REDLAND TECHNOLOGY CENTER

540 Gaither Road, Rockville, MD

Shawn Pepple
Construction Management

Final Thesis Report
April 7, 2009
Dr. Messner

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REDLAND TECHNOLOGY CENTER

Rockville, MD

Owner: Perseus Realty, LLC

CM: Clark Construction Group, LLC

Architect: DNC Architects, Inc.

MEP Engineer: Meta Engineers, P.C.

Structural Engineer: SK&A, P.A.

Delivery Method: Design-Bid-Build

Cost: $ 52,800,000 negotiated GMP

Construction Dates: December 2007 - May 2009

Architecture

- 3 building office complex with parking garage built in 2 phases, building 1 built in 2004
- 24.5 acre site near I-270 corridor and Shady Grove Metro station of Washington D.C.
- Building 2: 9 levels, 210,240 SF
  Building 3: 6 levels, 136, 430 SF
  Parking Garage: 6 levels, 314,600 SF
- Architectural precast façade with ribbons windows, curtain wall, stone medallion accents
- State-of-the-art fitness center and café
- Fully adhered EPDM rubber sheet membrane roofing system
- Work of renowned Washington D.C. glass artist Mindy Weisel to be displayed in lobbies
- Pursuing LEED Silver certification

Mechanical

- Self-contained air conditioning units on each floor with typical capacity of 24,750 CFM
- Three 293 ton water cooling towers on roof
- Medium pressure ductwork
- Variable air volume units to control environment in tenant areas efficiently
- Separate heat pump units for café, fitness center, and elevator machine room

Structural

- Structural steel framing with 3" composite metal deck and 3" lightweight concrete slab
- Typical bay size is 30'-0" x 30'-0"
- Braced frames to resist lateral loads
- 5" normal weight slab-on-grade with grade beams and 46 caissons
- 13'-4" typical floor-to-floor height
- Open floor plans, column free corners

Electrical

- Two 2500A, 460Y/265V feeds to building
- Two 2000A, 460Y/265V copper bus ducts supply power to upper floors
- Three transformers to step power down to 208Y/120 for tenant use
- 600KW, 480Y/277 diesel generator set
- 277V Lithonia luminaries

Construction

- Existing 140,000 sqft. parking lot demolished
- Close proximity to residential neighborhood and office buildings, noise ordinances
- 150 daily average construction workers onsite

Shawn Pepple

Construction Management Option

www.engr.psu.edu/ae/thesis/portfolios/2009/sap5001

2.0 ACKNOWLEDGMENTS

I would like to thank the following people for their help and support throughout my senior thesis:

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Clark Construction

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- Ed Suchodolski

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- Alla Ketsnelson

WSP Flack + Kurtz

- Albert Flaherty

Tindall Corporation

- Jeff Lepard
- Chirs Kelleher

Friends and Family

- Couldn't have made it without you

3.0 Executive Summary

This senior thesis report provides background information on Redland Technology Center, along with in-depth research and analyses of the construction and technical aspects of the project. One theme carried throughout the report is energy efficiency.

As part of the critical industry research in this thesis, chilled beam mechanical systems were researched as a potential new technology to be more energy efficient. Results were very positive for chilled beams with the only major downside being that the technology is unfamiliar. Case studies were discovered that detailed buildings with savings in energy of up to 40%. Initial costs tend to hold back chilled beams from potential installation as they cost 5-15% more than all air systems. Chilled beams have been proven to have a payback period of less than 5 years.

To further learn about chilled beams, this first analysis applied the lessons learned in the critical industry research about chilled beams to Redland Technology Center. Cost analysis showed that chilled beams would be more expensive initially than the VAV system used for the project. However, savings in energy consumption could potentially be up to $133,713 per year. The chilled beam system reduced the ductwork by 70% and eliminated the self contained AHUs on each floor, providing more valuable office leasing space. Payback period for the chilled beams systems was less than one year.

The second analysis of this thesis focused on the feasibility of saving energy whenever the wire size for electrical circuits are upsized beyond the National Electric Code minimum size. The analysis proved that it is feasible in some scenarios, it works best whenever the loads consistently high. Data center equipment, large constant speed motors, and HVAC chillers are potential areas where this technique can be implemented successfully. Payback for the larger wire size can be as little as 2 years.

The third and final analysis of this thesis used a 4D BIM model to resequence the parking garage at Redland Technology Center. Through the BIM model, a revised sequence was formulated that would have allowed the project team to complete the construction of the parking garage 43 days earlier than with the original construction sequence. The resequencing also allowed the site work to be completed before the cold winter months of January and February.

4.0 Project Information

The Redland Technology Center is a three building office complex in Rockville, MD. The first building was constructed in 2004 by Davis Construction. Clark Construction is currently building the remaining two office buildings and a parking garage. The new construction at the Center will add 350,000 SF of office space whenever it is completed in May 2009.

The total project cost is $52,800,000 with a negotiated GMP contract between Clark Construction and Perseus Realty, the developer of the project. The project is being delivered as a Design-Bid-Build.

Building II is 9 levels and has a total area of 210,240 SF. Building III, which is a mirror image of Building I that was built in 2004, is 6 levels and has a total area of 136,430 SF.

5.0 Project Schedule Summary

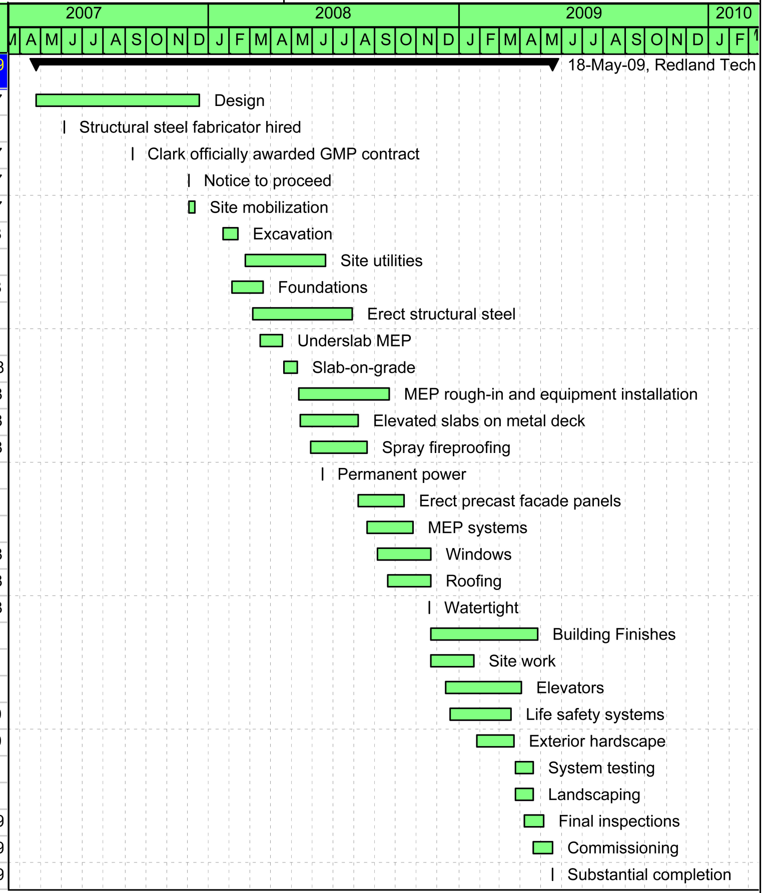
DNC Architects performed 4 months of preliminary design for the project in 2004 following the completion of phase 1 of the Redland Tech Center complex. Whenever the project was given notice to proceed in early 2007 by Perseus Realty, DNC resumed up with the preliminary design and was able to deliver construction documents in 8 months.

