ft, and near one of the main ski towns in Colorado, snow loading was a very real design concern. Using the 2016 Colorado Design Snow Loads code, published by the Structural Engineers Association of Colorado, the ground snow load was calculated to be 126 pounds per square foot when compared to the design load from a fully-loaded emergency ATV crossing the bridge, the ground snow load controlled the structural design of the bridge. These calculations were made by the entire class as part of our homework and kept us all engaged in the structural engineering aspect of the bridge design. The loading calculations paved the way for the bridge type selection process

The cadet team looked at primarily two designs: the open-web steel joist and the glulam beam design. Figures 5 and 6 highlight the differences between the two, and certain factors influenced the team's bridge type selection.

Figure 5. Open web steel joist bridge type located at Maroon Bells. Note the cord and web members beneath the bridge

First, the Forest Service communicated the importance of the "wilderness aesthetic", using earth tones, and establishing a more natural look for the bridge to appear more cohesive in the forest. Second, ease of construction was an important factor in this decision making process – after all, we were pretty inexperienced with bridge construction! Third, the materials required for the respective bridge types would be slightly different, which was a factor considering the fact that all of the construction would take place on the bridge site, with no anticipated prefabrication. Finally, the capability of each bridge to meet the projected requirements from each subdiscipline team was a necessity. The primary differences between the open-web steel joist and glulam beam designs was the material used for the main stringers (beams). It was a question of using steel versus using glued laminated wood beams. After internal cadet team discussions and consultation with the Forest Service, the decision was made to use the glulam beam design. The Forest Service favored the glulam design since it used only wood and looked "natural", while the steel in the former design was too "industrial". Additionally, the glulam beam design was also used at Maroon Bells only two years prior, making it easier to construct since many of the difficulties had been ironed out – something we may not have had time for with the steel joist design. Along with this, the steel joist design would require additional

Figure 6. Glulam beam design at McCullough Gulch

materials and skill sets to facilitate welding of the steel components. This could have been done but may have presented an issue for hikers still using the temporary bridge during construction due to the welding flash. Also, extra safety measures for the cadets and the dry forest would have been required in order to weld, which would have added an additional burden to the construction progress. Not to mention, none of us were that great at welding during FERL… Objectively, the merits pointed toward the glulam beam design; subjectively, as a Mechanical Engineering major, I thought it would have been more interesting to try out a different design and build with steel. I was outvoted.

The course focus then narrowed to the design characteristics of the glulam beam bridge. We had to identify which wood to use for the stringers given altitude, humidity, wetness, and loading factors. Knowing this allowed the team to optimize the solution and not "over-engineer" where unnecessary. These calculations incorporated the loading conditions solved for earlier in the semester and resulted in a stringer design of 3.125"x21" of Alaskan Yellow Cedar, which could safely carry the loads and was environmentally acceptable – resulting in an economical design. After the stringer design was completed, the deck, handrail, and handrail posts were designed. We were provided a starting point since we planned to use the same design as the Maroon Bells bridge, constructed two years prior. This made the calculations more of a check that the previous design would work given the loading conditions, and not so much of an original design. The design was based on the Forest Service's *Transportation Structures Handbook*, with design calculation specifics based on the American Wood Council's *National Design Specification for Wood Construction* and the accompanying NDS S*upplement*. Calculations confirmed that 2"x6" Douglas Fir Larch wood members would suffice for the railings and rail caps on the bridge. The rail posts also required a check on loading and involved a similar method to the railings. The *Transportation Structures Handbook* provided the loading on the post and resulted in using a 6"x6" Douglas Fir Larch No. 1 wood timber for each of the posts on the bridge. These design calculations concluded the "number crunching" portions of the project, but still

