FINAL REPORT

A Campus Project

Northeastern US

Garrett Schwier

Advisor: Craig Dubler

A Campus Project

Northeastern US

Construction Manager: Balfour Beatty Construction

Construction Dates: Sept 2012 to Sept 2014

Architect: FENTRESS ARCHITECTS, HASSA

Project Cost: $89.5 million

Cultural Center

Size: 20,600 GSF 2 stories
Purpose: Organizational space
Building Systems:
- CIP Concrete Structure
- VAV Mechanical System

Architectural Features:
- Stone Panel Exterior
- Metal Brake Trim Belt Course
- PVC Roofing Membrane
- Pointed Metal Skylight Dome

Convent/ Monastery

Size: 31,500 GSF 4 stories
Purpose: Guest housing
Building Systems
- CIP Concrete Foundations
- Steel Superstructure
- VAV Mechanical System

Architectural Features:
- Stone Veneer Exterior
- Wood Batten Decoration
- Clay Tile Roof
- Curtain walled Courtyard

Fellowship Hall

Size: 9,600 GSF 1 story
Purpose: Restaurant
Building Systems:
- Reinforced Concrete Foundations
- CMU Wall & Steel Structure
- VAV Mechanical System

Architectural Features:
- Portland Cement Exterior
- Wood Batten Decoration
- Lead Sheet Metal Roofing
- 2 Stone Veneer Minaret Chimneys

Mosque

Size: 24,700 GSF 1 story
Purpose: Religious gathering
Building Systems:
- CIP Concrete & CMU Structure
- VAV Mechanical System
- Radiant Floor System

Architectural Features:
- Two 128’ Minarets
- Central 50’ Dome
- Stone Veneer Exterior
- Lead Sheet Metal Roofing

Turkish Bath

Size: 50,100 GSF 4 stories
Purpose: Community gathering space
Building Systems:
- CIP Concrete Structure
- VAV Mechanical System
- Radiant Floor System

Architectural Features:
- Stone Panel Exterior
- Wood Batten Decoration
- Lead Sheet Metal Roofing

Garrett Schwier **Construction Management** **Faculty Advisor: Craig Dubler**

http://www.engr.psu.edu/ae/thesis/portfolios/2014/gss5066/index.html

Acknowledgments

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Balfour Beatty Construction

FENTRESS ARCHITECTS

Personal

Alyssa Stangl and Jeffrey Martin, Friends, Cute Couple

My family. Especially my Father.

Executive Summary

Throughout the 2013/2014 academic year, this Campus Project was analyzed and researched in an effort to identify areas that could benefit from an alternative solution, primarily in construction. Through interviews and independent research, four major items were chosen for additional analysis. The purpose of this thesis and the analyses performed were completed for educational purposes only. The conclusions are not meant to critique the performance of the project team in any way.

Analysis I: Structural Redesign

The first analysis sought to take advantage of the high prevalence of cast-in-place (CIP) concrete structures on site. Only two of the five buildings were built with a predominantly steel structure. These buildings, the Fellowship Hall and Convent/Monastery, were redesigned with a CIP concrete structure. The goal of this change was to take advantage of worker affinity to CIP concrete, and create a consistent structural element across the project. Following the redesign, the structures were examined to determine how the change would affect the schedule and cost of the project. For the Fellowship Hall, the cost and schedule were both increased by $2,005 and 80 days respectively. Similarly, the Convent/Monastery experienced increases by $252,129 and 945 days.

Analysis II: Restructure of Concrete Bid Package

Further research was conducted into the size and scope of the concrete bid package for the project. CIP concrete was the most used structural element, constituting a significant portion of the total cost. Furthermore, a number of complex shapes and designs, primarily on the Mosque and Turkish Bath, required complex form for CIP construction. This placed significant pressure on the subcontractor in charge of the concrete scope, particularly since nearly all of their work would critically affected the schedule. This analysis sought to divide the concrete scope into smaller bid packages that could be awarded to multiple subcontractors, reducing the pressure and allowing them to focus on their construction efforts. The analysis results recommended a two bid package division which was awarded to two selected local subcontractors. This division will require careful coordination and some contractual language modifications, but it will also give the subcontractors more opportunity to plan for the challenging work they will complete.

Analysis III: Workforce Management Plan

As a multi-building project, construction of this Campus Project presented a unique opportunity to employ a larger workforce resulting in higher productivity. Construction operations could occur in several different locations, particularly coordinated by building. Unfortunately, the larger site caused additional challenges in terms of tracking and managing the workforce. Through this analysis, a Workforce Management Plan was developed to give the project team tools to track, analyze, and manage site work.

Scheduling methods, such as Last Planner and Pull Planning, were explored as methods of coordinating work, identifying problem areas, and improving productivity. Additionally, tips for managing the foreign workforce on the project were provided based upon research conducted into their culture and typical working practices.

Analysis IV: Foreign Worker Safety Plan

As part of the cultural design aspects of the project, a significant number of foreign artisans will be brought to the project from their home country in order to construct many of the architectural finishes. Due to differences in culture, language, and work practice, this will create a safety risk for the workers on site. With a potentially limited knowledge of English and US construction regulations, the foreign workers could inadvertently place themselves, and others, in dangerous situations. Case studies, journals, and other articles were examined to gain an understanding of the safety principles that can be employed on a construction site. Using this information, a Foreign Worker Safety Plan was developed with general and site specific recommendations. The plan focused on several major areas of concern and provides detailed recommendations of how to improve safety.

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1.0 Project Overview

This Campus Project located in the northeastern US is a multi-building, multi-use project, serving as a community and cultural gathering place. It consists of an underground parking garage, a geothermal well field, and five unique buildings – Turkish Bath, Convent/Monastery, Mosque, Cultural Center, and Fellowship Hall. Each building serves a different purpose with the common goal of creating a culturally welcoming site. An overhead rendering of the intended design of the site is shown in **Figure 1**.

Figure 1. *Overhead Rendering of this Campus Project*

1.1 Project Origins

The design for the project originated in western Asia. After the plan reached approximately 50% to 75% design completion, the owner and his US representative, Transtech, brought the design to the United States to be developed to 100% completion in accordance with US laws and building codes. Balfour Beatty Construction was awarded preconstruction and design fees to accomplish this task. They hired Fentress Architects, Capitol Design Development, Inc., and other consultants as necessary to complete the design according to US codes. Once the design was brought to 100% completion, the owner concluded that Balfour Beatty was qualified to lead construction and hired them as the construction manager for the project.

1.2 Client Desires

The owner's primary request for the purpose of this document is to remain anonymous, and therefore his identity shall be withheld through the completion of this report. In terms of project goals, the owner wishes to have a quality product completed in accordance with his design standards. Cost is not of significant concern to the owner, except in order to purchase materials of adequate quality. At times, additional funding is given to purchase more expensive materials that better fulfill the owner's goals. Remaining on schedule is also important to the owner, but no more than would be reasonably expected on a construction project. As such, the owner's primary desire for the project is a high caliber product that meets the objectives and missions that they have requested. Incorporation of a foreign workforce is desired to fulfill cultural building requirements, and to integrate the culture with construction.

1.3 Delivery Method and Project Staffing

Balfour Beatty was awarded a guaranteed maximum price (GMP) contract of $69.5 million, with an additional allowance of $20 million to be used with authorization by the owner, primarily for higher quality materials. The architect, consultants, and subcontractors hired by Balfour Beatty were brought on as Lump Sum agreements. The engineers and consultants who helped develop the project design were contracted by Fentress Architects, rather than Balfour Beatty. During construction, subcontractors were contracted with Balfour Beatty directly. The organizational chart below shows the contractual relationships between project team members **(Figure 2)**.

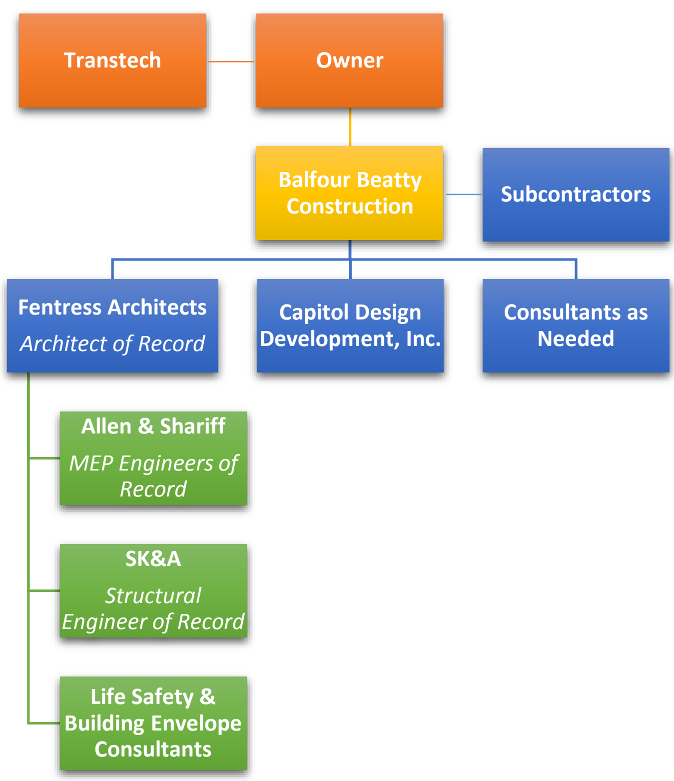

Figure 2. *Contractual Relationships of this Campus Project*

In order to complete the project, Balfour Beatty staffed it with a number of employees from both the office and on-site. From the office, the project is led by Senior Vice President Mike Phillips and Vice President Richard Ryan. These individuals primarily fill a leadership role and are not actively involved with the project past the early stages. In the field, construction is directed by Senior Project Manager Dave Convis and Superintendent Chris Kirkwood. They also have several assistants and Project Engineers that assist with site operations. The organizational chart below shows the hierarchy of personnel involved with the project **(Figure 3)**. Also shown are members of Transtech, Ali Cayir and Craig Melicher, project representatives of the owner.

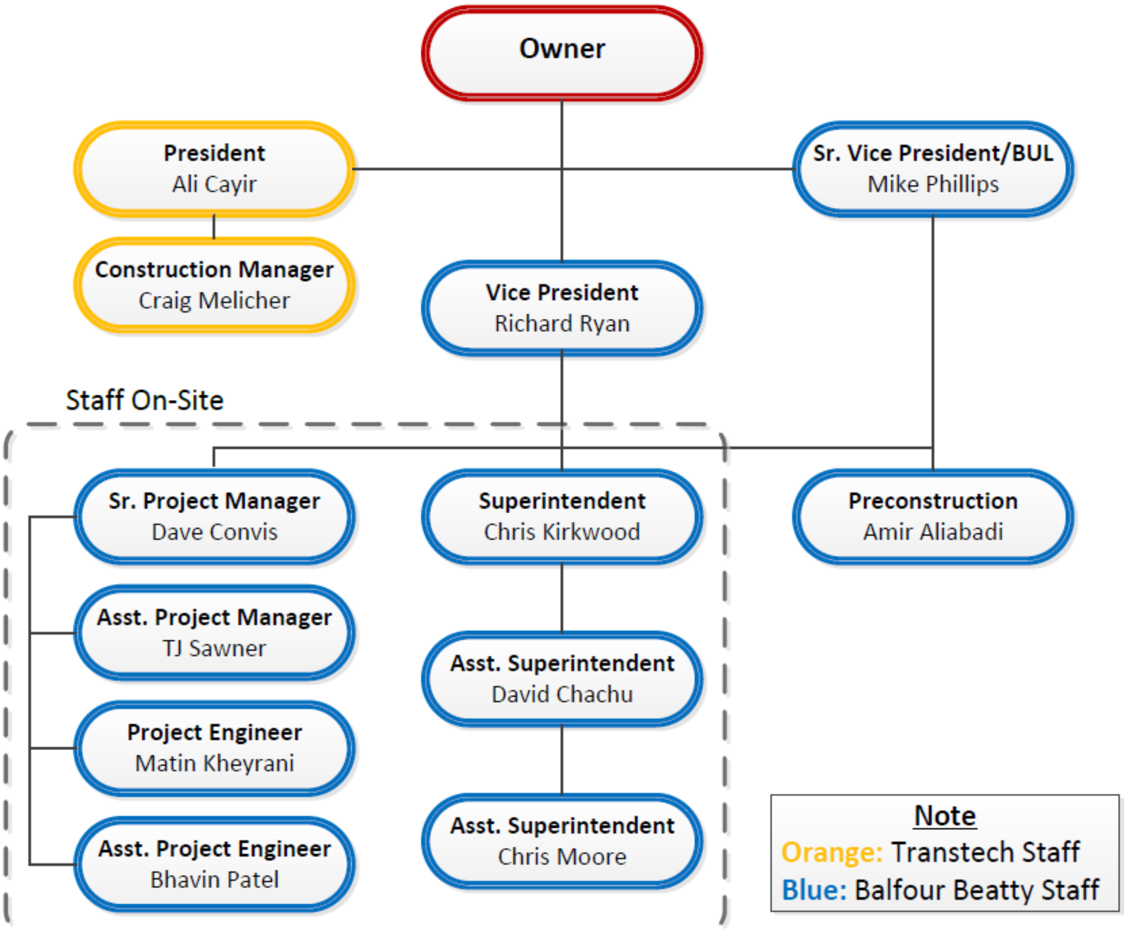

Figure 3. *Organizational Hierarchy of this Campus Project*

1.4 Existing Conditions

The geographic location of the project is withheld, out of respect for the owner's privacy. The area selected was previously undeveloped and was primarily covered with forest and foliage. A few small buildings and retaining wall were demolished prior to construction. The forest was also cleared for the new buildings as necessary. The primary material that will be excavated from the site is red-clay. It has strong bearing capacity, allowing for setbacks or sloped excavation. In situations where additional support is necessary, wall tiebacks and sheet piling are used to support the excavation. **Figure 4** shows the site as it appeared before construction. The approximate site boundary is shown in red.

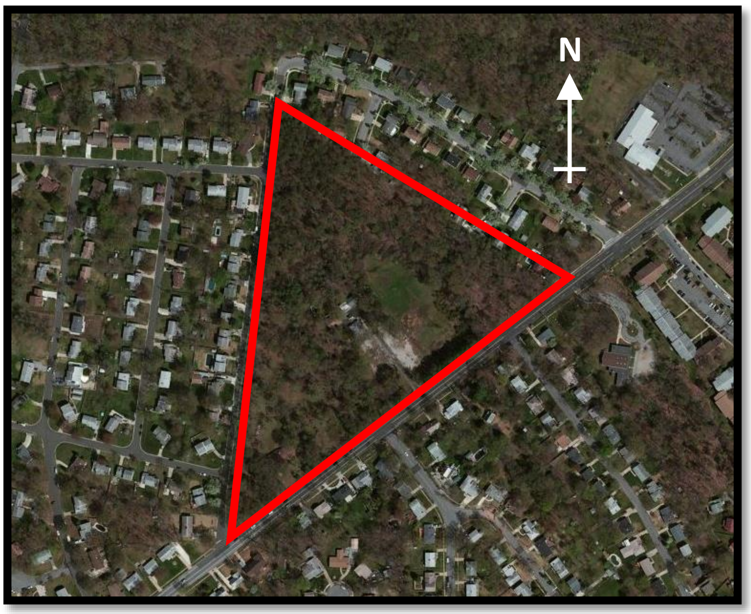

Figure 4. *Aerial View of this Campus Project Site*

The area surrounding the site is primarily residential, with no large scale buildings. Along the southeast perimeter, the site is bordered by a two way divided highway. This road serves as the principal transportation route for deliveries and vehicles to the construction site. During construction, there will be two access gates to the site along this side. The western boundary is bordered by a two way road which serves as access to the neighborhood and will also provide access to the site for construction workers and laborers. The primary gate to the site is located along this side, as well as, several temporary gates for auxiliary access as needed. Domestic water and electrical service enter the site from the northeastern side through a metering vault, and then connect with the systems of the Turkish Bath. Sanitary service enters the site from the southern side, through connections in the underground Parking Garage.

1.5 Building Descriptions

This section is dedicated to describing the architectural appearance and exterior façade of each building. In addition, the purpose of each building is identified for clarification.

Site Organization

The layout of the buildings within the site is shown below **(Figure 5).** This image also serves as a representation of how the site was utilized during construction. As can be seen, two tower cranes were strategically located to facilitate construction. A mobile crane was used at the western end of the Parking Garage for areas not accessible to the tower cranes. Various changes in the site utilization plan were made to accommodate the different phases of construction, but this diagram serves as the typical layout.

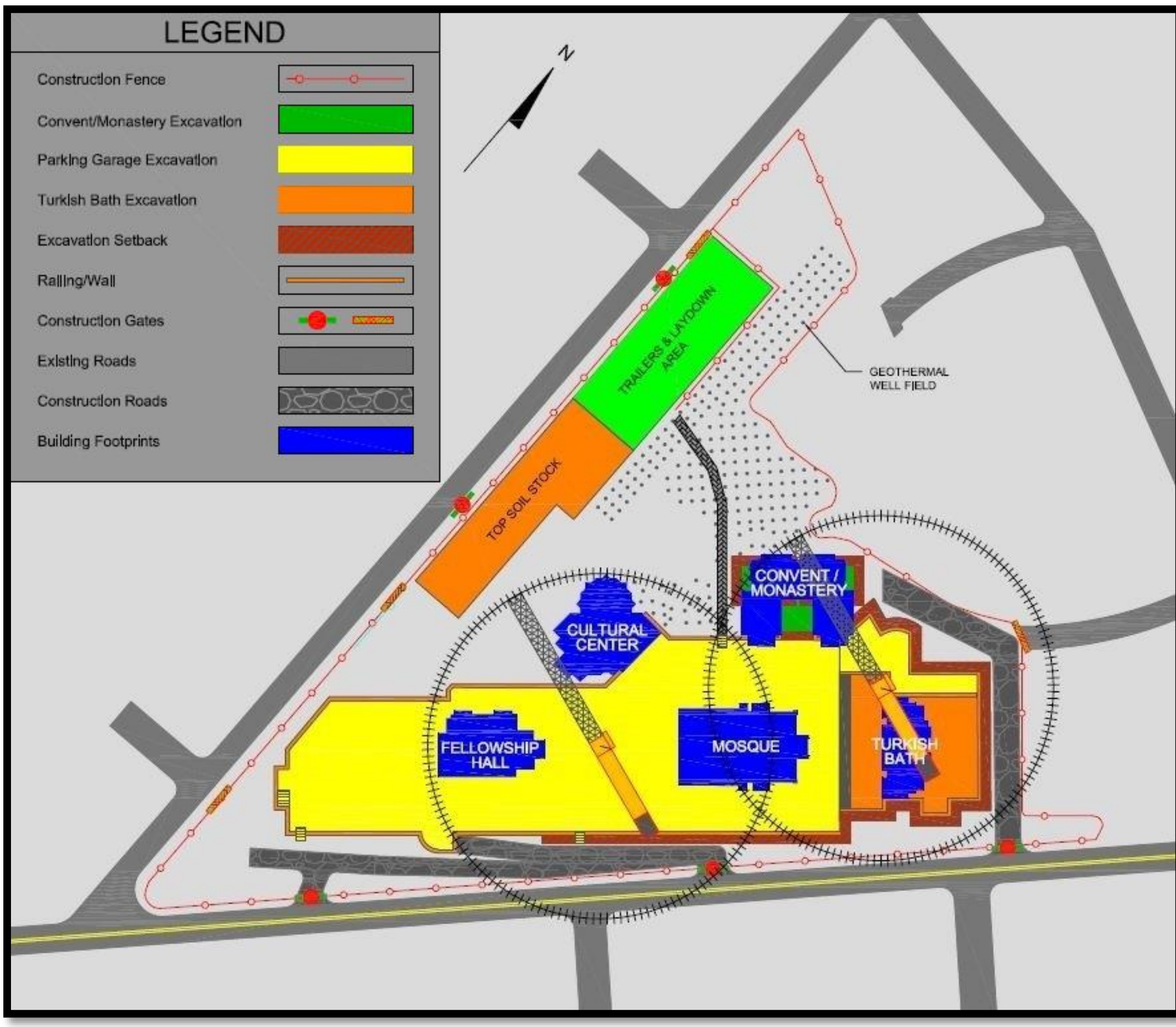

Figure 5. *Campus Project Site Utilization Plan*

Convent/Monastery

The Convent/Monastery is an U-shaped apartment style housing complex for visitors to this Campus Project. One wing rises only two floors above ground while the base and the other wing rise three floors above ground. Underground is a basement area with space for laundry facilities and mechanical equipment. Window channels of the second floor cantilever out slightly to create additional floor space within the apartments. There is a pronounced cornice to provide shading to the upper windows.

Figure 6. *Rendering of Convent/Monastery*

The exterior façade of the first floor is an anchored stone veneer on cold formed metal stud. Between each floor runs a belt course of thinner stone veneer adhered to Portland cement lath on cold formed metal stud. Portland cement on metal lath makes up the façade of the second and third floors, as well. The interior of the U is lined by a ground to roof curtainwall system supported on HSS steel columns and aluminum mullions. The exterior of the U features groups of windows which are trimmed by wood siding and rigid furring channels.

The roof is a simple hipped roof style, using clay tile as the primary material. The roof tiles are nailed to a self-adhering sheet underlayment adhered to roof sheathing. This assembly rests on roof deck supported by cold formed metal roof truss. Between the sheathing and the deck are layers comprised of board insulation with a minimum of R-10, drainage panels, and waterproofing membrane.

Cultural Center

The Cultural Center is a two-story building consisting of libraries, stores, study rooms, and auditoriums. It is designed to be a place of gathering for clubs, organizations, and visitors. The architectural focal point of the Cultural Center is the pointed glass dome on the roof. The building circulates around this point, highlighting a round conference hall at the rear and an exhibition hall near the front entrance. The main entrance appears very grand, featuring a large glass door and surrounding curtain wall, topped by ornamental stone. Portions of the second floor cantilever out from the wall, creating an undulating surface that is further accented by the pointed pattern of the rear cornice.

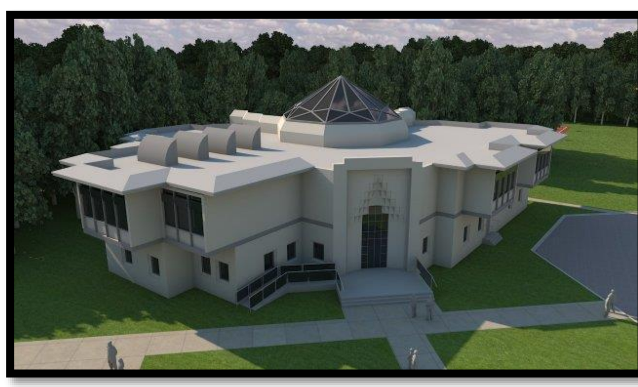

Figure 7. *Rendering of Cultural Center*

The primary façade consists of stone panels supported on a channel and rail system mounted on CMU wall. Brake metal trim forms a belt course around the entire building, separating the first and second floors. The front entrance is comprised of a Glazed Curtainwall System. At the rear of the building, the roof slopes down, decreasing the wall height. In this area, the brake metal trim takes on a zig-zag pattern to accent the changing height.

The roof is primarily of simple flat design with a prominent cornice and pediment. Above the conference hall, the roof slopes down to accent the decline of the floor inside the hall. The roofing is composed of polyvinyl-chloride roofing membrane sheet adhered to a cover board, backed by board insulation and a vapor retarder. All of this is supported by either structural concrete slab or substrate board on roof deck. The parapet of the roof is made of standing-seam metal roof-panels supported by the CMU wall. Also on the roof are several fixed skylights, formed from insulated metal wall panels. The pointed dome is constructed of metal-framed skylight system.

Fellowship Hall

The Fellowship Hall is a one-story building that serves as a restaurant for visitors and guests to the site. The south face features a façade long loggia with wooden railings, arches, and ornate trim. The northeast corner is a substantial wooden deck for visitors to congregate outside. Inside, the building is separated into a dining hall, reading room, kitchen, and entrance area. The dining hall and reading room both include a central ornamental fountain to accent the space. In addition, there is stairwell access past the dining hall that leads to the parking garage underneath.

Figure 8. *Rendering of Fellowship Hall*

The exterior wall of the Fellowship Hall is comprised of Portland cement plaster on metal lath supported by cold formed metal steel. Ornamental wood trim is attached to the surface of the Portland cement across the entire façade, creating detailed patterns. The loggia along the southern wall is adorned with ornamental wood doors and wall decoration. The windows are covered either with an ornamental double hung wooden shutter, which can be opened to uncover the window, an ornamental metal lattice window screen, or an ornamental gypsum window screen.

The roof is designed in a hipped fashion. The roofing material is lead sheet metal over a red rosin slip sheet with a self-adhering sheet underlayment. The underlayment is adhered to roof sheathing, so the lead sheets can be secured with nails. This assembly rests on roof deck on cold formed metal roof truss, which is sprayed with polyurethane foam insulation and covered with mineral-wool board insulation with an R-25 on the interior. Two minaret-shaped stone veneer chimneys rise above the roof at the west and east ends of the building, mirroring the minarets of the Mosque. Brass ornaments can also be found at the peak points of the roof.

Mosque

Architecturally the Mosque is the focal point of the entire site. It is located at the center and is the largest and most impressive building, and serves as a religious and cultural gathering space. Underground, it contains the central utilities plant of the mechanical systems throughout the site. The main dome rises approximately 75 feet above the ground, taller than the highest points of the other buildings. The minarets, flanking the dome, rise roughly 50 feet higher to a total of 127 feet. In front of the Mosque is a large courtyard surrounded by an arcaded loggia. Smaller domes line the roof surrounding the courtyard and the main dome. A significant level of detail is placed into the design of the mosque, which can be better observed in a picture than described in words. Overall, the design has strong religious context and a style indicative of Mosques in the Middle East.

Figure 9. *Rendering of Mosque*

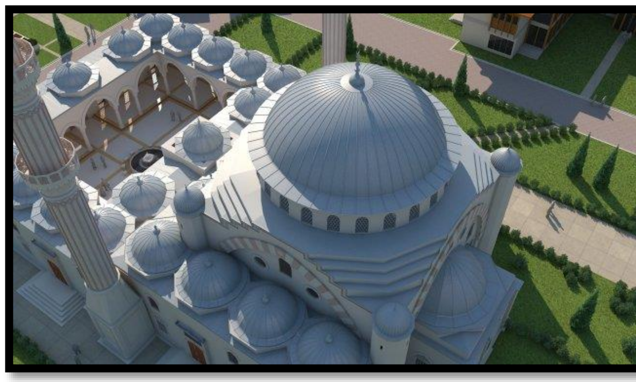

Figure 10. *Overhead Rendering of Mosque*

The façade of the mosque is entirely anchored stone veneer. The stone is attached to either cast-in-place concrete or CMU wall. Lower windows are rectangular in shape and feature an ornamental exterior stone frame with grille. Upper windows are either arched or circular in shape and are typically stained glass on the inside with vision glazing on the outside. Decorative patterns of stone are used on all sides, and are used in particular to accent the shape of the arches.

The roofing is lead sheet metal roofing on a mortar underlayment with wire reinforcing. This is backed by vent/drainage composite galvanized metal strapping, closed-cell spray polyurethane foam insulation, and a fluid-applied membrane air barrier. Intermittent zee-furrings support the assembly which is attached to cast-in-place concrete over Portland cement on metal lath. All of the domes are constructed from cast-in-place concrete and required specially built screeds and forms. The smaller domes are formed from 6' to 8' diameter Styrofoam hemispheres and a rotating screed was used to smooth the exterior surface of the concrete. The main dome was formed by a metal truss hemisphere covered in formwork panels.

Turkish Bath

Figure 11. *Rendering of Turkish Bath*

The Turkish Bath is prominently located at the main entrance of the site. It serves as a welcoming center and a gathering place for spiritual and recreational purposes. Lounges are located at either end of the two above ground floors, underneath the hipped roofs. Two domes, set side by side, form the roof between the hipped roofs. Underneath these are the warm rooms, serving as a spiritual and personal cleansing area. The front entrance is covered by an extensive dark colored roof, which contrasts the lighter color of the façade. Two curtainwall systems flank the entrance doors, letting light into the space. Two large areas underground are present for a swimming pool and basketball court. A mezzanine creates a second floor balcony area underground that overlooks both the swimming pool and basketball court.

The façade of the Turkish Bath is composed of two parts. The first floor is enclosed by stone panels supported on a channel and rail system and pinned to a CMU wall behind. The second floor walls surrounding the warm rooms also utilize this system. The second floor of the lounges has a façade of Portland cement plaster on metal lath secured to CMU wall. Wood battens are nailed into the lath to create patterns and contrast with the cement. Two decorative metal screens jut out from the second floor of the east wall; and two curtain walls flank the main entrance into the building on the ground floor.

The hipped roofs above the ground floor entrance and the lounges are composed of the roofing assembly of the Fellowship Hall. Flat roofs, such as those flanking the front entrance, are composed of polyvinyl-chloride roofing membrane adhered to a cover board. Behind this is roof board insulation with a minimum R-15 backed by a vapor retarder. The assembly is supported by either structural concrete slab or substrate board on roof deck. The four domes are made of the same roofing assembly as used on the Mosque.

1.6 Building Systems

The purpose of this section is to describe the primary systems used to support the site and each building.

Mechanical and Plumbing Systems

The mechanical system of the site is centered on an HVAC control plant located in the basement of the Mosque. A modular chiller/boiler unit regulates water temperature and pumps it throughout the site using the Parking Garage as a convenient raceway to connect the plumbing systems of each individual building. For the most part, the condensate water lines are thermally controlled by a geothermal well system located to the north of the garage. This well field contains 250 wells, drilled 450 feet deep. They are coordinated in circuits of 10 and are ultimately connected to an underground geothermal vault. This vault contains the necessary pumps and valves used to control water flow and is accessible via a ladder in case of maintenance requirements. The lines are connected from the vault to the control plant via two 8" diameter cast-iron pipes.

The domestic water supply feeds into the site from the east, connecting into the Turkish Bath before being distributed to the control plant in the Mosque basement. It is initially connected into an underground service vault where the water is metered and regulated, before being sent to the Bath. Sanitary service is sent into the site from the southeastern corner of the garage. It is connected to the utility line via connections run underneath the neighboring roadway. Natural gas lines connect to the site from the west end of the garage. They are distributed throughout the site and are used to fuel boilers, cabinet unit heaters, and hot water heaters.

Typically, building systems are Variable Air Volume HVAC systems and drain-waste-vent plumbing systems. Each building also has its own energy recovery ventilators to maximize efficiency, and has slight additions or modifications to the systems that accommodate their specific building usages. The Cultural Center has slightly larger sized roof top air handling units, in order to provide enough air volume to the Conference and Lecture Halls. The Convent/Monastery utilizes two roof top air handling units: one to provide air for transient spaces, the other for living spaces. Each apartment also has its own cabinet unit heater and several fan coil units to provide specific user customization.

The Mosque utilizes underground air handling units to provide air flow to the enclosed worship area, which also includes a radiant floor system to further control user thermal comfort. The Fellowship Hall uses two rooftop air handling units: one controls the major areas of the building and one is dedicated to the kitchen. The system is carefully controlled in order to regulate exhaust air coming from the kitchen. Intake louvers and dampers are programmed to close when exhaust is at 100% to prevent contaminated air from reentering the supply air system. The Turkish Bath features specially sized air handling units to handle the humidity produced by the underground swimming pool and basketball court. An additional unit services the above ground areas which are also regulated by an extensive radiant floor system. These areas are kept at high temperatures to promote physical and spiritual cleansing practices.

Electrical Systems

Electrical service for the site is distributed through a central electrical room located in the Turkish Bath. Utility service is metered through the same east underground vault that the domestic water supply is connected through. The central electrical room is located between the east entrance ramp of the garage and the north wall of the Bath. Two rooms here are dedicated to providing electrical power to the site: one housing the distribution and switchboards needed to feed power to all of the buildings and the other holding backup generators and fuel tanks that provide emergency power when needed. It takes five generators, three for 208V and two for 480V, to provide the necessary power to supply the entire site in the case of power failure. A 2500 gallon diesel storage tank provides enough fuel for approximately one week of operation and two 150 gallon fuel cubes provide daily fuel requirements.

The main distribution panels located in the central electrical room are typically sized at either 2000A or 3000A. Various transformers are used to step down the power, the largest of which is 150 kVA. From here, electrical distribution is rather typical. Different types of conduit are used according to specification requirements. Each building has its own main distribution panel, smaller switchboards, and auxiliary panelboards as needed. The Convent/Monastery has a high electrical cost due to an individual panelboard needed in each apartment. This requires distribution of higher gauge wire and corresponding equipment.

Fire Protection Systems

Fire protection systems used throughout the project are typical wet and dry sprinkler systems. Dry systems are used throughout the Parking Garage and in most of the underground areas. Wet systems are used in all above ground areas. Water main connections for fire department tie-in are located throughout the garage and within each building. In order to limit encroachment on the architectural design of the Mosque, horizontal sprinkler heads are mounted along the base of the domes. They are triggered by a heat and smoke sensor located at the dome's apex.

Structural Systems

Structural elements throughout the site vary by building. Foundations are typically cast-in-place concrete spread or continuous footings, unless otherwise noted. Excavation is supported with tieback walls and sheet piling as necessary. The ultimate compressive strength of the concrete varies by type, ranging from 3000 to 5000 psi. Lateral bracing and guy-wiring is employed to support the superstructure until full welds are completed.

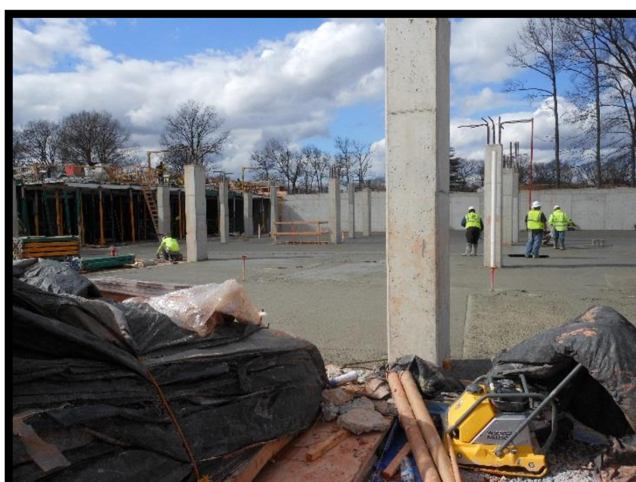

Figure 12. *Structure of the Parking Garage*

The entire Parking Garage is formed of cast-in-place reinforced concrete. In order to support the heavy loads of buildings, pedestrians, and vehicular traffic, the slabs are heavily reinforced. Over 100 spread footings support the weight of the garage and range in size from 4' x 4' to 15' x

15'. The largest footings reach a thickness of 50" and are needed to support the heavy loads of the Mosque, in particular the minarets. The slab on grade for the structure is 5" thick and the elevated slab at grade level is oversized to 12" thick so as to support increased loads caused by emergency vehicles as required by code.

The structure of the Cultural Center is comprised of reinforced concrete beams and columns. Columns, typically 24" x 10" in size, rest on spread footings ranging in size from 5' x 5' to 10'6" x 10'6". Post-tensioned concrete beams support the Exhibition Hall on the ground floor and the Library on the second floor; they are stressed with a highest force of 675 kips. Curved steel beams are used to support the roof above the Conference Hall, which changes in shape as the floor of the hall slopes. Beams are typically W8x10 or W30x90 with a largest span of 56' over the conference hall. Eight unique C-shaped columns form the support of the octagonal area below the pointed roof, which is composed of HSS tubes. These columns are heavily reinforced and are approximately 6' in span.

The foundations and underground floors of the Convent/Monastery are cast-in-place reinforced concrete beams, columns, piers, and slabs. Spread footings range in size from 4'6" to four oversized footings in sizes of 18'6" x 16'9" and 18'7" x 7'2". These larger footings support two interior stairwells, one elevator pit, and living spaces. Extending from the ground floor, the remaining structure is steel beams, columns, and metal floor decking. Columns are typically W8x31 or HSS 6x6x3/8 and beams range in size from W8x10 to W14x90. Layout is rather organized and evenly-spaced in order to accommodate consistent apartment sizes. Spans are typically 20’ to 30’ to maximize the amount of usable space within each apartment.

The foundations and structure of the Mosque are nearly entirely constructed of cast-in-place reinforced concrete, including the arches and domes. The minarets are formed of 8" CMU walls with periodic concrete beams. At the top, the cones are made of HHS tube steel. Since it is located within the footprint of the underground Parking Garage, the structure rests on foundations designed with the garage. Underneath the minarets, the foundations are enlarged to 20' x 26' x 38" in order to support the heavy load.

The structure of the Fellowship Hall is primarily composed of steel beams and columns. Beams range in size from W8x10 to W18x86. Exterior columns vary between W10x33 and HSS 7x7x3/8. There are a reduced number of interior columns in order to maximize open floor space. These are typically sized at W12x40. This steel superstructure is supported by a network of CMU walls approximately 4' in height, which also support the floor decking, raising up the entire building. The entire structure is supported on foundations developed in the underground parking garage.