Clark was able to sign the steel fabricator under contract because of their early involvement in the preconstruction process. This allowed the steel fabricator to place its order for steel and prepare to fabricate this long lead time item. The start date of the construction was moved earlier due to the earlier steel delivery.

Clark was given a notice to proceed in December 2007 and immediately started work on the site. Site excavation and foundations were completed by March 21, 2008. In that time, 15,000 CY of soil were excavated and 46 caissons were drilled. Structural steel erection took almost 5 months to complete by the end of July 2008, erecting 1,300 tons for Building 2. The building is scheduled to be watertight by November 20, 2008, after which the interior finishing trades can commence their work. Final inspections and commissioning will take most of the April and May 2009 with substantial completion expected May 18, 2009.

Please view the project schedule summary on the next page.

Activity ID	Activity Name	Original Duration	Start	Finish
Redland Tech Center		541	23-Apr-07	18-May-09
A1000	Design	172	23-Apr-07	18-Dec-07
A1010	Structural steel fabricator hired	0	04-Jun-07	04-Jun-07
A1020	Clark officially awarded GMP contract	0	12-Sep-07	12-Sep-07
A1030	Notice to proceed	0	03-Dec-07	03-Dec-07
A1040	Site mobilization	7	03-Dec-07	11-Dec-07
A1050	Excavation	15	23-Jan-08	12-Feb-08
A1060	Site utilities	85	25-Feb-08	20-Jun-08
A1070	Foundations	35	04-Feb-08	21-Mar-08
A1080	Erect structural steel	106	05-Mar-08	30-Jul-08
A1090	Underslab MEP	25	17-Mar-08	18-Apr-08
A1100	Slab-on-grade	15	21-Apr-08	09-May-08
A1110	MEP rough-in and equipment installat...	96	12-May-08	22-Sep-08
A1120	Elevated slabs on metal deck	60	15-May-08	06-Aug-08
A1130	Spray fireproofing	60	29-May-08	20-Aug-08
A1140	Permanent power	0	17-Jun-08	17-Jun-08
A1150	Erect precast facade panels	48	08-Aug-08	14-Oct-08
A1160	MEP systems	50	19-Aug-08	27-Oct-08
A1170	Windows	56	04-Sep-08	20-Nov-08
A1180	Roofing	45	19-Sep-08	20-Nov-08
A1190	Watertight	0	20-Nov-...	20-Nov-08
A1200	Building Finishes	112	21-Nov-...	27-Apr-09
A1210	Site work	45	21-Nov-...	22-Jan-09
A1220	Elevators	80	12-Dec-...	02-Apr-09
A1230	Life safety systems	65	19-Dec-...	19-Mar-09
A1240	Exterior hardscape	40	27-Jan-09*	23-Mar-09
A1250	System testing	20	24-Mar-...	20-Apr-09
A1260	Landscaping	20	24-Mar-...	20-Apr-09
A1270	Final inspections	20	07-Apr-09*	04-May-09
A1280	Commissioning	20	21-Apr-09*	18-May-09
A1290	Substantial completion	0	18-May-...	18-May-09



Actual Work | Critical Remaining Work | Summary
Remaining Work | Milestone

TASK filter: All Activities

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6.0 Building Systems Summary

6.1 Structural Steel

Redland Tech Center Building 2 is a 9 story structural steel office building with a braced frame to resist lateral loads. The steel fabricator and erector, Strait Steel, Inc. of Greencastle, PA, erected the 1,300 tons of steel in Building 2 in 3 months with a 150-ton crawler crane. Due to the size of crane used and sequencing method, Strait was able to use one pick location and lay down area during the erection of Building 2. The typical column size of the structure ranges from a W14x311 section at the first floor to a W14x43 section at the penthouse level. The typical beam size is a W21x44. Typical bay size is 30’ x 30’. Building 2 uses a 3” composite metal deck system for the elevated floor slabs. Building 2 has 3 braced frames in the West-East direction and 2 braced frames in the North-South direction. Each braced frame uses 12” pipe in conjunction with the beams and columns to complete the lateral resisting system.

6.2 Cast-in-Place Concrete

The extent of cast-in-place (CIP) concrete work for Building 2 is limited to the caissons, grade beams, slab-on-grade (SOG), and elevated slabs. There are 46 caissons in Building 2 with a diameter ranging from 30” to 78”. The caissons used 3,500 psi concrete. Typical caisson depth is approximately 30’. The grade beams also used 3,500 psi concrete and ran only between the outer perimeter of columns. The SOG is a 5” thick normal weight concrete slab. The elevated slabs are a composite metal deck system with 3” thick deck and 3” thick light weight concrete. A pump truck was used to place all concrete.

6.3 Precast Concrete

Arban and Carosi, Inc. supplied the architectural precast façade panels for Building 2. There were 292 panels needed to cover the exterior of the building. All the panels were cast in Arban’s yard in Woodbridge, VA. The panels were erected by a 50-ton truck crane with a 150’ boom and a 50’ jib. Arban worked in a clockwise manner around the building and positioned the crane as needed to best erect the panels. The panels use bolted connections to connect to the clips welded to the steel structure.

6.4 Mechanical System

Each floor of the building has its own mechanical room with a self-contained air conditioning unit (SCU) to control the environment in the tenant and common spaces. Each SCU flows on average 24,750 CFM. There are 3 water cooling towers on the roof. This system uses forced air through medium pressure ductwork to supply conditioned air to the building. Variable air volume (VAV) units are used throughout each floor to meet the tenant’s needs more efficiently. There are separate heat pump systems for the café, fitness center, and elevator machine room.

6.5 Electrical System

Two 2,500 amp, 480Y/277V service feeders provide electricity to the building. Each service runs into a common electrical room on the first floor where the power is distributed throughout the building. Two 2,000 amp, 480Y/277V copper bus ducts supply power to the upper floors. There are three transformers to step power down to 208Y/120 for tenant use. A 600KW, 480Y/277 diesel generator is located in a separate structure behind the building and will provide emergency power should the power grid fail. Lighting fixtures are mostly 277V fixtures manufactured by Lithonia.