Figure 7. Maroon Bells glulam beam, constructed by USAFA Class of 2017

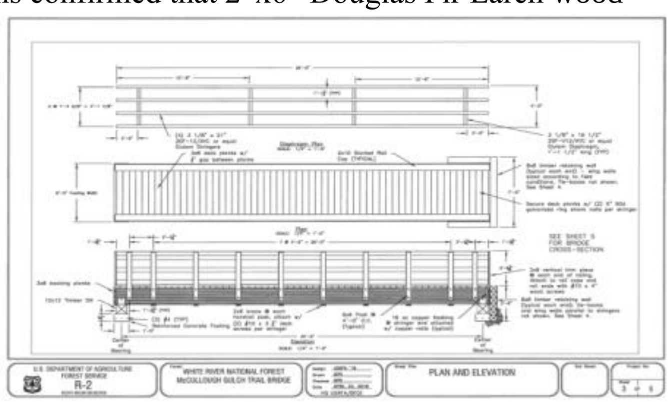

Figure 7. One of the pages from the approved plans used during the construction of the bridge.

significant work remained to prepare for the quickly approaching summer construction period. Draft construction plans and specifications were produced, which went through several iterations. After valuable and enlightening review comments were received and responded to, the Forest Service approved the revised plans and specifications, and the cadet team moved on to construction planning and scheduling.

Although the bridge and plans were approved, we still needed to order materials and ensure they were at the bridge site when needed. Each member of the team developed a "material take-off" list, which outlined every item that was to be used to construct the bridge, down to the quantity and types of nails needed. Each member went through the bridge plans with their proverbial "fine tooth combs" and dissected the bridge we had just designed. After each person compiled their list, they were all compared to ensure no steps were skipped so we would have all of the necessary materials for purchase and available on the first day of construction. This included everything from the wood used for the bridge, to the concrete forms for the bridge abutments, to the stain used on the very last day. What we had failed to consider was how many screws we would use for the field latrine… more on that later.

In addition to the material take-off list, a project schedule was developed to maintain a timeline and ordered objectives during the construction over the summer period. Similar to the material take-off, each team member mentally constructed the bridge from start to finish and recorded the necessary steps along the way, and how long each might take. A critical path on this schedule was developed which showed the tasks that would prevent the project from progressing if not completed. Tools necessary for each step of construction were annotated on the project plan. This gave the team an idea of the required items to take from the USAFA machine shop and laboratory, as well as the items that would need to be requested from the Forest Service. Like the material take-off, these were compared and compiled among all of the team members to ensure an accurate timeline for the summer construction. The final project schedule predicted bridge completion in about two and a half weeks after the start of work – meaning that as long as there were no construction delays, we would be finished within the three week time window available to us.

Figure 10. "By-hand" excavation of the north side of the bridge

Figure 9. Location of the new bridge site on day one

Construction

There is no debate that the highlight and selling point of this project was the summer construction. This was a very unique opportunity to take something engineered in the classroom and build it according to the specifications and tasks determined by the cadet team. Despite all of this, showing up to the site on the first day and looking at the undisturbed earth made the project a little daunting – especially with the three week timeline already in the back of our minds.