The Turkish Bath is primarily constructed with reinforced concrete. Footings range in size from 4'6" x 4'6" to 10' x 21'. A 42' x 84' one foot thick heavily reinforced slab sits underneath the pool area to support the massive weight of water. Foundation walls are typically 1' to 2'6" thick and are tied into large retaining walls supporting the surrounding soil. These cantilevered retaining walls reach heights of 22' and thicknesses of approximately 2'. Seventeen post-tensioned reinforced concrete beams support the mezzanine and ground floor levels. They reach a largest size of 5' x 4.5' x 70' and a maximum tensile force of 2916 kips. Concrete columns are sized up to 3' x 3' and are formed from concrete of strengths 5000 and 6000 psi. At grade and above, floor slabs are heavily reinforced in order to span the large open area below. Some minor steel is used to form the roof structures.

1.7 Project Costs

The total cost of the project, including buildings, landscaping, and other fees is $69.5 million. The Mosque and Turkish Bath are the most expensive buildings at $17.2 million and $15.7 million, respectively. The Fellowship Hall is the least expensive building at $5.0 million. The costs of all the buildings are shown in **Table 1**. The owner also granted a $20 million allowance that can be used to pay for project elements as approved. This allowance is requested by Balfour Beatty periodically, particularly for project elements of higher quality or to meet the owner's expectations and desires.

Table 1. *Individual Building Costs of this Campus Project*

Location of Work	Cost
Convent/Monastery	$7,718,000
Cultural Center	$7,285,000
Fellowship Hall	$5,012,000
Mosque	$17,153,000
Parking Garage	$12,145,000
Turkish Bath	$15,683,000
Site Work	$4,520,000
Subtotal	**$69,516,000**
Owner Allowance	$20,000,000
Total	**$89,516,000**

The systems within the buildings constitute a substantial portion of the project costs. These can be divided into structure, mechanical, electrical, plumbing, and other systems categories. The most expensive costs are for the cast-in-place concrete structural systems and for the mechanical and plumbing systems, which are $15.5 million and $10.6 million, respectively. The prodigious amount of cast-in-place concrete used on the project is a potential issue that is addressed in later analyses. Of note is an additional cost of work completed by HASSA, a company of foreign workers from the host country. These operations include stone work, decorative metals, ornamentations, and other finishes throughout the buildings. A summary of the system costs throughout the project are presented in **Table 2**.

Table 2. *Building Systems' Costs of this Campus Project*

System	Cost	Percent of Total Cost
Structure – CIP Concrete	$15,500,000	22.3%
Structure – Steel	$1,583,842	2.3%
Mechanical/Plumbing	$10,630,000	15.3%
Electrical	$7,260,811	10.4%
Fire Protection	$695,800	1.0%
Subtotal	**$35,670,453**	**51.3%**
Work by HASSA	$8,442,047	12.1%
Total	**$44,112,500**	**63.5%**

1.8 Project Schedule

Construction of the project commenced September 19, 2012 and will continue through September 18, 2014. Operations on site are completed in a staggered and overlapping manner with the aim of shortening the length of the project schedule. This method creates float in the schedule in anticipation of any issues that would delay construction. Furthermore, since there are five buildings on site, there is significant opportunity to construct them simultaneously, further reducing the timeline of the schedule. Two schedules are provided in the appendix to represent construction activities: a complete project schedule and an individual building schedule for the Turkish Bath.

Figure 13. *Completed Elevated Deck*

The project schedule, found in Appendix A-1, is a general overview of the entire project from start to completion. It provides a basic understanding of how construction of each individual building fits together and how they overlap. Each building is highlighted in a different color for clear organization. The critical path of the schedule is controlled by the Parking Garage, the Turkish Bath, and the Hardscaping and Landscaping. Excavation for building foundations proceeds from west to east, and constitutes a majority of the critical path. Following that, the erection of the foundations and the ground level slab of the garage is of primary importance. Any delay to these activities will have negative consequences to the overall project schedule. Operations within the Turkish Bath are of key importance due to the deeper excavation required for the underground facilities. This will require additional time, effort, and temporary bracing to support the larger soil loads. Landscaping activities are naturally on the critical path because they are some of the final tasks that are conducted to prepare the project for hand-off to the owner.

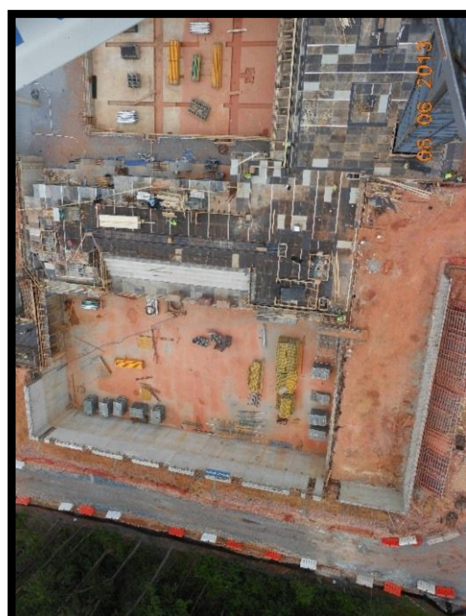

Figure 14. *Turkish Bath Foundations*

Figure 13, shows the completed elevated deck of the Parking Garage. Exterior walls of the Mosque have begun construction and their preparation can be seen in the center of the image. The completed deck space is used as storage for the materials and equipment needed to continue construction. The picture is taken from the top of the eastern tower crane, overlooking the site to the west. **Figure 14**, shows the progress of the excavation and foundations of the Turkish Bath. Both pictures were taken on the same day, from the same vantage point, and are oriented in the same direction. These images show the progress of construction in early June. The majority of the Parking Garage structure has been completed, while much of the Turkish Bath remains to be constructed.

An additional item of note is the Work by Turkish Labor, noted towards the end of the schedule. This work involves culturally significant finishes and construction. These tasks can only be completed by Turkish workers, in the interest of preserving the cultural elements of their design. The work lasts approximately a whole year, with the majority taking place on the Mosque, due to the extensive amount of limestone cladding across the interior and exterior. Additional finishes include interior and exterior wood trim, ornamental wooden windows and lattice work, and other detailed finishes for aesthetic purpose. Differences in work practice for the foreign workers, could potentially cause delays to the schedule due to difficulty of information flow with American workers. These activities will require specialized attention and care to ensure they are completed on schedule. In addition, it is important to take precautions for these activities in order to keep workers safe on site, which will be addressed in Analysis 4.

The second schedule, found in Appendix A-2, is a detailed look at the construction process for the Turkish Bath. The Turkish Bath is a recreational facility totaling approximately 50,000 GSF, and consisting of four total floors, two of which are below grade. The second basement is at a depth of 37', the deepest excavation on the project. An underground swimming pool and basketball court are located here, as well as a mechanical room to service those areas. The basement is at a depth of 15', with a mezzanine overlooking the pool that is at a depth of 20'. This floor contains fitness and gym areas as well as an additional mechanical room. The two above grade floors consist of spas, lounges, and warm rooms featuring radiant floor heating systems. Those spaces serve a purpose of spiritual connection and relaxation.

Construction on the Turkish Bath lasts approximately 18 months, from December 5, 2012 to May 26, 2014. A great majority of this time and the activities involved reside on the critical path of the schedule. The reason the Bath critically affects the schedule is because of the depth of excavation as well as the electrical and domestic water utility connections. For instance, it will take approximately one year from the time excavation begins to complete the elevated deck at grade level. The two above grade stories are entirely dependent upon how underground work proceeds, and they will feel any delays that may occur. All activities that have a direct impact on the schedule are shown in red.

Significant structural support is needed to support the loads of the pool, the above grade floors, and the soil pressure around the underground areas. Large retaining walls are used to hold back the soil. The wall between the Bath and the Garage posed some challenges during construction, due to an imbalance of surcharge loads that could have toppled the retaining wall. However, these loads were reconciled through the use of gravel backfill on the pool side of the wall. Several post-tensioned concrete beams are used at grade level to support the weight of the above ground floors. These beams vary in dimensions, but can reach sizes of up to 5' wide x 5' deep x 70' long. The extensiveness of excavation and foundations controls a majority of the construction sequence. Seven months, from December 5, 2012 to July 24, 2013, are dedicated to finishing these tasks, over half of which is foundation work.

The project is also dependent upon the connection of the electrical system into the Turkish Bath. Utility service is fed into an underground room near the entrance ramp to the Parking Garage. From here it is distributed to the rest of the site via several different switchboards. Domestic water service connects to the basement mechanical room by underground utility service. Then, it is pumped to the HVAC control center in the basement of the Mosque before distribution throughout the site. The completion of the project depends upon these two services being installed and functional. Since the systems will need to be tested prior to occupancy, the earlier they are operational and ready for testing the better it is for the schedule.

Rough-in of MEP systems first begins on the second floor on October 17, 2013. From here it proceeds down the building by each floor. Electrical utility service will be connected to the building in November and the bath will have permanent operating power on November 7, 2013. Final MEP finishes should conclude on March 13, 2014, about five months later, on the basement level. These are predominantly plumbing finishes, which is understandable as this is where domestic water service is connected.

1.9 Cultural Background

Figure 15. *Turkish Flag*

One of the most unique aspects of this Campus Project is the culture. Not only does it have a role in the end product, but it also has a strong influence on construction itself. The owner has consistent and frequent input into the progress of construction and into the design. He gives his input to ensure that the design meets his specifications and desires, which includes adhering to his cultural requirements. In addition, a large quantity of finishes are required to be completed by foreign artisans. Their work is coordinated into the schedule and they are brought to the United States to complete their work. For the purposes of this thesis, the Turkish culture will be examined, but should not be considered the culture of the foreign artisans brought on-site.

Turkey is a country located in the transitional area between Western Asia and Eastern Europe. It is a democratic nation that has gradually grown economically and politically, becoming a regional power. The national language, Turkish, is spoken by the majority of the population. There is no official religion, but the most common practice is Islam. Several holidays within the Islamic faith may come to influence construction, the most notable of which is Ramadan, commonly known as fasting. For one month Muslims fast from dawn to sunset, denying themselves both food and drink. It is a time of spiritual reflection, improvement, and devotion. Abstaining from eating and drinking teaches self-discipline, self-control, sacrifice, and empathy for the less fortunate.

There are exceptions to participating in Ramadan, such as travel, severe illness, or pregnancy. However, anyone who is unable to fast is still required to make up the missed days later. Muslims are allowed one meal before sunrise and one meal after sunset. Fasting can greatly weaken those who are participating. If a construction worker is fasting, they should receive lighter workloads until Ramadan is over, in order to protect the worker's safety, particularly if it is during the hot and humid summer months. Religious practice is a strong element of the Turkish culture, apparent by the country's registered mosques, which number over 80,000.

There are also a number of cultural differences that may affect the construction process. These include religious practice, cultural holidays, typical construction practices, and language barriers. An understanding of the Turkish culture is necessary to help bridge this gap for two purposes: (1) to assist in the construction process to remain on schedule and on budget and (2) to better understand the meaning of the project culturally. Through this knowledge and understanding the project can perform better and be delivered to meet the owner's specifications.

There are several differences between the way construction proceeds in the United States and the way construction proceeds in Turkey. Here, construction is a very regimented and cost based activity. The goal is almost always to deliver the final product quickly and at the lowest possible cost. The schedule is heavily managed and planned in order to optimize the flow of work across the construction project. This requires near constant information flow so each trade can understand the work of those around them. Typically, information and planning is developed prior to the start of construction. For example, shop drawings are developed before work is begun so that different trades involved in a process can coordinate and plan the work efficiently. Planning and design prior to beginning construction is the standard practice.

In Turkey, priorities are not exactly the same. Due to differences in labor laws and hourly wages, schedule is not necessarily their primary concern. Shortening the schedule may not result in significant cost savings. In addition, shop drawings and designs are not as thoroughly documented, because the workers there have been working and building for numerous years. They know their craft; they know their construction process. They do not necessarily need drawings to know where items connect or to know how different layers of an assembly intersect and overlap. These details are something that they already intimately know.

This is a profound difference from the way construction takes place in the States. Here, clearly documented designs are essential to getting and keeping work. If you do not have them, then you are failing to work with the other members of the team, and you will be quickly replaced. Explicit designs help construction managers maintain control over the project and ensure quality as work goes into place. It is a form of documentation of the work that was completed and proof that the work was according to specification.

The difference between these construction practices is not necessarily a positive or negative point. It is simply a difference; and when two extremes such as these meet and try to cooperate, it can be quite challenging. The project team has faced issues where this lack of information can be frustrating or can hinder construction. For example, while attempting to coordinate the work surrounding the windows of the Mosque, the project team did not receive shop drawings for the installation of limestone panels, work that would be completed by the Turkish workers. Without these shop drawings they could not determine where flashing, metal trim, or other elements should be installed and integrated with the panels. Unable to coordinate the process before construction, as would be typical here, the team observed the process in the field and then developed the plan to complete the work. Fortunately, this instance did not engender a delay in the schedule. However, this will not be the case for all construction activities, and ultimately some setbacks may ensue.

These issues of insufficient information are apparent project wide, but are heavily focused on the Mosque, where the majority of Turkish work is located. An additional issue that the team has faced is the design of the lead sheet metal roofing. The owner has not provided shop drawings of the roofing, which would indicate sheet sizes, seam locations, and other useful information. Without these drawings, the assembly, which includes flashing, trim, and Z-bars, cannot be coordinated. The consequence of these issues is that the team must figure out the construction sequence in the field, without adequate planning of the work.

2.0 Analysis I: Structural Redesign

2.1 Problem Statement

The most common structural element used on the project is cast-in-place (CIP) concrete. CIP is used for nearly the entire structure of the Mosque, Turkish Bath, Cultural Center, and Parking Garage, giving all of these buildings a similar design and consistent architectural feel to them. On the construction side, the high prevalence of CIP concrete work promotes a worker affinity to this type of activity. Familiarity with concrete work could potentially cause the workers to have increased productivity. The two remaining buildings, Fellowship Hall and Convent/Monastery, have a structure composed of steel columns and beams with a façade type that differs from the other buildings. This difference in construction material could have influence on material requisition, for example, bringing steel instead of concrete on site could influence worker productivity because it is a different style of construction. Most likely, this will not result in delays, but it does not take full advantage of the prevalence and familiarity of concrete work on site.

2.2 Potential Solution

To take advantage of worker affinity to concrete work, the structure of the Fellowship Hall and Convent/Monastery could be redesigned from steel to concrete. This will maintain a consistent work type across the site, taking advantage of the workers' ability to complete familiar work faster. The steel portions of the structure will be replaced with concrete. Removing the majority of steel construction from the site should alleviate any challenges with material requisitions and deliveries.

2.3 Analysis Process

This analysis will be completed by first gathering information on the structural and cost data of the project. Information on the steel and concrete structures will be used to develop and calculate the loads that will be considered when sizing the concrete structure. Sizing the structure will be accomplished using the CRSI Design Handbook, explained in section 2.6. Then, Structural Point computer programs will be used to verify the results. Lastly, the architectural, schedule, and cost implications of the concrete structure will be examined to determine whether or not the redesign is a viable option.

A sample of pages from the CRSI Design Handbook that were used in this analysis are provided in Appendix A-3.

2.4 Background

The primary structural construction material used on the project is cast-in-place (CIP) concrete. It is used for the Cultural Center, Turkish Bath, Parking Garage, and Mosque. The Mosque has a particularly impressive design considering the many domes, arches, and unusual geometric shapes. Nearly 25,000 cubic yards of concrete will be used on the project, totaling $15.5 million, or approximately 25% of the total cost. CIP concrete's prevalence creates the potential for slightly accelerated construction work due to worker affinity to the process. The façade style of these buildings is indicative of the Ottoman style of architecture which emerged in the 14th and 15th centuries. Geometric shapes and concrete design were a highly used element for both the structure and façade of buildings.

In contrasting style, the Fellowship Hall and the Convent/Monastery are built with a predominantly steel superstructure and with a façade appearance that is representative of modern Turkish design. The incorporation of these two buildings seems to be a visual combination of the two design styles used in Turkey – a convergence of the old and the new. This design integration is a further example of the cultural design elements that are incorporated into the project. The glass panels comprising the curtainwall are supported by HSS steel columns in order to take advantage of their small size and high strength.

The costs of the Fellowship Hall and Convent/Monastery are $5.1 million and $7.9 million respectively, around 20% of the total project cost. The total cost of the original structures is $1.5 million and $827,000 respectively. These include the costs of masonry, concrete, and steel used to structurally support the buildings. Construction of the Fellowship Hall proceeds from May 14, 2013 to June 11, 2014, approximately 269 working days. Structural operations begin on May 14 and conclude on October 2, 2013. Some construction activities on the Fellowship Hall critically affect the schedule. However, the majority of these are not involved with structural operations. They are primarily interior finishing and fit-out tasks. Construction of the Convent/Monastery occurs from August 22, 2013 to August 14, 2014, approximately 251 working days. Structural operations begin on August 22 and finish on January 17, 2014.

Background research was also conducted into the concrete design used for the other buildings on site. The typical concrete used for beams, columns, and slabs was 5000 psi strength. The formwork used to shape the concrete was steel framed plywood sheathing, providing flexibility and high reusability around the site. The concrete was delivered on site via concrete truck and was placed into the form using a crane and bucket. Structural elements throughout the buildings vary in size; **Table 3** summarizes the most common measurements. The typical size of structural elements was considered when choosing dimensional characteristics of columns, beams, and slabs. They were chosen to be similar to the dimensions below in order to maintain a level of consistency across the site to take full advantage of worker affinity to concrete work.

Table 3. *Typical Dimensions for Structural Elements of this Campus Project*

Structural Element	Dimension
Beams	12”x18” --- 12”x30” --- 18”x30”
Columns	12”x24” --- 16”x24” --- 30”x30”
Slabs	8” --- 10” --- 12”

2.5 Considerations

Several factors were taken into consideration when continuing the analysis from this background information. Due to the smaller size and connection detail of the HSS steel columns along the curtainwall, they cannot be replaced by concrete columns. The larger concrete columns would alter the design style as well as make connection with the glass panels more challenging. Therefore, the HSS steel columns will remain as part of the redesign. This will also mean that the beams connecting the HSS steel columns to the concrete columns on the interior will remain steel flange beams. It is extremely difficult, if not impossible, to integrate a concrete beam with a steel column. However, the reverse, integrating a steel beam with a concrete column, can be accomplished through the use of an anchor plate embedded into the concrete. Therefore, the HSS steel columns will remain, the interior columns will be redesigned to concrete, and the steel beams connecting the two will remain.

Originally, this analysis proposed altering the façade construction of the Fellowship Hall and Convent/Monastery to match that of the other buildings. This alteration also facilitates worker affinity to concrete construction. However, it is apparent that this would take away from the aesthetic purpose of the current design. The two architectural styles on site are representative of a merging of the old and new styles of Turkish architecture. To alter this design would take away from the original intention of the owner, therefore, the façade style will not be changed in any way.

2.6 Breadth 1: Structural Redesign

To redesign the structures of the buildings, a sample structural bay was chosen for each. This bay would be extrapolated out to then represent the entire building. Both sample bays were selected because they have the largest spans. Any structural member designed for these bays would be of adequate size for anywhere else in the building because the other spans would be smaller. The Concrete Reinforcing Steel Institute (CRSI) Design Handbook was used to size the structural elements based upon loadings calculated under typical Load and Resistance Factor Design (LRFD) practices. An example calculation will be shown to present the methodology used to complete the structural design. **Table 4** shows the unfactored loads used when calculating the weight on each structural member. All of these design live loads were found within the drawing sets provided by Balfour Beatty. The dead loads were selected based upon the material construction. Material weights were found using various online resources.

Table 4. *Unfactored Loads for this Campus Project*

Load Type	Live Load (psf)	Dead Load (psf)
Fellowship Hall		
Roof	30	20
Convent/Monastery		
Roof	30	25
Floor – Apartments	60	30
Floor – Public Rooms/Corridors	100	30
Exterior Wall	--	22

Fellowship Hall

The sample bay of the Fellowship Hall is highlighted in blue in **Figure 16**. In this building, the beams and columns only support loads created by the roof, therefore no elevated slab is needed. Instead they will support lightweight roof trusses that support roof construction. For the purposes of this redesign, the column lines were assumed to be straight to make the calculations easier, as can be seen in **Figure 17**. Using the unfactored loads given in **Table 4**, the factored load, W_u, was calculated using equation 1, where the dead load is D and the live load is L.

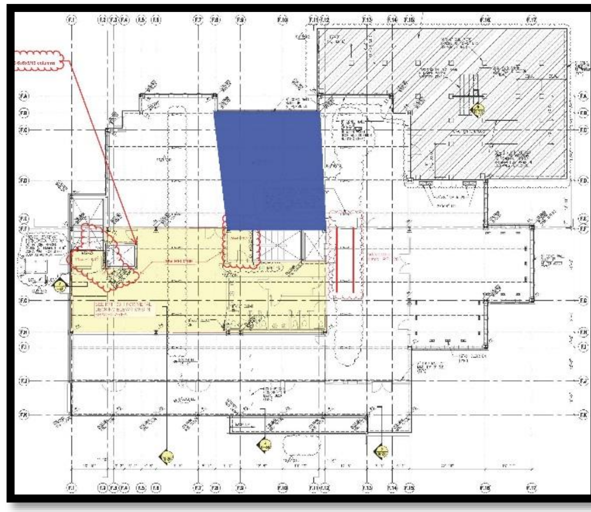

Figure 16. *Fellowship Hall Designed Area*

$$W_u = 1.2D + 1.6L \quad (1)$$

$$W_u = 1.2(20psf) + 1.6(30psf)$$

$$W_u = 72psf$$

This value remained consistent throughout the entire building. On the following page, a step-by-step example is provided to demonstrate the process of sizing a beam and a column within this bay. This method was used for all structural members in the building.

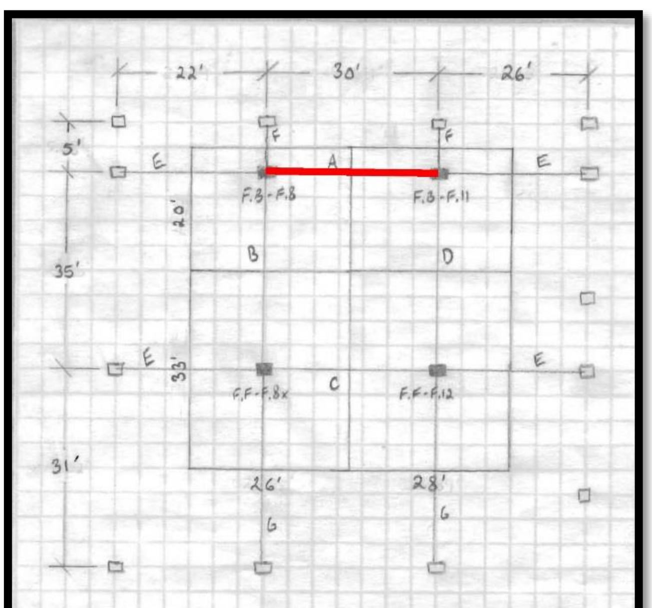

Figure 17. *Fellowship Hall – Beam A*

The example problem shown is for Beam *A*, or Beam *F.B-F.8* → *F.B-F.11*, as highlighted in **Figure 17**. The span length of this beam, L_n, is 30 feet. The tributary width, w_{trib}, is calculated below, using equation 2. It is the distance perpindicularly from Beam *A* to the next closest beams divided by two, and is used to calculate the load that will be imparted across the length of the beam.

$$w_{trib} = \frac{(Dist._{Beam\ 1} + Dist._{Beam\ 2})}{2} \quad (2)$$

$$w_{trib} = \frac{(5' + 35')}{2} = 20'$$

The self-weight of the beam, W_{SW}, is also included when designing the structure. The dimensions used to calculate the self-weight were a preliminary guess based upon the span length and tributary load. The calculation for the self-weight of the beam is shown in equation 3.

$$W_{SW} = \frac{(\text{Height})(\text{Width})(\text{Density of Concrete})}{(in.^2\ to ft.^2\ conversion)} \quad (3)$$

$$W_{SW} = \frac{(18")(12")(150\text{ pcf})}{144\ {in^2}/{ft^2}} = 225\ plf$$

Now, the load per linear foot of the beam can be calculated using equation 4a. This is the value that will be used in the CRSI Design Handbook to determine the appropriate beam size.

$$L = (W_{trib})(W_u) + W_{SW} \quad (4a)$$

$$L = (20')(72\ psf) + (225\ plf)$$

$$L = 1665\ plf = 1.67\ klf$$

For edge beams, where the weight of the exterior wall is supported by the beam, equation 4b will be used instead of 4a because it accounts for this additional load. Equation 5 shows the calculation that will be used to calculate the weight of the exterior wall, W_{wall}. Note, equations 4b and 5 are not used in this example.

$$L = (W_{trib})(W_u) + W_{SW} + W_{wall} \quad (4b)$$

$$W_{wall} = (Height)(Pound\ per\ ft^2\ of\ wall) \quad (5)$$

Using the CRSI handbook is a simple task of looking at numbered values within the correct sections. In chapter 12, on page 65, an appropriately sized beam can be found that can support the load found previously. The dimensions of the beam are 18” x 12”, within the proposed dimensions used to calculate the beam self-weight. Reinforcing within the beam is given as two #8 bars along the bottom and two #10 bars along the top. Stirrups are given as #3 bars, spaced at every 7”, so there are at least 19 in total. The load the beam can hold is 1.81 klf, more than adequate to support the calculated load.

This process was repeated to size all of the beams supported by the columns within the chosen area. The design information for each beam could then be used to estimate the loads supported by the four columns. Equation 6 is used to calculate the reaction force created at either end of the beam due to the load acting upon its length. This equation assumes that the beam is simply supported by pin connections at each end.

$$R = \frac{(L)(L_n)}{2} \quad (6)$$

$$R = \frac{(1.67\ klf)(30')}{2} = 25.05\ kips$$

Calculating the total load on the column is completed by simply summing the reaction force of each beam supported by that column. For Column *F.B-F.8*, the column supports Beams *A, B, E,* and *F*, which are summed below in equation 7.

$$P = (sum\ of\ reaction\ forces) \quad (7)$$

$$P = A + B + E + F$$

$$P = 25.05 + 39.73 + 34.84 + 5.43 = 105.05\ kips$$

Using this load and examining the tables in the CRSI handbook, the column size can be determined. The column is sized as 12” x 12” square. Four #6 rebar spaced symmetrically in a square pattern are used to reinforce the column transversely, which are secured by #3 ties every 7”. This column design is of adequate strength for all of the columns within the designed area, and therefore it is adequate for all of the columns in the building. Identical design will make construction easier for workers and will require less material because the same reinforcement size and formwork will be used for all of the columns.

Convent/Monastery

The same process is used to size the structure of the Convent/Monastery, however, in this case three levels of columns and beams must be considered. The first two floors support apartments and corridors, while the third floor supports the roof. Additional loadings must be included as necessary, such as the weight of the exterior wall which will be supported by edge beams. An elevated slab must also be designed to support loads between the beams on the second and third floors. The chosen design area is highlighted in the floor plan shown in **Figure 18**.

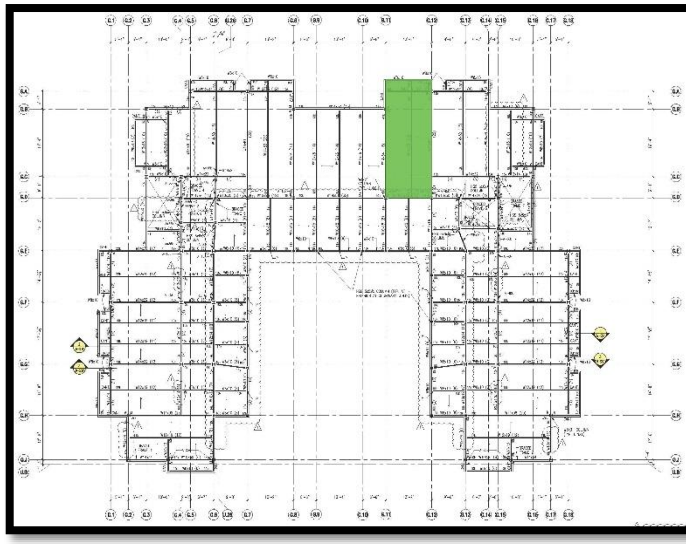

Figure 18. *Convent/Monastery Designed Area*

The slab design is based upon the longest clear span and the floor load it will support. The longest clear span is 30' 6" and the factored load is calculated as 196 psf. A two-way solid flat slab was selected with square drop panels at the columns for additional support, because it is the type of slab typically used on the project. Using the CRSI manual, the slab selected had a thickness of 10.5" between drop panels. Drop panels are square in shape and have a depth of 8.25" and a width of 10.33'. The slab and panels are reinforced with a total steel of 3.93 psf. A minimum column size of 20" is required to support edge panels of this size. These dimensions will be the basis of the column size used when they are designed. Since the majority of spans are 20' or shorter an additional drop panel size was selected for these smaller spans. These panels have a depth of 2.25" and a width of 7', and are reinforced with steel of 2.45 psf.

An additional challenge to sizing this building was that certain beams along the exterior are cantilevered. This creates a moment on the top of the column, putting the concrete in tension. Checks were made against the moment created on the column to ensure that it was within the performance characteristics of concrete, which typically performs poorly under tension. In order to limit the amount of vertical space taken by concrete beams, joist-band beams were used. They are significantly wider than normal concrete beams, so their advantage is a shorter depth than would otherwise be required. This preserves more space between the

Figure 19. *Cantilevered Beam G.B-G.11*

ceiling and beam for MEP systems. For the purposes of this example, the Beam *G.B-G.11* will be sized. It is an end span, cantilevered beam that supports apartment loads, and is highlighted in **Figure 19**. The factored load supported by the beam includes the self-weight of the slab, found by multiplying the weight of concrete (150 pcf) by the thickness of the slab. It does not include the weight of the exterior wall, which is calculated separately as part of the load per linear foot. Calculating the load created by the exterior wall is done by multiplying the height of the wall by the weight of the wall. The floor-to-floor height, H, is 13'2" and the weight of the wall, W_{wall}, is 19 psf. The span length of the beam is 10' and the tributary width is approximately 6' 7". Below, the necessary calculations for factored load, beam self weight, and load per linear foot are shown using equations 1, 3, and 4b. The weight of the exterior wall was calculated using equation 5, but is not shown.

$$W_u = 1.2D + 1.6L \qquad (1)$$

$$W_u = 1.2[30 + (150\ pcf)\left(\frac{10.5"}{12\ {}^{in}/_{ft}}\right)] + 1.6(60) = 289.5\ psf$$

$$W_{SW} = \frac{(Height)(Width)(Density\ of\ Concrete)}{(in.^2\ to\ ft.^2 conversion)} \qquad (3)$$

$$W_{SW} = \frac{(12.5")(24")(150\ pcf)}{144\ {}^{in^2}/_{ft^2}} = 313\ plf$$

$$L = (w_{trib})(W_u) + W_{SW} + W_{wall} \qquad (4b)$$

$$L = (6'7")(289.5\ \text{psf}) + 313\ \text{plf} + (13'2")(19\ psf)$$

$$L = 2469\ plf = 2.47\ klf$$

Using this value, the joist-beam sized from the CRSI manual is 12.5" x 24" with reinforcing of three #6 bars on the bottom and four #5 bars on the top. At least ten stirrups should be used at a spacing of 5" along the length. The beam can support a load of 3.77 klf, which is more than adequate to support the load found. This procedure was repeated for all beams within the area across all three floors. Calculating the reaction force at the end of the beam is slightly different because a cantilevered beam is only supported at one end, while the other is unsupported. The moment that the supported end experiences must also be calculated. These calculations are shown on the following page, using calculations 6 and 8. The equations are standard equations assuming the beam is simply supported as a cantilevered beam.

$$R = (L)(L_n) \quad (6)$$

$$R = (2.47\ klf)(10') = 24.7\ kips$$

$$M = \frac{(L)(L_n)^2}{2} \quad (8)$$

$$M = \frac{(2.47\ klf)(10')^2}{2} = 123.5\ ft \cdot k$$

Once the end reaction and moment forces are calculated for each beam, the column can be sized using the same procedure used for the Fellowship Hall. Due to the weight of the elevated slab, the support columns were oversized for the loads to be 20" quare. Four #9 bars are arranged in a square, symmetrical pattern to support loads transversely, and are secured with #3 ties. This column can adequately support the vertical loads acted upon it as well as any moment created by a cantilevered beam. Since the exterior wall is not continuous across all three floors and is divided at each floor, moment will not transfer down the columns by floor. Therefore, only the moment on that particular column needs to be considered. Vertical loads however do transfer down the column and were included in lower column design.

A secondary check was conducted to ensure that the designed columns and beams were capable of supporting the loads acting upon them. This was accomplished by using Structure Point computer programs for columns and beams. This check reasserted that all of the structural members were capable of supporting their respective loads as designed. The complete set of hand written calculations used for the analysis can be found in Appendix A-4.

2.7 Results

Fellowship Hall

Following the procedure described in the previous section, the structure of both buildings was designed as cast-in-place concrete. The design of the Fellowship Hall featured 12" square columns with four #6 bars for transverse reinforcement. Although several different beams were sized, the specifications of 24" x 16" with five #10 bars for reinforcement were used for all of them in order to remain consistent. In both structural members, #3 stirrups and ties are used to contain the transverse bars.

A quantity take-off was conducted for the designed area, estimating a total of 32 cubic yards of concrete and 5.5 tons of steel reinforcement. Including materials, labor, and equipment, this came to an estimated cost of $52,000. In terms of schedule, this level of work should take approximately 151 hours, or 19 days. The statistics for the designed area can be used to estimate the total cost and schedule of the entire building by use of areas. The size of the designed area is about 1562 square feet and the size of the entire building is 9600 square feet. Using this to make a ratio, the estimated cost of the structural redesign for the entire building is $321,000 and the duration of work is 116 days.

Compared to the original structure, the concrete redesign increases the cost and schedule by $2,005 and 80 days, respectively. It is assumed that concrete structural cost will replace all or most of the steel cost, and therefore the steel cost is assumed to be zero in the redesign. **Table 5** below summarizes the difference between the original structure and the concrete structure.

Table 5. *Fellowship Hall Redesign Summary*

	Original Structure	Concrete Redesign	Difference
Total Structural Cost	**$826,758**	**$828,763**	**+$2,005**
Masonry	*$128,670*	*$128,670*	*$0*
Concrete	*$215,000*	*$536,000*	*+$321,000*
Steel	*$318,995*	*$0.00 or negligible*	*-$318,995*
Roof Truss	*$164,093*	*$164,093*	*$0*
Duration	**36**	**116**	**+80**

Convent/Monastery

The design of the Convent/Monastery utilizes 20" columns with four #9 bars for transverse reinforcement. There are several different beam sizes based upon the loads that they support but the most common are 12" x 12", 18" x 12", 12.5" x 24", and 16.5" x 36". The latter two are joist-band beams who's higher width allowed for a shorter depth. Reinforcement varies upon the beam loads but they are commonly two #5, #8, or #10 bars along both the top and bottom. For the joist-band beams, the reinforcement is typically four, five, or six #6 or #11 bars along both the top and bottom. As usual, #3 stirrups and ties are used to contain the transverse bars. The elevated slab used to support the 2^{nd} and 3^{rd} floors is 10.5" thick between drop panels. It is reinforced with a number of different reinforcing bars for a total of 3.93 psf of steel. The drop panels are sized at either 2.25" or 8.25" in depth at a square size of 7' or 10.33', respectively.

A quantity take-off of the designed area yielded 172 cubic yards of concrete and about 12.5 tons of steel reinforcement. Including materials, labor, and equipment, the cost of the design area is $109,928 and the duration of work is 143 days. The size of the designed area is 1312 square feet per floor for a total of 3936 square feet for all three floors. The size of the entire building for the above ground floors is a total of 27000 square feet. With this ratio, the cost of the entire structural redesign is $754,079 and the duration is 984 days.

In comparison to the original structure, the concrete redesign increases the cost and schedule by $252,129 and 945 days respectively. A cost of $80,000 was assumed to represent the steel columns and beams that remained as part of the new structure. **Table 6** summarizes the cost differences between the original structure and the concrete structure.

Table 6. *Convent/Monastery Redesign Summary*

	Original Structure	Concrete Redesign	Difference
Total Structural Cost	**$1,497,202**	**$1,669,331**	***+$252,129***
Masonry	$0	$0	*$0*
Concrete	$728,000	$1,482,079	*+$754,079*
Steel	$581,950	$80,000	*-$501,950*
Roof Truss	$187,252	$187,252	*$0*
Duration	**39**	**984**	***+945***

2.8 Architectural Implications

A disadvantage concrete has as a structural element is its larger size in comparison to steel. Therefore, it is necessary to analyze the architectural effects of switching from a steel design to a concrete design. The larger structural size can affect both the usable area in the room and the vertical space allotted for MEP systems in the ceiling. These considerations only need to be taken into account in the Convent/Monastery. The Fellowship Hall design supports the roof, so it has no slab to take up space. Furthermore, the floor-to-roof height is 15’10”, allowing for plenty of extra space for a larger concrete beam.

The steel beams used in the Convent/Monastery range in size from W8x10 to W14x61. These beams have a depth of approximately 8” and 14” respectively. Metal deck with a thickness of 2” and a topping of 3-¼” of concrete will be laid on top of the beams. The floor-to-floor height is 13’2” and the ceiling is suspended 9’6” above the floor, or 3’8” below the floor above.

