Construction of High-Bay Lab Reaction Frame Foundations

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This paper details the construction process of two concrete modular foundations designed to meet specific design standards for various testing methods. The project, positioned within the California Polytechnic State University, San Luis Obispo (Cal Poly) High Bay Lab, will provide the Architectural Engineering (ARCE) and Construction Management (CM) departments with valuable insight into industry structural elements. The project required extensive forethought and thoroughness due to the complex designs, including 200 all-thread coupler attachments and a cumbersome rebar cage. This paper outlines the primary phases of construction, including material procurement and quality control, and discusses how the final product was obtained. Furthermore, the paper delves into the mistakes made during the process, with the intention of facilitating potential similar projects leading to more efficient means of success. The project serves as a remarkable demonstration of quality control and strategy when managing a construction project. By outlining the construction process and mistakes made, this paper provides valuable insights for future projects in the field and study. The construction of these two concrete modular foundations will aid students in the ARCE and CM departments for years to come, providing them with a better understanding of specific industry structural elements.

Key Words: Foundations, All-Thread, Structural Testing, Procurement, Quality Control

Introduction

Initiated by the ARCE department’s need for modular foundations to aid in structural element stress testing that is conducted by ARCE students on the reaction frame in the High Bay Lab, our senior project team effectively constructed two modular testing foundations. These footings measuring 2’-11 ½" by 5’-11 ½" by 1’-6”, as shown in Figure 1 below. The total concrete volume contained in each footing is 26.44 cubic feet (about the volume of a large refrigerator) or about 1 cubic yard. Many lessons were learned during this project and overall, the project was a success for everyone involved.

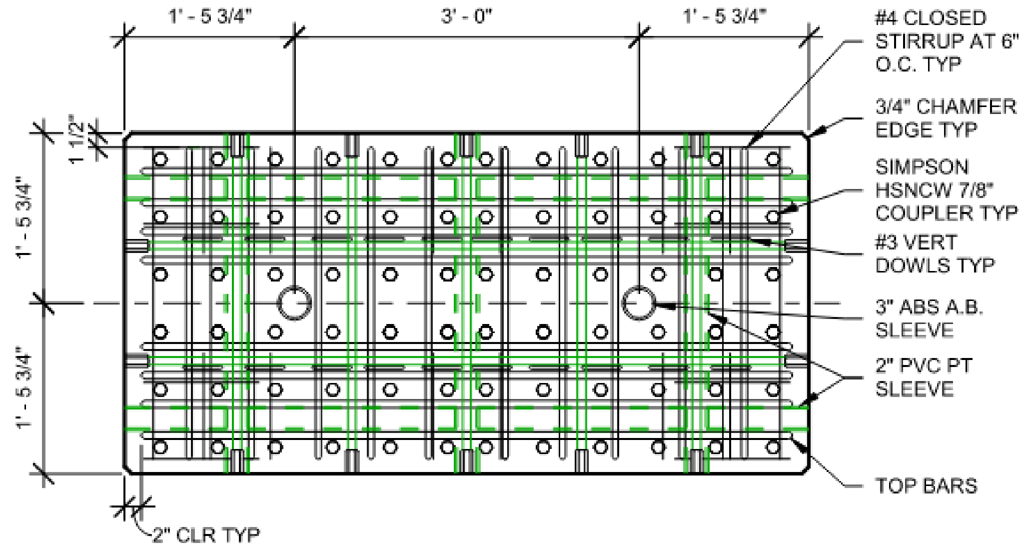

Figure 1. Modular Foundation Design.

Due to the stresses that will act upon the modular foundations, there are several high strength requirements. Each modular foundation required 72 vertical and 14 horizontal all-thread bars. The top surface of the foundation houses couplers used to connect the vertical All-Thread within the foundation to vertical All-Thread externally that will secure various structural walls to be tested. The horizontal surface of the foundation houses couplers that are used to connect the horizontal All-Thread within the foundation to the other modular foundations, as well as secure the foundations to the floor when they are flipped on their side for specific structural testing.

The modular foundations also consisted of a complex rebar cage and PVC pipe. This paper will include minor errors and suggestions for the future construction of modular foundations by detailing situations where we faced several complications. In addition to the 145 feet of All-Thread, the rebar cage consists of 330 feet of rebar, as shown in Figure 2 below. This made the foundation boxes extremely cumbersome with metal, resulting in a few clashes with the PVC piping. There are two vertical and five horizontal PVC pipes used for combining the foundations and floor connection. The modular foundations that we have constructed will serve the ARCE department for many years and enable ARCE students to perform structural analysis of the shear walls they build.