The construction team was composed of the 13 cadets, a recent USAFA graduate who was now commissioned as a 2nd Lieutenant, Dr. Rader - the advisor, Col (ret.) Greg Rosenmerkel, who helped with the project on behalf of the Forest Service, and Mr. Leo Dube, who was the father of the son to which the bridge would be dedicated. Together, this team would construct the bridge from start to finish in less than three weeks. Each day began at 7:30 A.M. at the bridge site and typically lasted until 4:00-5:00 P.M., followed by a team debrief back at the lodging facility and a plan for the next workday. The project began with the challenge that if we stayed ahead of schedule, Fridays would be given off (read: 3-day weekend!). Needless to say, everyone was motivated. The first day was primarily staging the equipment and preparing the site for construction. Ideally, we would stage the tools and materials at the bridge site, cordon off potential hazards for hikers, receive a brief by Colonel Rosenmerkel and the Forest Service, and begin to tackle some of the assignments for the day. But, as with any project, not everything went smoothly. The tools that were not available in the laboratory at USAFA were ordered by the Forest Service, but a miscommunication resulted in those tools not arriving until noon instead of the scheduled 7:30 A.M. time hack. This made for a slow start, especially when the motivation to start working was very high. Nonetheless, after the tools arrived, we quickly began dividing up the work and began excavating (by hand) the abutment on the far side of the stream and constructing the field latrine. The excavation was tedious – it was apparent that the soil at the abutments were more rock than dirt, making the progress pretty slow. Adding to the slow progress was the amount of people ready to help on the project. The 13 cadets ready to help sometimes translated to a lot of standing around since only a few people could be working in the hole at once. Everyone did get their fair share of digging, and even the token Mechanical Engineer had some time in the dirt – although I didn't help my case when the one time I did dig, a rock flew up from the dirt and hit me square in the eye… Not a great look for the "team lead" on the first day, no pun intended. This made safety a much larger focal point for the whole team moving forward, and we stressed the importance of wearing personal protective equipment (PPE) when required. Thankfully, no other injuries occurred after this (at least while working on the project); weekends spent mountain biking was a different story.

Figure 11. Cadet constructed field latrine

Figure 12. One of the bridge abutments with a concrete form in place

Following the excavation, the team formed and placed the concrete footings on which the stringer bearing shoes would rest. This was important since the concrete had to cure to develop its strength prior placing the four, 500 lb. stringers on top of the abutments.

Figure 13. Prefab location, just down the hill of the bridge site

Figure 14. Rigging setup used to lift the stringers across the stream

The surveying team ensured that these footings were level, square, and properly located. If they were not, the bridge would be crooked! Meanwhile, predrilling and cutting of the wooden components of the bridge was taking place at the staging area to make quick work of assembly during the next two weeks. The team scrutinized the construction plans and identified the corresponding wood members to size and cut for use later in the project. Based on our previous material take-off list, we were provided with just enough wood to complete the project, so a close attention to detail was necessary. The old saying, "measure twice, cut once" was something we all put into practice. The design process was greatly influenced by the previous project at Maroon Bells; however, Maroon Bells was considered a designated wilderness area, which meant no mechanized equipment or power tools could be used in the vicinity. The McCullough Gulch trail was different; the team had the luxury of using electric drills, circular saws, rigging, generators, etc., for the pre-fabrication and construction of the bridge. One point that was overlooked as a result of this new capability was the power requirement for the tools. There were many holes that needed to be drilled with big holes needed in each post and stringer. Our drills could barely make it through the 6"x6" pieces of timber, and we found ourselves burning up drills and draining batteries quicker than they could be charged. This put some of the team on the sidelines waiting for things do since we did not have back-up hand tools to help make progress. Instead, we were sometimes literally just waiting for batteries to charge.

Figure 15. Stringers in place with diaphragms being installed

Despite the unanticipated delays from power tool limitations, the team still managed to complete the scheduled construction tasks (in hopes of earning a 3-day weekend). Precutting and predrilling of the bridge materials continued as the bridge progressed to completion. The Forest Service brought out members of their team to install rigging to lift the glulam stringers over the stream. Without them, it would have made for a very precarious cadet endeavor – and that risk was something we were very much looking to mitigate. The rigging portion involved a set of anchor points, one on each side of the river. Hand winches were set on each side of the stream bank, one to pull the cable to slide the stringer across, and one to relieve tension in the cable for when the stringer was moving. This process was repeated four times, for each of the four stringers, which were then placed in the bearing shoes on the abutments. With the stringers in place, the bridge started to take shape! Once the stringers and shoes were attached to the abutments, installing the diaphragms was next. The diaphragm pieces provided rigidity and lateral stability to the stringers and were placed perpendicular to each stringer along the length of the bridge. We all expected them to go in much quicker, but soon began to realize the tedious assignment that was ahead. Each diaphragm had face mounting brackets, which were nailed into both the diaphragm and the stringer. Each face had seven slots for nails, for a total of 14 nails per side. The difficulty was twofold: the wood used for the diaphragm was relatively hard, so the satisfying feeling of completing a nail in three hammer swings was nonexistent– this often led to bent nails or nails that would just get stuck in the wood, causing a lot of frustration. Predrilling the holes only helped when the mounting bracket wasn't installed – the drill would get in the way of the stringers, so the correct holes could not be accessed. Additionally, the few nails that could be swung at were located in such a way that it was nearly impossible to have any room to move the hammer – a combination of the stringer/diaphragm joint location, as well as having to sit uncomfortably on the stringer to complete the hammering. At Maroon Bells, the team was only allowed to use framing hammers due to the wilderness requirements; we only had framing hammers but were not restricted to them. As the frustration intensified, part of the team was dispatched to retrieve pneumatic palm nailers, which made a very frustrating task much easier. With the diaphragms installed, the four pieces of wood that spanned the river were now turning into a bridge!