6.6 Curtain Wall

Building 2, unlike Building 1 and 3, has extensive curtain wall on its front façade, along with ribbon windows on the other three faces of the building. Only Building 2 has the curtain wall because it is the feature building of the complex and is meant to stand out from the other two buildings. The system includes prefinished aluminum frames with green tinted glazing. Depending on the location of each piece of glazing, the transparency of the glazing varies. The glazing is less transparent at floor level to block the view of the concrete slabs from the outside of the building. The curtain wall and ribbon windows were installed from the exterior of the building with workers working from swing stages. Due to the simplicity of the curtain wall for this project, the architect was able to design the system without needing a design-build contractor like some other complex projects would need.

7.0 Project Cost Evaluation

All cost information in this evaluation is data from Clark Construction's budget for the Redland Tech project.

7.1 Actual Building Construction Cost

Total square footage of the project is 210,240 SF

Construction Cost	$22,409,286
CC/SF	$106.59/SF

Construction costs do not include land costs site work, permitting, etc.

7.2 Total Project Cost

Total Project Cost (TC)	$25,025,270
TC/SF	$122.30/SF

7.3 Building Systems Costs

Cast-in-Place Concrete (CIPC)	$1,701,700
CIPC/SF	$8.09/SF

Architectural Precast Façade Cost (PFC)	$1,925,000
PFC/SF	$9.16/SF

Structural Steel Cost (SSC)	$2,921,200
SSC/SF	$13.89/SF

Glass and Glazing Cost (GGC)	$3,000,000
GGC/SF	$14.27/SF

Elevator Cost (ELC)	$1,100,000
ELC/SF	$5.23/SF

Mechanical/Plumbing Systems Cost (MC)	$3,095,910
MC/SF	$14.73/SF

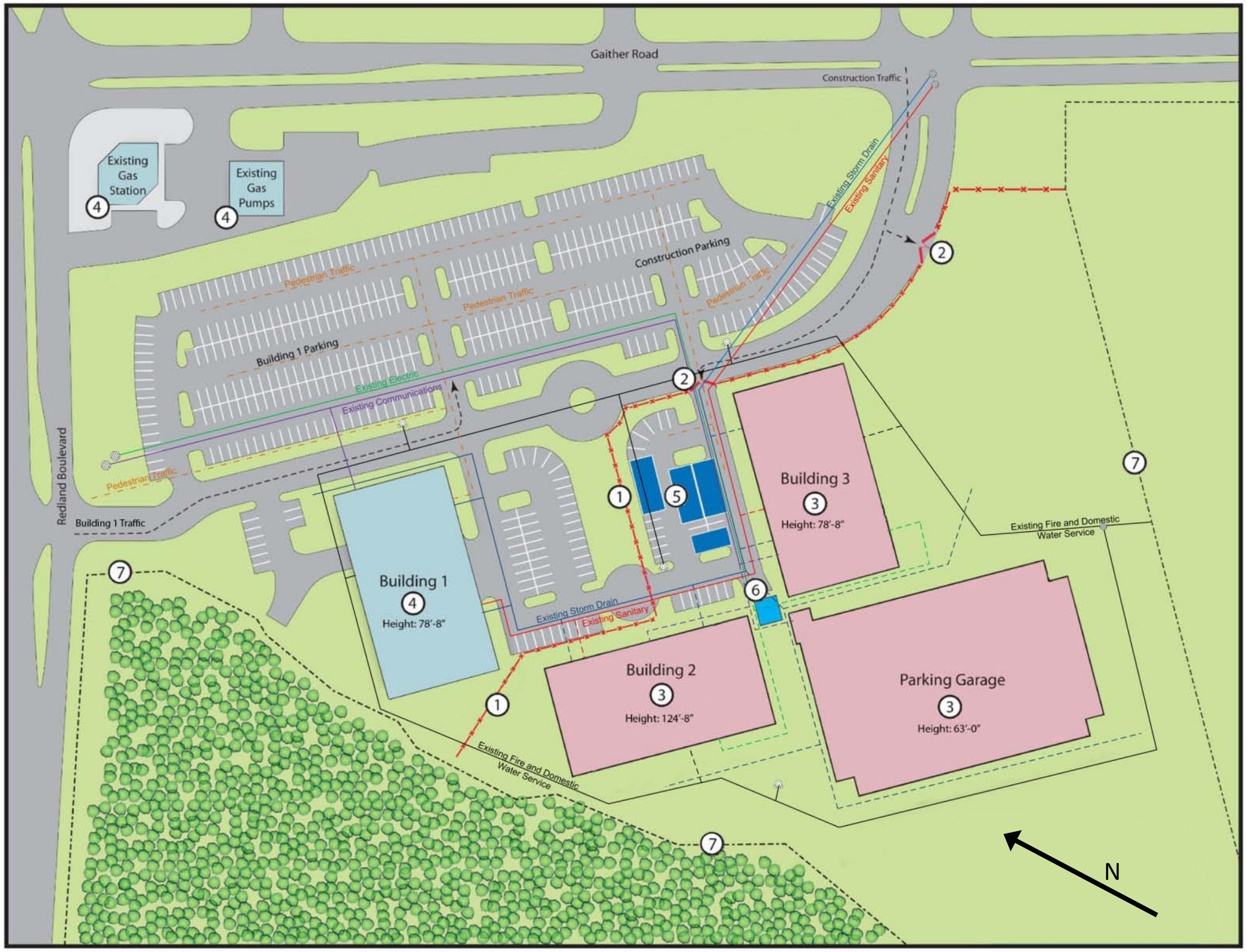
Electrical Systems Cost (EC)	$1,462,809
EC/SF	$6.96/SF

8.0 SITE PLAN OF EXISTING CONDITIONS

The Redland Tech Center is located ½ mile off I-270, exit 8, which allows easier access to the site for construction deliveries and workers. During the height of precast deliveries for the buildings and parking garage, there will be 30 tractor-trailer deliveries per day. This will create congestion on the site that needs to be managed by Clark to not be bothersome to Building 1's occupants and the surrounding community. A review of the site plan show an expansive site, but space will be very limited during peak delivery times.

Whenever Building 1 was constructed in 2004, the contractor on the job installed most of the utilities for the complex at that time. Tie-ins to the existing system will need to be coordinated with Building 1's occupants to not interrupt their utility services.

Please view the site plan of existing conditions on the next page.



Redland Technology Center

Rockville, MD

Site Plan of Existing Conditions

Legend

1. Construction Fence
2. Construction Entrance & Gate
3. Buildings Under Construction
4. Existing Building
5. Trailer
6. Temporary Power Location
7. Existing Fence Line

9.0 LOCAL CONDITIONS

Construction in the Washington D.C. metro area is predominately cast-in-place (CIP) concrete with post tensioned elevated slabs. This trend stems from Washington D.C. having a height restriction for new buildings. A CIP post tensioned concrete structure is able to have more floors than similarly tall steel structured buildings. Structural steel projects are not common in the area which results in few companies in the area capable of fabricating the steel and erecting it.

Onsite parking is shared with the occupants of Building 1. While there is more parking than at a typical project in downtown D.C., the lot is at maximum capacity almost every day. Construction workers are encouraged to carpool when possible and to park their vehicles on the surrounding neighborhood streets. The onsite lot has ticketed parking, but construction workers can stamp their tickets inside the Clark construction trailer and park for free.