The concrete joist band beams with the new design have a depth of either 12.5” or 16.5”. The elevated slab has a thickness of 10.5”, and will be partially integrated with the beam to reduce the depth impact. Drop panels further increase the depth by either 2.25” or 8.25”, but only 7’ or 10.33’ square around a column.

The change in structural depth will vary based upon the structural members in that location. An 8” steel beam with the metal deck has a structural depth of 13-¼”, and a 14” steel beam has a depth of 19-¼”. The depth for the steel structure will fit within this range across the entire building. Considering the ceiling height, this allows approximately 2’¾” to 2’6-¾” of clear space for MEP systems. Switching to a concrete system will reduce this gap significantly. A 12.5” joist-band beam with a 10.5” concrete slab on top increases the structural depth to 23” total. Drop panels will increase the depth by either 2-¼” or 8-¼”. This leaves approximately 1’¾” to 1’6-¾” of clear space for MEP systems. This is a significant decrease in the space above ceiling, but only occurs near the columns. In between drop panels, where systems are more likely to run, there is approximately 1’9” of clear space for MEP systems.

A 16.5” joist-band beam will increase the structural depth by four inches. This will leave clear space of 8-¾” or 1’2-¾” at the drop panels and 1’5” in between them. This is still adequate space to install the majority of MEP systems, however MEP components would be located closely together, which does not facilitate easy installation or maintenance.

Another item of concern is how the larger columns will affect the available area within each room. The steel columns of the original design are W8x31, which cover a small area of approximately 0.50 square feet. The 20” square columns replacing them occupy a much larger 2.8 square feet of space. There are approximately 42 columns per floor that will be changed from steel to concrete. The concrete column design will occupy 118 total square feet, while only 21 square feet is occupied with the steel design. Considering the total area per floor is approximately 9600 square feet, this means less than 2% will be occupied by the concrete columns. This is a negligible amount of lost space in the overall design.

However, an issue may arise about the wall construction around the column. The columns will be significantly wider than both the interior and exterior walls, meaning there will be box outs to accommodate the columns that will alter the architectural appearance and feel of the room. For instance, the exterior walls are 1’ to 1.5’ in width and interior partitions are 0.5’ in width. A 20” column is substantially thicker in most cases so it will be quite visible as an extrusion from the wall. The architect will need to verify whether this is an acceptable change or if it will alter their intended design too drastically to be warranted. Furthermore, it should be considered whether or not the box-outs would be inconvenient to the future residents of the apartments.

2.9 Recommendations

After considering all of the information available, it is not recommended to alter the structure of the Convent/Monastery. It is recommended to explore redesigning the structure of the Fellowship Hall. The increased cost and massively lengthened schedule of a concrete structure for the Convent/Monastery prohibit its use. This is furthered by the negative impacts that the larger concrete columns have on the architecture, in particular the decreased clear space above the ceiling. Although some advantages may be garnered from worker affinity to concrete work, the disadvantages outweigh them. On the other hand, changing the structure of the Fellowship Hall to concrete could be advantageous to the project. The overall construction costs are roughly the same and there will be no major negative implications to the architectural style. The increased schedule duration is something of concern, however, since some activities are clearly critical to the schedule. An additional 80 days of structural work will most certainly influence critical path activities. Therefore, the project team will need to determine whether they can accommodate or reduce this duration.

3.0 Analysis II: Restructure of Concrete Bid Package

3.1 Problem Statement

With three of the five buildings on site almost entirely structured using CIP concrete and the entire underground Parking Garage formed of CIP concrete, the concrete scope on the project is very large. In addition, there are a number of complex shapes and designs that need to be formed, particularly on the Mosque. This places a significant amount of pressure on the shoulders of the subcontractor in charge of the concrete package, who will be referred to as Contractor X. If they fall behind in their work due to error or unforeseen circumstances, it will almost certainly affect the entire project. A majority of their structural work lies upon the critical path, whether directly or indirectly. It is absolutely essential that Contractor X remain on task so that their work remains on schedule and does not negatively impact other subcontractor work.

3.2 Potential Solutions

Division of the concrete scope is a potential solution that will spread the workload between multiple subcontractors, hopefully allowing them to focus their efforts into preparing for and addressing challenging construction situations. The bid package will be divided into smaller, separate packages so that it can be split between multiple subcontractors. There are a number of opportunities to divide the project into separate areas that will each be part of a bid, and these will be explored through the completion of this analysis. Depending on the division of the concrete scope, a structural analysis may be required to ensure that the divided structures still retain their strength.

3.3 Analysis Process

Initial research will be conducted into the concrete market available around the project location, in order to determine what other concrete subcontractors in the area could viably complete the project. This involves researching the size, culture, project history, capabilities, and location of each company. Using this information, contractors that are deemed capable of completing the project will be chosen to contend for a portion of the restructured bid package.

Then, the concrete scope will be divided by best judgment based upon size, cost, volume, complexity, and duration of each division. There are different opportunities to divide the scope and these will be explored to select the best option. Once the scope is divided, each bid package will be awarded to the subcontractors selected in the prior assessment. Further analysis will examine if there is a need for additional contractual requirements due to multiple concrete bid packages and examine potentially challenging areas where subcontractors will have to work against one another.

3.4 Background Research

The total cost of concrete work on the project is $15.5 million. With the cost of all construction work totaling about $65 million that means the concrete scope is almost 25% of the entire project cost. In addition, the entire concrete scope totals nearly 25,000 cubic yards of concrete. The three areas that have the majority of the cost within the concrete scope are the Parking Garage, the Mosque, and the Turkish Bath. **Table 7** below provides a brief breakdown of concrete, steel, and MEP costs on the project.

Table 7. *Cost Breakdown for this Campus Project*

	Volume of Concrete (CY)	Cost of Concrete	Cost of Steel	Cost of MEP
Parking Garage	13200	$6,320,000	--	$2,889,000
Mosque	2900	$3,800,000	--	$3,774,000
Turkish Bath	5400	$3,463,000	$151,000	$5,870,000
Cultural Center	1400	$974,000	$181,000	$2,155,000
Convent/Monastery	1300	$728,000	$769,000	$2,163,000
Fellowship Hall	400	$215,000	$483,000	$1,516,000
Total	**24,600**	**$15,500,000**	**$1,584,000**	**$18,367,000**

On the schedule, much of the concrete work lies on the critical path of the project or can have influence on items that are on the critical path. In particular, nearly all of the foundation and superstructure concrete work of the Bath is critical. This is a challenging work area due to a difference in elevation of almost 20 feet, large retaining walls, and long post-tensioned beams. It requires a significant depth of excavation, and extensive use of shoring and temporary bracing as structural elements are put into position. Difficult work is also present on the Mosque, which is composed of a multitude of uniquely shaped columns, arches, and domes and two minarets. These shapes require custom formwork that takes both time and money to construct. For example, several different forms have to be used for each minaret because the exterior shape changes as the height increases.

The Parking Garage does not have critical activities, but its completion affects nearly every other building on the project, especially the Mosque. The foundations of the Garage are closely located near every building, and the elevated deck forms the ground level of the site. Short delays here do not have a direct effect on the schedule, while long delays will most certainly affect the critical path. The design of the Garage is fairly simple and should not be challenging to complete. However, its sheer size requires in depth activity, which could be delayed if there are material shortages or complications with deliveries.

During the project, Contractor X has fallen behind at some points, typically due to unforeseen challenges with construction, such as issues with the Styrofoam dome. Styrofoam domes were used to shape the smaller domes of the Mosque. Once the concrete cured, it was unexpectedly difficult to remove the Styrofoam from the concrete. This required Contractor X to spend additional time both removing the domes from the concrete and preparing the domes prior to placing the concrete, in an effort to make removal easier once cured. It is possible that some of these difficulties could have been avoided or prepared for if the scope of work was smaller and a contractor was able to focus on one building rather than all of them.

3.5 Project Concrete Contractor – Contractor X

As stated previously, the concrete contractor selected to complete the concrete work on the Cultural Center will be referred to as Contractor X. The company was founded in 1987 as a general contractor and specialty concrete contractor. Over the years, the company has grown along the east coast and has completed a number of impressive projects, growing its industry reputation. The company has experience in dozens of sectors and is known for assisting projects in the design phases.

One of Contractor X's specialties is in the design of formwork. They have many formwork engineers who plan and develop the systems that will form concrete shapes. Before major pours, the engineers are required to inspect the formwork to ensure that it is installed correctly. Furthermore, Contractor X is recognized as the largest US owner of PERI formwork products, a state-of-the-art European designed system. PERI formwork is known for its ease of use and transportability. There are many different styles of PERI formwork, making it great for unique shapes and forms like those on the Mosque. For Contractor X, this large stock of formwork is beneficial because they will be able to continue work even with the high amount of concrete that must be formed.

Contractor X consistently stresses that safety is extremely important to the way they do work. On the project, they create and enforce a culture of safety that holds everyone accountable for safe procedures. As stated before, formwork engineers are required to inspect all formwork before the concrete is poured. This is an extra step that is taken to ensure not only that the formwork is correct, but that it will hold and perform safely under the concrete load. Contractor X's efforts to create safe project sites were recognized when they were given an award for 760,000 man hours on a project without a single accident that resulted in lost time. That is a tremendous feat that proves how capable Contractor X is at maintaining safety on site.

Contractor X should also be recognized for the innovation that they have shown on this Campus Project. The majority of the formwork used to form the shapes of the Mosque were hand made by their craftsmen. Other forms, such as for the large dome, were made with laser cutting in order to keep accuracy high. For the smaller domes, Contractor X built their own rotating screed system because there was no other simple way to create a smooth finish. This ingenuity has been invaluable on the project and is a testament to their experience and creativity.

3.6 Description of Assessment

This section is dedicated to explaining the method of assessing the concrete contractors that could be selected to complete the additional bid packages created later in this analysis. These contractors will be carefully chosen based upon their qualifications and similar work experience to the project. The mission is to use this assessment to select a contractor or contractors that will be well suited to complete the concrete work on the project. The assessment criteria used to analyze the strengths and weaknesses of each contractor will be explained. Then, each contractor will be examined, summarized, and evaluated using this criterion, and the total ranking each contractor receives will be used for selection.

Overview

An assessment system was created to analyze each contractor's ability to complete the project based upon the information that was available for them. It is categorized into their Project Experience, Resource Availability, Extent of Work, Location, Safety, and Innovation/Creativity. These six criteria represent the most important company characteristics that will influence their ability to complete the concrete package of the Cultural Center. A brief description of each criterion is provided below to explain the rationale behind their selection.

Contractor A, Contractor B, and Contractor C will be evaluated using these criterion, each of which will be ranked on a scale of 1 to 4. A ranking of 1 will signify that the company has very low or no ability in this category, while a ranking of 4 will signify that the company has exceptionally strong ability. A ranking of 2 or 3 will fall in between those levels. The total value obtained by adding all six rankings will be the company's rating for the project. A contractor with a higher value will be viewed as better suited to complete the work on the project than a contractor with a lower value. These rankings will be used to select the number of contractors needed to complete the bid package divisions established later.

Project Experience

This category addresses a company's experience with projects that are similar or larger in size and scope to this Campus Project. It is an important category because the company needs to be comfortable working on large scale projects, without getting overwhelmed by the workload. The ranking is based upon the total value of the bid package, the building area, and the volume of concrete on the project. For reference purposes, these are the statistics of the project that were considered:

- Concrete Package Value: $15,500,000
- Total Building Area: 287,400 square feet
- Volume of Concrete: 24,600 cubic yards

In addition, example projects will be examined to determine if the contractor has any experience with multi-building projects. A ranking of 4 is awarded if a contractor has project experience that is equal to or greater than these three requirements. The ranking decreases per each value that the contractor is deficient. If this information is not provided by the contractor, then a best guess is made. However, the highest value the contractor could receive in this case would be a 3, and only if highly justified.

Resource Availability

This category addresses the level of resources that the contractor has in its possession. This includes materials, equipment, formwork, scaffolding, and all other essentials that are needed to complete their work. The ranking is not based specifically on number of materials, but rather a general scope. A four is awarded if the contractor has resources within all of the previously listed categories, and in significant numbers. A one is awarded if the contractor has resources in only one or two categories. If no information about a contractor's resources was found, then the contractor will receive a generic value of 2.

Extent of Work

This category addresses how much work related to concrete that the company completes in house. Work related to concrete includes producing, delivering, forming, placing, and finishing. A company that completes all of these tasks in house has better control over the process than a company that contracts a separate entity to produce and deliver the concrete. A four is awarded if the contractor completes all of the above tasks, and a two is awarded if the contractor completes only forming, placing, and finishing. If there is no information provided by the contractor, it will be assumed that they should receive a ranking of 2 because this is the basic work that a concrete contractor would complete.

Location

This category addresses how close the contractor and its resources are located to the project site. Proximity is essential to getting materials and equipment on site quickly and efficiently, especially if they are needed on short notice. A four will be awarded if the contractor is located within 20 minutes of the site, and a three if they are located more than 20 minutes but within 45 minutes. A two is awarded for times longer than 45 minutes and a one is awarded for times longer than 1 hour and 30 minutes. If no information is provided, then the contractor will receive a rating of 2.

Safety

This category addresses the company's ability to promote and enforce safety on their projects. It takes into account both their past project performance, the requirements they have on employees, and their goals for implementing safety in the future. This criteria is difficult to judge because specific information is not often provided by the contractor. The ranking will be based upon best judgment, but a four will only be provided if the contractor has a safety initiative or plan clearly stated.

Innovation/Creativity

This category addresses a company's ability to develop unique strategies to handle challenging situations on projects. This is very important because the project has a number of difficult shapes and designs. This criteria is almost entirely based upon assumption since there is very little related information available on contractor websites.

3.7 Contractor Ranking

Contractor A

Contractor A was founded in 1974. Originally, the small company only took on jobs to form, place, and finish concrete. As the company grew and expanded, it took on more roles within the concrete market. Now, they are capable of completing all work in house, from production to finishing the concrete. This gives them a significant competitive advantage because they are in control of the process and can limit delays that may occur if a separate entity was involved.. Even more beneficial is the proximity that Contractor A's batch plants have to the construction site. The closest plant is within 18 minutes of the site and no plant is located more than 80 minutes away. This keeps a plentiful volume of concrete readily available to the project.

Contractor A also has experience on large projects of similar or greater size. The largest contract they have completed was a hotel project at a value of $57,000,000. The project consisted of a 22-story and 28-story multi-tower, with a 5 story parking garage under each building. The total amount of materials used was 100,145 cubic yards of concrete, 11,465 tons of rebar, and 370 tons of post tension steel. Impressively, Contractor A was able to finish the large job 5 weeks ahead of schedule. Other projects that they have completed vary in size and cost, but the majority is comparable to this Campus Project.

The only project that Contractor A has completed that involved multiple buildings was a research facility project. Three separate buildings were constructed simultaneously as primarily office space. The concrete scope was not significantly high at only $2,250,000, but it is a benefit to Contractor A's capabilities that they have had experience with a multi-building project.

In terms of safety, Contractor A requires that all employees participate in weekly Tool Box Talks that serve as short training and information sessions. Additionally, in order to use most equipment, employees must take a company provided training and safe operation practices class. If there happens to be any incidents on site, Contractor A's safety department will investigate the incident and follow up with the injured employee or employees as necessary. They report that nearly 50% of the entire staff is OSHA trained and actively renews as regulations change. Also, substance abuse testing is required upon hiring and at random monthly intervals. If a positive result is received, the employee is terminated immediately.

Overall, Contractor A's biggest advantages are their industry experience, close proximity to the site, and complete in house process. These features make them a viable candidate to work on the project.

Rankings

- Project Experience: 4
- Resource Availability: 2
- Extent of Work: 4
- Location: 4
- Safety: 3
- Innovation/Creativity: 2

Contractor B

Contractor B was founded in 1947 by lifelong friends. In over 65 years of operation, the company has completed more than $5 billion in concrete construction projects. They have had continued success due to their committed client relationships, ingenuity, and hardworking spirit. Similarly to Contractor A, Contractor B also completes all of the tasks related to concrete in house.

They complete this array of work with the help of a 22 acre maintenance and storage facility that maintains and houses the construction fleet, equipment, and materials of the company. Here, they have their own mobile and tower cranes, pump trucks, hoisting equipment, scaffolding, shoring systems, and formwork. All of their equipment is maintained at this site by their own employees, making their workers very familiar with their equipment and technology. However, no information on the location of storage facility or of the batch plants was available.

Detailed information, such as cost, volume of concrete, or tons of steel, on the past projects Contractor B has completed is not provided. However, they do have an impressive list of large projects completed with well-known companies, such as Davis, Clark, Turner, and Whiting-Turner. The largest project they have completed measured over 2.5 million square feet, so they are clearly experienced with large scale projects. No examples of multi-building projects could be found on the company site.

Contractor B has a strong safety program that requires all employees to be trained both immediately upon hiring and 90 days later. The later training involves more specific training related to the trade they have chosen. In addition, certain employees will be trained as Scaffold, Fall Protection, or Excavation Competent so that they can ensure those activities and systems on site are installed and used properly. In 2012, the company initiated a warm-up program to get all workers moving and active in the morning. The intent is to get employees ready for work by getting them mentally alert and by loosening the muscles.

A unique skill that Contractor B brings to projects is their design assistance. They are typically brought on projects early in the design process in order to assist with value engineering, modifications, or other means that could improve the project. This early involvement could be useful on this Campus Project because of the complicated shapes and designs, where there is a potential for early planning that would benefit construction operations. An example of Contractor B's ingenuity is their creation of the Infinity System. Used for multifamily dwellings, it is a quickly assembled noncombustible steel and concrete structural framing option. The system offers speed, flexibility, and customization to the owner and project team. This kind of creative thinking could benefit the project if it is established early.

Contractor B's key advantages are their vast experience, extensive storage yard, strong safety program, and innovative company team. These features make them a very strong candidate for the project.

Rankings

- Project Experience: 2
- Resource Availability: 4
- Extent of Work: 4
- Location: 2
- Safety: 3
- Innovation/Creativity: 4

Contractor C

Contractor C was founded in 1968 in Ohio. Since then, they have grown nationally, completing increasingly larger projects and expanding into 12 regional offices across the US. The office closest to the Cultural Center is approximately 25 minutes away, making it a close commute. Based on research, it is not certain whether or not Contractor C completes all of the concrete tasks from production to finishing.

Contractor C as an entire company reports that they have over 1,800 units of heavy construction equipment and over 1.3 million square feet of forming and shoring units. This equipment and materials would be invaluable on the Cultural Center, but it is unspecified how much of these resources are located near the regional office.

The largest project scope that was completed by the regional office nearest the Cultural Center totaled 44,000 cubic yards of concrete. Additional projects in this area were typically buildings totaling several hundred thousand square feet of area. It is obvious that the regional office has experience with large projects, but it is unclear to what depth.

Contractor C does have a strong safety initiative with an Incident and Injury Free (IIF) mentality. Employees are required to participate in weekly "Tool Box" discussions and field supervisors are required to go through weekly safety trainings. In addition, the company actively schedules OSHA recertification training and offers specialized training courses to employees. Contractor C emphasizes that their employees care for not only the safety of themselves, but for the safety of all workers on the project. This is an excellent mentality to have and will benefit this Campus Project because of the high number of workers that will be on site from different organizations.

Contractor C's biggest advantages are their experience, large company size, and strong safety initiatives. Their equipment and material base could also be an advantage, but it is unspecified how much is allocated to the regional office. It should be noted that Contractor C was ranked highly on ENR's 2013 list of the top 600 specialty contractors in the US. This is an indication that they have a strong performance record with their clients. With these qualities, Contractor C is also a good candidate to work on the project.

Rankings

- Project Experience: 2
- Resource Availability: 3
- Extent of Work: 2
- Location: 3
- Safety: 4
- Innovation/Creativity: 3

Summary

Through compilation of the individual rankings each contractor received, the total scores are 19 for Contractor A and B, and 17 for Contractor C. Some of this difference could be attributed to the increased availability of information for Contractors A and B. However, the ranking is a reasonable assessment because Contractor C was deficient in several areas in comparison to A and B. A summary of the assessment can be found in **Table 8** below. Highlighted values signify the contractor that had the highest value within each criterion.

Table 8. *Assessment of Contractors*

	Contractor A	Contractor B	Contractor C
Project Experience	4	2	2
Resource Availability	2	4	3
Extent of Work	4	4	2
Location	4	2	3
Safety	3	3	4
Innovation/Creativity	2	4	3
Total	**19**	**19**	**17**

Based upon the bid package divisions established next, Contractors A and B will be chosen to accept bid packages first. If three packages are used, all three contractors will be selected; however, Contractors A and B will be given the larger or more intensive bid packages to reflect their higher score.

Additional Contractors

Other contractors located near the project site were also researched; however the majority was not selected for one reason or another. Some contractors were of adequate size, but lacked the experience for building projects because they mostly worked on infrastructure projects. Other contractors had the necessary experience, but were too small in size to effectively work on this project. These decisions are not meant to impart any negative connotation upon the contractors. They simply did not meet the minimum requirements that would be needed to work on the project as established in this assessment.

3.8 Bid Package Division

This section is dedicated to evaluation of the different methods in which it could be divided to lessen the work. There are several different options for division that would be possible, and this assessment will attempt to choose the most viable and potentially valuable option. An overview of the current bid package on the project can be found within the section 3.4. Each potential new division will be introduced and evaluated on realistic means of implementation. Once a division is selected, any implications to the contract and structural integrity will be discussed.

Division 1: Two Bid Packages

The first potential division is to separate the concrete scope into two bid packages. Package 1 will solely contain the Parking Garage, and Package 2 will contain the remaining five buildings. This division effectively divides the concrete scope in half by volume of concrete. Package 1 will consist of 13,200 cubic yards of concrete, and Package 2 will consist of 11,400 cubic yards. Cost will not be divided as evenly as the packages will have a value of $6,320,000 and $9,180,000, respectively.

The advantage of this division is that both contractors will be on site at the same time for the minimum amount of time. Once the Parking Garage is completed, the contractor completing Package 1, Contractor 1, will be able to vacate the site. The contractor completing Package 2, Contractor 2, will only be on site for portions of Contractor 1's operations, namely excavation of the Turkish Bath. Contractor 2 will remain on site and continue constructing the five buildings after contractor 1 has completed. This will limit the amount of congestion on site and will make site logistics a little easier to manage. For the time span that both contractors are on site, site utilization plans will have to carefully detail how the contractors will use site entrances and layout areas. This can be difficult to plan, but can be accomplished successfully with good cooperation and communication between the contractors and the project team.

The disadvantages of this division are that the scope of work is not evenly divided and Contractor 2 will be almost entirely reliant upon Contractor 1's ability to complete their work on schedule. Although the volume of concrete is evenly divided between the packages, the scope of work is mismatched. The Parking Garage has a very simple and repetitive structure, making it an easily managed process for Contractor 1. In contrast, the scope of work within Package 2 is considerably more challenging. Contractor 2 will have to manage the complex shapes and designs of the Mosque, the deep excavation and extensive foundations of the Turkish Bath, and varying structures of the Fellowship Hall, Cultural Center, and Convent/Monastery. In essence, this bid package division does nothing to distribute the difficult to construct areas of the project to both contractors, and instead places them entirely upon the shoulders of one contractor.

Furthermore, since much of the work within Package 2 cannot begin until Package 1 is complete, Contractor 2's schedule will be almost entirely dependent upon Contractor 1 following their schedule. If Contractor 1 falls behind in their work load, it will delay Contractor 2. This places a difficult handicap on Contractor 2, who can do very little to change their situation. In addition, Contractor 2 will also have to trust in the structural integrity of the Parking Garage completed by Contractor 1. Some of the foundations or other supports of the Parking Garage lend structural support to the other buildings, particularly the

Mosque and Fellowship Hall. If there is an issue or failure within the Garage structure, it will heavily influence the structures of the other buildings.

Both of these situations create contractual and legal nightmares because neither contractor will want to carry the risk or liability of the other. This division would most certainly require detailed contractual language to address these and other situations that could arise. Due to these major disadvantages versus a rather minor advantage, this division is not recommended. The benefit of dividing the bid packages this way is not worth the additional challenges and effort required.

Division 2: Three Bid Packages

The second optional division separates the concrete scope into three bid packages. Package 1 will include the Parking Garage, Mosque, and Fellowship Hall for a total volume of concrete of 16,500 cubic yards and a total value of $10,335,000. Package 2 will include the Cultural Center and Convent/Monastery for a total volume of concrete of 2,700 cubic yards and a total value of $1,702,000. Package 3 will solely include the Turkish Bath for a total volume of concrete of 5,400 cubic yards and a total value of $3,463,000. This division does not separate either the volume of concrete or value evenly, but it does attempt to separate the scope of work in an even distribution.

This even distribution is the main advantage that this division supplies. The three contractors involved will have similar scopes and complexities of work to complete. Ideally, this will give the contractors the opportunity to focus on their required work and anticipate and plan for challenging situations. With this preparation, the contractors will be able to address any situations that arise without causing delays to the schedule. This is a strong benefit to the project and is the goal of this analysis.

The disadvantage of this division is that there will now be three separate contractors responsible for completing the concrete scope of work. This will create added confusion and congestion on site because of dramatically increased operations with three contractors versus one. Site utilization and logistics will have to be very carefully considered in order to keep operations organized, coordinate deliveries, and track contractor progress. Communication between the contractors will be essential to completing the work effectively without interfering with one another.

Similar to Division 1, a further disadvantage will be that Packages 2 and 3 are dependent upon Package 1 for schedule and structural integrity. However, these dependencies are not as strong as they are in Division 1. Through proper bracing and communication, Packages 2 and 3 can take place concurrently with Package 1. However, since much of the work will tie together or will take place very close together, some contractual language may need to be updated to address risk and liability for those situations. Furthermore, it would be beneficial to analyze these situations where different contractors will be working closely together and plan for them well in advance.

Overall, this division offers strong benefits of more evenly distributed scope of work. The packages are divided to separate complex areas so that each contractor will only have one major area of difficulty. However, the drawbacks of more challenging site logistics discourage the use of this division. Coordinating three separate contractors on site would be a very challenging logistical situation. Therefore, this division is not recommended.

Division 3: Two Bid Packages

The third division option is very similar to Division 2. Package 1 will include the Parking Garage, Mosque, and Fellowship Hall, as in Division 2. Package 2 will include the Turkish Bath, Cultural Center, and Convent/Monastery – effectively combining Packages 2 and 3 of Division 2. This will evenly divide the complex work on the project and more evenly divide the volume of concrete and cost. Furthermore, it will require only two contractors on site, simplifying the logistical needs that would be required if three contractors were needed. Division will again involve 16,500 cubic yards of concrete and have a value of $10,335,000, but now Division 2 will involve 8,100 cubic yards of concrete and have a value of $5,165,000. Although Division 1 is still significantly larger in cost and size, this is mostly attributed to the underground Parking Garage, which has a simple, consistent design as mentioned previously.

As in Division 2, this separation provides the advantage of an evenly distributed scope of work, because the most challenging areas of the project, the Mosque and the Turkish Bath, are split between the contractors. As explained in Division 2, this will give the contractors more opportunity to plan and address those difficult areas. Where Division 3 excels beyond Division 2, is that only two contractors are needed for the work. It will be far easier to manage two contractors on the project than it would be to manage three. It will also make it easier to designate areas around the site for staging, layout, and material storage for each contractor. Also, this division, for the most part, keeps each contractor out of one another's way. Contractor 1 can maintain their work and designated areas within the footprint of the Parking Garage, while Contractor 2 can keep their work and areas outside of it. This separation should make work and management easier for the contractors.

Similar to the other divisions, the disadvantage of Division 3 is that Contractor 2 will be reliant upon the work completed by Contractor 1. As explained in Division 2, this issue can be rectified with good communication and proper bracing. Some coordination will be required between the two contractors, but the work should be able to proceed unhindered. However, contractual language may be needed to clearly define who carries the risk in this situation.

Overall, Division 3 offers the strongest advantages compared to Division 1 and 2. The scope of work is evenly distributed on the contractors as well as located to keep a separation between their work spaces. As with the other divisions, the disadvantage is that the work within Package 2 is reliant upon the structure and completion of Package 1. This difficulty will require careful management and planning, and may also require some contractual language to define liability and risk. Because it has the strongest advantages, Division 3 is the recommended bid package separation to pursue.

3.9 Contractual Implications

Restructuring the concrete bid package with Division 3 will require some additional contractual language to be employed. The entity who carries the risk and liability of the common building structures will need to be clearly defined. This may also include who will provide and maintain the temporary bracing installed. Contractual language should also explain any information sharing and collaboration procedures required of the contractors. Some of these expectations could be a sharing of structural information and as-built drawings which will be useful for the contractors as they plan construction operations and surcharge loads. Balfour Beatty should carefully develop this contract with the contractors so that all parties will understand their roles and responsibilities. They may also need to carry the risk associated with these operations to ease the requirements on the contractors.

3.10 Structural Integrity

Due to the chosen method of structural division, it was deemed that a structural analysis was not necessary. The foundations and structures of each building are kept predominantly separate. The Fellowship Hall and the Mosque rely on the structural support of the underground Parking Garage, but this will not pose an issue since Contractor 1 will be responsible for these three buildings. Furthermore, the structures of the Cultural Center, Convent/Monastery, and Turkish Bath do not tie directly into the Parking Garage, and therefore are not reliant upon it. The main area of concern is the retaining wall that separates the Parking Garage and Turkish Bath. There is an elevation difference of nearly 30’ here and it is very important that the wall is installed correctly because it will be supporting the surcharge construction loads and dead loads of the Parking Garage.

The sequence of events that should be followed to complete this wall properly are as follows. The wall itself should be poured according to schedule within the excavation and foundation phase of the Turkish Bath. The pool area, at the base of the wall on the Bath side, should be backfilled first. Then, the elevated deck of the Parking Garage can be built on the Garage side of the wall. In this process, the surcharge loads will be evenly matched to ensure the integrity of the retaining wall. If the elevated deck is constructed prior to the pool being backfilled, the unmatched loading could severely damage the retaining wall. Therefore, it is imperative that the pool be backfilled before the elevated deck begins construction.

3.11 Recommendation

Based upon the analysis conducted, it is recommended to implement Division 3 of the concrete bid package. This division will maximize the contractors’ ability to plan and coordinate work effectively, particularly when addressing the unique challenges of the work. Contractors A and B should be selected to complete the work because they have the best qualifications and experience to complete the work effectively. Furthermore, some specific contractual language should be developed to address the work that will be conducted, particularly with concern of how the contractors interact and cooperate with one another.

4.0 Analysis III: Workforce Management Plan

4.1 Problem Statement

This Campus Project has a unique opportunity to utilize a larger workforce, and therefore have a higher productivity, because of multiple buildings on site. Construction operations can occur in many different spaces throughout the site, giving subcontractors flexibility and opportunity when completing work. Additionally, subcontractors can actively adjust their working schedules to accommodate for any hindrances or interruptions that may occur. For example, if Trade A is scheduled to begin work in the Cultural Center, but cannot because Trade B is still working in that area, Trade A can relocate and work in another building. This flexibility prevents the presence of idle workers and keeps Trade A working.

However, this situation does present an issue returning to the schedule when Trade B finishes and Trade A needs to resume work according to the designated schedule. Trade A would need to complete the work in their present area before returning to the previously scheduled area because it would be inefficient to do otherwise. This could cause further delays to the timetable if not managed properly. More importantly, site management becomes more challenging with a larger, diverse workforce. In order to better direct this workforce, the project team will need to develop a detailed and comprehensive management plan.

4.2 Potential Solutions

There are many different techniques that can be used to accurately manage and track the work force on the project. These options will be researched and analyzed for the effectiveness and applicability to this project. This data will then be used to develop a Workforce Management Plan that can be used on projects with diverse and extensive workforces. Ideally this plan will be used to alleviate the challenges with managing the workforce in these scenarios, by providing the project team with guidance and helpful strategies.

4.3 Analysis Process

To complete this analysis, thorough research was first conducted into the common work practices of the foreign artisans. This information was critical to determining if their work practices, methods, or directives differed from that of the domestic workers. It will be used to assist with the creation of the supervisory section dedicated to foreign artisan management. In addition, typical poor productivity causes and the management techniques to address them were researched. Information within this section comes from journals, as well as, class material collected from AE 570: Production Management. All of this data will be used to develop a workforce management plan based upon the site conditions. This plan can be used to manage the Cultural Center and similar sites in order to improve and sustain productivity.

4.4 Background Research

Through discussions with Balfour Beatty, the project team vocalized that managing the workforce is an integral part of the project. Construction operations in multiple buildings grant a greater opportunity for a larger workforce and production in different areas occurring simultaneously. Project management takes full advantage of this capability by employing a large workforce and constructing all of the buildings concurrently. However, with that practice it is much more difficult to track all of the different activities going on across the site, and to keep an accurate record of work as it is completed. It becomes a challenge to track all of these operations while ensuring that they are proceeding in a safe and proper manner.

The schedule also requires integration of foreign artisan work, which must be carefully coordinated with other construction activities. The foreign artisans typically conduct work such as installation of lead sheet metal roofing, installation of exterior and interior stone panels, detailed finishing work on the interior, and installation of ornamental trim. Much of this work ties into the operations of other subcontractors, so consideration of their work is important to keep to the schedule. An accurate way of tracking the workforce would be a valuable tool for updating and monitoring the schedule and incorporating the work done by foreign artisans.

4.5 General Workforce Management Techniques

Loss of labor productivity can be attributed to three main causes: ineffective utilization of resources, unfavorable working conditions, or adverse weather. Resources including labor, materials, equipment, and information, need to be managed effectively in order to be productively utilized. Good planning, material scheduling, and other techniques can be used to accomplish this. Congestion, out-of-sequence work, and other site issues all attribute to unfavorable working conditions that will hinder worker productivity. These complications can be avoided through strong site management techniques and site utilization planning. Adverse weather is unfortunately an unpredictable factor on construction sites. However, make-up work days can be included in the schedule to prepare for any potential delays due to weather.

Even though decreases in labor productivity can be attributed to these three causes, at the core of most issues with productivity is poor or ineffective management. Field workers will naturally complete work in a productive manner. It can be argued that since they are paid hourly, it is in their interest to work slowly in order to gain more hours. However, this is not often the case. A worker will be much more satisfied with their effort if they complete it in a timely manner or according to schedule. Furthermore, employers are more likely to terminate employees that continuously cause delays and fail to complete their work on time. There are, however, numerous variables that can affect how quickly the worker can complete their work. These variables must be accounted for by the project team in order to ensure productivity. This is also where teams can fail at managing a construction site, particularly if they have not spent time preparing and planning.

Planning is the key ingredient that goes into good site management and organization. This should occur both before and during construction so that the team can be prepared for different scenarios that can transpire on site. Managerial duties include scheduling work, actively directing crews, coordinating materials, and limiting interruptions to critical work activities. These tasks are only part of the wide scope of items that should be planned for on the project, but are some of the more important issues.

The schedule of the project is one of the most critical aspects of planning the work on site. It needs to be detailed, accurate, and proceed in a logical fashion. The overall project is made prior to the start of construction, but should be updated periodically to monitor and track the progression of work. Weekly schedules can and should be made to provide detailed information about the specific trades and work going on site. This information can be used to plan how the site will be utilized and better manage the workers. Useful techniques to accomplish this are Pull Planning or Last Planner. Pull Planning is a technique that works backwards through the schedule to examine the relationships between different trades and how they are dependent upon each other. Last Planner is a method of coordinating construction work each week by discussing activities with all of the foremen or superintendents involved.

Further schedule planning can look at the length of each work day and work week and how breaks are coordinated around daily work. Depending on the amount of work that needs to be accomplished, each work week can be 4 or 5 days. The amount of hours expected each day can also vary from 8 to 10 hours, usually beginning at 6:00 or 7:00 AM and ending by 3:00 or 5:00 PM. Contractors typically prefer a 4 day, 10 hour day work week. This allows them to have a three day weekend, or a make-up day on Friday to complete additional work as needed. Depending on the requirements of the project this can be adjusted to be more productive and effective. Obviously, overworking the workers by requiring them to work long hours can hinder productivity over time because the morale decreases or the workers become too tired to work efficiently. On the other hand, working too few hours will hurt worker morale because they may not be making sufficient money. It is important to find a balance that is most applicable to the project.

In addition, the daily work schedule should be coordinated to take advantage of periods of high productivity. It has been seen that from 10:00 AM to 2:00 PM is when workers are most productive. Therefore, breaks should be coordinated around this time if at all possible. For example, a morning break could be given at 9:00 AM, lunch given at 11:30 AM, and an afternoon break given at an unscheduled time in the afternoon. This would create longer periods of work which allow workers to be more productive because they can get into a work rhythm.

Weekly or periodic scheduling sessions should be used to actively manage and direct the workers on site. Ambiguity in the workplace is a very quick way to lose productivity. Work spaces and activities should be clearly defined so that workers know exactly what they are expected to be doing. Management should also make periodic investigations of the site to ensure that work is of quality and that workers are on task. However, it should be kept in mind that over-managing will negatively affect productivity and can hurt morale. If managerial staff continuously and frequently check on workers, the workers may feel as if they are not trusted to accomplish their work, leading them to lower morale. A beneficial and trusting relationship between workers and management is much more effective and productive than an overbearing management attitude.