Figure 2. Rebar Cage and All-Thread Top View.

Procurement

The procurement for this project was simple in comparison to the quality control. The modular foundations required formwork panels, Simpson Strong-Tie All-Thread along with hardware, rebar, PVC pipe, and concrete. Of those materials, we only had to procure the small hardware package, the rebar package, and the concrete package. Prior to our project, we learned another project had used the same exact SST all thread that we needed and still had plenty of excess material. For the means of repeating this project, it is highly recommended to order materials in this process: rebar and SST All-Thread, as those are the largest packages and will take more time. Then, formwork panels and lumber should be ordered, as those are easy to obtain and fabricate. Finally, concrete should be ordered once a pour date has been determined.

Simpson Strong-Tie All-Thread and Hardware

In the preconstruction phase, David performed a quantity takeoff of what material was needed and what material was available from prior projects that we could use for ours. The takeoff resulted in having enough 7/8 inch All-Thread and at the time, what we thought there were enough couplers.

Halfway through the project we were forced to procure another package of couplers. One of the critical aspects of preparing the-all thread for installation was the removal of nuts and plates from at least one side of the bar. Upon receipt of the remaining all-thread from the previous project group, it became evident that the 7/8 inch all-thread was in lengths of 2'-6", which necessitated cutting down to 1'-3 1/2" to align with project requirements. However, the provided rods had high-strength distorted thread center locknuts, which presented a significant challenge in terms of time and effort required for removal. To address this issue, David employed a combination of a vice and manual torque application to facilitate the detachment of the nuts, a process that required careful handling to prevent damage to the all-thread or any of its components, and a process that took a lot of time and some patience.

Rebar

As said before, these foundations consist of a significant amount of rebar; therefore, it is certainly recommended to get an early start on the procurement of all reinforcement. Fortunately, this was not an issue for our team as we had plans that showed all the rebar dimensions and sizes, and a take-off was provided to us by the ARCE department. We contacted Air Vol Block in San Luis Obispo to get a quote for the fabrication of #3 vertical dowels and hoop ties, #4 closed stirrups and straight bars, and #6 straight bars. They were able to send us a quote for all the rebar and the Arce department funded it. Three weeks after we placed the order the rebar was ready to be picked up. Henry took his flatbed truck to Air Vol’s yard and had all the rebar loaded with a forklift. We unloaded it all in our designated work area in the corner of the SST building and commenced with the project.

Concrete

After we had finished the first footing and had made some headway on the second, we reached out to CalPortland to schedule a pour for the footings. CalPortland graciously agreed to donate half of the concrete to the project and the Construction Management Department covered the other half. A specific mix design was specified on the plans which we sent to the batch plant ahead of time. This design was for 5,000psi ¾" aggregate mix with a 4” slump.

Quality Control

Quality control is especially important on cast-in-place concrete projects because the project's esthetic and structural configuration will be a direct result of the formwork's quality. Furthermoore, with the plan being to put chamfers on all edges of the footing, it was paramount that everything was double checked before pouring.

Formwork Panels

The formwork was one of the very first things that we tackled on this project as it was the easiest milestone to complete. One aspect that aided the process and minimized the concern for quality control was the ARCE department's offer for us to utilize the CNC machine. This is shown in Figure 3 below. A CNC machine is a Computer Numerical Control machine that reads code inputs defined by an x-y-z axis to shape the material. In our case, the code was preset from a prior project, therefore, all we had to do was lay the eight by four pieces of plywood on the table, start the machine, and change the drill bit type depending on the cut. The cuts it made included the perimeter of the formwork, all thread inserts, PVC inserts, and predrilled holes for securing the formwork together. Overall, the CNC machine was certainly the most accurate and efficient way to cut our formwork.

Figure 3. CNC Machine.