The project site is located in the middle of a residential neighborhood and beside the occupied Building 1 office building. During construction, Clark needs to be sensitive to the community environment around it. There are noise ordinances in effect between 7 pm and 7 am through the weekdays and between 5 pm and 10 am on the weekend. There are many construction material deliveries to the site and Clark needs to ensure that they do not block the flow of traffic through the community and especially through the parking lot shared with Building 1.

Northern Virginia Waste (NOVA) is the provider of dumpster and recycling services for the Redland project. One dumpster is onsite at all times and is pulled as needed. NOVA takes the dumpster back to their facilities and sorts, recycles, and furnishes reports of the materials. The reports are need to obtain LEED credits in construction waste management. NOVA's reports have the tonnage of each material in the dumpster and how much of the material was recycled. NOVA charges $100 to pull the dumpster and approximately $80/ton to dispose of the material.

Geotechnical reports of the site show existing fill which contains a mixture of silt and clay, with varying amounts of organic debris, which was encountered up to depths of about 13 feet below existing site grades. Much of this material is believed to be part of an old stockpile placed during the site development of an adjacent property. Below the fill or topsoil, the natural soils consist of loose to very dense silt or sandy silt, or very stiff to very hard silty clay. Groundwater was recorded at depths of 23.5 to 49 feet below existing site grades. Variations in the location of the long-term water table may occur as a result of changes in precipitation, evaporation, and surface water runoff.

10.0 Client Information

The owner of the Redland Tech Center project is Perseus Realty, LLC of Washington D.C. Perseus is a relatively new company; it was founded in early 2004 by Perseus president Robert Cohen. Perseus's initial corporate strategy was to buy and manage commercial property. More recently Perseus has expanded their portfolio of capabilities to include office, industrial, retail and residential development. Perseus's first new construction development project is the Redland Tech Center. They now have another mixed-use building in the design phase that will be constructed In the near future. Perseus saw new project development as a way to grow their company and capitalize on the strong office and retail space needs of the Washington D.C. area.

The Redland Tech Center will be above average quality, Class A office space. Many materials have been specified, such as stone and stainless steel, to attract higher end tenants to the complex. Perseus expects a brisk delivery schedule, which is part of the reason Clark was selected as the contractor for the project. Clark was able to build the two buildings and the parking garage simultaneously. Obtaining a LEED Silver rating is the goal of Perseus for the project.

11.0 PROJECT DELIVERY SYSTEM

Redland Tech Center was delivered as a design-bid-build (traditional) project. A traditional delivery method was selected by the project team due to the size and type of project and also because of the owner's construction experience. Clark Construction, LLC was the construction manager at risk on the project. Clark was awarded the contract as the CM @ risk in September 2007 after negotiations on the GMP contract price. Clark provided some preconstruction services to the owner and architect during the design process including estimates, scheduling, and constructability reviews. Due to Clark's early involvement with the project team, Clark was able to bring the structural steel and structural precast fabricators (for the precast garage) on board early and start the process of fabricating the materials needed for the project. This was essential to the quick transition from design to construction and will enable the project team to deliver the project to the owner earlier than originally expected. Please view Figure 1 below for the project organization chart.

Clark Construction was selected as the contractor due to three main reasons. First, two other contractors of the Washington D.C. area were considered to build the project. Only Clark was able to build both office buildings and the parking garage of Phase 2 at the same time. This led to the entire project being finished sooner. Second, Clark's contingency and fee was lower than the competitors. Third, while this was Perseus Realty's first construction project that they built, many of the employees and executives of Perseus had experience with Clark at previous companies. This led to the belief that it was in their best interest to select a contractor they were familiar with and that they knew would be able to construct the project successfully.

A GMP contract between Perseus and Clark was the best solution to the fast paced design and construction startup. Clark was able to start procuring the subcontractors and getting ready to build the project while DNC was finalizing details in areas such as finishes, bathrooms, and landscaping. Clark assigned allowances to these details in their GMP contract price that will be settled after the drawings and specifications for the allowances are released and given a true construction value. There is a savings clause to the GMP contract that shares the savings between Perseus and Clark.

Clark awarded its contracts to their subcontractors mostly through a low-bidder process. However, if Clark felt a sub for a trade had a better overall value, they may have awarded the contract to a higher priced sub. Clark has lump sum contracts with all their subcontractors on the project. As the final details are released for construction, Clark will issue a change order to each of the subs affected by the design allowance.

Clark has a general liability insurance policy for the project of $17 million coupled with an excess umbrella liability insurance policy of $25 million. The umbrella policy allows Clark to protect itself further from excessive claims over the $17 million liability coverage of the general policy. Clark has a $2 million automotive policy for all the jobsite vehicles. The liability insurance coverage required by Clark for the subcontractors varies for each sub between $2 and $5 million. Clark has Subguard, a subcontractor surety bond, to manage the risk of subcontractor or supplier default. Clark pays 1% of each subcontractor's contract for the surety bond.

The contract types selected for this project seem to be logical and the best option for the project. Clark's GMP contract allowed them to get work started early and buy long lead items such as steel and granite early to avoid schedule growth and cost escalation. The lump sum low-bid contracts Clark had with their subs kept costs down and enabled them to deliver the project to the owner with the best value possible. Figure 1 below shows the project team at the Redland Tech Center.

