Design and Construction of a Corrugated Metal Roof for Rebuilding Together in San Jose, CA

Zachery T. Pollard, Undergrad Student
California Polytechnic State University
San Luis Obispo, CA

This paper will examine the design development, estimation, and construction of a corrugated metal roof for Rebuilding Together, a nonprofit in San Jose, CA. The contents herein discuss the multitude of steps required to see a construction project from its inception to its completion. Beginning with its schematic design, the project went through many revisions as the conceptual design was modeled in a 3D modeling program called ARCHICAD. Once modeling was complete, the material required to completed the project was taken off using four different material sets – estimates were then complied for each of these material sets and sent to Rebuilding Together for review. Once given direction on which materials to move forward with, the pitched rafters were structurally sized using dead load calculations and live load assumptions, ensuring the structural integrity and lifespan of the project. This paper also examines the step-by-step processes used to physically erect the roof structure atop of the existing CMU block wall, including each of the tools used. Over the duration of both the design and construction phases many obstacles were overcome, and overall the entire project served as an extremely beneficial platform to utilize all the skills acquired throughout the Cal Poly construction management curriculum.

Keywords: Sawn-Lumber Construction, Corrugated Metal Roofing, Simpson Strong-Tie

Introduction

Rebuilding Together is a national non-profit organization that has been providing in-home repairs and modifications for low-income home owners since 1988. In an effort to preserve affordable homes and aid those unable to make home improvements on their own, they provide a multitude of services that alleviate the day to date struggle of those in need. Each year, each of the many offices across the US put on two major "build days," in which they coral hundreds of volunteers to remodel a home for a selected family in need. In addition to these build days, they also provide services for dozens of smaller projects during the year, like installing American with Disabilities Act (ADA) required ramps, grab bars, wheelchair lifts, and even making repairs on water heaters, sinks, washing machines, etc. With a multitude of projects continually ongoing, Rebuilding Together is constantly looking for volunteer labor to work on their projects. In this way, when a request was sent to Rebuilding Together to build a project for their team, they immediately mentioned that they were in dire need of a roof to be built over a storage area located behind their warehouse in San Jose, Ca. In this way, a mutually beneficial opportunity arose and work on the project began right away. With the most obvious deliverable being the construction of the project itself, it quickly became apparent that both a design, estimate, and construction schedule would also be required to complete the project. Due to the nature of the project, a model was also included in the deliverables to truly capture the skills acquired in the Cal Poly curriculum. Each of the deliverables discussed above are touched on in either the design development, or construction means and methods phases below.

Design Development

The design of the roof project consists of pressure-treated douglas-fir framing attached to an existing CMU block wall with two, double leaf gates along the front wall. The structural component of the structure consists of sawn lumber framing attached to the existing CMU block wall with ½" expansion anchors, embedded in the wall per the manufacturers specifications. The roof of the structure is framed in a “shed roof” style with a 4:12 pitch – 14’ - 6 ¾” sloped 2x6 rafters sit upon a 4x4 top sill along the back wall, and upon a 4x6 header supported by 4x4 columns along the front wall. Atop the 2x6 rafters are 8’-0’ x 2’-4” corrugated metal roofing panels that are fastened to the rafters using Simpson metal-lumber fasteners with gaskets. The design criteria provided by Rebuilding Together were only that the storage area need not be entirely enclosed, but sufficiently detour the majority of rain water that may fall on the area.

Schematic Design

The schematic design for the roof structure was formulated with the following considerations in mind: dead load, live load, material cost, attachment to existing structure, aesthetics, and rafter span. The first consideration in the design process was to first determine which style roof would best suit the existing structure. After much thought, it was determined that a “shed” roof structure would be best suited both aesthetically in the space as well as for the use of the space. It was described by Rebuilding Together that the roof enclosure did not need to be entirely water-tight, and only defer the majority of rain water outside the enclosure. In this way, the open nature of the un-enclosed shed roof design suited the project perfectly. The dimensions of the existing CMU enclosure were then provided by Rebuilding Together and using this schematic design, the physical design process began with sketches on engineering paper. Once the general idea of each structural member was determined, the project was modeled in ARCHICAD, a 3D architectural BIM software for design. It was at this point in the design process that it was realized that there was a scope gap in the design. While flying through the model, it was realized that while there were rafters to bear the load of the roofing material, there also needed to be purlins to run perpendicular to the rafters. Using the model, floor plans and elevations were extracted, allowing the project to be accurately estimated.