Material coordination is also essential to maintaining productivity. Materials need to be readily available, easily found, and in adequate quantity to facilitate construction work. Productivity can be seriously affected when workers are unable to locate needed materials or parts due to material shortages or unorganized storage. Workers can actually spend more time searching for materials than they do completing work if the materials are assembled haphazardly or are difficult to locate. Carefully managing the supply chain and organizing material storage on site is an important process for managerial teams. Ideally, materials should be located as close as possible to where they will be needed and will be stacked in an organized manner. In addition, the material stockpile should be of adequate size for the work that will be completed. Insufficient materials on site will cause a drop in productivity because workers will not have the materials available to complete their work.

Management should also strive to limit interruptions to construction activities, particularly critical ones. Work stoppages or changes that disrupt the flow of work will hinder worker productivity. As stated previously, it is best to create prolonged periods of work because these will naturally lead to higher productivity. Management should attempt to avoid disrupting the flow of work and should plan to address any situation so that interruptions are not long lasting. When planning work this requires coordinating contributory work, such as site cleanup or organization, around value adding work, such as brick laying, painting, welding, or concrete placing. The actual work that adds value should always have priority. Work that assists or contributes to the actual value adding work is necessary to complete, but should be completed concurrently and without interrupting the actual work.

These myriad techniques can be employed to utilize resources effectively and to keep working conditions favorable, but the last challenge, adverse weather, is difficult to address. The weather is very unpredictable and although many activities can be completed regardless of the weather conditions, there are some that cannot. In addition, weather can cause damage to equipment, materials, and work in place if it is not properly protected. Rain can slow excavation or foundation work if pumps are not place to drain the site. On most projects, the weather can be attributed to several days of delay because work was slowed or stopped altogether. In order to prepare for this, the project team should attempt to incorporate extra days in the schedule. These spare days, or weather days, will be "used up" when there is inclement or serious weather. This will allow the project to remain on schedule despite losing days to weather. In addition, the project team should ensure that all materials, equipment, and constructed work is properly protected once on site. Rain damage to materials can destroy the integrity of the material, such as drywall, making it unusable, or it can create a health risk, such as mold on mechanical ductwork. Fortunately, through precaution and planning, the project team can protect their site from delays and damages due to weather.

4.6 Workforce Management Plan

The following Workforce Management Plan for the Cultural Center project will be used to better manage and control the employees on-site. The techniques presented will be used to identify and solve issues, as well as provide techniques to manage the work. Through the implementation of these methods, the project team will be able to actively manage the site and maximize productivity.

A. Management Structure

It is important to clearly define and establish a management structure or hierarchy for the project. This structure can be used to assign different site responsibilities to each person. Since the project has multiple buildings and an extensive workforce, several different management personnel can be applied across the site. Their duties and responsibilities will be defined based upon the area they are responsible for overseeing. Defining this structure will increase site organization and understanding of job responsibilities.

Due to the conditions on site, different methods of arranging this hierarchy are possible. Field superintendents can be assigned a specific building or area of the site, depending on how the project team wants to separate the project. The size, complexity, and location of each area need to be considered when dividing the site into sections. Furthermore, assigning too many superintendents to the project is actually a negative action because it clouds and complicates the leadership organization. For the project, it is recommended to have two to three field superintendents governed by one overall site superintendent.

Each field superintendent will be in charge of a different portion of the site. The most effective way to section the site would be to separate it by buildings. Superintendent A would manage construction of the Parking Garage, Mosque and Fellowship Hall, while Superintendent B would manage construction of the remaining buildings. If a third subcontractor was added, they could manage construction of the Turkish Bath. These would be effective separations that define each superintendent's responsibilities for the entire project staff. Furthermore, it divides the site into smaller, more easily managed sections so that superintendents can work more effectively.

In order to bring unity to the site, the overall superintendent will be in charge of managing each supervisor. Daily meetings should be held so that the superintendents can review progress and daily work. It will be necessary for them to coordinate deliveries and work activities, particularly crane operations. The two tower cranes on site will facilitate more operations, which will be more convenient for construction. However, the superintendents should ensure that they carefully plan each week in order to maintain productivity and avoid work collisions.

B. Data Collection Tools

There are many different techniques that can be used to monitor and record worker productivity on-site. Some of the most commonly used methods are interviews, questionnaires, surveys, or manual recording. These can be used by the management team to learn how the work is progressing and how workers view its progress. Often, new delay causing issues or challenges can be discovered that were not previously expected. Workers typically realize and report more detailed issues than management can notice through their own observations. Useful interviews, questionnaires, and surveys should poll employees across all different levels of management in order to get a broad view of operations.

These polls can be conducted in person, on paper, or through other techniques if they are more effective. Careful and thorough documentation is necessary to track all of the responses and by examining them, the reasons for site delays can be discovered. It can seem useful to send out as many polls as possible in order to get a high volume of responses. However, too much information can be detrimental to analysis because it becomes difficult and time consuming to document, organize, and track each response. It is more useful to send out a manageable but thorough scope of polls in order to get useful responses.

Manual observation of construction activities and productivity can be a very challenging task. The observer needs to take detailed and thorough notes that can be understood later during review. This can be a complicated task if the activity involves complicated work, a high number of workers, or a large work area. The movement and work of each worker, material, and equipment needs to be carefully tracked and recorded. Videos and pictures are undeniably helpful means of collecting this information. The activity can be recorded and then analyzed in detail at a later time. It needs to be noted that this action takes a considerable amount of time and effort, but the information garnered can be very useful and beneficial.

The data collection tools that will be used on the Cultural Center are on-site, in-person interviews with foremen, superintendents, and occasionally workers. Photographs will be used to assist with this collection and provide supporting evidence for analysis. Information garnered through this approach will be used to help identify delay creating issues in the construction process. Once these issues are recognized they can be addressed by the project team for a solution.

C. Data Analysis Tools

Several different tools will be used to analyze, organize, and present the information collected so that it can be used beneficially by the project team. There are many different analysis tools that can be used, each best suited for different situations. The project team should determine which tool will serve most valuable based upon the parameters surrounding the project and the activity. The tools that will be utilized in this plan are a crew balance chart, process chart, and labor utilization factor.

A crew balance chart may be created to examine crew sizes and assess if they are appropriate for the level of work and production. These charts are good at visually showing how each worker completes useful tasks within the time period observed. The time spent being productive or wasteful can be easily seen in a column chart format. Using this, the team can decide whether or not the crew needs to be resized or rearranged in order to be more effective. Often times, the crew will be larger than necessary and some employees may be idle for significant portions of time. Therefore, the crew size should be decreased and the idle employees given different assignments where they can be more productive and beneficial to the project. Reorganizing the crew will design its size to fit the amount of work that needs to be completed.

To develop a crew balance chart, the crew should be observed through several cycles of operation in order to have a more accurate assessment. The recorded information should track each crew member and record the amount of time they spend working and the amount of time they are idle. The chart will show where in the process the workers are idle and for how long. Time should run along the vertical access and the names for each crew member should run along the horizontal. **Figure 20** shows an example of a crew balance chart. The dark gray signifies time spent accomplishing work while the light gray signifies time wasted or spent idly. Clearly, Worker 3 spends a significant amount of time idly. It should be explored if they can be reassigned to a different crew so that this activity can be completed productively by Workers 1 and 2. An actual chart may have as many as 10 crew members so it is important to provide clear names for each worker to keep it organized and understandable. These charts are very useful because it is often not the crew or the individual workers that are the reason for low productivity, but rather the crew is not the appropriate size for the work they are completing.

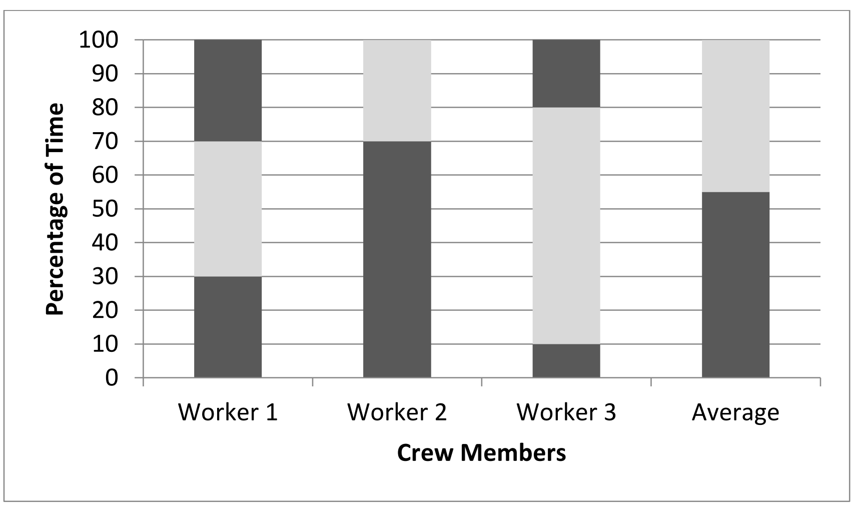

Figure 20. *Example Crew Balance Chart*

The process chart will be created to map out the sequence of events that comprise the observed activity. This includes all parts of the activity, including gathering or moving materials and setting up equipment. Once the process has been mapped, the chart can be used to determine steps in the process that need improvement. For instance, if materials are repeatedly lifted or moved during the activity, then the storage location should be adjusted or redesigned to bring the materials closer to the work area, decreasing the time spent retrieving them.

To develop a process chart, the activity steps should be accurately recorded and individually timed. Documenting the sequence of activities is key to developing an accurate chart. The simple example shown in **Figure 21** is not representative of the complexity of steps that will likely be in an actual process chart. It is possible that the process will have as many or more than 10 steps. Once the chart is developed, it can be analyzed to find ways to improve the process. For example, to save a little over a minute of time, the materials could be brought closer to the machine. This is a small amount of time within one cycle, but if the process is repeated hundreds of times, it can add up to several hours of saved time. Symbols can also be added to the chart to signify the type of process each step is. Process types are typically categorized into operation, transportation, inspection, delay, and storage. For activities that have a significant amount of steps, sorting them into these categories is useful to see where time is spent.

Typical symbols that are used are circles, triangles, squares, arrows, and other simple shapes. There is no standardized method so a key should be included so that readers understand what the symbols mean. The chart should be developed by placing Time on the horizontal axis and the process steps on the vertical axis. Process steps should be clearly named and identified so that they are easily understood. Time that is spent idly or wastefully should be included in the list of steps so that it can be considered in the final assessment.

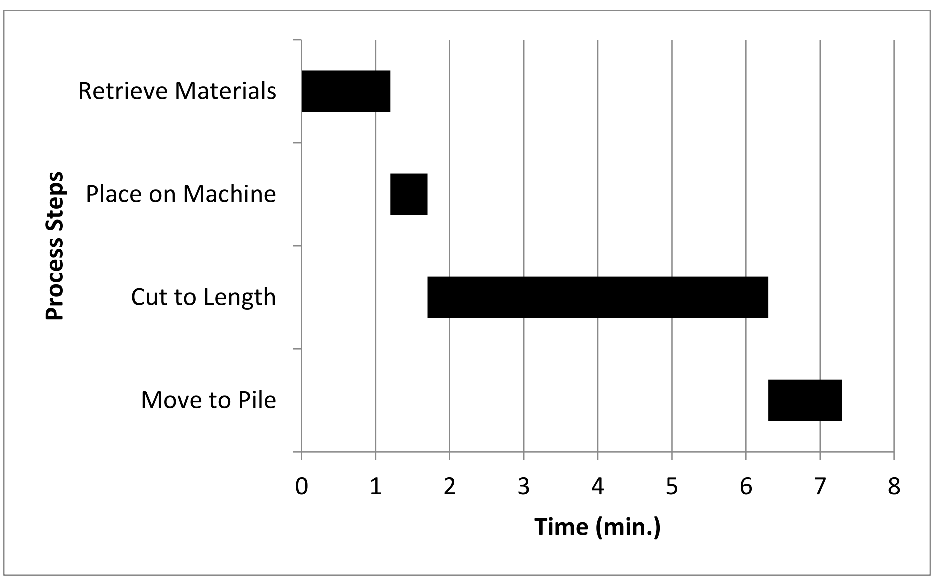

Figure 21. *Example Process Chart*

A labor utilization factor (LUF) is a measure of the effective labor that a worker performs. During an activity, work is grouped into three categories: effective, contributory, and ineffective. Effective work is the actual processes that lead to the creation of an output; for example painting a wall or laying brick. Contributory work is necessary to achieve the output, but it is not directly adding to the output; for instance, crew movement, clean-up, or information sharing. Sometimes it can be difficult to distinguish between effective and contributory work because they both add some sort of value to the final output, but the distinction between the types of work should be made as a best judgment. Ineffective work adds no value to the output, such as rework, double handling materials, or doing nothing. The processes in an activity need to be categorized into these three types in order to calculate the LUF.

Two formulas can be used to calculate the LUF. One formula only considers effective work versus the total work observed, while the other formula considers both effective and contributory work. The full value of contributory work is not included since it does not have a direct impact on the output, and therefore only a quarter of the contributory work will be considered effective labor. These equations can be seen below in equations 9 and 10.

$$LUF = \frac{Effective\ Work}{Total\ Work\ Observed} \tag{9}$$

$$LUF = \frac{Effective\ Work + (0.25\ \times Contributory\ Work)}{Total\ Work\ Observed} \tag{10}$$

The labor utilization factor calculated will vary based upon the crew, their experience and productivity, and the type of work being performed. It is important to consider all aspects of the work because a low LUF may not mean that the work is unproductive. For example, complicated, detailed, or difficult work may have a low LUF because the work may proceed at a slower pace to ensure accuracy and quality. However, LUF can be used to gain an idea of the pace that a crew will complete work which is useful for planning purposes.

Crew balance charts, process charts, and labor utilization factors will be used by the project team to analyze how effective and productive workers are on-site. The team will be able to identify problem areas and labor delaying causes. Then, by using this information, they can address issues and keep work continuing productively by employing the techniques and methods presented in the following section.

D. Management and Planning Tools

With the information gathered through the previous methodologies, the management team is now prepared to implement additional tools to address delay causing issues and improve productivity. The tools that will be used on the project are Last Planner and Pull Planning. These scheduling techniques will help the team to plan, predict, and manage work effectively.

Last Planner is a scheduling technique that takes place at least once a week, at the beginning of the week. The meeting will be held in the Balfour Beatty trailer, and the expected attendees will be subcontractor superintendents, foremen, and the project management team. Last Planner will be used to coordinate work and deliveries each week and to inform all of the project staff of the activities that will be taking place that week. According to the Lean Construction Institute, the following benefits will be gained from implementing Last Planner:

- Master Scheduling
- Make Work Ready Planning
- Weekly Work Planning
- Learning
- Phase “Pull” Planning

Master Scheduling refers to setting milestones, strategizing the schedule, and identifying long-lead items. These activities are not only important when developing the schedule but also to ensure that the schedule can be made with current work progress. This schedule should be updated and reviewed regularly to keep it accurate. In addition, the schedule can be used to coordinate and schedule when long-lead items should be ordered or delivered.

Make Work Ready Planning is a look ahead method to make certain that work will be ready for installation or to identify areas where rework is needed. This can be both prefabricated work, such as column forms or restroom chases, and in-place work, such as brick laying or painting. Make Work Ready Planning identifies the manpower, equipment, and materials that are needed to begin work and verifies when they are in place. It is the final assessment needed to ensure that construction operations are ready to proceed.

Weekly Work Planning is the discussion and coordination of work being conducted that week. It seeks to establish commitments and deadlines and ensure that the work will be completed according to those deadlines. Through this planning, weekly operations can be coordinated to assure proper sequence and workflow of construction activities. Equipment and materials can be organized and allocated for the week and crane operations can be coordinated to avoid overlaps and confusion.

Learning is the information that the project team gains from conducting Last Planner meetings. Gathered information is measure of work completed and work in progress, establishment of deadlines and goals, understanding of what issues may slow construction or have slowed construction, and identification of modifications that can be made to improve the flow of work. This information is invaluable to a project team, and Last Planner creates a constructive setting where it can be gathered freely. This information should be used in tandem with the information gathered with the Data Collection Tools presented earlier. This combined knowledge should give the project team a thorough understanding of the project, any issues present on the site, and methods to address them.

Phase or Pull Planning is technically a separate scheduling technique, but is one that can be implemented easily and to great benefit with Last Planner. Pull Planning examines the schedule in reverse in order to identify key hand-off locations. These are locations where work is "passed" from one subcontractor to the next subcontractor. It is necessary to identify these locations in order to ensure that the work is ready for the next subcontractor. This includes the work being completed, the area being clean and ready, and the preceding subcontractor having left the area. Furthermore, any special site considerations or information that should be passed to next subcontractor should be included in this identification. The hand-off sequences should be identified to both parties so that they can communicate with one another and create a flowing process.

Both Last Planner and Pull Planning will be implemented on this Campus Project in order to realize the aforementioned benefits. The Balfour Beatty project staff will lead the discussion during these meetings and facilitate the flow of information. Subcontractors and superintendents will be expected to communicate effectively, participate in the discussion, and commit to necessary deadlines. Coordination and cooperation is expected by all parties in order to be effective and productive throughout construction.

E. Foreign Artisan Management Techniques

To better manage the foreign artisans on the construction site, it is necessary to understand the typical working practices and the hierarchy that they follow. This knowledge can be used to develop a thorough management plan in terms of safety and productivity. Implementing this plan would allow supervisors to oversee the foreign workers in more effective and better quality conditions. This background on the foreign artisans will examine leadership styles, motivational techniques, and other practices.

In the foreign country, the artisans are typically uneducated workers from farming communities. They are introduced to construction work because it is a growing industry in their country and does not often require prior knowledge to complete. Companies will also provide training courses to new employees, as a requirement of the hiring process. The foreign artisans also come from a predominantly patriarchal society, where men are considered to be the dominant gender. This societal norm could possibly influence their response to different leadership styles.

In their country, the artisans typically follow an authoritarian style of leadership. Workers are accustomed to receiving explicit instruction and direction from their superiors. This could stem from their desire to avoid accepting the responsibility associated with choosing and completing their work; in which case, if they perform inadequately it could be detrimental to their position. Instead, the artisans prefer that their superiors provide them with clear direction and avoid ambiguity when defining their instructions. A democratic style where lower workers are involved in decision-making is rarely seen in the foreign country. Furthermore, as a patriarchal society, the foreign artisans may be unaccustomed to following female leadership. Consideration should be given for the artisans to adjust to the more gender neutral style of the US. On this project, it is in the best interests of the management staff to use a commanding and authoritarian style of leadership when directing the artisans.

The artisans may also have different expectations of the management staff, in regards to working hours and dedication to the project. For instance, the artisans would expect higher staff members to arrive at work before them and leave after them. It is important for the management staff on the project to follow this idea in order to avoid low expectations from the workers they lead. If the perception is that management is dedicating less time to the project than the workers, it could damage the morale of the project and hurt worker productivity. Furthermore, increased knowledge and technical experience is expected of management personnel. In the foreign country, higher ranking personnel are usually promoted based upon their knowledge, rather than age or time spent with a company. Artisans will expect the management team to be knowledgeable and capable in their positions.

Several different motivational techniques can be employed on the project to ensure workers maintain their operation and remain productive. Numerous papers have cited that verbal recognition of an individual's effort and work are greatly appreciated. Periodically, the management team should make every effort to recognize the work efforts of the foreign artisans as individuals, not just as a team. Furthermore, inciting speeches have been noted as an effective means of inspiration. These can be used to increase morale, motivate workers, and inspire higher productivity. Lastly, a clearly defined disciplinary system serves as a strong motivator for the foreign artisans. This action ties into the artisan's desire for clear definition of work responsibilities and expectations. Explaining the disciplinary protocols serves as a means of removing ambiguity and motivating the foreign workforce.

On this Campus Project, the following endeavors and techniques will be used to manage and motivate the foreign artisans. When providing instruction, direction, or general knowledge, the management team will speak clearly and directly, avoiding ambiguity while acting as authoritarian leaders. To follow along these lines, one superintendent will act as the primary contact between the management team and the foreign artisans. That way the artisans will know who to direct their comments and questions towards. Furthermore, management will be expected to arrive 30 minutes prior to the start of construction and stay 30 minutes after construction has ceased. In this way, they will be present for the start and finish of construction and the artisans can see that they are dedicated to the project.

To motivate the foreign artisans, the management team will develop a clear disciplinary system for the project. It will define the consequences for various actions so that there is no confusion for the workforce. These protocols will be explicitly defined to the project crews so they are aware. Furthermore, management will individually recognize workers as possible in order to acknowledge their efforts and boost their morale. All of these measures will be coordinated with the supervisory staff of the foreign artisans.

4.7 Recommendations

In order to effectively manage the workforce on site, the project team should implement a comprehensive and effective Workforce Management Plan. The purpose of this plan is to identify delay causing issues and give the project team the tools to address and solve these issues. It is recommended that the project team gather information using observations, interviews, and questionnaires and then analyze this information using Crew Balance Charts, Process Charts, and Labor Utilization Factors. With this data, the project team can identify problems and can solve those using scheduling techniques such as Last Planner and Pull Planning. Lastly, the project team should implement different techniques to manage and motivate the foreign artisans, such as a clear disciplinary system or individual recognition.

4.8 MAE Requirements

To fulfill the requirements of the MAE Program, coursework from AE 570: Production Management was utilized throughout this analysis. The data collection and analysis tools were discussed in this class in detail, as well as, the scheduling techniques used to correct potential issues on site. This information was invaluable in developing the Workforce Management Plan in this analysis. The knowledge gained in this course helped to build the foundation that the plan was constructed upon.

5.0 Analysis IV: Foreign Worker Safety Plan

5.1 Problem Statement

According to the contract, much of the interior and exterior finishing work must be completed by foreign artisans. This is done to preserve the architectural and cultural integrity of the design and integrate the culture into the construction process. The purpose of this is very understandable as the entire complex is dedicated to cultural and communal growth and organization. However, it does present some challenges and potential difficulties with the typical work practices of the foreign artisans. These artisans do not necessarily follow the same codes, laws, and general procedures in their country that are followed in the United States. Furthermore, it is a safety concern because the artisans may have little to no understanding of English, and therefore will not understand typical warning and hazard scenarios and signs that are used here. It is also a code concern because OSHA can fine the project if the foreign artisans are not following construction laws. With both a linguistic and cultural barrier separating the foreign artisans from the typical workforce, special action may be needed in order to ensure their safety on the jobsite.

5.2 Potential Solution

To address the risk of having an extensive foreign workforce on site, a specific foreign worker safety plan will be developed for the project. This plan will anticipate the unique challenges that this workforce poses to the project team and propose potential solutions to address them. The plan will focus upon safety and how it can be improved despite language and cultural differences. Strategies developed within this plan can be used to anticipate challenges on the site and improve the project's ability to deal with them.

5.3 Analysis Process

Before developing a foreign worker safety plan, a comprehensive study of typical site safety issues and foreign work preferences must be garnered. This data was found within journals, articles, and interviews found both online and in hard copy. Compilation of this research is necessary to have a complete understanding of the culture and the safety challenges it may present. Further research will also be conducted into the common methods of presenting and enforcing safety on site, both in English speaking and non-English speaking methods. These usual methods will be analyzed to determine if they could be beneficially implemented on this Campus Project. Upon completed research, the foreign worker safety plan will be developed for both general cases and the specific case on this site. The research collected will form the foundation of the plan and justify the decisions therein.

5.4 Background Research

On the project, Balfour Beatty required foreign artisans to participate in safety training before they were allowed on site. This involved briefings with safety personnel, facilitated by an interpreter because of the language barrier. This was necessary because the worker's host country does not have the same rules and regulations on construction that are placed here in the United States, specifically OSHA, which is an American organization, one that is not found throughout the world. When the workers are here in the US, they must follow all of OSHA's regulations, potentially requiring some changes in their work behaviors, or else the project could be fined. Furthermore, those regulations are in place to help workers operate in a safe manner. It would be hazardous for the foreign artisans to operate in a way that does not comply with OSHA standards.

Furthermore, foreign artisans do not have the same work practices that we have here. Shop drawings are used extensively in the US for coordination and planning purposes. It is essential to communicate these to the entire team so that other subcontractors can utilize them in their own design and planning. However, in the foreign country, shop drawings are not used frequently or do not have the level of detail that is typical here in the US. This is an actual issue on the project because information on the work completed by foreign artisans is not readily available. Other subcontractors need this information in order to plan their work accordingly. For example, the foreign artisans are to install lead sheet metal roofing on several of the buildings. There is a lack of shop drawings and detailed information on how the sheets are attached, the spacing between them, and other data that would be useful to the other subcontractors working in that area.

There is also a cultural difference between the foreign country and the US that results in differences in holidays, particularly due to the religion of the foreign country, Islam. The Islamic religion includes various holidays that are not federally recognized within the US. However, some of these holidays are very strictly practiced due to the devotion and belief of the Muslim community. These holidays need to be considered within the schedule of the project, with a concern of safety for the foreign artisans. For example, Ramadan, is a holiday that requires Muslims to fast for an entire month, eating and drinking only before sunrise and after sunset. This is a very physically, emotionally, intellectually, and spiritually demanding holiday. Its importance within the Islamic religion is profound, requiring all members of the faith to participate, so consideration should be made for it within the project schedule. During this holiday, foreign artisans will be more prone to injury and illness, particularly because it occurs during the summer. Safety considerations need to be made so that the artisans are not placed in dangerous situations because they will be physically weaker due to the challenge they are placing on their mind, spirit, and body.

5.5 Typical Safety Issues on Site

The construction industry is naturally one of the most dangerous industries in the world. Hazardous situations are created simply by the manner of work, the equipment used, and the risks that are present on site. According to the OSHA records for 2012, there were 3,945 worker fatalities in private industry, 775 of which were in construction. Over half of these deaths are caused by only four types of accidents: falls, being struck by an object, electrocution, or caught in between objects or machinery. Falls alone cause the most fatalities, with 278 deaths due to falls in 2012, over a third of the total fatalities in construction.

More commonly, accidents result in non-fatal injury to workers. Total statistics for these accidents are not typically kept across the industry, but they can number in tens or even hundreds of thousands per year. Individual companies often track this data in order to analyze and improve the safety measures they employ. It is every company's goal to maximize safety and reduce accidents on site to zero. In pursuit of this goal, a company typically will develop a safety program or initiative to be followed at the company or project level. For example, Balfour Beatty US recently developed the Zero Harm program, which is designed to inform their employees that safety is everyone's responsibility and if everyone does their part, eventually they can achieve zero accidents.

Reducing the number of accidents to zero requires prevention of unsafe scenarios, recognition of unsafe conditions or activities on site, and resolution of these unsafe conditions into safe activities. Prevention involves developing a thorough safety plan, conducting training sessions, establishing safety measures on site, ensuring equipment is in sound condition, and using personal protective equipment. Prevention can be very difficult because it is impossible to predict every eventuality. However, it is absolutely necessary and is the best methodology for a company to protect their employees. Recognition of unsafe conditions on site incorporates visual awareness and vigilant reporting by all personnel on the job site. All employees should be encouraged to report unsafe conditions so that they can be resolved before becoming a major hazard or causing an accident. In addition, safety personnel should walk the site frequently in order to maintain a presence and to search for unsafe conditions. Once an unsafe condition or activity has been noticed and reported, it needs to be resolved immediately. Depending on the scenario, this could involve many different solutions. The important thing is to ensure that the solution resolves the issue as permanently as possible so that it does not occur again.

In order to employ these three steps effectively, it is important to be aware of the typical issues that can cause an accident on site. These can be categorized into eight causes:

- Lack of Proper Training
- Deficient Enforcement of Safety
- Lack of Safety Equipment
- Unsafe Methods or Sequencing
- Unsafe Site Conditions
- Improper Use of Safety Equipment
- Poor Attitude Toward Safety
- Isolated Freak Accident

To clarify the meaning of each of these, the table on the following page presents a definition and an example scenario for each. Controlling these causes is not always possible, but an employer can effectively reduce the number of accidents by managing them as best as possible. This will require expertise in construction activities, an understanding of safety methods and requirements, an evaluation of the work and site conditions, an ability to interact with workers, and an ability to manage and control the work site. Managerial personnel will typically have the most influence over these eight causes of accidents. They have the supervisory power, due to their position, to command and organize the operations on site. Nevertheless, it should be stressed that it is every worker's responsibility to follow safety procedures and ensure they have the understanding needed to complete their work safely. It is physically impossible for a supervisor to be present for and monitor every single activity on site. There are simply too many operations and too little time in the day. Therefore, workers should be encouraged and expected to take safety into their own hands and enforce it across the site.

Table 9. *Typical Causes of Accidents on Construction Sites*

	Definition	Example Scenario
Lack of Proper Training	An employee is not properly trained in working procedures.	A worker is allowed to operate on site without undergoing entrance training.
Deficient Enforcement of Safety	Site personnel neglect to correct an unsafe condition, typically management.	A supervisor neglects to inform an employee that their fall restraint system is improperly used.
Lack of Safety Equipment	The proper safety equipment is not available for the employee to use.	A supervisor does not provide the correct safety equipment to an employee.
Unsafe Methods or Sequencing	The typical construction sequence is interrupted, making the task more hazardous.	A carpenter is told to begin framing before excavations have been backfilled.
Unsafe Site Conditions	The site itself is more hazardous than would be typical.	A site is not kept clean – materials and equipment are left scattered around.
Improper Use of Safety Equipment	An employee is given the proper equipment but does not use it or does not know how to use it correctly.	An employee does not attach their fall protection equipment to the proper holding point.
Poor Attitude Toward Safety	An employee does not cooperate with safety for one reason or another.	An employee does not follow safety procedures because they think it will slow their work.
Isolated Freak Accident	An accident occurs randomly through no foreseeable fault or lapse of judgment.	Fall protection equipment fails despite having passed inspection.

The entity that has the most control over these eight causes may vary depending on the project, contract method, site dynamic, and team involvement. Typically, a construction manager or general contractor will have the most control due to their uppermost position as project leadership. Their direction across the site can have a profound impact on the level of safety. Subcontractors also have a strong impact on the safety of construction operations. Not only do their foremen and superintendents monitor and direct work, subcontractor laborers are the employees completing the actual work. They need to be reminded and encouraged to follow proper safety protocols and procedures because they are the ones closest to where accidents can occur.

Owners can also have an effect on the level of safety on the site. Although they will not typically have dealings with field laborers or subcontractors, they can impart a higher culture of safety upon the project team. This can be included within contract requirements or simply stressed at project meetings. All members should buy into and encourage safety in order to create a culture of safety across the site. A strong site safety culture can vastly improve the quality and safety of a construction site.

5.6 Foreign Worker Safety Plan

The following plan is not meant to be all inclusive of the safety protocols that should be enacted on a typical construction site. It is purely focused upon the measures that can be taken to address challenges related to foreign workers, who have either profound differences in working culture or poor English speaking skills. These differences can create dangerous situations, putting workers at risk for injury. In addition, it can make communication very difficult and can put the entire project site at risk of receiving fines from OSHA or other regulatory agencies. The topics covered within this plan are as follows:

A. Training Foreign Workers
B. Interpreters and Translators
C. Teaching English
D. Worker-Management Communication Methods
E. Racism in the Workplace
F. Visual Safety Notification Techniques

The plan is also done in a general sense so that it can apply to any project. Assumptions will be made as needed to explain topics and promote ideas. Naturally, each project will have some unique cases that should be analyzed and addressed by the project team. No situation will be identical and it is the project team's responsibility to anticipate these challenges, understand them and the foreign culture as best as possible, and address them in an appropriate and successful method.

Through the completion of this plan, the reader will be able to successfully develop and implement strategies to address foreign worker safety on their construction site. The methods presented in this plan can be adjusted to specifically meet the needs of that site based upon the nationality and population of foreign workers. The plan will introduce each topic separately, provide potential strategies to address each topic, and explain the benefits that can be expected by implementing the strategies. A summary list of recommendations concludes each section and can be quickly used to narrow down the strategies that may be best suited for a specific site.

A. Training Foreign Workers

The first interaction a worker has with the project is typically in some sort of training environment. Since this is the first contact with the workers, it is very important that this process goes smoothly and effectively. The training program needs to be clear, comprehensive, and in-depth. Clarity is absolutely essential to delivering information effectively. Any confusion in detail will be amplified by the difference in language. Furthermore, it is probably more advantageous to use a different program to train foreign workers than to train other workers on site. More than likely, the program for foreign workers will include more information and detail. It should also be structured differently and proceed at a slower pace so non-English speakers can keep up.

The additional information will cover working practices in the US which may be vastly different from those abroad. Simple operational procedures, such as use of fall protection devices, are commonplace in the US construction industry. However, they may not be as well-known or regulated in other countries. These differences not only create a dangerous, unsafe situation, but also put the site at risk for OSHA violations. It may be necessary to review and teach many working procedures to foreign workers. If it is unknown how familiar a worker is with US construction practices, a simple quiz or dialogue can be used to examine how knowledgeable they are.

The length of the program will depend upon the amount of information that needs to be presented and the work that the foreign workers are completing. The program could last anywhere from one day to over a week. It is the project team's judgment to determine how long the program should be. The length may also vary based upon the position of the foreign workers. A laborer may receive the base level of training that all foreign workers will go through, while an experienced worker may undergo the base training plus additional training that will cover use of equipment and more complex work. Naturally, a supervisor will receive even more in-depth training, due to their managerial and leadership responsibilities that require them to understand all of the work.

The most valuable piece of information that can be garnered from a training session is the English speaking capabilities of the workers. This is not always apparent through observation and may require verbal questions or casual conversation. It is important to keep this calm and relaxed so as not to insult or humiliate the workers, which can damage their morale and hinder their work. Some foreign workers may feel ashamed if they have poor English skills, despite the fact that it is not shameful. In training situations they may remain mostly silent and nod when asked a question, rather than provide a verbal response. Even if they do not understand what is being asked, they are smart enough to know when to nod. Therefore, it is useful to make the training session more interactive in order to engage the workers. It is a great, non-intrusive way of gauging their English skills and determining how much of the training they understand.

With this basic understanding of the language capabilities of the workforce, the project team can determine what further strategies to employ to make the site safer. If a majority of the workforce understands English, then the team can know to focus their efforts on the non-English speakers. Furthermore, if there are any workers that are particularly strong English speakers, they should be used as a conduit for communication with the non-English speakers.

Recommendations

- Develop English speaking training sessions and non-English speaking training sessions and conduct them separately.
- Keep non-English speaking training sessions comprehensive and slow paced so that it covers everything they need to know at a speed they can follow.
- Engage workers throughout the training session either through casual conversation or verbal quizzes in order to gauge their English capabilities and understanding.
- Maintain a casual, informal atmosphere to keep workers at ease and avoid insulting or humiliating them.
- Take note of workers who have strong English skills so that they can be used to assist with communication.
- Use an interpreter to facilitate the training process. (*Note: see next section for more detail.*)

B. Interpreters and Translators

A professional interpreter or translator can provide invaluable support to the project, but it is important to note that there is a difference between their responsibilities. Interpretation is accomplished verbally, while translation is done in writing. An interpreter will be supremely useful in training sessions and on-site direction, while a translator will be beneficial with completing signs, documents, emails, and other written communications. Often times, a single person can be hired to complete both interpretation and translation, but in rare cases they may be separate positions.

In some instances, it may be possible to have the foreign workers complete interpretation and translation duties, provided one of them has strong English skills. This is a particularly useful situation because the worker also has a strong understanding of construction work, which a professional interpreter may lack. However, it is key to remember that these are duties beyond what they are contracted for and that they can be quickly overloaded if there is a significant amount of linguistics responsibilities. If there are no workers with particularly strong English skills, then a professional interpreter and/or translator will be required.

Some projects require an interpreter be provided for a certain amount of workers across the site, usually 4 or 5 workers per interpreter. This requirement becomes counterproductive as the foreign workforce increases in size. It is also an unnecessary requirement if the foreign workforce is managed by their own foremen or other supervisors. In those cases, an interpreter can be employed to provide language assistance with the supervisor, who will then relay instructions to the workers.

Interpreters and translators can provide invaluable assistance to the project if their skills are utilized effectively. If they are hired to assist the project, it must be remembered that they will likely have a limited knowledge of construction. Processes and activities should be explained in simple terms in order to keep the interpretation process easy and fluid. If necessary, the interpreter and translator can be placed through a brief training program to familiarize them with the project and typical construction terminology and scenarios. In extreme cases, the project team could spend time learning the foreign language so as to better manage the foreign workforce. Due to the cost and time needed to learn a language, this would only be recommended if the project has a particularly long duration or unusually large non-English speaking workforce.

Recommendations

- Use the same interpreter who facilitated the training process for other interpretation positions on site so the workers will be familiar with this person.
- Use a translator to complete sign translation and other document translation as needed, if these tasks are not completed by the interpreter.
- Utilize foreign workers with strong English skills to facilitate communication, but avoid overloading them with work because of it.
- If the foreign workers are directed by their own supervisor(s), hire an interpreter(s) to facilitate communication with the supervisor(s).

- If the foreign workers are directed by English speaking supervisors on the project, hire an interpreter(s) to facilitate communication with the workers. Consider hiring one interpreter per 4 to 5 workers for a small workforce, and one interpreter per 8 to 10 workers for a large workforce.
- Train professional interpreters and translators on the project and basic construction terminology, if needed.