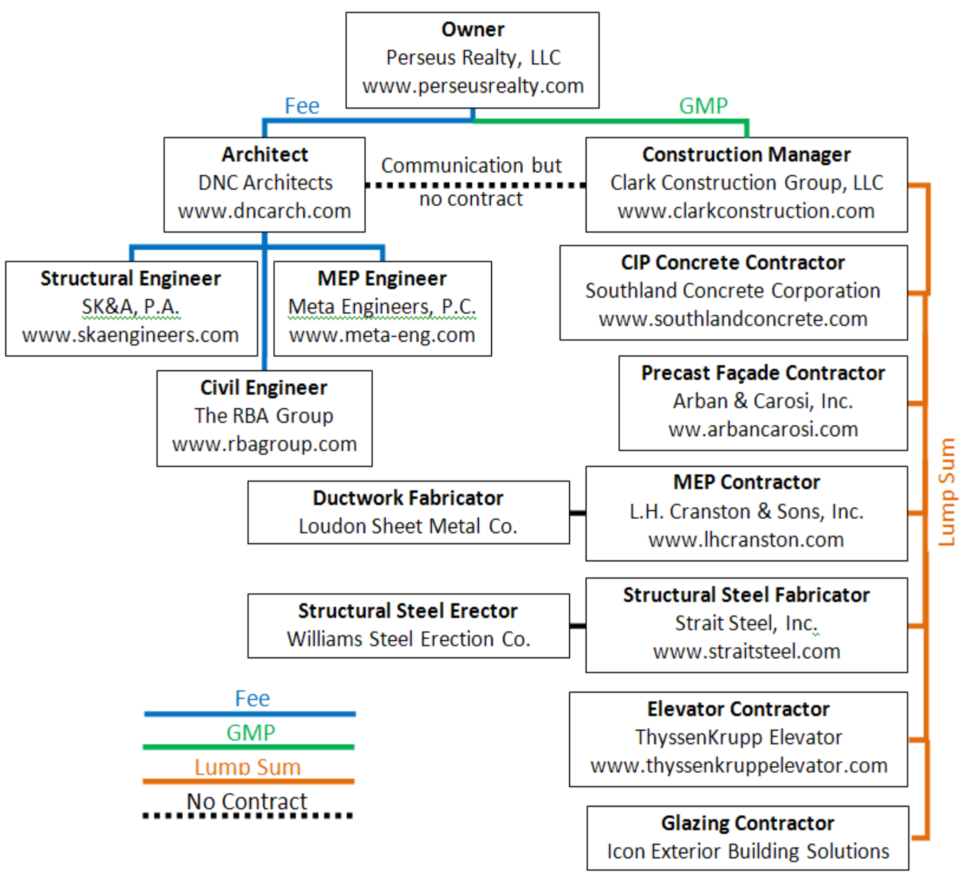


Figure 1 – Project Team at the Redland Tech Center

12.0 Critical Industry Research – Chilled Beam HVAC Systems (MAE)

12.1 Background

Electricity prices over the past 5 years have increased by close to 75% at peak times in July 2008. As a result of this, the energy efficiency of buildings has become more scrutinized. Inefficient buildings result in not only costing the owner of the building more to operate, but also puts the owner more at risk to price fluctuations and increases, decreasing their bottom line profits. Energy efficiency was discussed at the 2008 PACE Roundtable during the Energy & Economy break-out session. One topic that was discussed in the break-out session was the potential for new types of technology to help lower the energy consumption of buildings. Specifically, chilled beam HVAC systems were mentioned as a potential new technology which can make drastic improvements to the energy consumption of a building.

Europe, which consistently has much higher energy costs than the United States, has been using chilled beam HVAC systems for several decades. Chilled beams use far less energy than the typical VAV systems that are commonly used in the United States. Chilled beams require less ductwork, and AHUs, but require more piping, pumps, and insulation.

12.2 Research Goal

The goal of this research is to gain an understanding of how chilled beams work, their uses, advantages, and disadvantages. Cost, schedule, and sustainability impacts associated with chilled beam systems will be compared to typical HVAC systems used in the United States. This research will develop a foundation that can be built upon by owners, designers, and constructors in the future as they explore alternative mechanical systems.

12.3 Research Steps

Research on chilled beams HVAC systems will begin with reviewing online articles, journals, case studies, and vendor publications. Once a thorough understanding of chilled beams is gained, interviews with industry members from across industry will be conducted. This will include owners, engineers, constructors, and suppliers to understand chilled beam applications and their advantages/disadvantages. Once the research has been completed, the information will be compiled to provide a source of information that industry members can use to help them explore alternative mechanical systems.

12.4 Introduction to Chilled Beams

Chilled beam HVAC systems use chilled water to cool building spaces. The chilled water is pumped to finned heat exchangers placed in the ceiling grid. Because water is a more efficient medium to transfer heat to and from the building spaces, air handlers and ductwork sizes can be reduced substantially. In fact, a 1" diameter water pipe can transport the same cooling energy as an 18" square air duct. This allows plenum space to be reduced which could result in higher ceiling heights or reduced structure height. There are two main types of chilled beams, passive and active. Passive beams are the simplest types of chilled beams and provide only sensible cooling and must be used in conjunction with another HVAC system to meet ventilation and latent load requirements. Active beams provide both sensible and latent cooling along with ventilation to the space.

12.5 Passive Chilled Beams

Passive chilled beams do not have any moving parts to move air, but relies on natural convection to raise the warm room air up to the chilled beam, where it passes through the heat exchanger coil and drops back down to cool the room. Figure 2 below shows how buoyancy makes a passive chilled beam work.

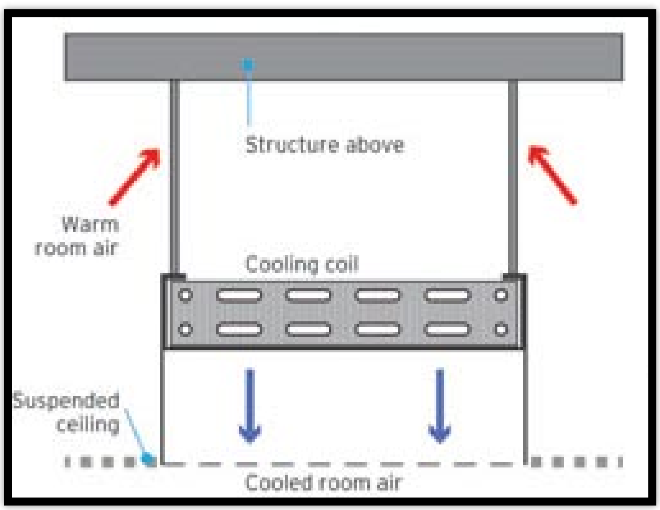


Figure 2 – Passive Beam Operation

As mentioned above, passive chilled beams only contribute to the sensible cooling of building spaces. A separate system must be used in conjunction to fulfill ventilation and latent load requirements. An under floor air distribution system is the most often used system used with passive beams, although many other systems would work as well. Because passive beams use natural convection to operate, they do not work for heating spaces, leading to the necessity of another system to heat the building.

Passive chilled beams typically are capable of removing 200 to 650 BTUH of sensible heat per linear foot of beam length. The output of passive beams depends on the beams width and the temperature differential between the entering air and circulated chilled water temperature. Output is typically limited by the convection air velocity. The velocity is controlled so that it does not create cold drafts for the building occupants.

Passive beams may be mounted above the ceiling or below the ceiling and exposed to view. This allows the designers to select a passive beam for each application. Figures 3 and 4 below shows examples of passive chilled beams.

Figure 3 – Exposed Passive Chilled Beams

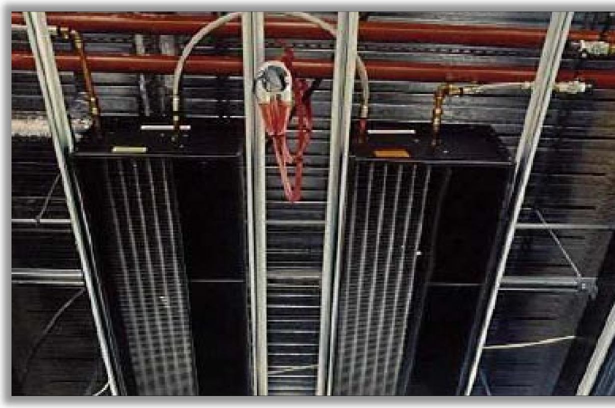


Figure 4 – Recessed Passive Chilled Beams

12.6 ACTIVE CHILLED BEAMS

Like passive chilled beams, active chilled beams have heat exchanger coils to cool passing air as it moves through the beam. Unlike a passive beam though, active beams also have conditioned air supplied to the beam. The conditioned air is called the primary cooling and the heat exchanger is called the secondary cooling. Active beams use forced air induction to lift the room air into the beam, mix the conditioned air and the room air, and then discharge the mixed air into the room through linear slots located along the outside edges of the beam. Due to the forced air induction, active beams are able to heat and cool a space. The latent load and ventilation air requirements are handled entirely by the primary air side of the chilled beam. The sensible load is split between the primary air and secondary cooling of the chilled beam. The secondary cooling of the chilled beam can typically extract 50-70% of the space sensible heat generated with the primary air extracting the remaining balance of the sensible load.