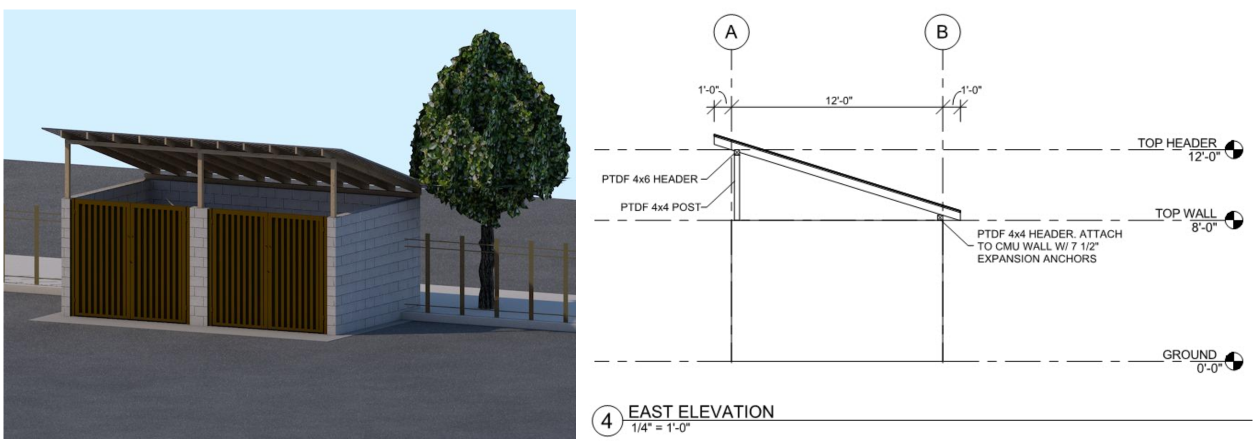

Figure 1: 3D rendering of model and elevation created in ARCHICAD.

Material Takeoff and Estimate

Once the model was complete, the floor plans and elevations created in ARCHICAD were exported from the program onto a customized title block found in the back of this binder. These documents were then imported into Bluebeam Revu, calibrated to scale, and the estimation process began. Using the linear takeoff and square footage takeoff tools, all roofing and lumber members of the structure were taken off. Bluebeam individually categorized each member type and gave total linear feet and square feet for each material as seen below.

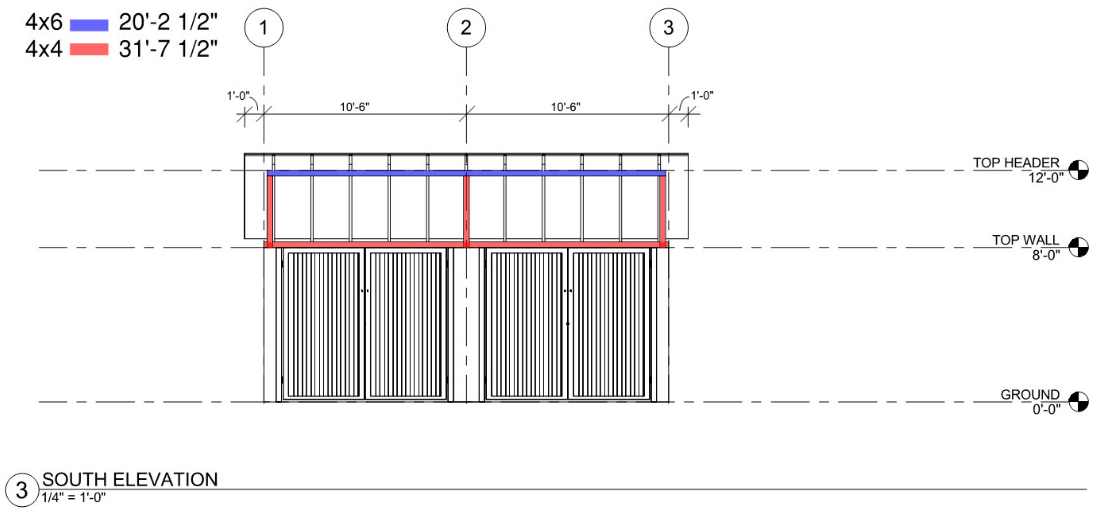

Figure 2: 4x4 and 2x6 column and header lumber takeoffs.

Using the quantities calculated in Bluebeam, each material was then imported into Microsoft Excel as individual line items which allowed estimates to be created. Being that no sizes were yet given to the actual lumber members yet, assumptions were made as to which sizes would be used for the columns, headers, and rafters of the structure. Building off these assumptions, material prices were taken off Home Depot's website (where the material was planned to be purchased) to create accurate estimates to complete the project. Once on the Home Depot website it was noted that were multiple different types of material that could potentially be used to complete the project. Using these different materials, four different estimates were put together using the following combinations:

1. Redwood with Corrugated Metal Roof
2. Douglas Fir with Corrugated Metal Roof
3. Pressure Treated Douglas Fir (PTDF) with Corrugated Metal Roof
4. Douglas Fir with OSB and Asphalt Shingles

After review of each estimate, option 3, Pressure Treated Douglas Fir with Corrugated Metal Roof was selected by Rebuilding together after evaluating the cost, aesthetics, and lifespan of each assembly.