Figure 16. Decking and rail posts are being installed

Once the diaphragms were installed, backing planks were attached to the ends of the stringers, which were protected with copper flashing to help mitigate deterioration due to moisture. Bridge decking was placed atop the stringers, aligned, and predrilled for the screws that would secure them to the stringers. Meanwhile, the predrilled rail posts were installed, and large timber bolts were inserted into the holes drilled through the posts and stringers. It was absolutely required that these holes be plum, level, and straight – any error would prevent the rail post from attaching to the stringer or being placed out of plumb and look bad. As we began installation, we realized our method of drilling was not precise enough – the inserted bolts would not go in straight and would not fit into the holes on the stringers. To fix our error, the team bored out extra material from the post to make sure there was just enough "wiggle room" to allow the timber bolts to successfully attach the posts to the stringers. A day later, all posts were fixed and installed!

Underneath the bridge, horizontal 2”x6” braces were installed at each of the handrail post locations. For some of these locations, installation was difficult since some of the braces had to go right over the stream. As this was being done, other members of the team were helping build the abutment retaining walls, made up of 8”x8” treated timbers. The power drills we had brought were barely sufficient for the task – they constantly overheated and drained batteries, making the progress painfully slow. But, with the stringers and diaphragms in place, more tasks could be worked on simultaneously – albeit still requiring power tools, but nothing to completely halt the progress, and kept the construction team busy.

Figure 17. Railing measuring and installation

Figure 18. Railings and rail caps installed

Eventually, more and more of the tasks on the project schedule changed from the “to-do” list to the “completed” list, and with every step, the project began to look more and more like a bridge. Before the decking was installed, the team measured the bridge structure diagonals to see how the “construction quality” looked, and only a ¼-inch difference! Not bad, considering I was told “CE” stood for “Close Enough”. Before the decking was screwed in, the team did some math to calculate the gap distance between each plank. The idea was to start with a set gap distance on each end of the bridge, meet in the middle, and narrow the gap if required. This would prevent getting an “accordion” affect that would be amplified toward each end of the bridge.

Figure 20. Ribbon cutting and memorial ceremony with memorialized man’s family and friends

The team made spacers to make the process go quickly for the spacing, and with decking proceeding from both sides simultaneously, the construction process began to look like a well-oiled machine. As half of the crew was decking, the other half was installing the railings on the posts. These were tricky since they had to be level to the bridge, to the eye, and to one another. While not super difficult, it required some thinking ahead to make sure that the handrails were in the right spot laterally, as well as high enough on the posts. A challenge at this part was dealing with some of the warped wood. We attempted to straighten the wood out by pulling on the members with tie-downs, but even then, it was not perfect. This was the unfortunate reality of working with imperfect wood, but the team tried as much as possible to mitigate the undesirable aesthetic. After these tasks were complete, rail caps were installed on the posts. Considerations as to which side should be facing up were made to help reduce splinters, as well as maintain the best possible handrail appearance. It was important when drilling these in that the screws would intersect the top railings, which provided a 1.5" target width to hit – not easy when the rail caps were at an angle and of the same thickness. As the rail caps were installed, the retaining walls were filled and compacted to create a level approach from the trail to the bridge deck. As we were finishing the rail caps, we realized we were short on screws! We were missing seven screws needed to complete the bridge. After looking for the screws to no avail, we began disassembling the field latrine that we had built on the first day. Lo and behold, seven screws were used in the construction of the latrine. Mystery solved.

