Construction of Concrete Modular Foundations - Procurement and Quality Control

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This project details the material procurement and quality control processes throughout the construction of two concrete modular foundations. The project focused on constructing the blocks as they were designed to ensure they meet strength parameters to be used in the High Bay Lab at California Polytechnic State University in San Luis Obispo (Cal Poly) for various testing performed as part of the curriculum for the Architectural Engineering (ARCE) and Construction Management (CM) departments. The complex designs, encompassing one-hundred coupler attachments and a dense rebar cage, required extensive attention and hours of labor and quality control review. This paper will cover the main phases of the construction process and how they were acquired. Furthermore, the considerations taken throughout the construction to provide a quality product will be discussed throughout the paper. The lessons learned during the build are important items discussed which will allow students in the future to build more foundations should the High Bay require broader testing capabilities. The foundations were built successfully on schedule and met the quality of the design requirements. The purpose of this project was to assist in creating more resources for research and classroom material to be completed at Cal Poly. With the use of the foundations, the ARCE department will be able to test various building components that are important for the construction industry as well as student understanding.

Key Words: Foundations, Testing, Quality Control, Procurement, Construction

Introduction

The concrete modular foundation project consisted of the design and construction of two blocks with 100 connections, as shown in Figure 1 below. Each footing was designed to aid in the testing capacities in the Cal Poly High Bay. The connections offer many different testing possibilities which will expand research pertaining to the architectural engineering and construction process.
Figure 1. Foundation Design

The project derived from an ARCE student’s need for movable foundations for their masters degree project within the high bay. The foundations that the ARCE student designed, hold one hundred connections, and can be anchored to the ground in different combinations to foster a range of connections. Of the one hundred connections on the block's surface, seventy-two are located on the top surface and the other twenty-eight are located on the vertical sides, as shown in Figure 2.

Figure 2. Rebar Cage and Formwork
Each connection is a coupler attached to high-strength anchors within the concrete. Also, a rebar cage was designed to ensure the blocks can withstand testing procedures. PVC pipe runs through the core of the blocks in all directions to allow for connecting the foundations to both the floor and each other. As the construction management students on the project, our role was to construct the two blocks as they were designed to assist in research for the ARCE department.

**Procurement**

The procurement of materials was one of the most difficult aspects of the project. This project was on a tight schedule of eight weeks from and there were many materials that had to be ordered before we could start the fabrication. The largest material packages required for the project was the rebar and the anchors. The focus early in the project was getting the lumber so the forms could be assembled before the fabricated rebar was ordered.

**Rebar**

The rebar package was assembled based on the design of the rebar cage. It consisted of straight bars, closed stirrups, vertical dowels, and hoop ties. We sent the shop drawings and material list to AirVol in San Luis Obispo where they sized and bent the bars as designed.

**Simpson Strong-Tie Embeds**

The next large procurement package required was from Simpson Strong-Tie, and it was the couplers, nuts, bolts, and plates for the connections. This was the largest and most expensive package and was donated by Simpson Strong-Tie. Once the formwork was completed, this was the quintessential package because it was the next step in the assembly process. There were approximately three hundred feet of ¾” high strength steel bar required that needed to be cut into various sizes.

Figure 3. Anchor lengths within foundations
The original thought was that the company would cut the bars into the sizes we needed, mostly made up of 1.35-foot pieces, however, they came in 6-foot bars that were eventually cut to size. Once the main packages were sorted and construction had begun, the last items; bracing 2x4s and PVC were purchased.

**Quality Control**

There were noted issues that happened when this project was completed previously, so a large focus during the build of the two blocks was on the ability to create a repetitive process for building these blocks in the future. The only way to successfully pour the blocks was going to be upside down because of the anchor connections on the top face of the block. The largest issue throughout the build was tying in the rebar cage amongst the one hundred anchors in the block. There was a lot of trial and error throughout the process, and many times we had to disassemble the formwork to fit a single piece in.

**Rebar**

The focus of quality control was on making sure clashes did not occur. In the vertical direction, there were seventy-two embeds from the bottom of the formwork to a little over a foot into the block. In the horizontal direction, the long side had four bars running the length of the block to brace the formwork. Similarly, there were ten bars running horizontally on the short side to brace the forms. These bars were essential during the pour for the strength of the formwork as well as the testing capacities of the blocks. It was important to constantly check for clashing between the bars and the rebar cage as the rebar cage was tied into place. Because all sides of the formwork could not be attached when tying the rebar, the horizontal anchors were not in place. There were many times when a combination of rebar pieces was tied in place, just to realize that it was in line with a bar location, which required us to backtrack. Later in the process, we began using pieces temporarily where the bars would be to tie the rebar around them.