Reinforcement

As seen in figure 4, a significant amount of hardware and reinforcement is embedded into these footings. Per the plans and specs, a rebar cage is to be constructed using various shapes and sizes of rebar ranging from #3 up to #6 diameter bar. Embedded into this cage lies 72 vertical and 14 horizontal 7/8-inch All-Thread rod. Each length of All-Thread has a coupler on the end that attaches to the form panel. This is done so that after the footing is stripped the product will have multiple bolt holes for people to bolt walls and other structures down to in the future. The dimensions for the rod lengths were listed in the plans so a significant part of the project was cutting everything to length ahead of time. All the All-Thread and couplers were donated by the CM department because they were left over from previous projects. The rebar, however, requests funds from the ARCE department, which they kindly granted upon request. We utilized Air-Vol Block, which is a well-known material supplier located on the South side of San Luis Obispo. Air-Vol provided the option to bend the bars as needed to fit our project for an additional 280 dollars. Upon approval from the ARCE department, we proceeded with this option as it helped us avoid the time impact of bending the rebar ourselves. The fabrication process took a single work week, and the bar was ready to pick up in time for us to maintain our project start date. Upon the initial take-off of material on hand from the last modular foundation project, we determined that all all-thread, hardware, and couplings necessary were on hand. This was true for All-Thread and hardware. Towards the completion of the second modular foundation, during a recount of materials, we discovered that the quantity remaining of the Simpson Strong Tie all-thread couplers was short of the original account by eight. These couplers are not provided in local building supply stores and need to be specially ordered from a Simpson Strong Tie Distributor. Luckily, a group member used their relationship with a material salesperson at White Cap to place the order immediately. Because White Cap constantly has shipments coming in from Simpson, we were able to pick up the remaining couplers two business days later. The most important aspects of the procurement process are lead times and correct quantities. Ensuring that you are ordering enough, or rather more than enough, materials to complete your project is crucial to timely completion. Our incomplete take-off posed an issue for our project that could have been avoided. Fortunately, lead times were not an issue, and we were still able to meet our pour date with time to spare.

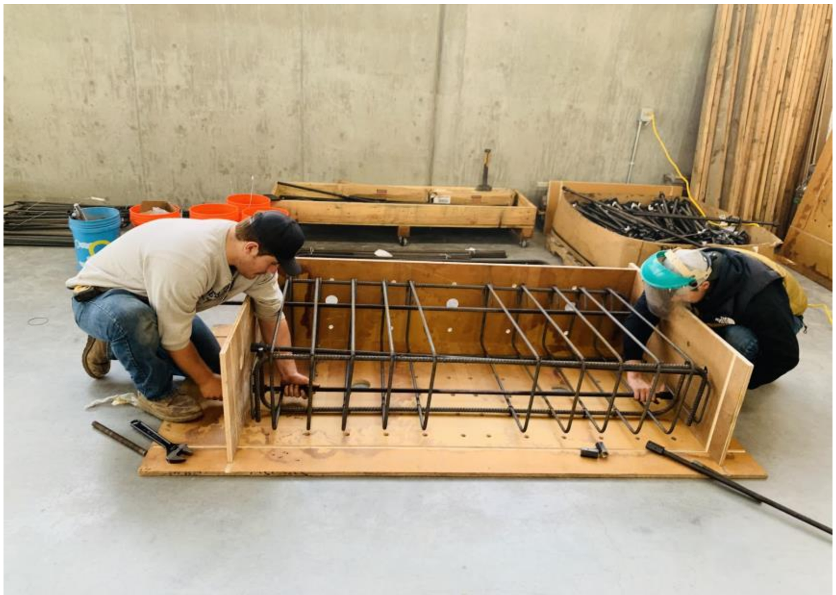

Figure 4. Henry and Blaize tying the rebar cage.

PVC

During our project, there were two fundamental issues when dealing with the PVC piping. To reiterate, PVC piping is for combining the foundations and floor connection. The first main issue had to do with the horizontal PVC pipe that stretched the longest length of the foundation and the rebar that hooked under the longest length of all thread rods. As we should have seen before installation, these two components clashed majorly. Our plan of attack was a bit wrong as we did not see any potential issues. However, once the formwork box became increasingly cluttered with rebar and all thread, we saw what was going to happen once we installed the two horizontal PVC pipes. Therefore, we had to undo many wire ties, move some rebar around, and shift the cage. All of this was quite difficult as all our formwork panels were in place. We faced a similar issue with the second foundation except only one of the PVC Pipes clashed with the edge of the overbend portion of the #6 closed stirrups. At this stage of the project, the footing was completely formed and removing portions of the formwork to shift the cage posed serious time impacts. We decided to use a cut-off wheel to trim back the overbend to make space for the pipe. This was the best fit solution as it allowed us to resolve the problem in just a half hour, and the overbend portion of the closed stirrups bears no structural importance to the footing. For future construction, we suggest leaving one formwork panel off until the rebar and piping are installed to make the area more accessible and easier to shift. The second main issue had to do with the concrete pour and the vertical PVC pipes. We were concerned that the pipes would move as the concrete pushed upon them. If the pipes moved around too much, then certain testing procedures would not be permittable for the ARCE students. Therefore, we simply used rebar tie wire to secure the vertical PVC pipes to the rebar cage in two places upon each pipe and adjusted their heights to be flush with the top of the concrete.