C. Teaching English

A good method of increasing safety on-site is to provide English classes to foreign workers. By improving their English capabilities, they will be able to interact with more workers on site and understand more safety cues. If their English becomes strong enough this could remove the need for a professional interpreter. A translator will continue to be needed for the multilingual signs, which should still be used.

The most difficult aspect of holding English teaching classes is motivating workers to attend them. After a long day of laboring out in the cold or heat, the last thing a worker will want to do is spend additional time in a class. Positive encouragement and marketing of the class will be needed to convince workers to attend. The class should be promoted on site both verbally and written. It should also be located somewhere that is convenient for workers to get to, preferably on site. If it requires a twenty to thirty minute drive to get to the class location, worker attendance will drop dramatically. The classes will also need to be provided free of charge. Very few workers will want to attend them if they are required to pay a fee.

A potential way of motivating workers to attend is to provide an incentive for their attendance. This could be recognition of achievement, pay bonuses, food vouchers, or some other reward. If there is a consistent reason for workers to attend then they will be more likely to do so. Therefore, it is imperative to continue promoting the classes throughout project duration. Once the classes are no longer promoted on site, attendance will gradually dwindle away to zero.

Monitoring attendance and progress is key to knowing how each worker will continue to understand English. Some workers may progress very quickly and become marginally fluent through completion of the classes. Keeping these workers motivated to attend can motivate others to attend the classes because they can provide assistance in the classroom. In addition, if they gain strong English skills they can be utilized on site to facilitate communication.

Recommendations

- Provide English classes to workers if the majority has poor English skills.
- Publicize the classes frequently and provide both verbal and written encouragement in order to gain the attention of workers.
- Conduct the classes on the project site or at a very close location so it is easily accessible.
- Provide the classes free of charge to the workers so they are not discouraged by having to pay a fee.
- Motivate workers to attend classes by providing incentives or bonuses of some kind.
- Maintain worker interest by continuing to publicize the classes and by providing incentives.
- Track attendance and progress in order to retain a record of any workers that gain strong English skills.

D. Worker-Management Communication Methods

The development of a successful and effective communication medium between foreign workers and site management is a crucial but difficult task. Obviously the workers and management will be able to speak to one another through the interpreter, but there will naturally be some instances where a different form of communication is more appropriate or is needed because the interpreter is unavailable. It is important to build this medium quickly and to make it clear in the training process that this is available to the workers.

One option to employ is a multiple language hazard reporting system. Most sites will have a way for employees to anonymously report hazardous situations that they witness, such as a hazard card dropbox. It is a great way for the management team to learn more about what is occurring on site, while also bringing the workforce into the safety discussion. To utilize this on a site with non-English speakers, the reporting cards can be posted in multiple languages. Then, all of the workforce, regardless of language, will be able to complete the cards, and no one group will be discouraged from doing so. Sometimes workers, especially foreign, will believe that they can be reprimanded or fired for reporting incidents. It is important to make it clear to them that this is not so, and that reporting of hazards is actually encouraged.

In lieu of an interpreter on site, there are other ways of communication that can be employed. Developing these should be done prior to their usage, probably during training, where they can be thoroughly explained. For instance, a list of simple commands could be prepared to be used when necessary. Obviously, these will not be able to communicate full ideas, but they can be applied in serious situations or where sudden changes in work are necessary, such as emergency stoppages. Along those lines of communication, hand signals are also another option. These would be similar to those signals used by picking crews and crane operators. It is a simple form of communication that can be universally applied across many languages. Any of these methods and many more can and should be used to present an alternate avenue of communication between workers and management.

Recommendations

- Inform foreign workers of all communication methods that be used to directly or indirectly speak with management personnel.
- Utilize a multilingual hazard reporting system to encourage the workforce, both English non-English speaking, to report unsafe or hazardous conditions.
- Ensure foreign workers understand that hazard reporting will not endanger their position on the project and is actually encouraged.
- Train all workers in simple verbal or hand commands to have a basic means of communication if an interpreter is unable. At the least, these commands should involve safety scenarios and cues.

E. Racism in the Workplace

One of the most morale damaging aspects of a multicultural workforce is racism. It is sad that racism still exists today, but it is a challenge that is dealt with all too frequently. On construction sites with different nationalities it can be quite prevalent. Often times it will not be outright in the open or verbal. Rather it can be found in the dialogues that take place in bathroom stalls or other locations. It is important to remove and repel this racism proactively so that it does not create a division between workers, which can have detrimental effects on site relations and productivity.

The best way to remove racism is to attempt to prevent it from ever happening. This can be quite challenging but can be accomplished with early efforts. During training sessions for all workers, foreign and domestic, it should be stressed that racism will not be tolerated in any form. Furthermore, it should be addressed that racism could result in a worker's temporary or permanent removal from the job site. Clearly stating the consequences of such demeaning actions is necessary to help discourage its practice. Ideally, taking these steps would be unnecessary, but they should be followed just in case.

Another form of prevention is to promote interracial bonding between workers. This can be effectively accomplished through bonding programs or scheduled activities outside of work. Some contractors found success by scheduling sporting events outside of work that encouraged interaction between foreign and American workers. Activities could also be social gatherings at clubs, restaurants, bars, or other recreational locations. These activities will promote site unity and build camaraderie through a mutual cultural understanding.

Recommendations

- Incorporate a zero-tolerance policy on racism into training sessions to inform workers that is not allowed in the workplace.
- Establish and communicate disciplinary actions that will result if racism is discovered on site.
- Proactively review the site and its conditions for any racist graffiti or conduct.
- Schedule interracial bonding events, such as sports games or happy hours, which will promote site unity and closeness.

F. Visual Safety Notification Techniques

When language barriers are present on site, there are a number of other techniques that can be employed to present visual safety information. These methods can be understood by anyone and do not require good English skills. Four usable methods that will be described are site signage, colored hard-hats, two card systems, and Talk-Sign. It is the project team's discretion to select which methods to utilize, however, signage and colored hard-hats are strongly recommended.

Safety culture should be augmented by thorough and appropriate signage across the site. This is typically provided by the construction manager or general contractor and should be posted throughout the site as applicable. Signage can come in many forms, but some typical are:

- Signs directing traffic or pedestrians
- Signs highlighting dangerous or hazardous areas
- Signs visualizing safety gear required on site
- Signs promoting safety culture or ranking safety performance on site
- Signs that report inspection and approval dates (used for scaffolding, ladders, etc.)

There are many other kinds of signage that can be used, many of which will be unique to the site. Signs should always be posted in English or the dominant language on site. They should also be posted in the second most prevalent language to accommodate non-English speakers. Some construction sites will have situations where there are a higher number of non-English speakers on site who have few, if any, common languages. For example, an international project could use English as the dominant language on site, and have secondary languages of Spanish, German, Polish, and Romanian. Providing signage in all of these languages is not feasible because it would create an overabundance of signage that would discourage workers from actually reading it. In this situation, it is probably best to only provide signage in English, unless one of the secondary languages is used by a portion of the workforce that is significantly larger than the other languages. There are other ways to address multiple language situations like this, such as Talk-Sign, which will be discussed later. Below, **Figure 22,** is an example of the more common situation of providing signage in two languages: English and Polish.

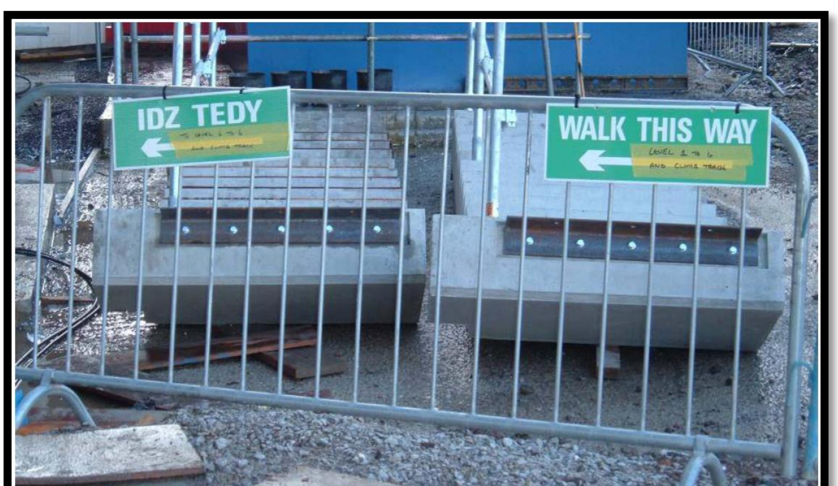

Figure 22. *Polish and English Signage*

Another simple method of communicating information is by using colored hard-hats to signify the managerial position of employees on site. Different colors can be used to distinguish between superintendents, foremen, field engineers, and laborers. The color choice is left up to the project team, but typically yellow, orange, or blue signify lower ranking employees, while red, black, and white signify upper ranking employees. This practice can be difficult to employ because most subcontractors and their employees already have hard hats. It may require special effort by the construction manager or general contractor to purchase the hard hats for the project and require the workers to utilize them. In any case, this is an easy method of communicating to workers the ranking of people on site, so they would have a better idea of who to approach with questions or concerns.

Additional information can also be posted on hard hats. For example, the flag of the country of the worker's origin, or, more usefully, the flag of the language that they are fluent can be posted on the hard hat. If the worker is English speaking then a clear American flag should be posted. If the worker is non-English speaking then an American flag crossed out by a black X should be posted. This technique will easily communicate the language capabilities of workers. However, it is important to be careful that this does not create too much clutter on the hard-hat if other types of symbols are communicated on the hat.

A two-card system is a way of communicating discipline universally across cultures. It utilizes a yellow card and a red card, the two cards used in soccer. Since soccer is a sport played across the world, it is believed that everyone would understand the meaning of the two cards. A yellow card is given to a worker as a warning for following some sort of minor unsafe behavior or indiscretion. A red card is given for a major violation and results in the workers immediate dismissal from the site. Through this system, the disciplinary actions taken for unsafe or inappropriate actions on site are clearly defined and understood by all workers. This is a beneficial strategy to employ because foreign workers often prefer a clearly defined disciplinary system.

The fourth method, Talk-Sign, is a less commonly used practice, but has potential benefits worth exploring. The Talk-Sign is an automated device that allows a worker to press a button and hear different safety regulations or messages in whatever language they choose. Talk-Sign lets the worker quickly and easily hear safety tips while out in the field, without having to ask or have an interpreter. The downside of this system is that the loud audio of the sign may discourage workers from using it because they may be embarrassed about having to use it. This was the case on one project site where the system was rarely touched. Nevertheless, the system could prove particularly useful on sites where many different languages are spoken. The image below shows a Talk-Sign with six different language options, providing great user flexibility.

Figure 23. *Talk-Sign*

It is up to the project team to discern what methods should be employed to visually communicate safety for foreign workers on site. Other methods can also be utilized so long as they provide an easy means of communication with workers, regardless of language capabilities. At a minimum, it is strongly recommended that site signage in multiple languages and a colored hard-hat system be employed.

Recommendations

- Establish visual communication systems and explain these to workers so they are aware of their presence on site.
- Provide site signage in English and in a secondary language as much as possible. Avoid creating too much signage which that could clutter the site and discourage workers from reading the signs.
- If there are multiple secondary languages on site, provide signage in only English so as not to discriminate against other languages. Provide English classes, interpretation, Talk-Sign, or other methods to create avenues of communication in the other languages.
- Develop a colored hard-hat system to signify the managerial position of workers on site. Explain this system in detail to workers so they fully understand and know who to approach with site issues.
- Utilize a two-card system, if desired, to easily represent a disciplinary system to the workforce. This is worth employing for foreign workers who desire a clear set of site rules.
- Install a Talk-Sign on site if there are a high number of secondary languages. Carefully choose the location of the Sign so the loud audio is not seen as intrusive to the site.

5.7 Site Specific Recommendations

Not all of the presented methodologies and strategies are applicable to this Campus Project. Although many of them can be very beneficial, the specifics and uniqueness of the project need to be taken into consideration when selecting strategies to employ. Through this assessment, the following tactics will be used on the project.

A. Training Foreign Artisans

A full training course will be developed to train the foreign artisans on safety procedures, safe equipment use, and general construction practices. The artisans will need to use scaffolding and fall protection devices for work well above grade so operational procedures on these measures will be reviewed. A professional interpreter will be used to facilitate the training sessions and communicate with the artisans. The interpreter will receive a brief introduction to the project and typical construction terminology so they can better communicate with the artisans.

The training course will also be used as an opportunity to record the English capabilities of each artisan. If there are any artisans with strong English skills, they will be recognized and used to assist with communication in the field. The course will be held on site in Balfour Beatty's operational trailer. It will be held for a minimum of one week, but may be extended if it is necessary to communicate additional information. Artisans will be paid for attending the training sessions.

B. Interpreters and Translators

As stated previously, a professional interpreter will be hired to facilitate the training sessions given to the foreign artisans. In addition, one or two interpreters will be hired to assist with on-site communication. The interpreters will enable communication with the foremen and supervisors of the foreign artisan crews. If there artisans with strong English skills, they may be asked to assist with interpretation duties. However, this will be avoided if at all possible so that the artisans can focus on the construction work they are tasked to complete.

A translator will be hired to translate the signage that will be posted across the site. All signage must be posted in both English and the foreign language. If an area is deemed to be congested with signage, it will be considered on a case by case basis by the project team. Project leaders may allow changes to this protocol in an effort to reduce sign congestion only. The translator will also be responsible for translating contract documents, working drawings, standard safety material, and site protocol documents. These will be disseminated to the foreign artisans as necessary. Periodically, the translator will be asked to translate hazard reporting or comment cards that the artisans submit to management.

C. Teaching English

English classes will be offered to foreign artisans during the first month that they are on site for construction. They will be held twice a week in Balfour Beatty's trailer immediately after the work day to make them more convenient. The classes will be offered free of charge to workers, who will be provided food and drink at each session. Attendance and progress will be tracked at each session so that the workers who show the greatest progress can be awarded an incentive prize, such as a gift card to a local restaurant. The classes will be publicized through announcements and posters on site. The foreign superintendents will be asked to encourage their workers to attend the classes. If sufficient interest is maintained at the classes at the end of the month, the project team may elect to extend these classes further.

D. Worker-Management Communication Methods

A bilingual hazard reporting system will be used on site to allow workers to report situations that they felt were hazardous in nature. Dropboxes will be available for these submissions at the trailers and at a remote location close to the jobsite. The reporting cards will be available in both English and the foreign language to accommodate all workers on site. Furthermore, an additional dropbox will be located at the trailers that will allow workers to submit concerns or queries that are not safety related. These will also be provided in English and in the foreign language and will be a method to allow workers to anonymously submit any concerns or questions that they may have. During the training programs, workers will be encouraged to enter the site trailers at any time with any questions. An open and welcoming site will be promoted.

E. Racism in the Workplace

During the training programs for all workers, foreign and domestic, it will be stressed that racism will not be tolerated on site. The site will be an equal opportunity locale that does not discriminate against anyone regardless of their race, color, or beliefs. Workers will be encouraged to notify management if they witness or are victim to any form of racism or discriminatory practice. They will also be required to sign a contract stating that they will not engage in any acts that may be construed as racist or discriminatory. The disciplinary actions that will be carried out if a worker is found guilty of racial or discriminatory acts are:

- 1st Offense – Immediate dismissal from the site for the day of incident. Mandatory session with management to review conduct and reaffirm nondiscriminatory working practices.
- 2nd Offense – Immediate dismissal from the site for the day of incident plus three work days.
- 3rd Offense – Immediate dismissal from the site permanently.

If it is found that workers employed by the same subcontractor consistently have issues with this policy, Balfour Beatty staff will meet with the superintendents of that subcontractor to discuss the situation. In addition, if a worker is dismissed due to racial or discriminatory practice, the employer of that worker will be held liable to complete their full workload, regardless of losing a member of their workforce.

In an effort to prevent these situations from arising on site, several bonding events will be scheduled to increase domestic worker and foreign artisan interaction. A minimum of two happy hours will be scheduled outside of work hours to promote bonding in a casual environment. A cultural sharing day will be organized to introduce American workers to the culture of the foreign artisans. The goal is to further their understanding of the work they are completing and how it is culturally important to the artisans.

F. Visual Safety Notification Techniques

As stated previously, all signage on site will be provided in both English and the foreign language. In addition, a colored hart-hat system will be utilized to show management seniority on site. The colors of the hats will correspond in the following way:

- Balfour Beatty Personnel – White
- Project Managers – Black
- Superintendents and Foremen – Red
- General Workers – Blue, Orange, Yellow

General workers will utilize blue, orange, and yellow hard-hats but will be separated by subcontractor, so an entire subcontractor workforce has the same color. This color system will help distinguish seniority on site so that workers will know who they can approach with concerns. Furthermore, Balfour Beatty's safety manager will wear a white hard-hat with red stripes to further distinguish their presence.

A touch screen safety notification system will also be employed adjacent to the hazard reporting dropbox located at the site. This screen will allow workers to interactively learn about the specific safety concerns for each day. This information will be offered in English and the foreign language, will be updated daily, and will include tips on how to remain safe throughout the day's activities. This screen will be a benefit to both workers and management personnel who can learn more about the task being completed each day.

5.8 Politics and the Media

An additional consideration that often needs to be made on projects with foreign workers is the perception of the project to the public and the media. The public can often misunderstand the situations or requirements on a project. For example, if a large number of foreign workers are brought in to work on the project, the public may react negatively because they believe the project should hire Americans. Even if the project has specific requirements for foreign workers, the public or media may not know this and could view the hiring of foreign workers as discriminatory.

Clark Construction faced this issue during construction of the Smithsonian's National Museum of African American History and Culture. The project required that a percentage of the workers be of African American descent and a percentage of the contractors hired to the project be owned by African Americans. Clark held open forums to meet contractors and had an open hiring booth on site for anyone to submit applications. Through these techniques they were able to meet and exceed the percentages expected for the project. However, the public for some reason or another thought that Clark was not hiring enough local workers and picketed the project site. Clark received negative media attention and eventually had to meet with political officials to resolve the issue.

The situation was ultimately settled once Clark provided documentation to prove they were meeting the project expectations and hiring local workers. However, the situation did become tense because of the media attention and public perception of the project. Clark did nothing wrong on the project, but the media and public misunderstand what was occurring on the project.

It isn't possible to predict how the public or media will perceive the project, but it is possible to develop a reactionary plan of action. Media situations need to be handled very carefully and by a person with public relations experience. Immediate and careful action should be taken to ensure that the situation does not get out of hand. Negative press can have costly effects on both the project and the company image, even if the press isn't true.

5.9 Recommendation

It is recommended to implement the Site Specific Recommendations for foreign artisan safety on the project. These measures can be used to improve dynamics on the site, facilitate communication between management and the foreign workers, and improve the safety culture developed on site. Furthermore, consideration for the way the media or public will perceive the project should be made. Due to the high number of foreign workers that will be brought on site, they may see this as discriminatory hiring practices, although it is a requirement on the project.

6.0 Breadth 2: Rainwater Reuse System

6.1 Problem Statement

The landscape of this Campus Project site features an extensive amount of plantings that require irrigation and water to function. The majority of the site is covered in grass, trees, or other shrubbery for aesthetic appeal. There is also an Islamic garden between the Mosque and the Turkish Bath that will require specific water application. Lastly, there are two fountains that will require water control: one between the Fellowship Hall and the Mosque and the other in the Mosque courtyard. These water requirements will increase the water usage of the completed project and increase the cost expended on utilities.

6.2 Potential Solution

A rainwater and irrigation system could be installed to store rainwater and distribute it across the site for the purposes of irrigation. This system could decrease the utility cost of bringing water to the site to use for irrigation. Furthermore, since the system will use the stormwater already collected on site, it could eliminate the fee for directing stormwater to the utility service. The water will be used on site and will not need to be added to the utility stormwater system.

6.3 Analysis Process

The current stormwater management system installed on site will be researched and analyzed based upon the project drawings and specifications. This information will be used to assess the viability of implementing a rainwater reuse system and also to determine how this system could integrate with the stormwater management system. Then, the rainwater system will be sized appropriately to meet the demands of the project and the availability of collected precipitation.

6.4 Background Research

The total size of the project site is about 337,000 square feet. Of this, approximately 57,000 square feet comprises building footprint and 86,000 square feet comprises hardscaping, such as pavement and sidewalk. This leaves approximately 194,000 square feet of landscape, primarily grass. This landscape will require irrigation and other watering techniques in order to thrive and grow.

Technically, not all of the 194,000 square feet is fully permeable. Because of the underground Parking Garage which has a footprint of 248,000 square feet, only 89,000 square feet is fully permeable. The rest of the area is topsoil on top of the Parking Garage, which has a non-permeable, concrete elevated deck. However, the elevated deck of the garage is sloped and covered with a rubberized asphalt water membrane in order to drain water to the edges of the elevated deck. It is collected by a network of perforated PVC pipe set in stone beds, which carry the water to one of three underground stormwater management facilities. The facilities are located at the west, east, and north ends of the site as shown in **Figure 22.** The facilities distribute the water into the utility stormwater lines in a controlled way.

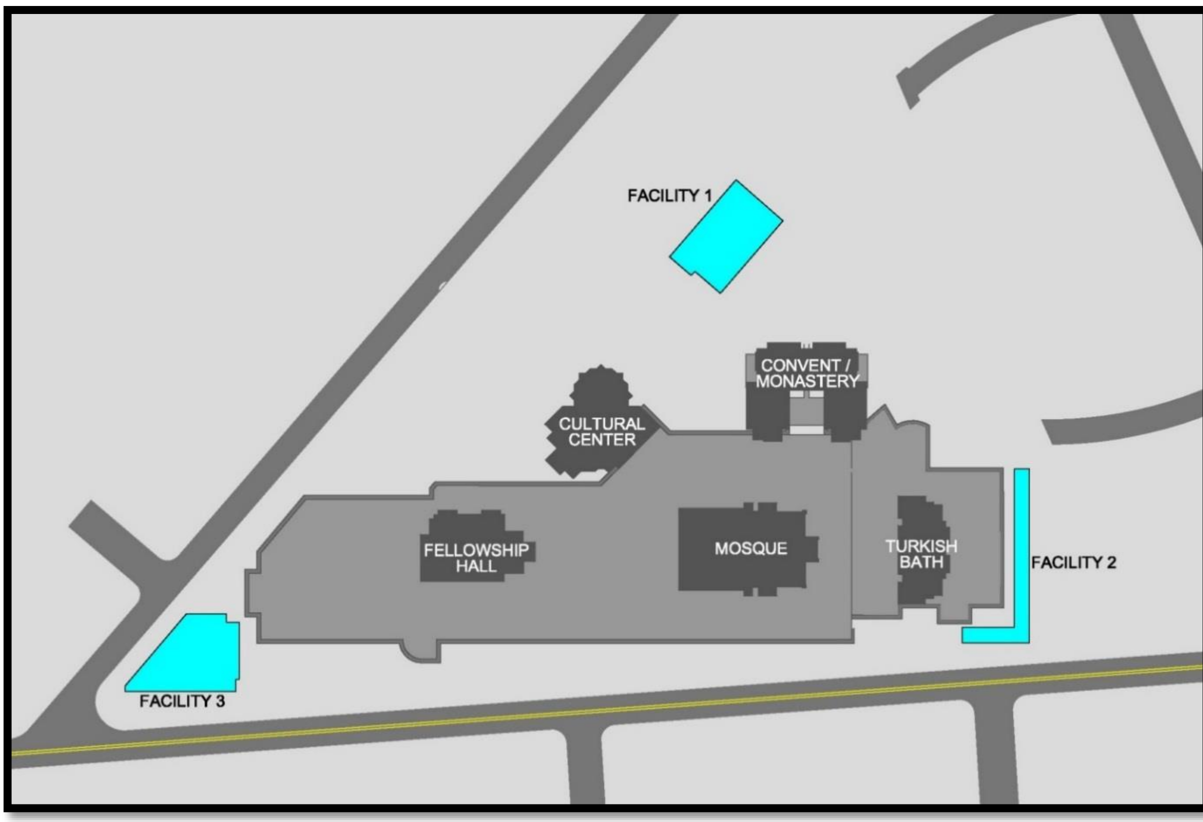

Figure 22. *Underground Stormwater Management Facilities*

The geographic location of the project receives approximately 42.30 inches of precipitation per year. The topsoil used on site is a mix of sand, clay, and silt, and has moderate draining capabilities. The climate of the area experiences an annual average temperature of 54.9°F and an annual average humidity of 73.14%. Using this information, the EPA's National Stormwater Calculator was used to analyze the rainfall and runoff that the site may annually experience. It can be expected that 70 days each year will have enough rainfall to be retained by a stormwater system. Varying upon the precipitation level, the site could retain up to 3 inches during a single period, but it is more typical to receive 0.5 to 1.5 inches.

6.5 Rainwater Reuse System and Requirements

Rainwater reuse systems are relatively simple in design. First, the water is collected through various methods, then is filtered and purified for storage, and finally is pumped to the irrigation system. The filtering and purifying systems needed are dependent on what the water will be used for. On this Campus Project, the water will be used for non-food crop irrigation and for the landscape fountains. As a minimum, the EPA recommends sedimentation as the primary treatment and biological, oxidation, and disinfection as the secondary treatment.

State regulations were also examined to determine if there were further requirements that needed to be met. Within this code, the water use was considered a slow-rate system, or a system where the water is used for irrigation with the consideration that it will eventually reach the ground water table. The recommended state treatment options were a 5 day biochemical treatment and a suspended solids removal process. The state code recommended considering additional processes depending upon the site specific case. Some other requirements that need to be considered are the depth and type of soil and other buffers around the site. These requirements are met by the designed conditions of the site, particularly since the majority of any water that is runoff from irrigation will be recirculated into the rain water system.

6.6 Benefits of a Rainwater System

The obvious benefit of using a rainwater system is to the environment through conservation of water. Naturally occurring rainwater is used to irrigate the site rather than use utility fed water. Furthermore, the continuous flow of irrigation will be better for the landscape's growth and health. The water used for irrigation will contain more nutrients and minerals than utility water because it will pass through the ground taking these minerals with it as it flows. A rainwater system also diminishes the demand on the utility stormwater system because the water is now used on site.

Cost benefits can be found from implementing this system in two ways. One, the water utility bill will be lowered because utility water that would be used to irrigate the site and fill the fountains will now be replaced by rainwater. Two, tax refunds and environmental refunds can be achieved for implementing stormwater control systems. The state tax that would normally apply to the site for using the utility stormwater system can be reduced or eliminated because the stormwater will be managed inclusively on site. The county government website for the site location states that the site "can get up to a 100% credit for doing remediation projects on their own property." In other words, the tax reduction or credit is directly related to the reduction in stormwater utility service provided to the site. If the rainwater system employed successfully utilizes all of the stormwater for on-site purposes, then the utility stormwater service will not be needed and the tax should be reduced to zero.

An on-site water reuse system such as this is also a great conversation piece. The owner of the project can be proud of their environmental achievements and talk about this system to visitors of this Campus Project. The landscaping on the project is an aesthetically beautiful part of the site, and maintaining it in an environmentally friendly way is a great sustainable accomplishment.

6.7 Designing the System

Since a robust stormwater management and collection system is already designed for the site, simply the storage and distribution services to the irrigation system will be designed. The storage tanks and pumps will be placed within the underground stormwater management facilities as necessary.

First, it is necessary to calculate the volume of water that will pass through the stormwater facilities during a typical period of rainfall. Based upon a typical rainfall of 0.5 to 1.5 inches of precipitation during a single period, the stormwater facilities could receive approximately 315,000 gallons of water in total, or 105,000 gallons each. This value was validated by calculating the minimum pipe diameter required for this volume of water. By using an online calculator developed by Washington State University, the minimum pipe diameter required is 2.5”. This size is within the actual size of the perforated PVC pipes used to process site stormwater which have a diameter of 4”.

Next, the volume of water needed for site irrigation should be calculated. This was found by using a calculation provided by Jess Stryker of Irrigation Tutorials. The calculation is based upon climate data for the area and site specific data. Equation 11 is used to complete this calculation. Eto is the water needed for irrigation based upon historic data for the area. PF is the plant factor, which is based upon the type of plants used on site and their need for water. A value of 0.85 will be used because a mix of grass, shrubs, and tress are used on site, with varying levels of water requirement. SF is the square feet of area that requires irrigation; this value is 194,000 square feet as discussed previously. IE is the irrigation efficiency, which will have a value of 0.8 because water used for irrigation will be collected and reentered into the system.

$$Gallons\ of\ Water\ per\ Day = \frac{Eto \times PF \times SF \times 0.62}{IE} \tag{11}$$

$$Gallons\ of\ Water\ per\ Day = \frac{0.4 \times 0.85 \times 194{,}000 \times 0.62}{0.8}$$

$$Gallons\ of\ Water\ per\ Day = 51{,}000\ gallons\ per\ day$$

The storage tanks placed in the stormwater facilities can now be sized based upon the gathered information. Each facility will experience approximately 105,000 gallons of stormwater per rain period and will use 17,000 gallons per day for irrigation, for a total of 51,000 gallons per day. The tank will need to be large enough to hold at least 105,000 gallons, preferably more in case there is a significant amount of precipitation. The largest capacity option would be an above ground prestressed concrete storage tank. However, these are exceedingly expensive and have a very large profile. The second largest capacity would be an above ground steel storage tank, but these have a large profile. Underground options exist but have a smaller capacity and several would be needed on site to have the necessary storage capacity. The cheapest option would be a fabric pillow storage tank, but these take up a large area of space. The figures below show pictures of these different options.

Figure 24. *Underground Steel Tank*

Figure 25. *Above Ground Steel Tank*

Figure 26. *Prestressed Concrete Tank*

Figure 27. *Fabric Pillow Tank*

Two options will be selected to give the owner the option to choose the one that is most appealing. Option 1 is three above ground steel storage tanks, each with a capacity of 200,000 gallons. Each facility will have one storage tank that will be placed as far from the buildings as possible and will be concealed with foliage, if at all possible, to minimize the architectural intrusion of the tanks. Each tank will measure 32’10” in diameter and 41’8” in height. Option 2 is twelve underground steel storage tanks, each with a capacity of 50,000 gallons. Placed underground, these tanks will be unobtrusive to the site but they will require additional cost for excavation, and extensive space, as each measure 12’6” in diameter and 54’6” in length.

Through these options a total of 600,000 gallons of water can then be stored within all three stormwater facilities. This is approximately equal to 2.85” of rainfall across the site. According to historical data, monthly rainfall for the site area ranges from 2.8 to 4.4 inches. These storage tanks should be of adequate size because it is unlikely that there will be period of severe rain that will total more than 2.85”.

The next step in the process requires sizing the pump that will direct water from the storage tank to the irrigation system. Prior to sizing the pump the following items must be known or assumed: pump type, irrigation method, foot head or water pressure, and gallons per minute (GPM).

The main types of pumps are displacement and centrifugal. Displacement pumps operate by forcing water to move through displacement. They are not typically used for irrigation, and were not researched further.

Centrifugal pumps come in different forms, but generally operate by using an impeller to rapidly spin the water through the pump using centrifugal force. An end-suction centrifugal pump was selected because it is commonly used for irrigation, can withstand high water pressure, and can deliver sufficient GPM.

The most common methods of irrigation are by drip or sprinkler. Drip irrigation is the most effective method because the highest percentage of water reaches the plants as possible, but it is more commonly used for food producing crops and is not appropriate for the site. Sprinkler irrigation comes in two forms: spray type and rotor type. Spray type sprinklers are stationary and deliver water in a steady fan shape. Rotor type sprinklers deliver streams of water as the head rotates. Since the stream produced by rotor types can cover larger areas, it is assumed that they will be employed on the site. Based upon information from Irrigation Tutorials, this means that a minimum of 104 feet head or 45 PSI is needed to use rotor type sprinklers.

Furthermore, the height that the water must be pumped vertically and the dynamic water height need to be considered. The dynamic water height is the typical distance from the water level to the top of the tank while the pump is running. To oversize the system, the height will assume that the storage tank is near empty when the pump is running. If Option 1 is selected, then the vertical height that the water must be pumped will be zero and the dynamic water height will be assumed to be 33', where 33' is measured to the eaves and does not include the roof. By adding the values for rotor type sprinklers, this totals 137 feet head or 60 psi. If Option 2 is selected, it can be assumed that the water must be pumped 10 feet vertically from the bottom of the facility to the ground level. This value is assumed because there is not detailed information on the dimensions of the underground stormwater facilities. The dynamic water height will be assumed to be 12'6". This yields a total foot head of 126.5 feet or 55 psi.

The rate that water must be sent to the sprinklers can be generally estimated. For every acre of grass on site, 20 GPM of water are needed. The irrigated area on site is 198,000 square feet, or 4.55 acres. This means approximately 91 GPM is needed within the system.

Now that all of the information has been gathered, the pump can be sized using the pump curve shown in **Figure 28.** To use this chart, the line begins from the Head-Ft or y-axis and proceeds right until it intersects the line corresponding to the required GPM. Then, the line proceeds directly upward to the intersecting Diameter and HP line. Option 1 and Option 2 have been graphically demonstrated in blue and red, respectively. According to the chart, both options will require a 5 HP pump with a 6" diameter impeller.

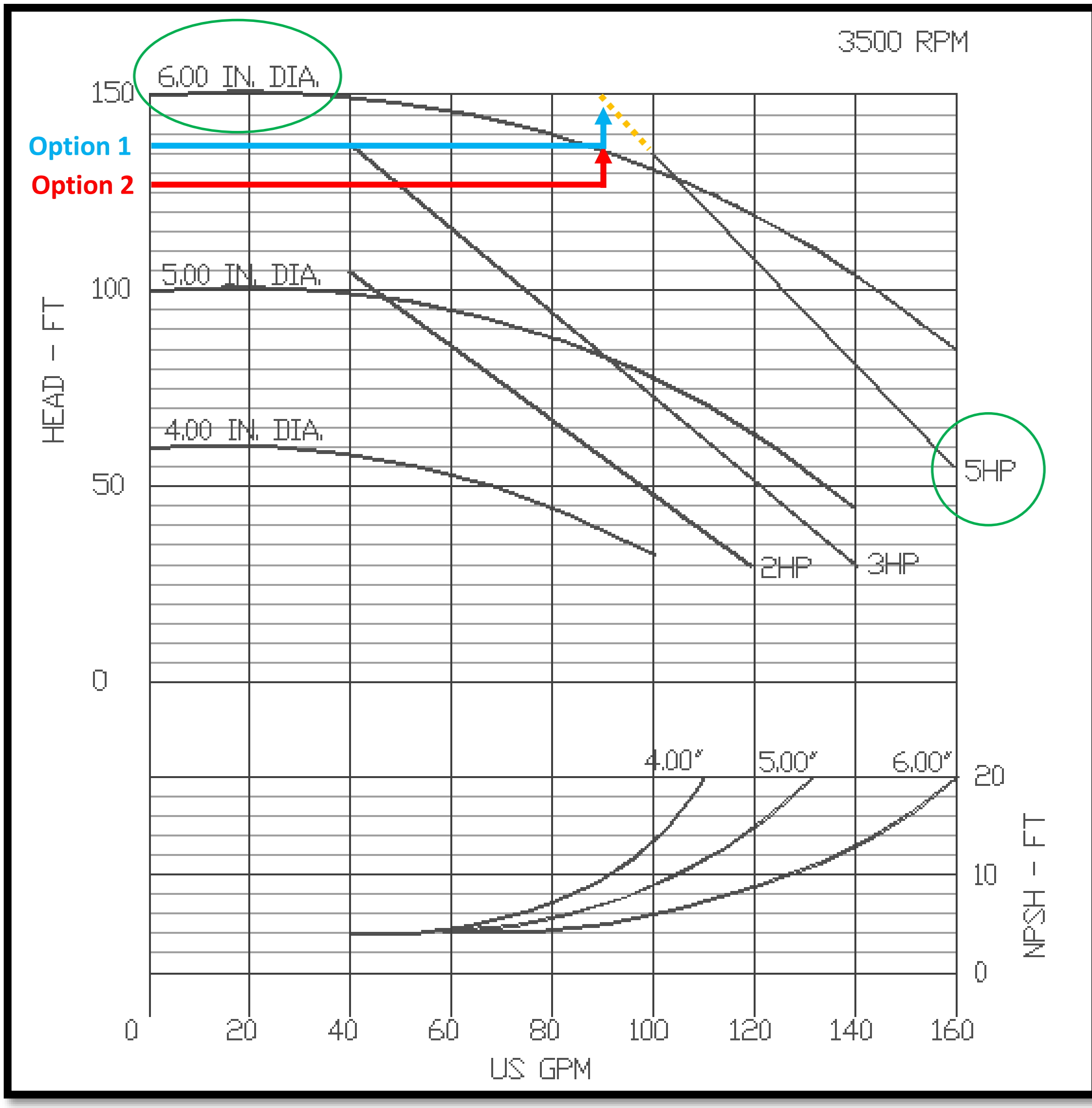

Figure 28. *Centrifugal Pump Curve*

6.8 Cost Benefits

As stated previously, the cost benefits that can be achieved from a rainwater reuse system come from a decreased water utility bill and as tax refunds and exemptions. An analysis was conducted to determine what the cost to the project would be if this system was not implemented, based upon the utility charges and meteorological data of the area. If the rainwater system was not used to irrigate the site, it can be assumed that the water utility service would be used to provide site irrigation. This would mean that the project would use 51,000 gallons of water per day from utility service to irrigate the site. At a charge of $6.76 per 1,000 gallons, that is a total of $345 per day. Assuming that irrigation would be conducted from spring to fall, it can be assumed that watering would occur 180 days per year. Taking away the days that it rains and irrigation is not needed, this leaves approximately 145 days. At $345 per day, this is a total water utility bill of $50,000 per year for irrigation, which would be alleviated by the rainwater reuse system.