**PVC**

Another area that required attention during construction was the PVC installation. Because of the way it was built, the PVC was the last item to be installed into the formwork. The PVC had to be straight for anchors to run through them attaching the blocks together or to the ground. There was only a small area where the PVC would fit between the rebar cage, as seen in Figure 4. In a similar fashion to the bars, we would temporarily place the PVC when tying in certain areas of the cage.
Formwork

The formwork design made the quality control very easy. The formwork was designed using AutoCAD and cut out by the CNC machine in the CAD Shop.
This ensured that each of the holes for the anchors was in its precise location. The machine also cut out grooves on the flat part of the formwork for the sides to fit into with small, predrilled holes to ensure proper connections.

The bracing of the formwork was designed to ensure the forms did not move during the concrete pour. Where the bars inside the block reached the couplers, a bar on the outside was connected and ran through a hole in a two-by-four. There was then a plate and a nut to secure the two-by-four bracing to the sides of the formwork. In this process, it was important to check the dimensions of the block because the strength of the tool used could gradually warp the shape of the formwork, taking away the design dimensions. Adjustments were made to the tightness of the nuts and couplers to ensure the block was the right length in each direction.

*Concrete Pour*

The concrete pour was two cubic yards (CYs) performed in the late afternoon, one CY per footing block. Our strategy to provide the correct pour without wasting time or concrete was to have both the blocks side by side with the high bay doors open, as seen in Figure 6.
The truck backed in with the chute hanging over the two forms allowing us to swing it back and forth during the pour so both blocks could be continuously poured.

The process of the pour was to dump into one form, where one person would shovel the concrete to spread it out and another person would use a vibrator. The chute was then swung over to the other block and concrete was dumped. This was repeated until the correct amount of concrete was poured into each of the forms. Two people would screed the concrete while another person would continue to vibrate. The concrete was a 5000-psi mix that required a lot of attention when vibrating to get the aggregate to make its way through the dense rebar cage and anchors. Once the concrete was vibrated and screeded, we applied a float finish and rounded the top edge to match the beveled edges in the formwork.
An important factor of the blocks was the strength of the concrete. Before we pulled the forms from the concrete, we wanted to ensure the concrete had cured enough and reached at least 4,000 psi. The issue we had however was being short-staffed during the pour, and therefore the cylinders were not properly filled. It is necessary to follow the correct methods when filling cylinders, including rodding the correct number of times. During the pour, correct methods were not followed, and it was reflected in our cylinder tests. After 21 days the test maximum was 3,400 psi and the cylinders were breaking in an abnormal way. This was a worry to us; however, we are confident that the lack of strength derives from not filling the cylinders accurately rather than the concrete mix. The concrete was mixed by Cal Portland as a 5,000-psi mix, but in the future, it is recommended to spend the necessary time preparing the cylinders.

**Lessons Learned**

The biggest lesson I learned during this process was how to work and communicate with a team. This was an interdisciplinary project with many parties involved and it taught me about communication in the industry. As a group of three of us working on a tight schedule, each with different advisors, while also communicating plans with the guys managing the high bay, there was a lot to be learned.
Material procurement was the largest issue that held us up from completing the project on a perfect schedule. One party thought the other oversaw certain aspects, which led to some materials getting ordered later than expected. If we clearly delineated the responsibilities of each party involved, the schedule would have been much tighter and likely led to an overall smoother process.

A technical lesson I learned while assembling the rebar cage, was the importance of having a clear plan before starting an activity. The course material I have learned while studying CM at Cal Poly has always been focused on broader scheduling of activities. I never had to think critically about a small portion of a project and the importance of each tiny phase within an activity. Assembling the densely packed rebar cage amongst the anchors and PVC was extremely challenging. Many times, throughout the first block, we had to take apart the forms to get certain pieces of rebar into the form. With some early critical thinking and realizing potential issues after the first block, the second one came together much easier.

The bracing and covering of the vertical PVC pieces were other areas that needed more attention. To make the screeding process easier, we cut the pieces of PVC to be flush with the top of the forms. It was discovered once we removed the formwork that one of the pieces of pipe had shifted during the pour, creating a slanted tube. This clearly will not serve its purpose of allowing a bar to pass through from the floor to provide stability. It would have been sufficient if the pipe was tied to something stable within the forms to prevent the curing of concrete to move the pipes. Another solution would have been to leave the PVC at a longer length. This would have made the screeding process more difficult, but the pipes would have more stability and would not have filled with concrete as they did.

Conclusion

Overall, this project presented the team with several challenges that required extensive communication to provide success. As we were able to build two foundations, the learning curve during the construction of the first foundation taught us a lot about the importance of planning out the specific stages of construction. The assembly of these blocks also felt like a puzzle because of the small pieces, and it was important to think critically and discuss the steps with the entire team. We had success working as a team that mimicked one we’re going to experience in the industry. This project truly encompassed the most important lessons taught in the Construction Management Curriculum.