Figure 5 below shows the operation of an active chilled beam.

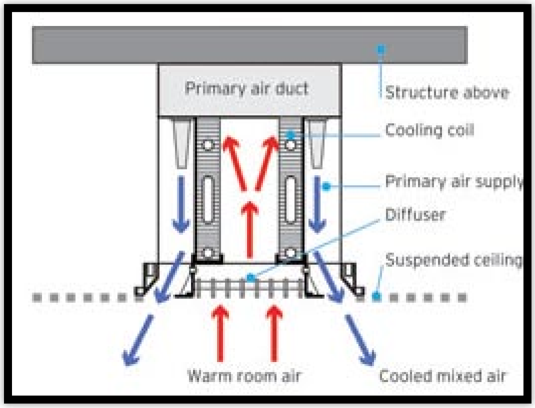


Figure 5 – Active Chilled Beam Operation

Active chilled beams can provide sensible cooling capacities as high as 1,100 BTUH per linear foot of beam. The specific performance capabilities depend on induction capabilities, coil circuitry, and chilled water supply temperature. Discharge air velocity needs to be analyzed to ensure occupant comfort.

Different types of active beams are even more numerous than with passive beams. They come in different lengths and widths, different nozzle types to affect the induction rate, and one, two or even four way discharge patterns.

Figures 6 and 7 below show different types of chilled beams.

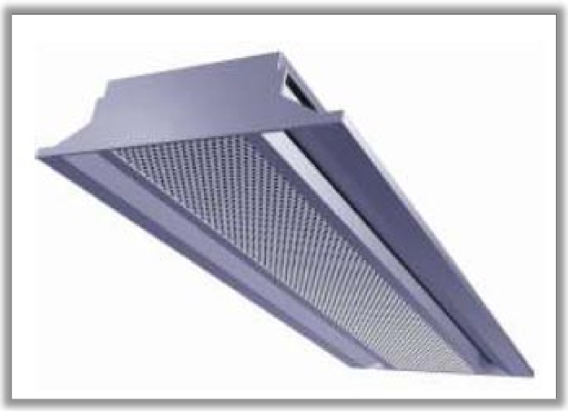


Figure 6 – 2-way Active Chilled Beams

Figure 7 – 4-way Active Chilled Beams

12.7 Multi-Service Chilled Beams

Multi-service chilled beams incorporate other building systems into the beam in a prefabricated unit. This prefabricated unit can be brought to the project site and drastically reduces the amount of time required to install all the building systems. Lighting fixtures and controls, speakers, occupancy sensors, smoke detectors, and even fire sprinklers can be incorporated into the beam. Mulit-service chilled beams come in both passive and active types.

Figure 8 below shows an example of a multi-service chilled beam.

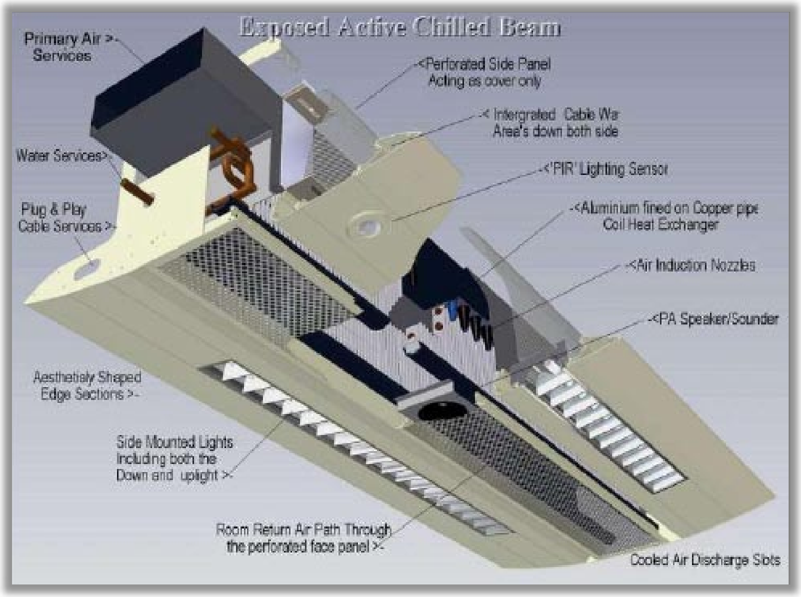


Figure 8 – Multi-service Chilled Beams

Figure 9 below shows passive multi-service beams and Figure 10 shows active multi-service beams.

Figure 9 – Passive Multi-service Beams

Figure 10 – Active Multi-service Beams

12.8 Chilled Beam Advantages

Chilled beam systems can drastically reduce the required primary air circulated throughout the building versus a conventional all air system. According to DADANCO, a chilled beam supplier, the required primary air is usually reduced by 75-85% when compared to an all air system. This reduction is made possible because water is much more efficient at moving energy than air.

In total, case studies have shown that chilled beam systems can save 20-40% in energy consumption when compared to an all air system. Albert Flaherty from WSP Flack + Kurtz said a recently built classroom building at The Massachusetts Institute of Technology with chilled beams has been using about 60% of the energy to operate the system when compared to a VAV system that would have typically been used. A laboratory building constructed at the University of North Carolina designed by Affiliated Engineers, Inc., cut energy consumption by 20%. Figure 11 below is a figure published by ASHRAE demonstrating typical power savings with chilled beam systems versus a conventional all air system.

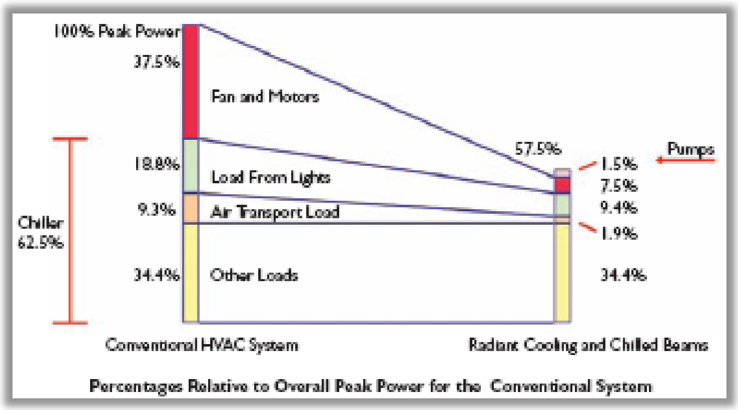


Figure 11 – Typical Power Savings for Chilled Beams; From ASHRAE

Chilled beams improve comfort within the building spaces. Increased comfort is achieved because the discharge air velocity of the chilled beam is slower than the all air system. Chilled beams are better at mixing the primary air and room air thoroughly (because of the induction principle), which results in uniform temperature throughout the room. With a chilled beam system, the ventilation air requirements are delivered to the building spaces at all times and at all loads, providing excellent indoor air quality and odor control.