Furthermore, there would be a significant stormwater utility bill if the rainwater reuse system was not implemented. With 42.3” of precipitation falling upon the site each year, this adds up to a total of 8,826,000 gallons of water per year. If this is collected by the stormwater facilities and directed into the utility stormwater service, then the site would be charged for this action. At a rate of $10.29 per 1,000 gallons, this is a total of about $90,000 per year. In addition, the site can receive rebates or tax reimbursements for managing the stormwater on site. At the minimum, the site will earn a $2,000 rebate each year for collecting the stormwater. Further environmental steps can be implemented to earn up to $20,000 in rebates but would require additional expenditure.

By implementing a rainwater reuse system, the site will receive a total of $142,000 per year in cost reductions. This is a substantial cost savings and is needed to calculate the payback period of the system. According to RS Means, above ground 200,000 gallon steel tanks will cost $295,900 each. The underground 50,000 gallon steel tanks will cost about $180,000 each. Also from RS Means, a rainwater grit removal filter will cost $42,780 each and a biological treatment system will cost approximately $50,000 each. Lastly, based upon online research, a 5 HP pump will cost between $2,500 and $3,000. With these values, Option 1 will have a total cost of $896,700 and Option 2 will have a total cost of $2,169,000, as summarized in **Table 11**.

Table 11. *Cost of Rainwater Reuse Systems*

		Option 1		Option 2	
Item	**Individual Cost**	**#**	**Cost**	**#**	**Cost**
200,000 Gallon Tank	$295,900	3	$887,700	-	-
50,000 Gallon Tank	$180,000	-	-	12	$2,160,000
Grit Removal Filter	$42,780	1	$42,780	1	$42,780
Biological Treatment System	$50,000	1	$50,000	1	$50,000
5 HP Pump	$3,000	3	$9,000	3	$9,000
Total			**$989,480**		**$2,261,780**

With a payback of $142,000 per day, the systems will be paid back in 7.0 years for Option 1 and 15.9 years for Option 2.

6.9 Recommendations

Based upon the cost of the systems and the payback periods, Option 2 is not recommended. The payback period is too long to be a viable option for the high upfront cost. On the other hand, Option 1 remains a viable option because of the significantly lower cost and the relatively short payback period. So long as the owner is accepting of the large profile of the storage tanks, it is a viable system to utilize.

7.0 Final Recommendations

Throughout the 2013/2014 academic year, this Campus Project was initiated in an effort to identify areas that could benefit from an alternative solution, primarily in construction. Through interviews and independent research, four major items were chosen for additional analysis. The purpose of this thesis and the analyses inside were completed for educational purposes only, and are not meant to reflect poorly on the project team in any way. The recommendations given were not implemented on the project but are given as options that could have potentially benefited the project.

Analysis I: Structural Redesign

The first analysis sought to take advantage of the high prevalence of cast-in-place (CIP) concrete structures on site. Of the five buildings, only two were built with a predominantly steel structure. These buildings, the Fellowship Hall and Convent/Monastery, were redesigned with a CIP concrete structure to take advantage of worker affinity to CIP concrete. For the Fellowship Hall, the cost and schedule were both increased by $2,005 and 80 days respectively. Similarly, the statistics for the Convent/Monastery increased by $252,129 and 945 days, respectively. Because of these implications and negative impacts to the architecture, it is not recommended to alter the structure of the Convent/Monastery, but it is recommended to explore a CIP concrete structure for the Fellowship Hall. If the effects to the schedule can be minimized then redesigning the structure may be beneficial to the project.

Analysis II: Restructure of Concrete Bid Package

Further research was conducted into the size and scope of the concrete bid package for the project. CIP concrete was the most used structural element of the project, constituting a significant portion of the total project cost. Furthermore, a number of complex shapes and designs make up the forms of construction, primarily on the Mosque and Turkish Bath. This analysis sought to divide the concrete scope into smaller bid packages that could be awarded to multiple subcontractors, lightening the pressure and allowing them to focus their construction efforts. The result selected a two bid package division with Division 1 including the Parking Garage, Mosque, and Fellowship Hall and Division 2 including the Turkish Bath, Cultural Center, and Convent/Monastery. Contractors A and B were selected to take these divisions as they had scored the highest scores and were most capable of completing the work. The structural integrity of the buildings should not be threatened by these packages. However, the contract will need to include additional language to ensure that the contractors collaborate and share detailed information about their designs and work.

Analysis III: Workforce Management Plan

As a multi-building project, construction presents a unique opportunity to employ a larger workforce and higher productivity over different work spaces. Construction operations can occur in several different locations, particularly coordinated by building. On the other hand, the larger site does pose additional challenges in terms of tracking and managing the workforce. A Workforce Management Plan was developed to give the project team tools to track, analyze, and manage site work. Two superintendents were recommended to manage field operations, while a third superintendent managed the overall site. Manual observation and data recovery was recommended as the means of gathering information, which would then be analyzed using Crew Balance Charts, Process Charts, and Labor Utilization Factors. These techniques will be used to recognize delay causing issues in construction, which will then be solved using Last Planner and Pull Planning. These methods should lead the project team to ensuring higher productivity and continuous construction operations. Furthermore, specific techniques are provided on how to better manage the foreign artisans, who have some unique work practices and beliefs.

Analysis IV: Foreign Worker Safety Plan

As part of the cultural design aspects of the project, a significant number of foreign artisans will be brought to the project from their home country in order to construct many of the architectural finishes. Due to differences in culture, language, and work practice, this creates a safety risk for the workers on site. With a potentially limited knowledge of English and US construction regulations, the foreign workers could inadvertently place themselves, and others, in dangerous situations. A Foreign Worker Safety Plan was developed with general and site specific recommendations within six critical categories of safety. This plan can be used by the project team to learn about safety issues and different ways to address them. For the project, it was recommended to conduct a full training course, hire on-site interpreters, provide English classes, develop a bilingual reporting system, promote an anti-racist construction site, and use colored hard hats to signify managerial positions.

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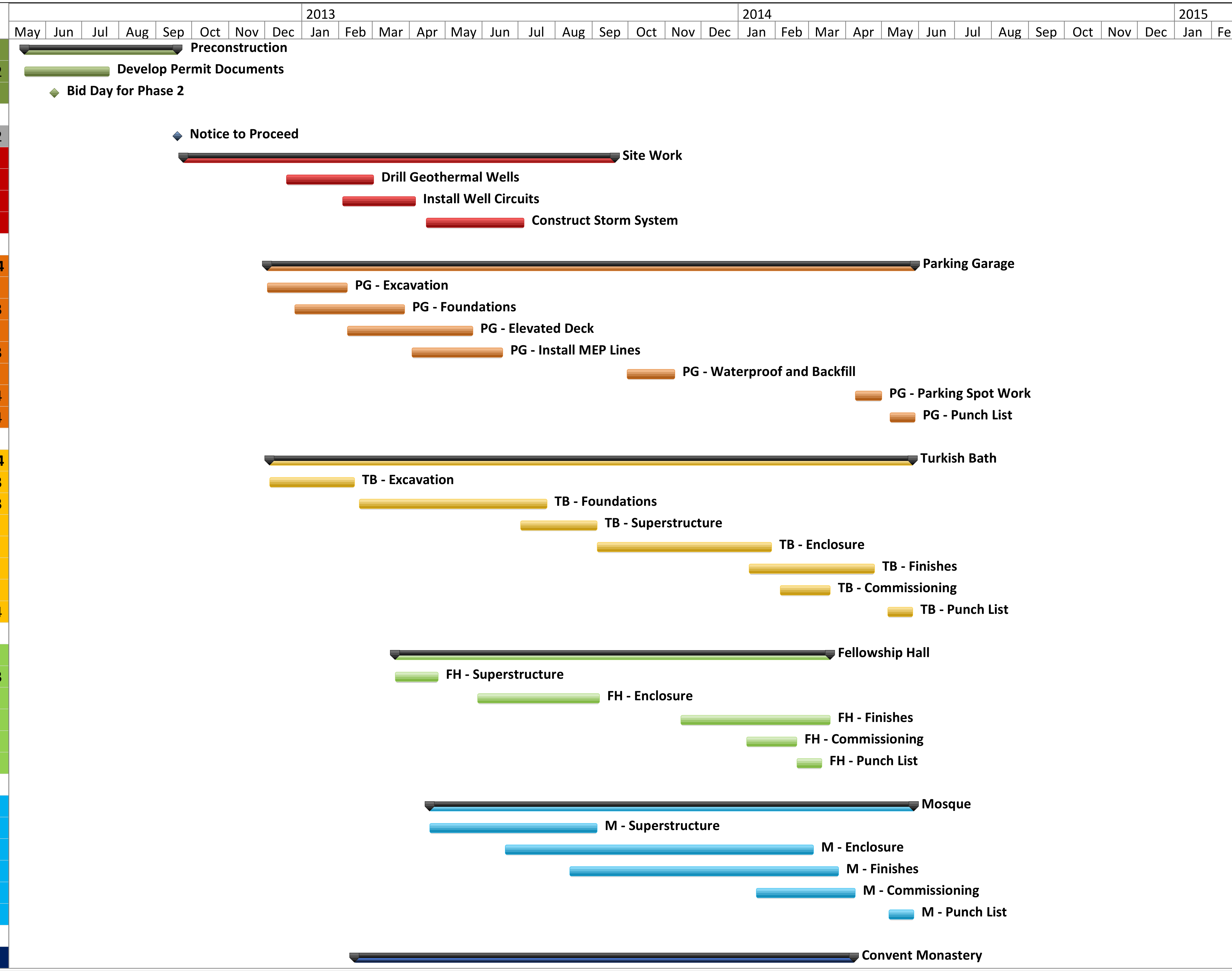
Appendix A-1: Project Schedule

Note: This Link will return the user to the previous section.

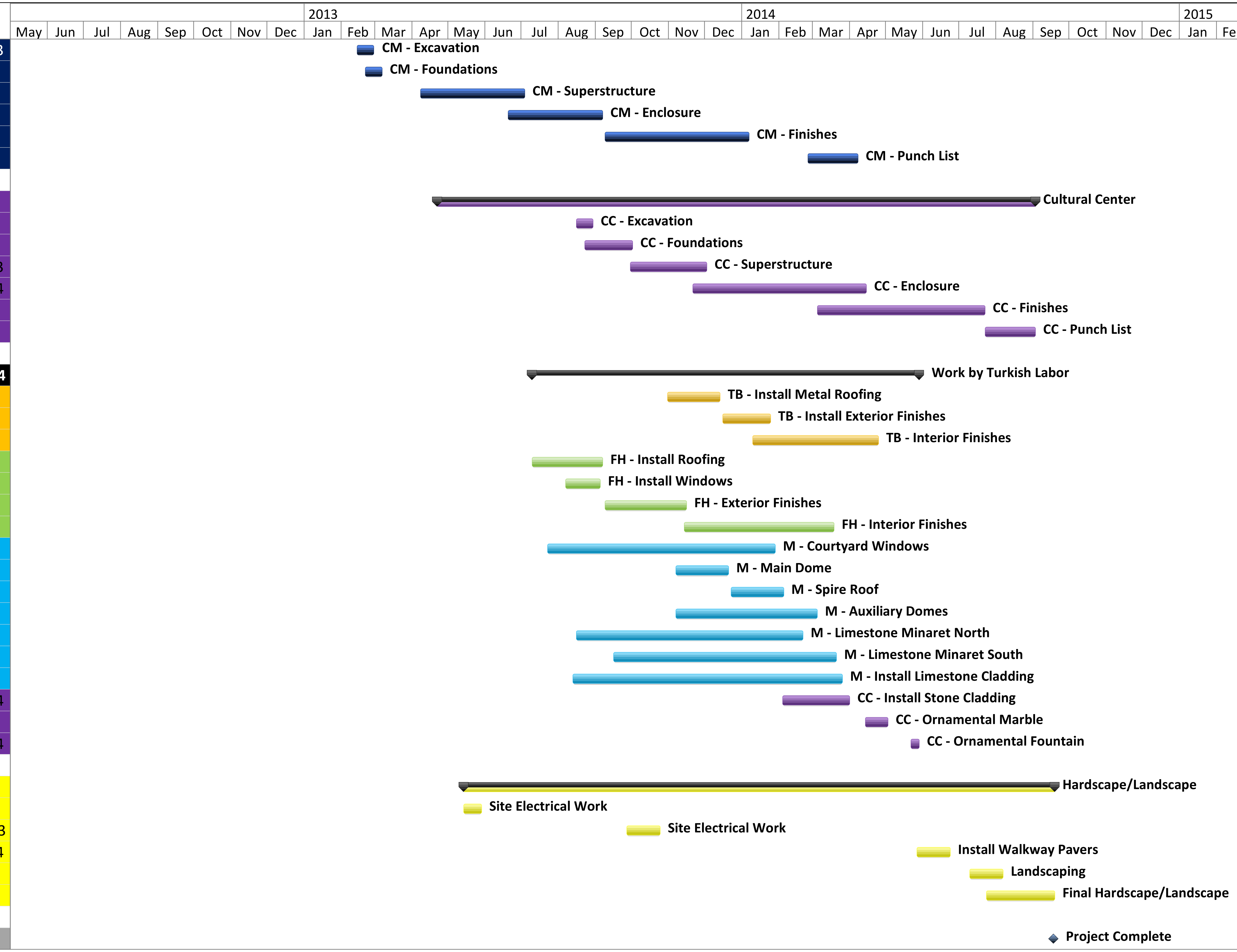
ID	Task Name	Duration	Start	Finish
1	**Preconstruction**	**92 days**	**Mon 5/14/12**	**Tue 9/18/12**
3	Develop Permit Documents	51 days	Mon 5/14/12	Mon 7/23/12
4	Bid Day for Phase 2	0 days	Fri 6/8/12	Fri 6/8/12
5				
6	Notice to Proceed	0 days	Wed 9/19/12	Wed 9/19/12
7	**Site Work**	**259 days**	**Mon 9/24/12**	**Thu 9/19/13**
9	Drill Geothermal Wells	53 days	Wed 12/19/12	Fri 3/1/13
10	Install Well Circuits	45 days	Mon 2/4/13	Fri 4/5/13
11	Construct Storm System	60 days	Mon 4/15/13	Fri 7/5/13
12				
13	**Parking Garage**	**388 days**	**Mon 12/3/12**	**Wed 5/28/14**
14	PG - Excavation	49 days	Mon 12/3/12	Thu 2/7/13
15	PG - Foundations	66 days	Wed 12/26/12	Wed 3/27/13
16	PG - Elevated Deck	75 days	Fri 2/8/13	Thu 5/23/13
17	PG - Install MEP Lines	54 days	Wed 4/3/13	Mon 6/17/13
18	PG - Waterproof and Backfill	30 days	Mon 9/30/13	Fri 11/8/13
19	PG - Parking Spot Work	16 days	Wed 4/9/14	Wed 4/30/14
20	PG - Punch List	15 days	Thu 5/8/14	Wed 5/28/14
21				
22	**Turkish Bath**	**384 days**	**Wed 12/5/12**	**Mon 5/26/14**
23	TB - Excavation	51 days	Wed 12/5/12	Wed 2/13/13
24	TB - Foundations	113 days	Mon 2/18/13	Wed 7/24/13
25	TB - Superstructure	46 days	Wed 7/3/13	Wed 9/4/13
26	TB - Enclosure	104 days	Thu 9/5/13	Tue 1/28/14
27	TB - Finishes	75 days	Fri 1/10/14	Thu 4/24/14
28	TB - Commissioning	30 days	Wed 2/5/14	Tue 3/18/14
29	TB - Punch List	15 days	Tue 5/6/14	Mon 5/26/14
30				
31	**Fellowship Hall**	**260 days**	**Wed 3/20/13**	**Tue 3/18/14**
32	FH - Superstructure	26 days	Wed 3/20/13	Wed 4/24/13
33	FH - Enclosure	74 days	Tue 5/28/13	Fri 9/6/13
34	FH - Finishes	89 days	Thu 11/14/13	Tue 3/18/14
35	FH - Commissioning	30 days	Wed 1/8/14	Tue 2/18/14
36	FH - Punch List	15 days	Wed 2/19/14	Tue 3/11/14
37				
38	**Mosque**	**289 days**	**Thu 4/18/13**	**Tue 5/27/14**
39	M - Superstructure	100 days	Thu 4/18/13	Wed 9/4/13
40	M - Enclosure	184 days	Thu 6/20/13	Tue 3/4/14
41	M - Finishes	161 days	Tue 8/13/13	Tue 3/25/14
42	M - Commissioning	59 days	Thu 1/16/14	Tue 4/8/14
43	M - Punch List	15 days	Wed 5/7/14	Tue 5/27/14
44				
45	**Convent Monastery**	**298 days**	**Thu 2/14/13**	**Mon 4/7/14**



Cultural Center, Northeast US
Project Overview
Technical Report 2

Task		Project Summary		Inactive Milestone		Manual Summary Rollup		Deadline	
Split		External Tasks		Inactive Summary		Manual Summary		Progress	
Milestone		External Milestone		Manual Task		Start-only			
Summary		Inactive Task		Duration-only		Finish-only			

ID	Task Name	Duration	Start	Finish
46	CM - Excavation	10 days	Thu 2/14/13	Wed 2/27/13
47	CM - Foundations	10 days	Thu 2/21/13	Wed 3/6/13
48	CM - Superstructure	63 days	Mon 4/8/13	Wed 7/3/13
49	CM - Enclosure	57 days	Thu 6/20/13	Fri 9/6/13
50	CM - Finishes	86 days	Mon 9/9/13	Mon 1/6/14
51	CM - Punch List	30 days	Tue 2/25/14	Mon 4/7/14
52				
53	**Cultural Center**	**357 days**	**Mon 4/22/13**	**Tue 9/2/14**
55	CC - Excavation	10 days	Fri 8/16/13	Thu 8/29/13
56	CC - Foundations	28 days	Fri 8/23/13	Tue 10/1/13
57	CC - Superstructure	46 days	Mon 9/30/13	Mon 12/2/13
58	CC - Enclosure	103 days	Thu 11/21/13	Mon 4/14/14
59	CC - Finishes	100 days	Wed 3/5/14	Tue 7/22/14
60	CC - Punch List	30 days	Wed 7/23/14	Tue 9/2/14
61				
62	**Work by Turkish Labor**	**231 days**	**Wed 7/10/13**	**Wed 5/28/14**
63	TB - Install Metal Roofing	32 days	Thu 10/31/13	Fri 12/13/13
64	TB - Install Exterior Finishes	30 days	Mon 12/16/13	Fri 1/24/14
65	TB - Interior Finishes	75 days	Fri 1/10/14	Thu 4/24/14
66	FH - Install Roofing	43 days	Wed 7/10/13	Fri 9/6/13
67	FH - Install Windows	21 days	Wed 8/7/13	Wed 9/4/13
68	FH - Exterior Finishes	50 days	Mon 9/9/13	Fri 11/15/13
69	FH - Interior Finishes	89 days	Thu 11/14/13	Tue 3/18/14
70	M - Courtyard Windows	136 days	Tue 7/23/13	Tue 1/28/14
71	M - Main Dome	32 days	Thu 11/7/13	Fri 12/20/13
72	M - Spire Roof	32 days	Mon 12/23/13	Tue 2/4/14
73	M - Auxiliary Domes	84 days	Thu 11/7/13	Tue 3/4/14
74	M - Limestone Minaret North	135 days	Fri 8/16/13	Thu 2/20/14
75	M - Limestone Minaret South	134 days	Mon 9/16/13	Thu 3/20/14
76	M - Install Limestone Cladding	161 days	Tue 8/13/13	Tue 3/25/14
77	CC - Install Stone Cladding	40 days	Tue 2/4/14	Mon 3/31/14
78	CC - Ornamental Marble	15 days	Mon 4/14/14	Fri 5/2/14
79	CC - Ornamental Fountain	5 days	Thu 5/22/14	Wed 5/28/14
80				
81	**Hardscape/Landscape**	**353 days**	**Tue 5/14/13**	**Thu 9/18/14**
82	Site Electrical Work	11 days	Tue 5/14/13	Tue 5/28/13
83	Site Electrical Work	20 days	Fri 9/27/13	Thu 10/24/13
84	Install Walkway Pavers	20 days	Tue 5/27/14	Mon 6/23/14
85	Landscaping	20 days	Thu 7/10/14	Wed 8/6/14
86	Final Hardscape/Landscape	41 days	Thu 7/24/14	Thu 9/18/14
87				
88	Project Complete	0 days	Thu 9/18/14	Thu 9/18/14



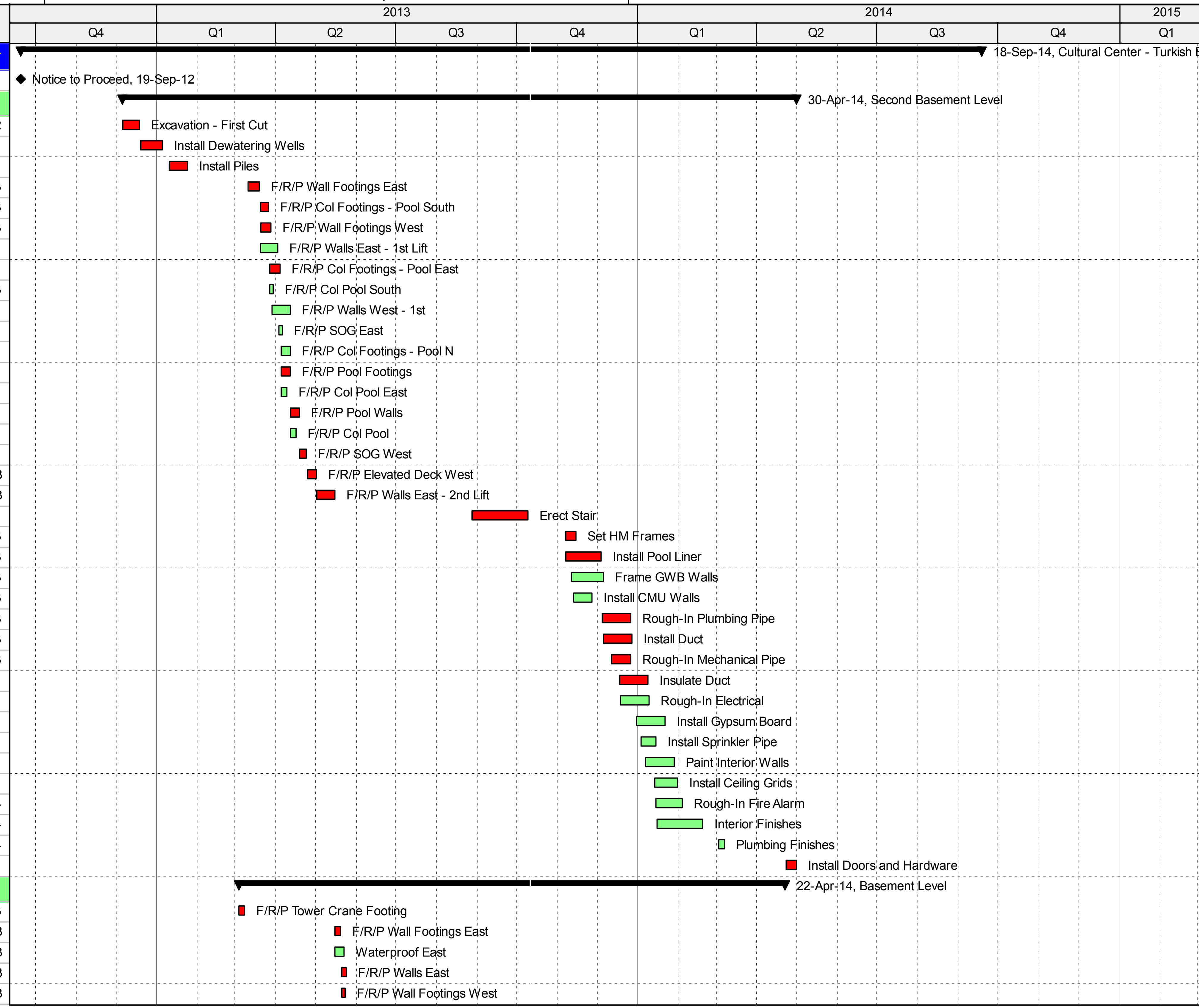
Cultural Center, Northeast US
Project Overview
Technical Report 2

Task	Project Summary	Inactive Milestone	Manual Summary Rollup	Deadline
Split	External Tasks	Inactive Summary	Manual Summary	Progress
Milestone	External Milestone	Manual Task	Start-only	
Summary	Inactive Task	Duration-only	Finish-only	

Appendix A-2: Turkish Bath Detailed Schedule

Note: This Link will return the user to the previous section.

Activity ID	Activity Name	Original Duration	Start	Finish
Cultural Center - Turkish Bath		514	19-Sep-12	18-Sep-14
A1000	Notice to Proceed	0	19-Sep-12	
Second Basement Level		359	05-Dec-12	30-Apr-14
A1010	Excavation - First Cut	10	05-Dec-12	18-Dec-12
A1020	Install Dewatering Wells	11	19-Dec-12	04-Jan-13
A1030	Install Piles	10	10-Jan-13	23-Jan-13
A1040	F/R/P Wall Footings East	7	11-Mar-13	19-Mar-13
A1050	F/R/P Col Footings - Pool South	5	20-Mar-13	26-Mar-13
A1060	F/R/P Wall Footings West	7	20-Mar-13	28-Mar-13
A1070	F/R/P Walls East - 1st Lift	10	20-Mar-13	02-Apr-13
A1080	F/R/P Col Footings - Pool East	7	27-Mar-13	04-Apr-13
A1090	F/R/P Col Pool South	3	27-Mar-13	29-Mar-13
A1100	F/R/P Walls West - 1st	10	29-Mar-13	11-Apr-13
A1110	F/R/P SOG East	3	03-Apr-13	05-Apr-13
A1120	F/R/P Col Footings - Pool N	5	05-Apr-13	11-Apr-13
A1130	F/R/P Pool Footings	5	05-Apr-13	11-Apr-13
A1140	F/R/P Col Pool East	3	05-Apr-13	09-Apr-13
A1150	F/R/P Pool Walls	5	12-Apr-13	18-Apr-13
A1160	F/R/P Col Pool	3	12-Apr-13	16-Apr-13
A1170	F/R/P SOG West	4	19-Apr-13	24-Apr-13
A1180	F/R/P Elevated Deck West	5	25-Apr-13	01-May-13
A1190	F/R/P Walls East - 2nd Lift	10	02-May-13	15-May-13
A1200	Erect Stair	30	28-Aug-13	09-Oct-13
A1210	Set HM Frames	6	07-Nov-13*	14-Nov-13
A1220	Install Pool Liner	18	07-Nov-13*	03-Dec-13
A1230	Frame GWB Walls	18	11-Nov-13*	05-Dec-13
A1240	Install CMU Walls	10	13-Nov-13*	26-Nov-13
A1250	Rough-In Plumbing Pipe	16	04-Dec-13*	26-Dec-13
A1260	Install Duct	16	05-Dec-13*	27-Dec-13
A1270	Rough-In Mechanical Pipe	11	11-Dec-13*	26-Dec-13
A1280	Insulate Duct	16	17-Dec-13*	08-Jan-14
A1290	Rough-In Electrical	16	18-Dec-13*	09-Jan-14
A1300	Install Gypsum Board	17	30-Dec-13*	21-Jan-14
A1310	Install Sprinkler Pipe	8	03-Jan-14*	14-Jan-14
A1320	Paint Interior Walls	17	06-Jan-14*	28-Jan-14
A1330	Install Ceiling Grids	14	13-Jan-14*	30-Jan-14
A1340	Rough-In Fire Alarm	15	14-Jan-14*	03-Feb-14
A1350	Interior Finishes	25	15-Jan-14*	18-Feb-14
A1360	Plumbing Finishes	5	03-Mar-14*	07-Mar-14
A1370	Install Doors and Hardware	6	23-Apr-14*	30-Apr-14
Basement Level		292	04-Mar-13	22-Apr-14
A1380	F/R/P Tower Crane Footing	5	04-Mar-13*	08-Mar-13
A1390	F/R/P Wall Footings East	3	16-May-13	20-May-13
A1400	Waterproof East	5	16-May-13	22-May-13
A1410	F/R/P Walls East	4	21-May-13	24-May-13
A1420	F/R/P Wall Footings West	3	21-May-13	23-May-13



Actual Level of Effort | Remaining Work | ◆ Milestone
Actual Work | Critical Remaining Work | summary

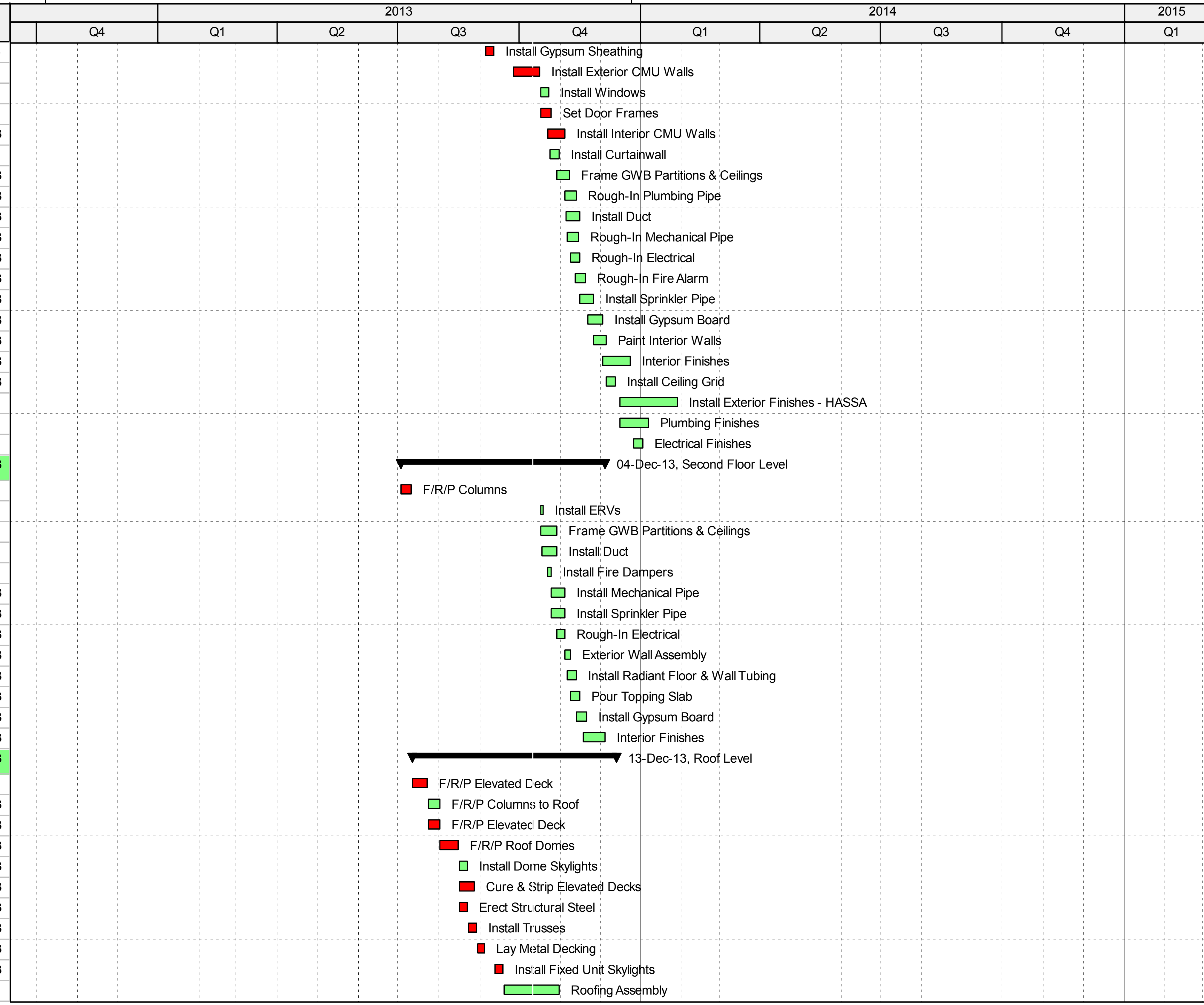
TASK filter: All Activities

Activity ID	Activity Name	Original Duration	Start	Finish
A1430	F/R/P Col Footings East	3	21-May-13	23-May-13
A1440	F/R/P Walls West	4	24-May-13	30-May-13
A1450	F/R/P Ramp Wall Footings	5	24-May-13	31-May-13
A1460	F/R/P Col East	3	28-May-13	30-May-13
A1470	F/R/P SOG East	3	31-May-13	04-Jun-13
A1480	F/R/P Col Footings West	5	31-May-13	06-Jun-13
A1490	Waterproof West	5	31-May-13	06-Jun-13
A1500	F/R/P Ramp Walls	5	03-Jun-13	07-Jun-13
A1510	F/R/P Elevated Deck East	10	05-Jun-13	18-Jun-13
A1520	F/R/P Col West	5	07-Jun-13	13-Jun-13
A1530	Backfill East	5	07-Jun-13	13-Jun-13
A1540	F/R/P SOG West	3	14-Jun-13	18-Jun-13
A1550	Backfill West	5	14-Jun-13	20-Jun-13
A1560	F/R/P Elevated Deck West	5	19-Jun-13	25-Jun-13
A1570	Cure & Strip Elevated Deck East	8	19-Jun-13	28-Jun-13
A1580	F/R/P Pedestal Elevated Deck	5	26-Jun-13	02-Jul-13
A1590	Cure & Strip Elevated Deck West	8	16-Aug-13	27-Aug-13
A1600	Erect Structural Steel at Stair 3	3	23-Aug-13	27-Aug-13
A1610	Set Generators	5	10-Sep-13	16-Sep-13
A1620	Set Door Frames	9	25-Oct-13*	06-Nov-13
A1630	Install Interior CMU Walls	5	05-Nov-13*	11-Nov-13
A1640	Permanent Power	0	07-Nov-13*	
A1650	Install AHUs	5	12-Nov-13*	18-Nov-13
A1660	Rough-In Plumbing Pipe	6	12-Nov-13*	19-Nov-13
A1670	Install CMU Walls	10	12-Nov-13*	25-Nov-13
A1680	Rough-In Mechanical Pipe	6	19-Nov-13*	26-Nov-13
A1690	Install Duct	11	19-Nov-13*	04-Dec-13
A1700	Insulate Duct	10	03-Dec-13*	16-Dec-13
A1710	Frame GWB Partitions and Ceilin	10	04-Dec-13*	17-Dec-13
A1720	Rough-In Plumbing Pipe	11	11-Dec-13*	26-Dec-13
A1730	Rough-In Mechanical Pipe	11	13-Dec-13*	30-Dec-13
A1740	Rough-In Electrical	19	20-Dec-13*	16-Jan-14
A1750	Rough-In Fire Alarm	10	31-Dec-13*	13-Jan-14
A1760	Install Gypsum Board	15	20-Jan-14*	07-Feb-14
A1770	Paint Interior Walls	13	29-Jan-14*	14-Feb-14
A1780	Interior Finishes	33	05-Feb-14*	21-Mar-14
A1790	Plumbing Finishes	10	28-Feb-14*	13-Mar-14
A1800	Install Athletic Equipment	10	07-Apr-14*	18-Apr-14
A1810	Install Doors & Hardware	7	14-Apr-14*	22-Apr-14
Plaza Level		55	19-Jun-13	05-Sep-13
A1820	F/R/P Cure & Strip Pour Strips	25	19-Jun-13*	24-Jul-13
A1830	F/R/P Concrete Piers East	5	19-Jun-13*	25-Jun-13
A1840	F/R/P Wall Above Ramp	5	03-Jul-13*	10-Jul-13
A1850	Waterproof Plaza	25	25-Jul-13	28-Aug-13
A1860	Backfill	15	15-Aug-13	05-Sep-13
Ground Level		102	05-Sep-13	28-Jan-14

Actual Level of Effort — Remaining Work — Milestone
Actual Work — Critical Remaining Work — summary