At this point, the bridge looked structurally complete. All that was left now was to apply stain to the bridge. We had about 4 buckets more than we needed, out of the 5 purchased. We shook our heads and considered it an investment in the next bridge project. Everything but the decking was stained – foot traffic on the bridge would wear the stain off anyway, so the team deemed it an unnecessary task. With plastic sheeting down on the deck, all hands were on the rails staining the wood and finishing up the final touches. After this, the site was cleaned up and restored to its original condition to the maximum extent possible. Some local seeds were scattered in the surrounding area to facilitate revegetation. Overall, the project took only two work weeks, instead of three, to complete from start to finish! The team exceeded expectations, despite the issues with the sometimes inadequate power tools. The rapid construction can be attributed to having more cadets on the construction team than would normally be required, as well the intrinsic motivating factor to get 3-day weekends (which we did!). The speed would not have possible if teams did not work on different parts of the project simultaneously.

The final day for the bridge was a commemorative ceremony for a local man from Breckenridge who had passed away in an untimely manner. His father joined the cadet team for the duration of the construction project and provided valuable assistance to the cadets. Two plaques, made in the Mechanical Engineering Department's machine shop at USAFA, were affixed to each side of the bridge. One explained the USAFA-Forest Service partnership and the project, and the other pointed to the mountains in memory of the young man, a local physical therapist who was due to assist the U.S. Olympic team. Donations made by his friends and family to The Summit Foundation, a local philanthropic organization, enabled this project to happen. The money donated was used to provide the cadet team with lodging near the site, which ensured the success of the project.

Lessons Learned

This project provided an invaluable learning experience for the entire cadet team. Although the team was faced with some challenges, a lot of the project went very smoothly as credit to them. As discussed previously, separating the team into smaller subdiscipline teams allowed multiple tasks to be completed simultaneously, and kept the project ahead of schedule. We conducted meetings following every work day to establish the work task teams for the following day. At these meetings, a debrief of the current day was held and potential challenges for the next day were discussed. This type of meeting was very effective in getting everyone on the same page and ironing out any wrinkles prior to executing at the site. With a 13-person team, it can become difficult to have everyone working and contributing to the objective when certain tasks only require so many people, whether it be due to a space or tools. Creating these subdiscipline teams helped to mitigate people not working, but even if they did not have any task that could be completed, assigning even a simple task would maintain their motivation and excitement. These simple tasks that could be easily done by myself were sometimes best delegated to others to keep them engaged and contributing to the task at hand.

A lot of these learning experiences came from situations that did not end so smoothly. For the next bridge project, feedback on power tools and power supply will be heavy in discussion as that was one of the largest limiting factors to the speed of the project. Of course, safety plays a large role in any construction operation. Fortunately, I was the only one that received an injury, and there was only one on the first day. Following that, hard hats, ear protection, and eye protection were emphasized. There was a high level of risk regarding safety, since the bridge was suspended over a white water stream and some of the tasks involved precarious placement of tools and cadets. Related to safety, attention to detail was very important to the success of the project. As mentioned before, there were only enough materials for construction of the bridge, based on the