Figure 5. Blaize trimming the conflicting rebar cage to slide PVC in place.

Concrete Pour

A day before the Concrete pour was scheduled to take place, Tim came over to the SST with the forklift and helped us move both footings over to the ARCE High-Bay. We set them on a level slab surface just inside the bay doors. The footings will end up in the High-Bay; therefore, it is easier to pour concrete over there, it made sense to move the forms over ahead of time. Since components may have shifted during the move, we were sure to confirm all the dimensions and measurements before the pour. We cut a 4’ 2x4 board to use as the Screed and were able to borrow a concrete vibrator from the ARCE department. At 8:30 am on Friday morning, a CalPortland concrete mixing truck showed up on campus. David was staged out on Highland Street to meet the truck and escort him into the High-Bay yard. After some tight maneuvering, the truck backed up to the footings, and we hooked on three sections of chutes. Before the pour began Henry told the driver to add five gallons to the mix as the specified slump was 4.5” and we knew it would be too dry to easily move through the rebar cage. The driver did this and as soon as the concrete started to come down the chute had him add another five in. About halfway into pouring the first footing, Henry instructed the driver to add another five gallons and this consistency was perfect for the rest of the pour. The engineer who created this mix design had little understanding of “workability” especially with the footings being so tight with all the reinforcement. During the pour the labor distribution consisted of David manning the chute and shoveling excess mud around, Blaize moving around mud and screeding, and Henry operating the stinger to vibrate down the mix 5). The stinger proved its worth during the pour since the voids in the rebar were so small the concrete needed vibration to settle down into the footing. After both footings were struck off and vibrated, the concrete truck went to the washout dumpster and the pour was completed. We allowed some time for the mud to set up and then commenced to Mag and trowel the exposed surface. We confirmed the layout of the vertical 3” PVC and adjusted them slightly as they had been moved by the pour. Overall, the pour went very smoothly, and we did not encounter any issues that we were not prepared for.

Figure 6. David, Henry, and Blaize pouring the footings.

Lessons Learned

During the process of construction of both footings we tried two different approaches to getting all the reinforcement in place. For the first footing we tied the entire rebar cage ahead of time then set it inside the form work and placed the All-Thread second. This turned out to be challenging because there is extraordinarily little wiggle room for the rod, and we had to retie the cage to accommodate this multiple times. For the second footing, we laid the All-Thread first, hung and tied the cage around. This also proved to be a challenge because tying the bottom rebar was impossible with the All-Thread in the way and there was minimal room to get our hands in the cage to tie. After getting all the reinforcement done in both footings, all of us feel strongly there is no perfect way to build these footings and no matter what there will be some degree of conflict, and or rework to be done, due to the amount of reinforcement and lack of space. Regardless, we were able to construct the second modular footing much faster than the first because we put more thought into the order of operations, and that was one of our key takeaways. Rather than putting our head down and attacking the work, like we did on the first footing, it is far more beneficial to think through the process and develop a game plan on how you are going to accomplish the tasks at hand. Another extremely important lesson we learned was the importance of completing an accurate take-off. The discovery of an incorrect coupler take-off near the project completion could have produced a serious time impact if the material were to have a long lead time. Thankfully, this was not the case. However, it is important to note that the best practice is to have all material on hand before it is needed, with extra if possible.

Figure 7. The finished product, both footings stripped with chamfer details.

Conclusion

In conclusion, the construction of the concrete modular foundations for the ARCE department has been a challenging yet rewarding project. Through extensive planning and execution, this durable and efficient foundation will provide a stable base for future projects and research in the department. The use of concrete as the primary material provides durability and longevity, ensuring the foundation's longevity and stability for years to come. Throughout the project, we gained valuable experience in formwork construction, rebar tying, material procurement, and concrete finishing. These skills will serve us well in our future careers as construction managers. Overall, the construction of the concrete modular foundation for the ARCE department has been a valuable learning experience and a testament to the skills and knowledge we have gained through the Cal Poly San Luis Obispo Construction Management program. The project's success reflects the dedication and hard work of the students, faculty, and staff involved in the project, and it will undoubtedly benefit the department for years to come. Lastly, we would like to thank Andrew Kline our SME, Tim Dieu from the ARCE workshop, and everyone else who contributed to our successful project.

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5	Blaize trimming the conflicting rebar cage to slide PVC in place.
6	David, Henry, and Blaize pouring the footings.
7	The finished product, both footings stripped with chamfer details.