TASK filter: All Activities

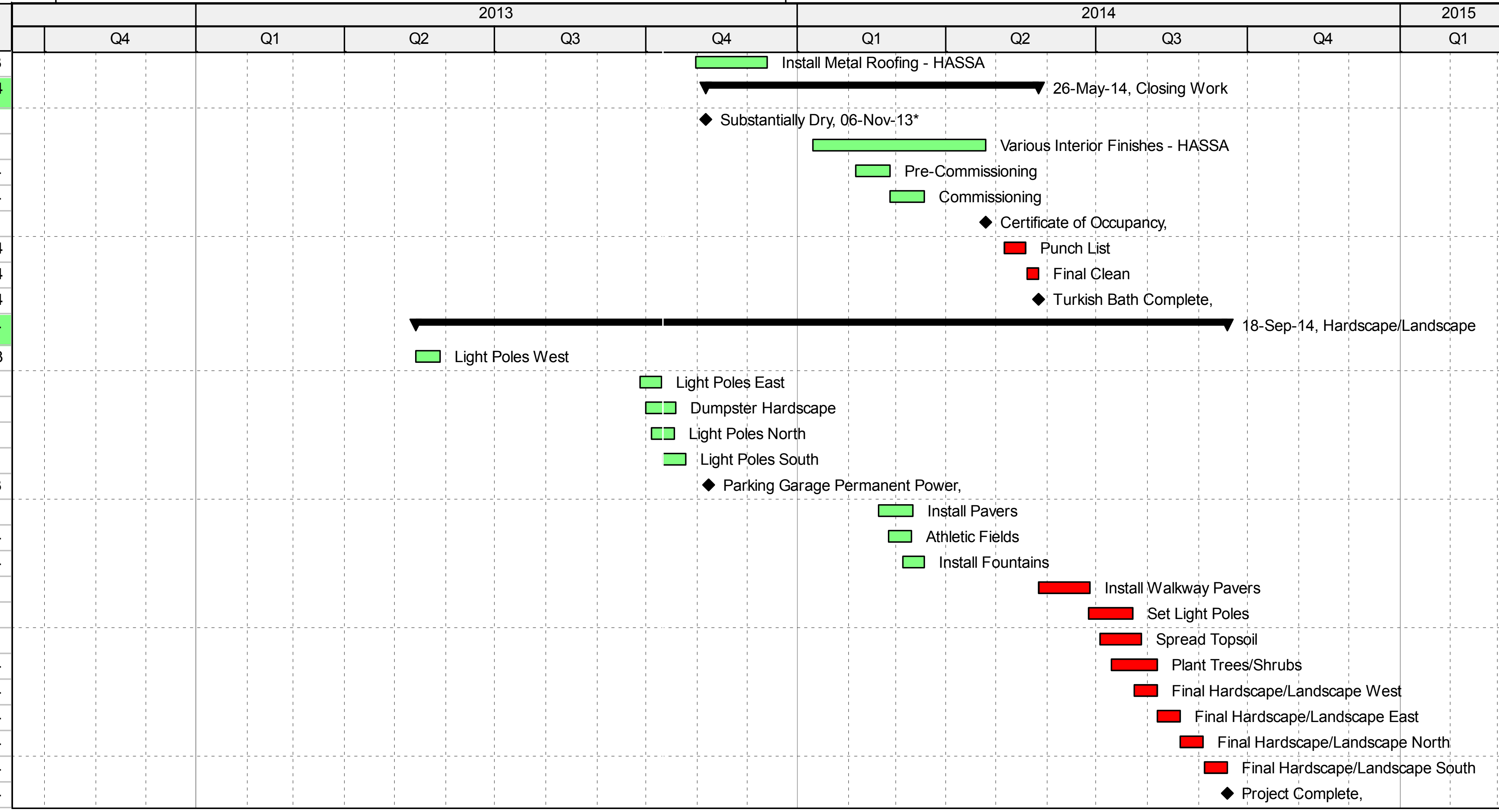
Activity ID	Activity Name	Original Duration	Start	Finish
A1870	Install Gypsum Sheathing	5	05-Sep-13	11-Sep-13
A1880	Install Exterior CMU Walls	15	26-Sep-13	16-Oct-13
A1890	Install Windows	5	17-Oct-13*	23-Oct-13
A1900	Set Door Frames	6	17-Oct-13*	24-Oct-13
A1910	Install Interior CMU Walls	10	22-Oct-13*	04-Nov-13
A1920	Install Curtainwall	5	24-Oct-13*	30-Oct-13
A1930	Frame GWB Partitions & Ceilings	8	29-Oct-13*	07-Nov-13
A1940	Rough-In Plumbing Pipe	7	04-Nov-13*	12-Nov-13
A1950	Install Duct	9	05-Nov-13*	15-Nov-13
A1960	Rough-In Mechanical Pipe	7	06-Nov-13*	14-Nov-13
A1970	Rough-In Electrical	6	08-Nov-13*	15-Nov-13
A1980	Rough-In Fire Alarm	6	12-Nov-13*	19-Nov-13
A1990	Install Sprinkler Pipe	7	15-Nov-13*	25-Nov-13
A2000	Install Gypsum Board	7	21-Nov-13*	02-Dec-13
A2010	Paint Interior Walls	7	26-Nov-13*	05-Dec-13
A2020	Interior Finishes	15	03-Dec-13*	23-Dec-13
A2030	Install Ceiling Grid	6	05-Dec-13*	12-Dec-13
A2040	Install Exterior Finishes - HASSA	31	16-Dec-13*	28-Jan-14
A2050	Plumbing Finishes	15	16-Dec-13*	06-Jan-14
A2060	Electrical Finishes	6	26-Dec-13*	02-Jan-14
Second Floor Level		108	03-Jul-13	04-Dec-13
A2070	F/R/P Columns	6	03-Jul-13	11-Jul-13
A2080	Install ERVs	2	17-Oct-13*	18-Oct-13
A2090	Frame GWB Partitions & Ceilings	9	17-Oct-13*	29-Oct-13
A2100	Install Duct	8	18-Oct-13*	29-Oct-13
A2110	Install Fire Dampers	3	22-Oct-13*	24-Oct-13
A2120	Install Mechanical Pipe	7	25-Oct-13*	04-Nov-13
A2130	Install Sprinkler Pipe	7	25-Oct-13*	04-Nov-13
A2140	Rough-In Electrical	5	29-Oct-13*	04-Nov-13
A2150	Exterior Wall Assembly	5	04-Nov-13*	08-Nov-13
A2160	Install Radiant Floor & Wall Tubin	5	06-Nov-13*	12-Nov-13
A2170	Pour Topping Slab	6	08-Nov-13*	15-Nov-13
A2180	Install Gypsum Board	6	13-Nov-13*	20-Nov-13
A2190	Interior Finishes	12	18-Nov-13*	04-Dec-13
Roof Level		109	12-Jul-13	13-Dec-13
A2200	F/R/P Elevated Deck	8	12-Jul-13	23-Jul-13
A2210	F/R/P Columns to Roof	7	24-Jul-13	01-Aug-13
A2220	F/R/P Elevated Deck	7	24-Jul-13	01-Aug-13
A2230	F/R/P Roof Domes	10	02-Aug-13	15-Aug-13
A2240	Install Dome Skylights	5	16-Aug-13	22-Aug-13
A2250	Cure & Strip Elevated Decks	8	16-Aug-13	27-Aug-13
A2260	Erect Structural Steel	5	16-Aug-13	22-Aug-13
A2270	Install Trusses	5	23-Aug-13	29-Aug-13
A2280	Lay Metal Decking	3	30-Aug-13	04-Sep-13
A2290	Install Fixed Unit Skylights	5	12-Sep-13	18-Sep-13
A2300	Roofing Assembly	30	19-Sep-13	30-Oct-13



Actual Level of Effort | Remaining Work | Milestone
Actual Work | Critical Remaining Work | summary

TASK filter: All Activities

Activity ID	Activity Name	Original Duration	Start	Finish
A2310	Install Metal Roofing - HASSA	31	31-Oct-13*	13-Dec-13
Closing Work		142	06-Nov-13	26-May-14
A2320	Substantially Dry	0	06-Nov-13*	
A2330	Various Interior Finishes - HASSA	75	10-Jan-14*	24-Apr-14
A2340	Pre-Commissioning	15	05-Feb-14*	25-Feb-14
A2350	Commissioning	15	26-Feb-14*	18-Mar-14
A2360	Certificate of Occupancy	0		24-Apr-14
A2370	Punch List	10	06-May-14*	19-May-14
A2380	Final Clean	5	20-May-14*	26-May-14
A2390	Turkish Bath Complete	0		26-May-14
Hardscape/Landscape		348	14-May-13	18-Sep-14
A2400	Light Poles West	10	14-May-13	28-May-13
A2410	Light Poles East	10	27-Sep-13	10-Oct-13
A2420	Dumpster Hardscape	15	30-Sep-13	18-Oct-13
A2430	Light Poles North	10	04-Oct-13	17-Oct-13
A2440	Light Poles South	10	11-Oct-13	24-Oct-13
A2450	Parking Garage Permanent Powe	0		07-Nov-13
A2460	Install Pavers	15	19-Feb-14*	11-Mar-14
A2470	Athletic Fields	10	25-Feb-14*	10-Mar-14
A2480	Install Fountains	10	05-Mar-14*	18-Mar-14
A2490	Install Walkway Pavers	24	27-May-14*	27-Jun-14
A2500	Set Light Poles	20	26-Jun-14*	23-Jul-14
A2510	Spread Topsoil	18	03-Jul-14*	28-Jul-14
A2520	Plant Trees/Shrubs	20	10-Jul-14*	06-Aug-14
A2530	Final Hardscape/Landscape West	10	24-Jul-14*	06-Aug-14
A2540	Final Hardscape/Landscape East	10	07-Aug-14*	20-Aug-14
A2550	Final Hardscape/Landscape Nortl	10	21-Aug-14*	03-Sep-14
A2560	Final Hardscape/Landscape Soutl	11	04-Sep-14*	18-Sep-14
A2570	Project Complete	0		18-Sep-14



Actual Level of Effort | Remaining Work | Milestone
Actual Work | Critical Remaining Work | summary

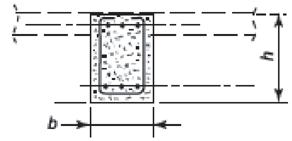
TASK filter: All Activities

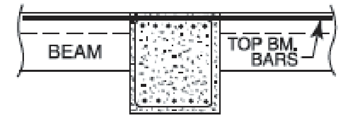
Appendix A-3: Sample Pages from CRSI Design Handbook

Note: This Link will return the user to the previous section.

f'_c = 4,000 psi
f_y = 60,000 psi

RECTANGULAR BEAMS, INTERIOR SPANS





STEM		BARS(1)				TOTAL CAPACITY $U = 1.2D + 1.6L^{(3)}$																				$+\phi M_n$ $-\phi M_n$	DEFL (C)
h in.	b in.	BOTTOM ℓ_n + 12 in.	BOTTOM 0.875 ℓ_n	Layers (2)	TOP	SPAN, ℓ_n = 24 ft LOAD (4) k/ft	STIR. TIES (5)	ϕT_n ft-kips	$A\ell$ sq. in.	STEEL WGT lb.	SPAN, ℓ_n = 26 ft. LOAD (4) k/ft	STIR. TIES (5)	ϕT_n ft-kips	$A\ell$ sq. in.	STEEL WGT lb.	SPAN, ℓ_n = 28 ft. LOAD (4) k/ft	STIR. TIES (5)	ϕT_n ft-kips	$A\ell$ sq. in.	STEEL WGT lb.	SPAN, ℓ_n = 30 ft. LOAD (4) k/ft	STIR. TIES (5)	ϕT_n ft-kips	$A\ell$ sq. in.	STEEL WGT lb.	(6) ft.-kip	(7) $\times 10^{-9}$ in.
18	10	2# 5		1	2# 7	1.17	113E	3	-	151	1.00	113E	3	-	161	0.86	103E	3	-	168	0.75	103E	3	-	177	42	1005
				1			293C	10	0.6	241		303C	10	0.6	255		323C	10	0.6	273		343C	10	0.6	291	78	
		2# 6		1	2# 8	1.63	143E	3	-	204	1.39	143E	3	-	217	1.20	153E	3	-	233	1.05	153E	3	-	246	58	1293
				1			293C	10	0.6	284		303C	10	0.6	302		323C	10	0.6	323		343C	10	0.6	345	100	
		2# 8		1	2# 9	2.35	163E	3	-	291	2.00	173E	3	-	314	1.73	183E	3	-	337	1.50*	193E	3	-	360	100	1189
				1			293C	10	0.6	366		303C	10	0.6	390		323C	10	0.6	418		343C	10	0.6	446	123	
		2# 8		1	2#10	2.79	173E	3	-	323	2.37*	183E	3	-	349	2.05*	193E	3	-	374	1.78*	203E	3	-	399	100	1121
				1			473A	10	0.6	471		503A	10	0.6	506		533A	10	0.6	541		343C	10	0.6	483	150	
	12	2# 6		1	2# 7	1.51	123E	3	-	179	1.29	123E	3	-	190	1.11	123E	3	-	202	0.97	113E	3	-	210	59	945
				1			243D	14	0.7	249		263D	14	0.7	269		273D	14	0.7	285		293D	13	0.7	306	79	
		2# 7		1	2# 9	2.20	153E	3	-	259	1.88	153E	3	-	276	1.62	163E	3	-	297	1.41	163E	3	-	314	79	1108
				1			244D	14	0.7	431		263D	14	0.7	346		273D	14	0.7	367		293D	13	0.7	394	125	
		2# 8		1	2#10	2.83	163E	3	-	322	2.41	173E	3	-	348	2.08*	183E	3	-	373	1.81*	193E	3	-	398	101	1031
				1			244D	14	0.7	491		264D	14	0.7	532		274D	14	0.7	563		294D	13	0.7	604	154	
		2# 9		1	2#11	3.49	173E	3	-	394	2.97*	183E	3	-	425	2.56*	193E	3	-	456	2.23*	203E	3	-	487	125	923
				1			244D	14	0.7	560		264D	14	0.7	606		274D	14	0.7	643		294D	13	0.7	689	182	
	14	2# 7		1	3# 7	2.22	143E	4	-	247	1.89	143E	4	-	263	1.63	143E	4	-	280	1.42	143E	4	-	296	79	964
				1			243D	18	0.8	315		263D	17	0.8	340		283D	17	0.8	366		293D	17	0.8	387	116	
		2# 8		1	3# 8	2.85	163E	4	-	315	2.43	163E	4	-	336	2.10	173E	4	-	361	1.83*	173E	4	-	382	103	954
				1			244D	18	0.8	493		264D	17	0.8	533		284D	17	0.8	574		294D	17	0.8	605	149	
		2# 9		1	3# 9	3.49	173E	4	-	390	2.98	183E	4	-	420	2.57*	183E	4	-	447	2.23*	193E	4	-	478	127	866
				1			244D	18	0.8	564		264D	17	0.8	611		284D	17	0.8	657		294D	17	0.8	694	182	
		2#10		1	3#10	4.24	184E	4	-	539	3.62*	194E	4	-	580	3.12*	203E	4	-	557	2.72*	203E	4	-	591	157	759
				1			245D	18	0.8	806		264D	17	0.8	707		284D	17	0.8	760		294D	17	0.8	804	222	
	16	2# 7		1	3# 7	2.24	133E	5	-	245	1.90	133E	5	-	261	1.64	133E	5	-	278	1.43	133E	5	-	294	80	790
				1			214E	22	0.9	412		223E	21	0.9	327		243E	21	0.9	353		263E	21	0.9	380	118	
		2# 8		1	3# 8	2.89	153E	5	-	313	2.46	153E	5	-	335	2.12	163E	5	-	360	1.85	163E	5	-	381	104	858
				1			214E	22	0.9	474		224E	21	0.9	505		244E	21	0.9	547		264E	21	0.9	588	151	
		2#10		1	3#10	4.34	174E	5	-	537	3.70*	183E	5	-	518	3.19*	193E	5	-	556	2.78*	203E	5	-	594	159	720
				1			215E	22	0.9	772		225E	21	0.9	823		244E	21	0.9	733		264E	21	0.9	787	227	
		2#10		1	3#11	4.43	174E	5	-	585	3.78	183E	5	-	571	3.26*	193E	5	-	613	2.84*	203E	5	-	654	159	671
				1			215E	22	0.9	821		225E	21	0.9	876		245E	21	0.9	948		264E	21	0.9	848	256	

(1) See "Recommended Bar Details", Fig. 12-1. For girders, use tabulated beam depth – 2 inches (b – 2").
(2) In "Layers" column, first line is number of layers for bottom bars, second line is for number of layers for top bars.
(3) For superimposed factored load capacity, deduct 1.2 × stem weight.
(4) Total capacities tabulated causing deflection in excess of $\ell_n/360$ are designated thus: * – $\ell_n/360$ < deflection < $\ell_n/240$
X – $\ell_n/240$ < deflection < $\ell_n/180$
Y – deflection > $\ell_n/180$

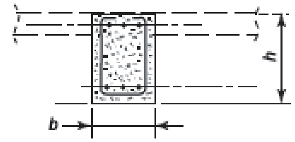
(5) For each beam design, first line is for open stirrups, second line is for closed ties. See Fig. 12-4. At free ends, use stirrups tabulated for "Interior Spans". For b > 24 in., provide 4 legs (two stirrups) of size and spacing tabulated. For stirrup nomenclature, see page 12-14.

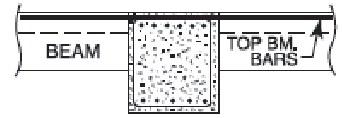
Other notation: N/A – STIRRUPS ARE NOT REQUIRED
** – MAXIMUM SPACING IS LESS THAN 3 INCHES. NOT RECOMMENDED
*** – SHEAR STRESS IS GREATER THAN $10\sqrt{f'_c}$
**** – TORSION STRESS EXCEEDS ALLOWABLE

(6) $+\phi M_n$ and $-\phi M_n$ are design moment strength capacities for rectangular section $b \times h$
(7) Midspan elastic deflection (in.) = $C \times (w/1.4) \times \ell_n^4$, where w = tabulated load (k/ft.), ℓ_n in ft.
"Average service load" is taken as $w/1.4$.

f'_c = 4,000 psi
f_y = 60,000 psi

JOIST-BAND BEAMS, END SPANS





STEM		BARS(1)				TOTAL CAPACITY $U = 1.2D + 1.6L$(3)																				$+\phi M_n$ $-\phi M_n$	DEFL (C)
h	b	BOTTOM		Lay-ers	TOP	SPAN, ℓ_n = 24 ft					SPAN, ℓ_n = 26 ft.					SPAN, ℓ_n = 28 ft.					SPAN, ℓ_n = 30 ft.						
in.	in.	ℓ_n + 12 in.	0.875 ℓ_n	(2)		LOAD (4) k/ft	STIR. TIES (5)	ϕT_n ft-kips	$A\ell$ sq. in.	STEEL WGT lb.	LOAD (4) k/ft	STIR. TIES (5)	ϕT_n ft-kips	$A\ell$ sq. in.	STEEL WGT lb.	LOAD (4) k/ft	STIR. TIES (5)	ϕT_n ft-kips	$A\ell$ sq. in.	STEEL WGT lb.	LOAD (4) k/ft	STIR. TIES (5)	ϕT_n ft-kips	$A\ell$ sq. in.	STEEL WGT lb.	(6) ft.-kip	(7) $\times 10^{-9}$ in.
16.5	24	2# 7	1# 7	1	4# 7	2.07	123E	8	-	358	1.77	113E	8	-	373	1.52	113E	8	-	394	1.33	103E	8	-	409	108	1206
				1			293C	33	1.2	531		313C	33	1.2	570		343C	33	1.2	617		363C	33	1.2	656	142	
		2# 9	1# 9	1	4# 8	3.17*	193D	8	-	544	2.70*	193D	8	-	576	2.33*	203D	8	-	614	2.03*	203D	8	-	646	173	1257
				1			293C	33	1.2	670		313C	33	1.2	720		343C	33	1.2	778		363C	33	1.2	827	182	
		2#10	1#10	1	4#10	4.08*	213D	8	-	734	3.48*	223D	8	-	786	3.00*	233D	8	-	837	2.61X	243D	8	-	889	213	1040
				1			294C	33	1.2	1097		314C	33	1.2	1177		344C	33	1.2	1273		363C	33	1.2	1043	274	
		2#11	1#11	1	4#10	4.76*	223D	8	-	813	4.06X	233D	8	-	871	3.50X	243D	8	-	928	3.05X	253D	8	-	985	254	989
				1			244D	33	1.2	1083		314C	33	1.2	1255		344C	33	1.2	1357		364C	33	1.2	1442	274	
	36	2# 8	2# 8	1	5# 7	3.12	N/A	15	-	414	2.66	N/A	14	-	445	2.29	N/A	14	-	477	2.00	N/A	14	-	509	188	817
				1			483A	58	1.9	916		523A	58	1.8	990		563A	57	1.8	1063		603A	57	1.8	1137	179	
		2# 9	2# 9	1	5# 9	4.45*	183D	15	-	734	3.79*	193D	14	-	787	3.27*	193D	14	-	833	2.85*	N/A	14	-	733	233	841
				1			483A	58	1.9	1099		523A	58	1.8	1186		563A	57	1.8	1273		603A	57	1.8	1361	285	
		2#11	2#11	1	5#10	6.11*	213D	14	-	1014	5.20*	223D	14	-	1086	4.49X	233D	14	-	1159	3.91X	243D	14	-	1232	344	723
				1			244D	58	1.8	1346		264D	58	1.8	1452		563A	57	1.8	1569		603A	57	1.8	1676	351	
		3#11	2#11	1	5#11	7.24*	223D	14	-	1244	6.17*	233D	14	-	1333	5.32X	253D	14	-	1429	4.63X	263D	14	-	1519	417	635
				1			245D	58	1.8	1872		265D	58	1.8	2020		284D	57	1.8	1813		304D	57	1.8	1936	417	
	48	3# 7	3# 7	1	6# 8	4.15	N/A	21	-	547	3.53	N/A	21	-	588	3.05	N/A	21	-	630	2.65	N/A	21	-	672	217	606
				1			**	84	5.4	547		**	83	0.0	588		**	83	0.0	630		**	82	0.0	672	280	
		3# 9	3# 9	1	6# 9	6.02*	183D	21	-	967	5.13*	193D	21	-	1037	4.42*	193D	21	-	1099	3.85*	N/A	21	-	997	346	632
				1			**	84	2.6	811		**	83	5.4	873		**	83	5.3	935		**	82	5.3	997	346	
		3#10	3#10	1	6#11	8.16*	213D	21	-	1320	6.95*	223D	21	-	1414	6.00X	233D	21	-	1508	5.22X	243D	21	-	1603	427	539
				1			294C	84	2.5	1827		314C	83	2.4	1960		**	83	2.5	1310		**	82	2.5	1395	508	
		3#11	3#11	1	7#11	9.71*	224D	21	-	1737	8.28X	234D	21	-	1857	7.14X	253D	21	-	1791	6.22X	263D	21	-	1903	508	485
				1			245D	84	2.4	2283		315C	83	2.4	2652		344C	83	2.4	2382		364C	82	2.4	2533	579	

(1) See "Recommended Bar Details", Fig. 12-1. For girders, use tabulated beam depth – 2 inches (b – 2").
(2) In "Layers" column, first line is number of layers for bottom bars, second line is for number of layers for top bars.
(3) For superimposed factored load capacity, deduct 1.2 × stem weight.
(4) Total capacities tabulated causing deflection in excess of $\ell_n/360$ are designated thus: * – $\ell_n/360$ < deflection < $\ell_n/240$
X – $\ell_n/240$ < deflection < $\ell_n/180$
Y – deflection > $\ell_n/180$

(5) For each beam design, first line is for open stirrups, second line is for closed ties. See Fig. 12-4. At free ends, use stirrups tabulated for "Interior Spans". For b > 24 in., provide 4 legs (two stirrups) of size and spacing tabulated. For stirrup nomenclature, see page 12-14.

Other notation:
N/A – STIRRUPS ARE NOT REQUIRED
** – MAXIMUM SPACING IS LESS THAN 3 INCHES. NOT RECOMMENDED
*** – SHEAR STRESS IS GREATER THAN $10\sqrt{f'_c}$
**** – TORSION STRESS EXCEEDS ALLOWABLE

(6) $+\phi M_n$ and $-\phi M_n$ are design moment strength capacities for rectangular section $b \times h$
(7) Midspan elastic deflection (in.) = $C \times (w/1.4) \times \ell_n^4$, where w = tabulated load (k/ft.), ℓ_n in ft.
"Average service load" is taken as $w/1.4$.

SQUARE TIED COLUMNS 10" x 10"

Short columns – no sidesway
Bars symmetrical in 4 faces

f'_c = 5,000 psi f_y = 60,000 psi
ϕM_n in inch-kips ϕP_n in kips

BARS	RHO	Max Cap ϕM_n	Max Cap ϕP_n	0% f_y ϕM_n	0% f_y ϕP_n	25% f_y ϕM_n	25% f_y ϕP_n	50% f_y ϕM_n	50% f_y ϕP_n	100% f_y ϕM_n	100% f_y ϕP_n	ε_t = 0.005 ϕM_n	ε_t = 0.005 ϕP_n	Zero Axial Load ϕM_n
4-#5	1.24	244	257	387	195	422	163	434	136	437	95	465	66	265
4-#6	1.76	252	272	413	203	451	168	467	138	478	90	505	54	349
4-#7	2.40	262	291	444	213	485	174	505	140	526	84	563	42	445
4-#8	3.16	273	313	479	226	523	181	548	142	580	76	616	23	553
4-#9	4.00	284	337	512	238	561	188	592	144	635	67	668	1	666
4-#10	5.08	298	368	552	254	606	197	644	145	700	54	727	-30	716
4-#11	6.24	305	402	571	264	624	198	662	139	723	31	720	-82	729
8-#5	2.48	251	293	419	217	461	178	480	145	495	88	526	21	467
8-#6	3.52	262	323	457	234	505	189	529	150	557	80	588	-12	588
8-#7	4.80	276	360	502	256	555	201	587	155	630	69	676	-46	657
SQUARE TIED COLUMNS 12" x 12"														
4-#6	1.22	430	369	663	290	741	244	780	207	798	147	874	110	457
4-#7	1.67	444	388	706	300	794	251	840	210	873	142	954	98	591
4-#8	2.19	461	410	756	313	855	260	908	214	959	137	1045	83	742
4-#9	2.78	478	434	810	326	920	269	979	218	1048	131	1137	66	903
4-#10	3.53	499	466	876	344	1001	282	1066	223	1158	122	1247	42	1101
4-#11	4.33	512	499	935	360	1050	287	1119	221	1222	105	1286	2	1278
4-#14	6.25	558	579	1081	406	1205	312	1296	228	1446	77	1539	-57	1497
8-#5	1.72	428	390	668	306	752	255	794	215	820	147	902	80	617
8-#6	2.44	445	420	722	323	817	267	872	223	915	141	1007	54	829
8-#7	3.33	466	457	786	345	896	282	962	231	1028	134	1128	19	1075
8-#8	4.39	489	501	860	370	986	300	1064	241	1157	125	1265	-23	1259
8-#9	5.56	515	550	939	399	1083	320	1171	251	1292	114	1405	-72	1385
8-#10	7.06	547	613	1037	436	1204	346	1302	263	1457	99	1572	-138	1537
SQUARE TIED COLUMNS 14" x 14"														
4-#7	1.22	692	503	1045	405	1188	340	1261	289	1322	209	1475	163	735
4-#8	1.61	716	525	1110	417	1267	349	1355	294	1440	205	1609	152	930
4-#9	2.04	740	549	1180	430	1352	358	1456	299	1565	201	1748	139	1139
4-#10	2.59	769	580	1268	448	1458	370	1583	307	1721	195	1919	121	1398
4-#11	3.18	790	614	1353	463	1554	381	1684	310	1832	182	2014	89	1642
4-#14	4.59	854	694	1553	508	1800	414	1952	324	2169	161	2360	32	2234
8-#5	1.27	669	505	994	412	1132	345	1197	293	1245	214	1394	145	765
8-#6	1.80	693	535	1063	429	1216	358	1297	302	1375	210	1543	122	1037
8-#7	2.45	722	572	1147	451	1317	373	1418	312	1529	206	1721	94	1357
8-#8	3.22	754	616	1242	477	1435	391	1558	324	1707	200	1922	59	1721
8-#9	4.08	789	665	1346	506	1562	412	1710	337	1896	193	2133	19	2092
8-#10	5.18	833	728	1475	543	1721	438	1901	354	2131	183	2391	-35	2370
8-#11	6.37	865	795	1596	578	1862	462	2053	364	2300	161	2540	-116	2486

(1) "0% f_y" indicates zero tension in bars on the tension side, "50% f_y" indicates 50% f_y stress in bars on the tension side, and "100% f_y" indicates 100% f_y stress (i.e., balance point) in bars on the tension side.

SQUARE TIED COLUMNS 16" x 16"

Short columns – no sidesway
Bars symmetrical in 4 faces

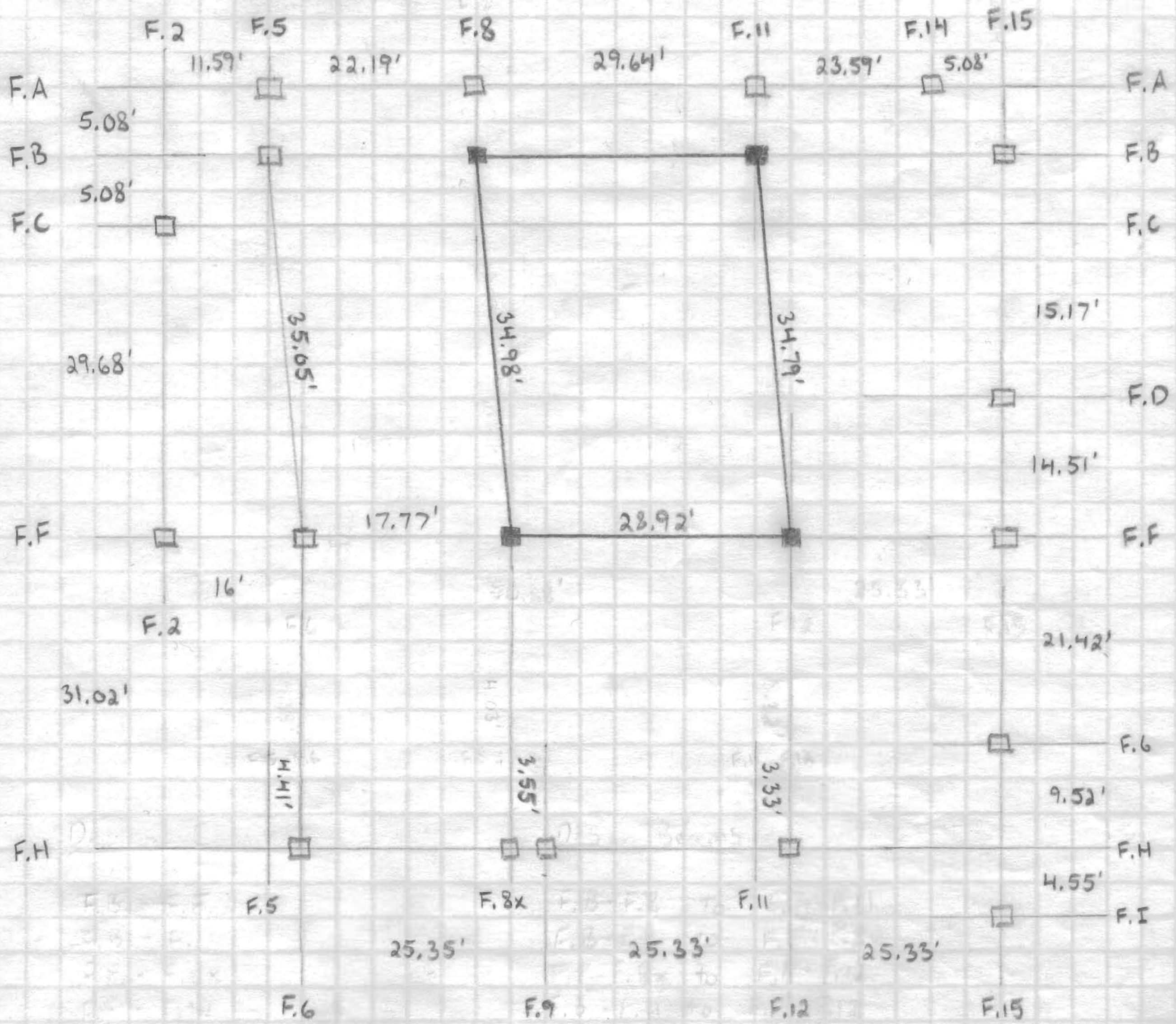
f'_c = 5,000 psi f_y = 60,000 psi
ϕM_n in inch-kips ϕP_n in kips

BARS	RHO	Max Cap ϕM_n	Max Cap ϕP_n	0% f_y ϕM_n	0% f_y ϕP_n	25% f_y ϕM_n	25% f_y ϕP_n	50% f_y ϕM_n	50% f_y ϕP_n	100% f_y ϕM_n	100% f_y ϕP_n	ε_t = 0.005 ϕM_n	ε_t = 0.005 ϕP_n	Zero Axial Load ϕM_n
4-#8	1.23	1045	657	1551	539	1786	453	1910	385	2030	281	2308	225	1117
4-#9	1.56	1078	682	1638	552	1891	462	2034	390	2196	278	2497	215	1373
4-#10	1.98	1118	713	1747	569	2024	474	2192	397	2403	275	2730	201	1694
4-#11	2.44	1147	747	1859	583	2149	484	2335	402	2562	264	2887	175	2005
4-#14	3.52	1232	827	2114	628	2460	516	2706	421	3017	249	3387	130	2752
4-#18	6.25	1422	1030	2710	745	3193	600	3548	465	4045	202	4463	-6	4459
8-#6	1.38	1016	668	1491	552	1721	463	1837	392	1936	285	2215	196	1244
8-#7	1.88	1052	705	1593	574	1846	479	1985	401	2134	282	2449	172	1638
8-#8	2.47	1094	749	1712	600	1990	497	2157	412	2364	279	2718	142	2089
8-#9	3.13	1142	798	1840	629	2147	518	2344	425	2614	276	3002	108	2569
8-#10	3.97	1198	860	2000	667	2344	545	2580	441	2926	271	3355	62	3165
8-#11	4.88	1241	928	2159	701	2529	568	2795	462	3168	254	3597	-7	3591
8-#14	7.03	1371	1088	2534	797	2993	636	3353	505	3853	228	4353	-144	4236
12-#10	5.95	1343	1008	2324	764	2736	622	3052	491	3557	260	4151	-27	4124
SQUARE TIED COLUMNS 18" x 18"														
4-#9	1.23	1502	832	2194	691	2552	581	2744	494	2935	361	3399	297	1607
4-#10	1.57	1552	863	2325	708	2711	593	2932	501	3185	358	3696	286	1988
4-#11	1.93	1592	897	2465	721	2866	602	3108	505	3415	351	3917	265	2367
4-#14	2.78	1701	977	2775	766	3243	633	3557	524	4003	343	4577	229	3269
4-#18	4.94	1943	1180	3507	881	4141	716	4631	574	5333	308	6051	120	5398
8-#6	1.09	1425	818	2015	693	2348	583	2507	497	2625	369	3038	277	1449
8-#7	1.48	1470	855	2137	715	2495	599	2682	506	2858	366	3330	256	1916
8-#8	1.95	1522	899	2278	741	2667	618	2887	518	3131	364	3667	230	2454
8-#9	2.47	1577	948	2431	770	2854	638	3109	530	3429	361	4027	200	3030
8-#10	3.14	1647	1011	2624	807	3090	665	3391	546	3805	357	4476	160	3750
8-#11	3.85	1708	1078	2821	842	3317	689	3656	559	4154	348	4816	100	4440
8-#14	5.56	1869	1238	3277	938	3879	758	4329	600	5040	335	5813	-19	5789
12-#10	4.70	1829	1158	3009	907	3555	745	3952	599	4557	349	5477	80	5139
12-#11	5.78	1916	1259	3279	963	3870	785	4322	622	5046	336	5964	-5	5958
SQUARE TIED COLUMNS 20" x 20"														
4-#9	1.00	2023	1000	2858	849	3349	715	3600	611	3822	454	4473	386	1840
4-#10	1.27	2083	1031	3012	865	3534	727	3818	617	4112	451	4835	377	2282
4-#11	1.56	2134	1065	3181	877	3720	735	4029	621	4384	444	5120	359	2727
4-#14	2.25	2270	1145	3546	921	4163	766	4556	639	5087	436	5944	330	3784
4-#18	4.00	2570	1348	4417	1036	5227	848	5826	688	6777	418	7826	241	6304
8-#7	1.20	1984	1023	2788	873	3281	734	3526	624	3731	461	4382	346	2193
8-#8	1.58	2047	1067	2953	899	3480	753	3763	636	4046	458	4789	323	2818
8-#9	2.00	2113	1116	3132	928	3697	774	4021	648	4391	455	5225	296	3490
8-#10	2.54	2197	1179	3356	966	3971	801	4349	665	4828	452	5772	261	4331
8-#11	3.12	2268	1246	3593	1000	4243	824	4663	677	5241	444	6211	208	5156
8-#14	4.50	2469	1406	4129	1096	4903	894	5453	719	6298	434	7454	103	7130
8-#18	8.00	2932	1812	5413	1343	6491	1070	7358	825	8841	406	10293	-195	9981
12-#10	3.81	2403	1326	3803	1066	4511	882	4999	719	5699	446	6980	187	6068
12-#11	4.68	2522	1427	4126	1122	4887	922	5439	743	6280	435	7612	112	7083
12-#14	6.75	2822	1667	4881	1272	5811	1034	6547	812	7764	419	9389	-42	9313
16-#10	5.08	2610	1473	4276	1167	5090	956	5692	767	6622	448	8194	109	7783

Appendix A-4: Hand Written Calculations

Note: This Link will return the user to the previous section.