Figure 21. The finished product at McCullough Gulch trail. Built by USAFA Class of 2019 cadets

detailed bill of materials. This meant careful attention to the plans and careful execution of every task was required. This was at the forefront of our minds when cutting any piece of wood, installing any screw, or drilling any piece of wood. If we were to make a mistake, it might have adversely affected the desired appearance of the bridge, which was unacceptable. Additionally, working over a stream presented challenges in of itself. When bits or screws were dropped, there was little chance that they would ever be retrieved. The only object that we were able to retrieve was a Lithium-Ion battery that had slipped out of my hands while changing it to a new driver. On any other surface, we could have grabbed it from the floor and continued. With my luck, it bounced a few times on the decking and then into the water, about 10 feet down. Not only were we short on batteries as it was, but this was our best one! A better risk management would have paid dividends in that moment. Finally, planning was a very important aspect of this project. Although the design was done over the academic year by the same people constructing it, there were so many more considerations to be made while building than were accounted for in the design of the bridge. In the CAD model, everything is straight and fits perfectly. In real life, almost none of that remains true. A lot of prior thought went in to the placement of the members to account for warping, spacing, and actual process of construction. In the classroom, we thought we had it all squared away, when there was really a lot more to consider during the actual construction.

Figure 22. Commemorative plaque made in USAFA's Mechanical Engineering laboratory

These types of take-aways from the project make this experience very unique for an undergraduate engineer. The course work provided by the project during the academic year had a relevance like no other course that I have taken – since the product of the course wasn't just the paper that was turned in at the end, but instead all of the calculations and decisions made influenced the build phase during the project and what the product would look like. The two events of course work and construction can be done separately, but a much better understanding of the engineering is obtained when they are united, like in this course. Not only did this course provide a real, hands-on application of the work in the class, it also tied in relevant concepts from previous classes that had at one point only been writing on paper. A real design challenge coupled with its construction, helps apply the concepts that were lectured in previous courses and explains the "why" behind a lot of engineering design choices. Not only are these choices explained but are seen firsthand in the construction of the project. These types of open-ended, capstone-like problems, similar to the ones solved in this project, help cultivate a creative-thinking, problem-solving attitude that is easily carried into other courses and beyond the classroom. For a mechanical engineering major, often times I felt out of my element with the Civil Engineering concepts being put into action but found some of the principles remained the same as during the bridge and structure design, while others could be studied offline for things like the hydrology and soil analysis. This experience of being exposed to some of the different disciplines in engineering provides a much broader understanding of the considerations that go into design and a lot of the things we take for granted. As a future Air Force officer, Civil Engineering provides the foundation for the operations that allow the vital functions of the Air Force to be executed. Understanding of how much goes into even a simple project like this gives a better insight into the operations of Civil Engineering and will allow those working in different career fields to work more cohesively across these borders.

Acknowledgements

The authors would like to thank the U.S. Forest Service staff of the White River National Forest for their support and partnership on this project. We would also like to thank The Summit Foundation for their generous grant in support of this project.

Biographical Information

RYAN J. HOWE

Cadet Ryan J. Howe is a senior at the United States Air Force Academy studying Mechanical Engineering with a minor in Nuclear Weapons and Strategy. He involved himself in Civil Engineering by signing up for the Civil Engineering Department's Field Engineering and Readiness Laboratory (FERL) offered during his junior year summer, and served as the cadet team lead during the Forest Service Bridge Construction project this past summer.

STANLEY P. RADER

Dr. Stanley P. Rader is Professor of Civil Engineering at the United States Air Force Academy teaching structural engineering. Graduating from the U.S. Air Force Academy in 1976 with a degree in civil engineering, he completed a 21-year career in Air Force Civil Engineering in 1997. He spent 13 years in private sector consulting engineering, including ten years as Director of Structural Engineering at Matrix Design Group in Colorado Springs.

MATTHEW P. SNYDER

Lt Col Matt Snyder is an Assistant Professor of Mechanical Engineering at the United States Air Force Academy serving as the structures lead and overseeing 7 courses. He graduated from Cedarville University in 2001 with a degree in mechanical engineering and has spent his 17 year active duty Air Force career as a developmental engineer primarily employed by the United States Air Force Academy and the Air Force Research Laboratory.