Chilled beams reduce the ductwork system size in the plenums and vertical air shafts. In some cases, the building's floor-to-floor height can be reduced or more floors can be built within the same building height. Due to the reduced primary air requirement, air handling units (AHUs) and the respective rooms that house the AHUs can be reduced.

Lower energy consumption results in lower operation costs throughout the lifecycle of the building. Chilled beams usually have a higher first cost, but according to Alla Ketsnelson of Syska Hennessy Group, the payback period for chilled beams are within a few years of construction, typically no longer than 5 years.

There are no electrical line power connections to install in the field. This decreases the coordination between trades necessary to install the system.

Controls are simpler and cheaper for chilled beams than they are for VAV systems. A simple low cost zone valve is used to for temperature control as opposed to the complicated and expensive controls of a VAV system. Some chilled beams come from the supplier fitted with all the controls needed for operation.

Commissioning is easier with a chilled beam system. Commissioning only requires adjustments of the water balancing valves and primary air balancing dampers through simple static pressure readings.

Chilled beams have no regular maintenance costs because there are no moving parts inside the chilled beam. Chilled beams need infrequent vacuuming of the unit's coil as required. Cleanings are usually required only every 4-5 years unless the beams are used in an especially dirty environment.

Because chilled beams have no moving parts and no fans in the building spaces, they operate very quietly. Chilled beams are typically are designed so the typical inlet static pressure is 0.5" w.c. or less. According to DADANCO, chilled beams, when designed in this manner, can achieve a background noise of less the 35dB.

12.9 Chilled Beam Disadvantages

First cost of chilled beams is typically higher than when compared to other all air systems. Chilled beam systems save money on VAVs, ductwork, AHUs and fans, and controls but add money for the chilled beams themselves, water piping, pipe insulation, and pumps.

Chilled beams are relatively unknown in the United States. They have been used in Europe for several decades, but the building industry in the US is just starting to receive data on cost, schedule, and efficiency impacts of chilled beams. There are not many case studies with data solidifying the benefits of chilled beams. Due to the lack of knowledge in the building industry about chilled beams, design and construction professionals are adding contingencies to chilled beams systems in order to protect themselves from the risk of unfamiliarity. Albert Flaherty of WSP Flack + Kurtz speculated that chilled beam systems should cost, on average, only 5-15% more to install. However, on the projects that he has worked on, he has seen a 30% premium for chilled beams.

Some types of building owners may not find the payback of the higher first cost from the reduced energy consumption attractive. Developers are usually not willing to pay a higher first cost. This is because tenants that lease out building space from them are unlikely to pay more for reduced utility bills. A college campus or government buildings would be a likely candidate to use chilled beams. In these cases, they own and operate the buildings and would benefit from a short payback period and lower utility bills.

Chilled beams cannot be used in areas where space humidity levels cannot be consistently maintained. The dew point temperature of the space air must remain below the temperature of the chilled water supply. Areas that would not be suitable would be lobby entrances, kitchens, exercise rooms, and pool areas.

The building envelope tightness must be adequate to prevent excessive moisture transfer into the building. Increased moisture in the building air has the potential to condense on the chilled beam coil and create moisture in the building spaces.

Chilled beams cannot be mounted on ceilings higher than 20 feet. This is due to the induction of the air brought into the beam must be from around the building occupants to properly condition the building spaces.

12.10 Chilled Beam Applications

Chilled beams are ideal for applications with high space sensible cooling loads such as office space, computer labs, and laboratories.

Retrofits of existing building are excellent candidates for chilled beam system. The Constitution Center in Washington D.C. is the largest chilled beam system in the United States. This particular building was demolished to just the structure and replaced with modern building systems and façade. The building's floor-to-floor height did not provide enough space to use a VAV system and the engineers decided to use a chilled beam system to condition the building.

Building codes may restrict the height of buildings and reduce the valuable floor space. It is possible to use lower floor-to-floor heights with chilled beams and potentially add another floor in the same height as a building with an all air system. This would add a lot of value to the owner and make the project more profitable. Chilled beams, especially when multi-service beams are used, can save 2-3' in plenum space per floor.

12.13 Conclusion and Recommendation

Results of the research conducted on chilled beam HVAC systems have returned some impressive findings. Chilled beams are able to extract 50-70% of the sensible load through the heat exchanger coil in each beam, which allows the designer to reduce the size of the primary air supplied to the building. Typically, chilled beams are able to reduce the primary air supplied to building spaces by 75-85%. Water is much more efficient at moving energy throughout the building, and therefore will reduce the buildings energy consumption by 20-40%.

Chilled beams have an initial first cost higher than all air systems. Typically, chilled beams will cost between 10-30% more than an all air system. However, the reduced operating cost of chilled beams results in a payback period typically less than 5 years.

Chilled beams are especially beneficial on projects that have height restriction issues or for existing building retrofits and renovations. Chilled beams are able to reduce the necessary plenum space required to run all the building systems.

Chilled beams may not be a viable solution for the mechanical system of buildings or areas of buildings that have high latent loads and variable humidity loads. The dew point of the room must be below the temperature of the chilled water running through the beam in order to avoid condensation throughout the building spaces.

13.0 Chilled Beam Cost and Schedule Impact (Mechanical Breadth)

13.1 Background Information

This analysis will use the lessons learned in the Critical Industry Research on chilled beam HVAC systems and apply it to the Redland Tech Center project, specifically Building II. The mechanical system of Building II is a VAV system and should be an excellent candidate for a chilled beam system.

13.2 Goal

The goal for this analysis is determine the HVAC loads of Building II, size and specify the new chilled beam system, and then determine the cost and schedule impact of changing the system. Whenever the costs have been calculated, if there is a higher first cost for the chilled beam system, the payback period for the alternate HVAC system will be calculated.

13.3 Method

- Establish the design loads and required outdoor air ventilation rate
- Size the chilled beams and calculate number of beams required per floor
- Analyze the cost impacts incurred by switching the HVAC system to chilled beams
- Develop schedule for installing the chilled beam system
- Conduct payback period for installing chilled beam system

13.4 Resources

- Alla Ketsnelson at Syska Hennessy Group
- META Engineers
- John Hoke and Steve Mills at L.H. Cranston
- Ken Laudermilk at TROX USA
- Jim Martinoski and Erin Gardner of Clark Construction
- R.S. Means

13.5 Expected Outcome

The feasibility of using chilled beams at the Redland Tech Center project will be determined. Cost, schedule, and energy efficiency impacts will be determined. The discounted payback period for the alternate HVAC system will be determined.