Structural Design

With the materials and general schematic design of the structure selected, the true sizes of the rafters could be sized based on roofing material weights. Using the product specifications on the Home Depot website as well as Weights of Building Materials, Agricultural Commodities, and Floor Loads for Buildings, the weight of each material was assembled in Microsoft Excel and the weight per square foot was calculated. Using these weights, the total dead load per square foot (psf) of the structure was calculated, as seen below.

Table 1

Rafter Sizing Dead Load Calculation

Material	**Length**	**Width**	**Area**	**Weight**	**PSF**
Weight of Corrugated Roofing (1)	8' - 0"	2' - 3 3/4"	18.64 ft2	7.10 lb	0.38
Weight of 1x4 Purlins	23' - 0"	-	-	.64 lb/ft (2)	0.23
Self-Weight of 2x6 Rafters	14' - 6 3/4"	-	-	2.0 lb./ft (3)	0.96
Total Dead Load					1.57 PSF

Assumptions for dead load calculations:

1. See Corrugated Metal Roofing Product Data
2. See Weights of Building Materials, Agricultural Commodities, and Floor Loads for Buildings
3. See Weights of Building Materials, Agricultural Commodities, and Floor Loads for Buildings

Being that the roof structure is not designed for people to access the roof, the minimum allowable design live load in California was assumed, 20 psf. Using the dead load calculation above, the assumed live load of 10 psf, and the known interior horizontal span of the rafters, 12' – 0", Table R802.5.1 (1) was referenced from Chapter 8, Roof-Ceiling Construction of the California Residential Code 2016. On the table, the maximum allowable span for a douglas-fir #1 2x4 with a dead load of 10 psf and live load of 20 psf each, is 8'-7", and the maximum allowable span for a douglas-fir #1 2x6 with a dead load of 10 psf and live load of 20 psf each, is 12'-6". Being that the calculated dead load on the roof structure of 1.57 psf < 10 psf, and the rafter span of 12'-0" < 12'-6", a rafter size of 2x6 at 24" O.C. spacing is the appropriate structural member for this project.

Lumber-Connection Design

The final component left to design was the fasteners and connectors to physically tie all the building materials together. To fasten each of the lumber materials to another, 3 different Simpson connectors were used. To connect the rafters to the 4x4 top plate along the back wall of the CMU enclosure, 18-guage hurricane ties were used in order provide wind-uplift resistance on the structure. Secondly, for the "T" connection between the center post and the 4x6 header along the front wall, an 18-guage "T" adjustable post cap connector was used. Thirdly, for both "L" connections between the 4x4 posts and the 4x6 along the front wall of the CMU enclosure, 20-guage end post cap connectors were used. For each of these Simpson connectors, #10 1-1/2 in. External Hex Flange Hex-Head Structural-Connector Screws were used at each of the pre-drilled holes to fasten the connectors to the lumber.

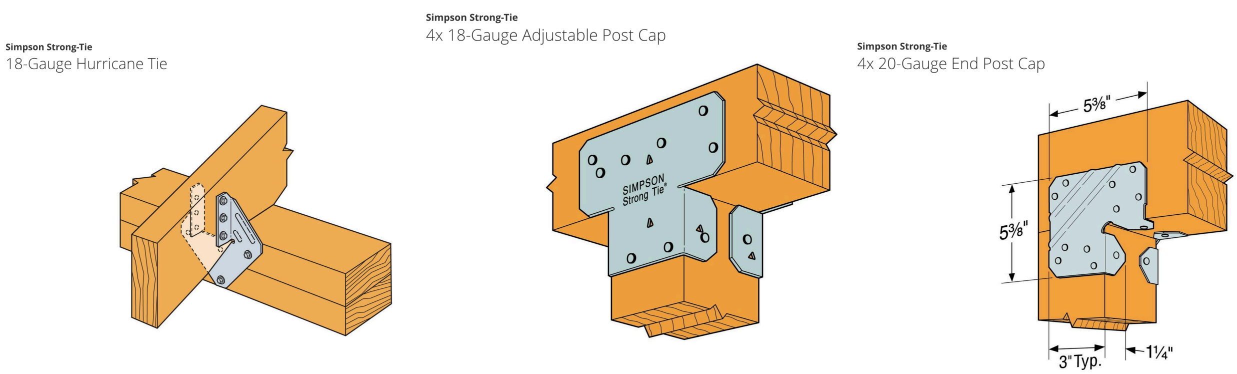

Figure 3: Simpson Strong-Tie lumber connections used.