Fellowship Hall



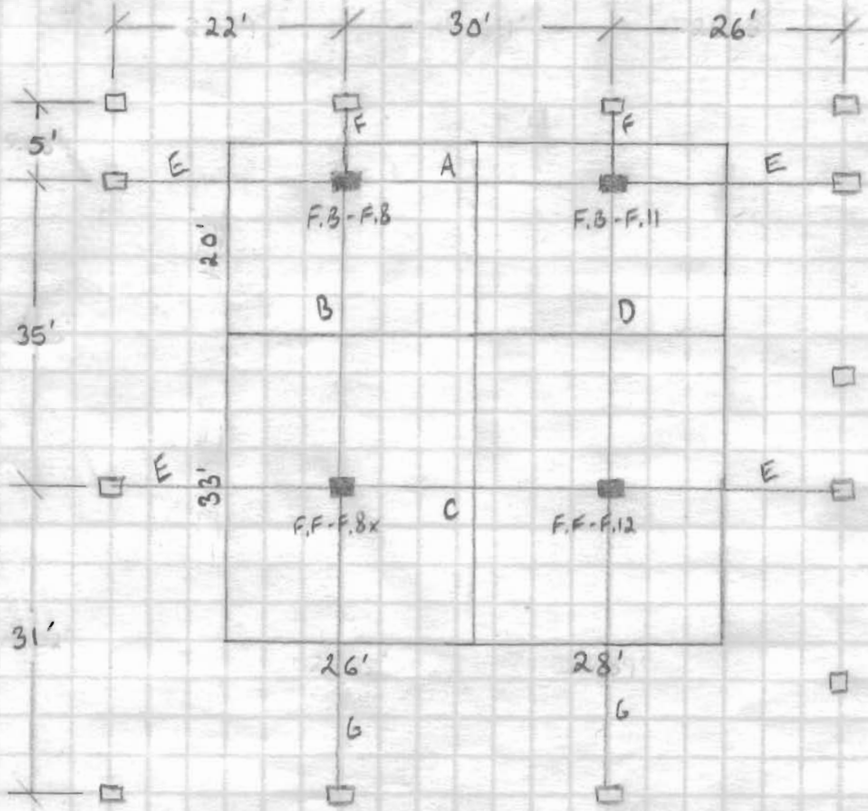
Design Columns

F.B - F.8
F.B - F.11
F.F - F.8x
F.F - F.12

Design Beams

F.B - F.8	to	F.B - F.11	(A)
F.B - F.8	to	F.F - F.8x	(B)
F.F - F.8x	to	F.F - F.12	(C)
F.B - F.11	to	F.F - F.12	(D)

Floor to Roof Height: 15'10"
Roof Live Load: 30 psf
Roof Concentrated Load: 300 lbs minimum
Flat Roof Snow Load: 17.5 psf
Superimposed Roof Dead Load: 20 psf
Concrete Design Strength: 5000 psi



$W_u = 1.2D + 1.6L = 1.2(20\ psf) + 1.6(30\ psf) = 72\ psf$

Beam A

Span Length = l_n = 30'
Trib. Area Load = (72 psf)(20') = 1440 plf
Beam Self Weight = (18")(12")(150 pcf)/(144 in/ft) = 225 plf

W_u = 1665 plf = 1.67 klf

pg 12-59 — 18" x 12" — Bottom: (2) #8 — Top: (2) #10 — Stirrups: 193E = (19) #3 : 1@2", 18@7" — Load: 1.81 klf

Beam B

Span Length = l_n = 35'
Trib. Area Load = (72 psf)(26') = 1872 plf
Beam Self Weight = (24")(16")(150 pcf)/(144 in/ft) = 400 plf

W_u = 2272 plf = 2.27 klf

pg 12-65 — 24" x 16" — Bottom: (2) #10 — Top: (3) #10 — Stirrups: 163H = (16) #3 : 1@2", 15@10" — Load: 2.80 klf

Beam C

Span Length = 30'
Trib. Area Load = (72 psf)(33') = 2376 plf
Beam Self Weight = (18")(16")(150 pcf)/(144 in/ft) = 300 plf

w_u = 2676 plf = 2.68 klf

pg 12-59 18" x 16" Bottom: (2) #10
Top: (3) #10
Stirrups: 203E = (20) #3 : 1@2", 19@7"
Load: 2.78 klf

Beam D

Span Length = 35'
Trib. Area Load = (72 psf)(28') = 2016 plf
Beam Self Weight = (24")(16")(150 pcf)/(144 in/ft) = 400 plf

w_u = 2416 plf = 2.42 klf

pg. 12-65 24" x 16" Bottom: (2) #10
Top: (3) #10
Stirrups: 163H = (16) #3 : 1@2", 15@10"
Load: 2.80 klf

Beam E

Span Length = 26'
Trib. Area Load = (72 psf)(33') = 2376 plf
Beam Self Weight = (18")(16")(150 pcf)/(144 in/ft) = 300 plf

w_u = 2676 plf = 2.68 klf

pg. 12-59 18" x 16" Bottom: (2) #10
Top: (3) #10
Stirrups: 183E = (18) #3 : 1@2", 17@7"
Load: 3.70 klf

Beam F

Span Length = 5'
Trib. Area Load = (72 psf)(28') = 2016 plf
Beam Self Weight = (12")(12")(150 pcf)/(144 in/ft) = 150 plf

w_u = 2166 plf = 2.17 klf

pg 12-52 12" x 12" Bottom: (2) #5
Top: (2) #6
Stirrups: 133B = (13) #3 : 1@2", 12@4"
Load: 2.72 klf

Beam G

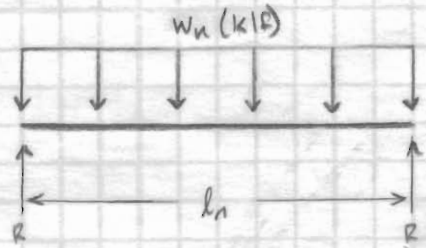
Span Length = 31'
Trib. Area Load = (72 psf)(28') = 2016 plf
Beam Self Weight = (24")(16")(150 pcf)/(144 in/ft) = 400 plf

w_u = 2416 plf = 2.42 klf

24" X 16"   Bottom: (2) #10   Stirrups: 153H = (15) #3: 1@2", 14@10"   pg 12-65
Top: (3) #10   Load: 3.55 klf

Beam A

ℓ_n = 30' w_u = 1.67 klf
R = (30')(1.67 klf)/2 = 25.05 k



Beam B

ℓ_n = 35' w_u = 2.27 klf
R = (35')(2.27 klf)/2 = 39.73 k

Beam C

ℓ_n = 30' w_u = 2.68 klf
R = (30')(2.68 klf)/2 = 40.2 k

Beam	Column Load (k)
A	25.05
B	39.73
C	40.20
D	42.35
E	34.84
F	5.43
G	37.51

Beam D

ℓ_n = 35' w_u = 2.42 klf
R = (35')(2.42 klf)/2 = 42.35 k

Beam E

ℓ_n = 26' w_u = 2.68 klf
R = (26')(2.68 klf)/2 = 34.84 k

Beam F

ℓ_n = 5' w_u = 2.17 klf
R = (5')(2.17 klf)/2 = 5.43 k

Beam G

ℓ_n = 31' w_u = 2.42 klf
R = (31')(2.42 klf)/2 = 37.51 k

Column F.B - F.8

P = A + B + E + F = 25.05 + 39.73 + 34.84 + 5.43 = 105.05 k

12" x 12"   (4) #6 rectangular, symmetrical
#3 Ties @ 7" min.

Column F.B - F.11

P = A + D + E + F = 25.05 + 42.35 + 34.84 + 5.43 = 107.67 k

12" x 12"   (4) #6 rectangular, symmetrical
#3 ties @ 7" min.

Column F.F - F.8x

P = B + C + E + G = 39.73 + 40.20 + 34.84 + 37.51 = 152.28 k

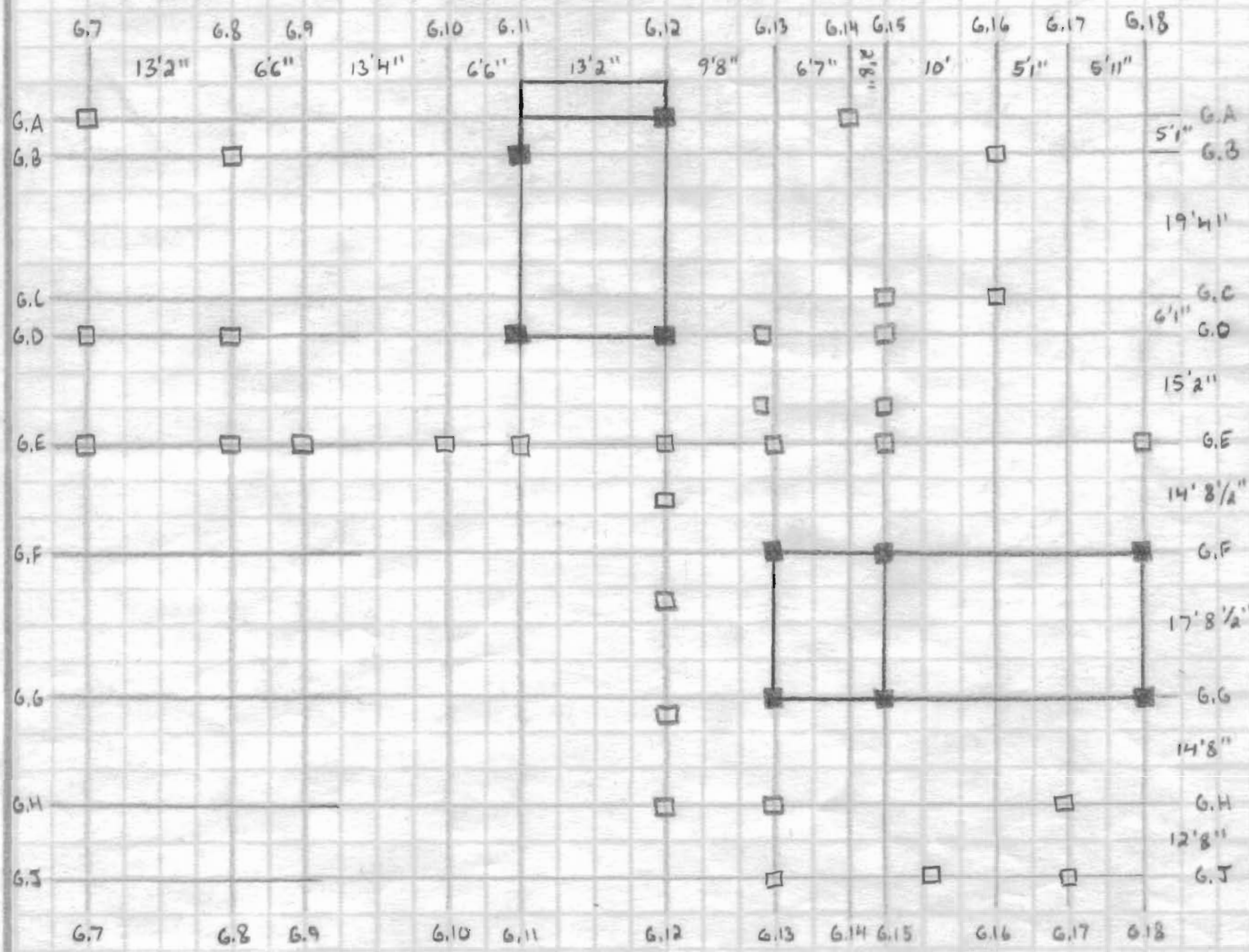
12" x 12"   (4) #6 rectangular, symmetrical
#3 ties @ 7" min.

Column F.F - F.12

P = C + D + E + G = 40.20 + 42.35 + 34.84 + 37.51 = 154.90 k

12" x 12"   (4) #6 rectangular, symmetrical
#3 ties @ 7" min.

CONVENT/MONASTERY



Design Column

G.A - G.12
G.B - G.11
G.D - G.11
G.D - G.12

G.F - G.13
G.F - G.15
G.F - G.18
G.G - G.13
G.G - G.15
G.G - G.18

Design Beam

G.B - G.11 (cant.)
G.A - G.12 (cant.)
G.B - G.11 to G.D - G.11
G.D - G.11 to G.E - G.11
G.D - G.11 to G.D - G.12
G.E - G.11 to G.E - G.12
G.A - G.12 to G.D - G.12
G.D - G.12 to G.E - G.12

G.F - G.13 to G.F - G.15
G.F - G.15 to G.F - G.18
G.G - G.13 to G.G - G.15
G.G - G.15 to G.G - G.18
G.F - G.13 to G.G - G.13
G.F - G.15 to G.G - G.15
G.F - G.18 to G.G - G.18

Floor to Floor Height: 13'2" [3rd Floor to Roof Height: 11'2"]
Floor Live Loads: Residential/Apartments: 60 psf
Public Rooms/Corridors: 100 psf
Roof Live Load: 30 psf
Roof Concentrated Load: 300 lbs minimum
Flat Roof Snow Load: 17.5 psf
Superimposed Roof Dead Load: 25 psf
Concrete Design Strength: 5000 psi

~~Superimposed Floor Dead Load~~

~~Typ. Floor Construction: 2" Metal Deck w/ 3¼" LW Concrete Topping~~

~~LW Concrete (90-115 pcf) ⇒ (3.25")/(12 in/ft)(115 pcf) = 31.15 psf~~
~~2" Metal Deck, 20 Gage ⇒ 2 psf~~
~~Miscellaneous Ceiling & Floor Components ⇒ 7 psf~~

~~Dead Load = 31.15 + 2 + 7 ≈ 40 psf~~

Redesigned Slab Below

Superimposed Exterior Wall Dead Load

1^{st} Floor – EWS-03CM

Anchored Stone Veneer	10 psf
5/8" Gypsum	2.75 psf
6" Metal Stud	3 psf
Glass Fiber Blanket Insulation	1 psf
4" Metal Stud	2 psf
5/8" Gypsum	2.75 psf
	22 psf

2^{nd} + 3^{rd} Floor – EWS-05CM

Portland Cement on Lath	10 psf
Metal Lath	2 psf
5/8" Gypsum	2.75 psf
4"-6" Metal Stud	3 psf
Glass Fiber Blanket Insulation	1 psf
	19 psf

pg. 10-29

Two-Way Solid Flat Slabs – Square Panels with Drops

Longest Clear Span = ℓ_n = 30'6"
Floor Live Load – Use Public Rooms/Corridors = 100 psf
Floor Dead Load = 10 + 20 = 30 psf (partitions and finishing materials)

$W_u = 1.2D + 1.6L = 1.2(30) + 1.6(100) = 196$ psf

Slab depth = 10.5" between drop panels

Edge Panel

Sq. Drop Panel – Depth: 8.25"
Width: 10.33'

Column Size: 17" sq. min.

Reinf. Column Strip – Top Ext.: (14) #5
Bottom: (13) #8
Top Int.: (27) #5

Reinf. Middle Strip – Bottom: (11) #7
Top Int.: (13) #6

Total Steel: 3.93 psf

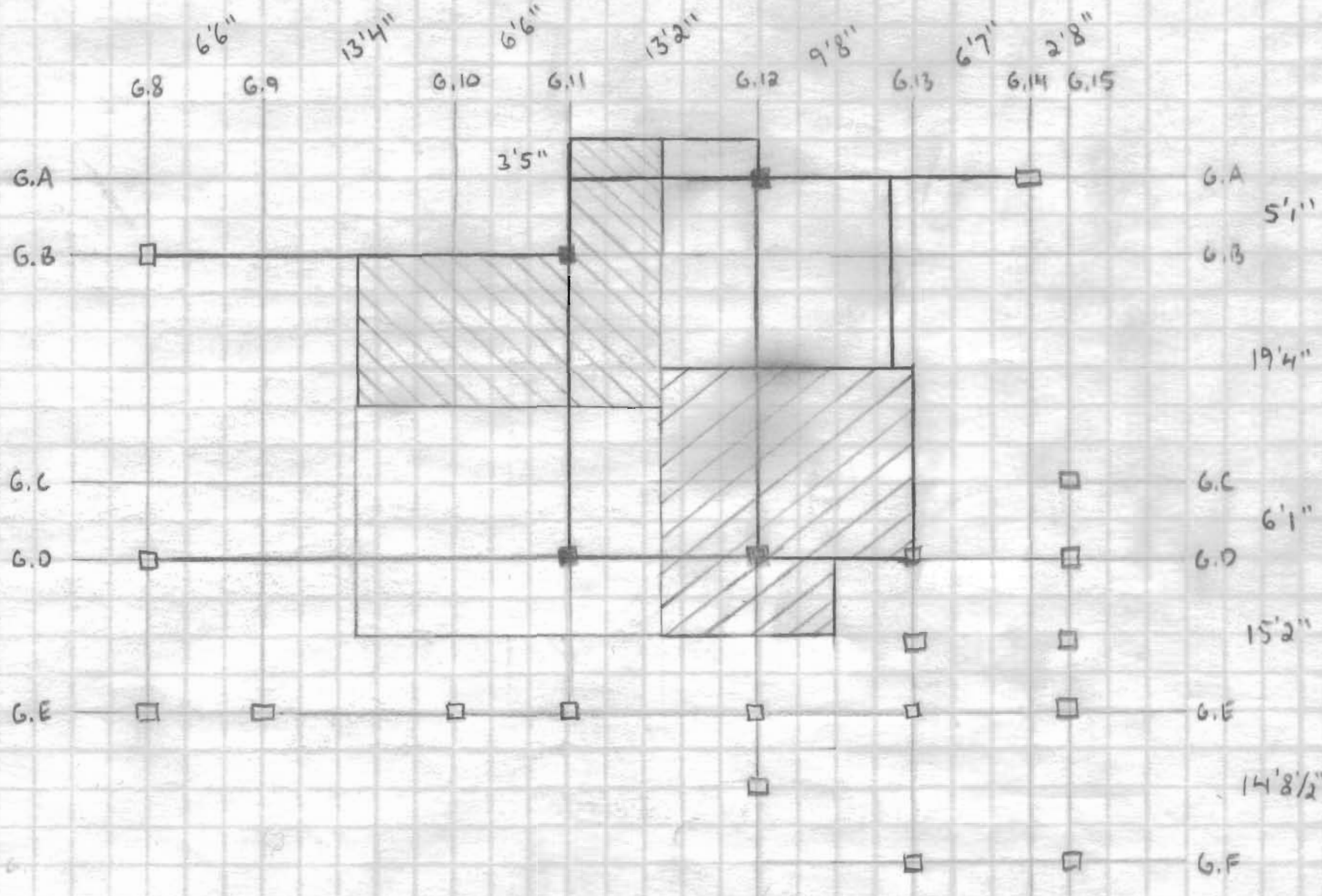
Interior Panel

Column Size: 20" sq. min.

Reinf. Column Strip
Top: (18) #6
Bottom: (11) #7

Reinf. Middle Strip
Top: (16) #5
Bottom: (14) #5

Total Steel: 3.41 psf



pg. 10-28

Two-Way Solid Flat Slabs - Square Panels with Drops

More Typical Span = ℓ_n = 20' or less
W_u = 196 psf
Slab Depth = 10.5" between drop panels (keep same)

Edge Panel
Sq. Drop Panel - Depth: 2.25"
Width: 7.00'
Column Size: 16" sq. min.
Reinf. Column Strip - Top Ext.: (10) #5
Bottom: (7) #6
Top Int.: (13) #5
Reinf. Middle Strip - Bottom: (8) #5
Top Int: (8) #5
Total Steel: 2.45 psf

Interior Panel
Column Size: 18" sq. min.
Reinf. Column Strip - Top: (12) #5
Bottom: (8) #5
Reinf. Middle Strip - Top: (8) #5
Bottom: (8) #5
Total Steel: 2.36 psf

3rd Floor Columns and Roof Beams

Beams

$W_u = 1.2D + 1.6L = 1.2(25) + 1.6(30) = 78$ psf

G.B - G.11 to G.D - G.11

Span Length: 25'5"
Trib. Area Load: (78 psf)(6'7" + 13'2") = 1540.5 plf
Beam Self Weight: (18")(12")(150 pcf)/(144 in²/ft²) = 225 plf

$W_u = 1540.5 + 225 = 1765.5$ plf $= 1.77$ klf

pg 12-59 18" x 12" Bottom: (2) #7 Stirrups: 153E = (15) #3: 1@2", 14@7"
Top: (2) #9 Load: 1.88 klf

G.D - G.11 to G.D - G.12

Span Length: 13'2"
Trib. Area Self Weight: (78 psf)(20'3.5") = 1582.75 plf
Beam Self Weight: (12")(12")(150 pcf)/(144 in²/ft²) = 150 plf

$W_u = 1582.75 + 150 = 1732.75$ plf $= 1.73$ klf

pg 12-52 12" x 12" Bottom: (2) #5 Stirrups: 143B = (14) #3: 1@2", 13@4"
Top: (2) #6 Load: 2.00 klf

G.D - G.12 to G.A - G.12

Span Length: 30'6"
Trib. Area Self Weight: (78 psf)(16'3") = 1267.5 plf
Beam Self Weight: (18")(12")(150 pcf)/(144 in²/ft²) = 225 plf

$W_u = 1267.5 + 225 = 1492.5$ plf $= 1.49$ klf

pg 12-65 18" x 12" Bottom: (2) #8 Stirrups: 193E = (19) #3: 1@2", 18@7"
Top: (2) #10 Load: 1.81 klf

G.B - G.11 Cantilevered End Span

Span Length: 10'
Trib Area Load: (78 psf)(6'7") = 513.5 plf
Beam Self Weight: (12")(12")(150 pcf)/(144 in²/ft²) = 150 plf

W_u = 513.5 + 150 = 663.5 plf = 0.66 klf

pg. 12-22 12" x 12" Bottom: (2) #5 Stirrups: 123B = (12) #3: 1@2", 11@4"
Top: (2) #5 Load: 1.79 klf

G.A - G.12 Cantilevered End Span

Span Length: 13'2"
Trib. Area Load: (78 psf)(10') = 780 plf
Beam Self Weight: (12")(12")(150 pcf)/(144 in²/ft²) = 150 plf

W_u = 780 + 150 = 930 plf = 0.93 klf

pg 12-22 12" x 12" Bottom: (2) #5 Stirrups: 133B = (13) #3: 1@2", 12@4"
Top: (2) #5 Load: 1.31 klf

G.B - G.8 to G.B - G.11 End Span

Span Length: 26'4"
Trib. Area Load: (78 psf)(12'8.5") = 991.25 plf
Beam Self Weight: (18")(12")(150 pcf)/(144 in²/ft²) = 225 plf

W_u = 991.25 + 225 = 1216.25 plf = 1.22 klf

pg 12-29 18" x 12" Bottom: (2) #8 Stirrups: 173E = (17) #3: 1@2", 16@7"
Top: (2) #8 Load: 1.30 klf

G.D - G.8 to G.D - G.11

Span Length: 26'4"
Trib. Area Load: (78 psf)(20'3.5") = 1582.75 plf
Beam Self Weight: (18")(12")(150 pcf)/(144 in²/ft²) = 225 plf

W_u = 1582.75 + 225 = 1807.75 plf = 1.81 klf

pg. 12-59 18" x 12" Bottom: (2) #8 Stirrups: 183E = (18) #3: 1@2", 17@7"
Top: (2) #10 Load: 2.08 klf

G.A - 6.12 to G.A - 6.14 End Span

Span Length: 16'3"
Trib. Area Load: (78 psf)(17'9.5") = 1387.75 plf
Beam Self Weight: (12")(12")(150 pcf)/(144 in²/ft²) = 150 plf

W_u = 1387.75 + 150 = 1537.75 plf = 1.54 klf

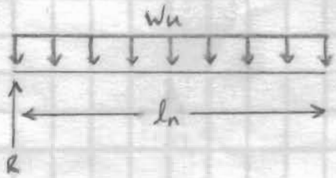
pg 12-22 12" x 12" Bottom: (3) #6 Stirrups: 233B = (23) #3: 1@2", 22@4"
Top: (2) #8 Load: 1.75 klf

G.D - 6.12 to G.D - 6.13

Span Length: 9'8"
Trib. Area Load: (78 psf)(12'8.5") = 991.25 plf
Beam Self Weight: (12")(12")(150 pcf)/(144 in²/ft²) = 150 plf

W_u = 991.25 + 150 = 1141.25 plf = 1.14 klf

12" x 12" Bottom: (2) #5 Stirrups: 133B = (13) #3: 1@2", 12@4"
Top: (2) #6 Load: 2.72 klf



G.B - 6.11 to G.D - 6.11

l_n = 25'5" W_u = 1.77 klf
R = (25'5")(1.77 klf)/2 = 22.5 k

G.D - 6.11 to G.D - 6.12

l_n = 13'2" W_u = 1.73 klf
R = (13'2")(1.73 klf)/2 = 11.4 k

G.D - 6.12 to G.A - 6.12

l_n = 30'6" W_u = 2.78 klf
R = (30'6")(2.78 klf)/2 = 42.4 k

G.B - 6.11 Cantilevered

l_n = 10' W_u = 0.66 klf
R = (10')(0.66 klf) = 6.6 k
M = (0.66 klf)(10')²/2 = 33 ft·k

G.A - 6.12 Cantilevered

l_n = 13'2" W_u = 0.93 klf
R = (13'2")(0.93 klf) = 12.2 k
M = (0.93 klf)(13'2")²/2 = 80.6 ft·k

G.B-6.8 to G.B-6.11	Beam	Column Load
	G.B - 6.11 to G.D - 6.11	22.5 k
	G.D - 6.11 to G.D - 6.12	11.4 k
	G.D - 6.12 to G.A - 6.12	42.4 k
	G.B - 6.8 to G.B - 6.11	16.1 k
	G.D - 6.8 to G.D - 6.11	23.8 k
	G.A - 6.12 to G.A - 6.14	12.5 k
	G.D - 6.12 to G.D - 6.13	5.5 k
	G.B - 6.11 Cantilevered	6.6 k 33 ft·k
	G.A - 6.12 Cantilevered	12.2 k 80.6 ft·k

G.B-6.8 to G.B-6.11

$\ell_n = 26'4''$ $w_u = 1.22$ klf
$R = (26'4'')(1.22 \text{ klf})/2 = 16.1$ k

G.D - 6.8 to G.D - 6.11

$\ell_n = 26'4''$ $w_u = 1.81$ klf
$R = (26'4'')(1.81 \text{ klf})/2 = 23.8$ k

G.A - 6.12 to G.A - 6.14

$\ell_n = 16'3''$ $w_u = 1.54$ klf
$R = (16'3'')(1.54 \text{ klf})/2 = 12.5$ k

G.D - 6.12 to G.D - 6.13

$\ell_n = 9'8''$ $w_u = 1.14$ klf
$R = (9'8'')(1.14 \text{ klf})/2 = 5.5$ k

Columns

G.B - 6.11

$P = 22.5 + 16.1 + 6.6 = 45.2$ k
$M = 33$ ft·k

12" x 12" (4) #6 square, symmetrical
#3 ties

G.D - 6.11

$P = 23.8 + 22.5 + 11.4 + [(78 \text{ psf})(9'10'')(15'2'')/2/1000] = 63.5$ k

12" x 12" (4) #6 square, symmetrical
#3 ties

G.D - 6.12

$P = 11.4 + 42.4 + 5.5 + [(78 \text{ psf})(15'2'')(11'5'')/2/1000] = 66.1$ k

12" x 12" (4) #6 square, symmetrical
#3 ties

G.A - 6.12

$P = 42.4 + 12.5 + 12.2 = 67.1$ k
$M = 80.6$ ft·k

12" x 12" (4) #6 square, symmetrical
#3 ties

2^{nd} Floor Columns and 3^{rd} Floor Beams

$W_u = 1.2D + 1.6L = 1.2(30 + [\frac{10.5}{12}(150)]) + 1.6(60) = 289.5$ psf

Beams [353.5 psf w/ 100 psf LL]

G.B - G.11 to G.D - G.11

Span Length: 25'5"
Trib. Area Load: (289.5 psf)(19'9") = 5717.625 plf
Beam Self Weight: (16.5")(36")(150 pcf)/(144 in²/ft²) = 618.75 plf

$W_u = 5717.65 + 618.75 = 6336.4$ plf = 6.34 klf

pg 12-101 JB 16.5" x 36" Bottom: (4)#10 Top: (5)#11 Stirrups: 203D = (20)#3: 1@2", 19@6" Load: 6.79 klf

G.D - G.11 to G.D - G.12

Span Length: 13'2"
Trib. Area Load: (289.5 psf)(20'3.5") = 5874.44 plf
Beam Self Weight: (12.5")(24")(150 pcf)/(144 in²/ft²) = 312.5 plf

$W_u = 5874.44 + 312.5 = 6186.94$ plf = 6.19 klf

pg 12-96 JB 12.5" x 24" Bottom: (5)#6 Top: (4)#8 Stirrups: 143C = (14)#3: 1@2", 13@5" Load: 7.05 klf

G.D - G.12 to G.A - G.12

Span Length: 30'6"
Trib. Area Load: (289.5 psf)(16'3") = 4704.38 plf
Beam Self Weight: (16.5 in)(36 in)(150 pcf)/(144 in²/ft²) = 618.75 plf

$W_u = 4704.38 + 618.75 = 5323.13$ plf = 5.32 klf

pg. 12-101 JB 16.5" x 36" Bottom: (4)#11 Top: (6)#11 Stirrups: 233D = (23)#3: 1@2", 22@6" Load: 5.73 klf

G.B - G.11 Cantilevered End Span

Span Length: 10'
Trib. Area Load: (289.5 psf)(6'7") = 1906 plf
Beam Self Weight: (12.5")(24")(150 pcf)/(144 in²/ft²) = 313 plf

Wu = 1906 + 313 + (13'2")(19 psf) = 2469 plf = 2.47 klf

pg 12-82 JB 12.5" x 24" Bottom: (3) #6 Top: (4) #5 Stirrups: 103C = (10) #3 : 1@2", 9@5" Load: 3.77 klf

G.A - G.12 Cantilevered End Span

Span Length: 13'2"
Trib. Area Load: (289.5 psf)(10') = 2895 plf
Beam Self Weight: (12.5")(24")(150 pcf)/(144 in²/ft²) = 313 plf

Wu = 2895 + 313 + (13'2")(19 psf) = 3458 plf = 3.46 klf

pg 12-82 JB 12.5" x 24" Bottom: (4) #6 Top: (4) #7 Stirrups: 143C = (14) #3 : 1@2", 13@5" Load: 4.21 klf

G.B - G.8 to G.B - G.11 End Span

Span Length: 26'4"
Trib. Area Load: (289.5 psf)(12'8.5") = 3679 plf
Beam Self Weight: (16.5")(36")(150 pcf)/(144 in²/ft²) = 619 plf

Wu = 3679 + 619 + (13'2")(19 psf) = 4548 plf = 4.55 klf

pg 12-87 JB 16.5" x 36" Bottom: (5) #11 Top: (5) #11 Stirrups: 253D = (25) #3 : 1@2", 24@6" Load: 5.32 klf

G.D - G.8 to G.D - G.11

Span Length: 26'4"
Trib. Area Load: (289.5 psf)(20'3.5") = 5874 plf
Beam Self Weight: (16.5")(36")(150 pcf)/(144 in²/ft²) = 619 plf

Wu = 5874 + 619 = 6493 plf = 6.49 klf

pg 12-101 JB 16.5" x 36" Bottom: (4) #11 Top: (6) #11 Stirrups: 223D = (22) #3 : 1@2", 21@6" Load: 6.58 klf

G.A-6.12 to G.A-6.14 End Span

Span Length: 16'3"
Trib. Area Load: (289.5 psf)(17'9.5") = 5151 plf
Beam Self Weight: (12.5")(36")(150 pcf)/(144 in²/ft²) = 469 plf

W_u = 5151 + 469 + (13'2")(19 psf) = 5870 plf = 5.87 klf

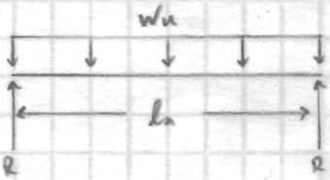
pg 12-82	JB	12.5" x 36"	Bottom: (11) #6 Top: (5) #10	Stirrups: 203C = (20) #3: 1@2", 19@5" Load: 6.61 klf

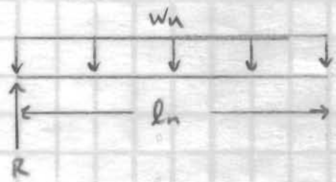
G.D-6.12 to G.D-6.13

Span Length: 9'8"
Trib. Area Load: (289.5 psf)(12'8.5") = 3679 plf
Beam Self Weight: (12.5")(24")(150 pcf)/(144 in²/ft²) = 313 plf

W_u = 3679 + 313 = 3992 plf = 3.99 klf

pg 12-96	JB	12.5" x 24"	Bottom: (3) #6 Top: (4) #6	Stirrups: 113C = (11) #3: 1@2", 10@5" Load: 5.73 klf





G.B-G.11 to G.D-G.11

l_n = 25'5" W_u = 6.34 klf
R = (25'5")(6.34 klf)/2 = 80.6 k

G.D-G.11 to G.D-G.12

l_n = 13'2" W_u = 6.19 klf
R = (13'2")(6.19 klf)/2 = 40.8 k

G.D-G.12 to G.A-G.12

l_n = 30'6" W_u = 5.32 klf
R = (30'6")(5.32 klf)/2 = 81.1 k

G.B-G.11 Cantilevered

l_n = 10' W_u = 2.47 klf
R = (10')(2.47 klf)/2 = 12.4 k
M = (2.47 klf)(10')²/2 = 123.5 ft·k

G.A-G.12 Cantilevered

l_n = 13'2" W_u = 3.46 klf
R = (13'2")(3.46 klf)/2 = 22.8 k
M = (3.46 klf)(13'2")²/2 = 299.9 ft·k

G.B-6.8 to G.B-6.11

$l_n = 26'4''$ $W_u = 4.55$ klf
$R = (26'4'')(4.55\text{ klf})/2 = 59.9$ k

G.D-6.8 to G.D-6.11

$l_n = 26'4''$ $W_u = 6.49$ klf
$R = (26'4'')(6.49\text{ klf})/2 = 85.5$ k

G.A-6.12 to G.A-6.14

$l_n = 16'3''$ $W_u = 5.87$ klf
$R = (16'3'')(5.87\text{ klf})/2 = 47.7$ k

G.D-6.12 to G.D-6.13

$l_n = 9'8''$ $W_u = 3.99$ klf
$R = (9'8'')(3.99\text{ klf})/2 = 19.3$ k

Beam	Column Load
G.B-6.11 to G.D-6.11	80.6 k
G.D-6.11 to G.D-6.12	40.8 k
G.D-6.12 to G.A-6.12	81.1 k
G.B-6.8 to G.B-6.11	59.9 k
G.D-6.8 to G.D-6.11	85.5 k
G.A-6.12 to G.A-6.14	47.7 k
G.D-6.12 to G.D-6.13	19.3 k
G.B-6.11 Cantilevered	12.4 k 123.5 ft·k
G.A-6.12 Cantilevered	22.8 k 299.9 ft·k

CD/3-1

Columns

G.B-6.11
$P = 59.9 + 80.6 + 12.4 = 152.9$ k $+ 45.2$ k $= 198.1$ k
$M = 123.5$ ft·k $+ 33$ ft·k $= 156.5$ ft·k

12" x 12" (4) #6 square, symmetrical
#3 ties

G.D-6.11
$P = 80.6 + 40.8 + 85.5 + [(353.5\text{ psf})(9'10'')(15'2'')/2/1000] = 233.3$ k $+ 63.5$ k $= 296.8$ k

12" x 12" (4) #6 square, symmetrical
#3 ties

G.D-6.12
$P = 40.8 + 81.1 + 19.3 + [(353.5\text{ psf})(15'2'')(11'5'')/2/1000] = 171.8$ k $+ 66.1$ k $= 237.9$ k

12" x 12" (4) #6 square, symmetrical
#3 ties

G.A-6.12
$P = 81.1 + 47.7 + 22.8 = 151.6$ k $+ 67.1$ k $= 218.7$ k
$M = 299.9$ ft·k $+ 80.6$ ft·k $= 380.5$ ft·k

12" x 12" (4) #6 square, symmetrical
#3 ties

co/3-1

1st Floor Columns

[2nd Floor Beams are the same as 3rd Floor Beams]

G.B - G.11

$P = 59.9 + 80.6 + 12.4 = 152.9 + 198.1 = 351$ k
$M = 123.5$ ft·k

12" x 12"   (4) #6 square, symmetrical
#3 ties

G.D - G.11

$P = 80.6 + 40.8 + 85.5 + 26.4 = 233.3 + 296.8 = 530.1$ k

12" x 12"   (8) #9 square, symmetrical
#3 ties

G.D - G.12

$P = 40.8 + 81.1 + 19.3 + 30.6 = 171.8 + 237.9 = 409.7$ k

12" x 12"   (4) #9 square, symmetrical
#3 ties

G.A - G.12

$P = 81.1 + 47.7 + 22.8 = 151.6 + 218.7 = 370.3$ k
$M = 299.9$ ft·k

12" x 12"   (4) #7 square; symmetrical
#3 ties

All columns need to be increased to:

20" x 20"   (4) #9 square symmetrical
#3 ties

In order to meet requirements set by elevated slab.

Since the exterior wall is separated by floor, moment does not transfer from upper columns to lower columns.