Finally, to fasten the 4x4 top plate to the back wall of the CMU enclosure and the 4x4 columns along the front wall, 5/8" holes were drilled into the top of the wall with a corded roto-hammer and ½" Red Head Wedge Anchors were tapped with a hammer into the wall. 5/8" holes were then drilled with a drill through the 4x4 top plate along the top wall then secured to the wall using a washer and nut on the wedge anchor.

Construction Means and Methods

Construction began by first prepping the work space with a thorough clean of the existing CMU storage area. Once all existing stored materials were removed from the area, ladders were erected to begin drilling holes into the top of the CMU wall to fasten both the 4x4 header along the back wall and the 4x4 posts to the front wall. Along the top of the back CMU wall, 10, 5/8" holes were drilled with a roto hammer, 4" deep at 18" O.C. Holes were then drilled at the same spacing through the 4x4 top plates. Once all holes were drilled, the 7 ½" Red Head expansion anchors were tapped into the drilled holes, and the 4x4 top plates were then set on top of the CMU wall and fastened to the expansion anchors using the washer and nut provided with the expansion anchors. Next, 4, 5/8" holes were drilled at all three column locations to match the Simpson E-Z column base hole locations. The 5 ½" expansion anchors were then tapped into these holes and the 3 Simpson E-Z column bases were set upon the expansion anchors and fastened using the provided washers and nuts.

The next step was to use a skill saw and cut the 4x4 columns and the 4x6 headers to size. Once these were cut, they were erected in place and fastened together with an impact driver, using the Simpson connectors and screws discussed above. With the 4x4 top plate along the back CMU wall in place and the 4x6 header erected along the front wall, the rafters could now be field measured in order to make the proper birds mouth cuts. Once measured, the inside diagonal distance between the top plate on the back wall and the head on the front wall were marked out along a 16’ 2x6. Once this distance was marked, using a framing square, a birds mouth was marked out on the 2x6 at a 4:12 pitch. The birds mouth was then cut out using a skill saw and erected into place to confirm that the birds mouth cuts were correct. Once this was verified, this rafter was brought back down to the ground and used as a template to mark out the remaining 10 rafters. In addition, the plumb cuts on the front and back ends of the rafters were laid out for a 4:12 pitch and cut with a skill saw. Once all rafter cuts were made, all 11 rafters were erected, laid out at 2’-0” O.C., and fastened to their supporting members using the Simpson hurricane ties and #10 1-1/2 in. hex screws.

With the rafters now in place, the 1x4 purlins could now be cut and installed. As mentioned before, the purlins were previously a scope gape and posed an issue during installation. Since the purlins were not a part of the initial conceptual design, their installation was not as well vetted as the other members. Instead of measuring the center to center distance from rafter to rafter and cutting the 8’ material according, the full 8’ 1x4s were installed on the left and right side of the roof. Due to this, the inside distance between each horizontal purlin needed to be measured, and cut individually, giving them a non-uniform look. In addition, instead of one purlin stopping and another starting on top of a rafter, where it would be concealed from below, the seam between the two pieces of wood was visible at the mid span of the rafter. In order to conceal this, 2' sections of 1x4 had to be cut and fastened to conceal the seam.

Conclusion

Being able to both design and build a construction project is an extremely eye opening experience and truly exposes the builder to the many hardships of brining a simple drawing to life. The multitude of Cal Poly construction courses expose students to the many different facets of construction: hand drawing details, 3D-modeling, estimating, take-offs, sizing structural members, and even physically building a project. However, there is no class that requires a student to do each of these tasks in succession, and see a project through its completion. Having this experience is invaluable and truly teaches one to put all the pieces together and build something that was once just an idea. Although many hardships were overcome, the overall project itself was a great success that finished just barely over budget, and earlier than expected.

Lessons Learned

An impactful lesson taken from this project was the value of a 3D-model being created prior to construction beginning. As mentioned earlier, a major scope gap was found by modeling the schematic design that was previously only drawn out by hand. Due to a lack of experience in roof design, purlins were initially overlooked in the design and would have cost a tremendous amount of time and money if they were not discovered to be missing until the construction phase. By modeling the design, a new perspective on the project as gained and a quick solution could be implemented long before construction started.

However, the greatest lesson taken away from this project was to not take any short cuts. Having to see a project from beginning to end forces the builder to avoid this, because it is almost certain that the short cut will cause an issue somewhere down the road. Learning only a single scope of the construction process—like estimating—while necessary, can allow one to have the mindset that if they overlook something, it won’t matter. This idea comes from the fact that they will not actually have to utilize that estimate in the future to bring that project to life. If nothing else, this project taught the builder that each step of the design and construction process are extremely important, no matter how small they may seem at the time. Seeing a project through from a simple idea to its physical construction is the most beneficial exercise any builder can go through, and truly makes one appreciate both the Cal Poly curriculum and the construction industry as a whole.