13.6 Sizing the Chilled Beams

For this analysis, active chilled beams will be used as the replacement HVAC system for the Redland Tech Center. Active beams were decided upon because they do not require an alternate air source for ventilation and latent loads whereas passive beams would need one. Multi-service beams would add another level of complexity to the analysis that is unnecessary to determine the feasibility of chilled beams as an alternate HVAC system.

Only the open office space on each floor will be included in this analysis of changing the mechanical system. The HVAC systems for the lobby, exercise room, café, corridors, and bathrooms will be not be changed for this analysis. Both the exercise room and café have their own separate systems and will not have to be considered in any part of this analysis. The lobby, corridors, and bathrooms are part of the whole buildings HVAC system and will need to be considered whenever sizing equipment.

To maximize the potential energy savings of this design, the primary air supply flow rate (CFM) will be calculated using ASHRAE 62.1-2007 for minimum outdoor air rates. This will provide the minimum amount of air flow to the building spaces. Whenever the flow rate for the primary air is established, the required humidity ratio will be calculated to determine the maximum humidity ratio which will control the latent loads of the building spaces.

The first step in sizing the chilled beams for Building II is to determine the design conditions and loads that the system will need to control. The following assumptions will govern the calculation of design loads:

- CFM provided to the office space through the VAV represents the design sensible load
- 100 ft^2/person
- 72^oF room air, 55^oF supply air for current design
- Latent load = 200BTUH/person for latent load

By using the CFM provided with the VAV system, it is possible to calculate the design loads the original mechanical engineers used for their design. Table 1 below shows the calculated design loads and outdoor air requirements for each floor. These values will be used to size the chilled beam system.

Floor	Description	Area (SF)	Population	VAV CFM	Sensible Load (BTUH)	Latent Load (BTUH)	Outdoor Air Requirement (CFM)
1	Open Office	11,380	114	9,500	174,420	22,760	1,565
2	Open Office	19,862	199	12,000	220,320	39,724	2,731
3	Open Office	20,534	205	12,000	220,320	41,068	2,823
4	Open Office	20,534	205	12,000	220,320	41,068	2,823
5	Open Office	20,534	205	12,000	220,320	41,068	2,823
6	Open Office	20,534	205	12,000	220,320	41,068	2,823
7	Open Office	20,534	205	12,000	220,320	41,068	2,823
8	Open Office	20,534	205	12,000	220,320	41,068	2,823
9	Open Office	20,534	205	12,000	220,320	41,068	2,823

Table 1 – Design Conditions and Loads for Building II

Below are the sample calculations to calculate the design loads for Floor 1. Similar calculations were used to calculate the values for the other floors.

$$Population = \frac{Floor\ Area}{100\frac{ft^2}{person}} = \frac{11{,}380}{100} = 114\ people$$

$$Sensible\ Load = 1.08 \times CFM \times (T_R - T_S) = 1.08 \times 9{,}500 \times (72 - 55) = 174{,}420 BTUH$$

$$Latent\ Load = 200\frac{BTUH}{Population} \times Population = 200 \times 114 = 22{,}760 BTUH$$

The outdoor air requirements were calculated according to ASHRAE 62.1-2007. All values used to calculate the necessary CFM were from Table 6-1 and Table 6-2 of ASHRAE 62.1-2007. The required outdoor air has two parameters that determine the amount needed: people outdoor air rate and area outdoor air rate. Table 2 below shows the required outdoor air rate (V_{OZ}) for each floor.

Floor	Description	Area (A_z)	Population (P_z)	R_axA_z (CFM)	R_pxP_z (CFM)	V_{bz} (CFM)	V_{oz} (CFM)
1	Open Office	11,380	114	683	569	1252	1565
2	Open Office	19,862	199	1192	993	2185	2731
3	Open Office	20,534	205	1232	1027	2259	2823
4	Open Office	20,534	205	1232	1027	2259	2823
5	Open Office	20,534	205	1232	1027	2259	2823
6	Open Office	20,534	205	1232	1027	2259	2823
7	Open Office	20,534	205	1232	1027	2259	2823
8	Open Office	20,534	205	1232	1027	2259	2823
9	Open Office	20,534	205	1232	1027	2259	2823

Table 2 – Required Outdoor Air Flow Rates

Below are the sample calculations to calculate the outdoor air requirements for Floor 1. Similar calculations were used to calculate the values for the other floors.

$$Area\ Outdoor\ Air\ Rate = R_a \times A_z = 0.06\frac{CFM}{ft^2} \times 11{,}380ft^2 = 683CFM$$

R_a = Outdoor Airflow Rate per Person from ASHRAE 62.1-2007 Table 6-1

$$People\ Outdoor\ Air\ Rate = R_p \times P_z = 5\frac{CFM}{person} \times 114people = 569CFM$$

R_p = Outdoor Airflow Rate per Unit Area from ASHRAE 62.1-2007 Table 6-1

$$Breathing\ Zone\ Outdoor\ Airflow(V_{bz}) = R_a \times A_z + R_p \times P_z = 683CFM + 569CFM = 1{,}252CFM$$

$$Outdoor\ Airflow(V_{oz}) = \frac{V_{oz}}{E_z} = \frac{1{,}252CFM}{0.8} = 1{,}564CFM$$

E_z = Air Distribution Effectiveness from ASHRAE 62.1-2007 Table 6-2

For comparison sake, the below Table 3 shows the original design air flow rate to the space and the outdoor air flow rate used for this analysis.

Floor	Original CFM	Analysis Outdoor Air CFM	% of Original
1	9,500	1565	16.5
2	12,000	2731	22.8
3	12,000	2823	23.5
4	12,000	2823	23.5
5	12,000	2823	23.5
6	12,000	2823	23.5
7	12,000	2823	23.5
8	12,000	2823	23.5
9	12,000	2823	23.5

Table 3 – Comparison of Original Design and Analysis Air Flow Rates

The above table shows the air supply flow rate to the building spaces will be reduced by almost 77% when a chilled beam system is used. This reduction in air flow will save money in ductwork, AHUs, fans, and operating costs.

Now that the required outdoor air flow rate has been determined, the next step is to determine the required humidity ratio of the supply air which will provide enough capacity to handle the latent load of the building occupants. In this calculation, we will assume the room is to be maintained at 72°F and 50% relative humidity. This condition corresponds to a humidity ratio (w_{ra}) of 0.00836 lb_w/lb_{da}, found from the psychometric chart in Appendix A. Table 4 below shows the supply air humidity ratio required for each floor.

Floor	Supply Air Humidity Ratio (w_{sa})
1	0.00535
2	0.00535
3	0.00535
4	0.00535
5	0.00535
6	0.00535
7	0.00535
8	0.00535
9	0.00535

Table 4 – Required Supply Air Humidity Ratio

Below are the sample calculations to calculate the outdoor air requirements for Floor 1. Similar calculations were used to calculate the values for the other floors.

$$Humidity\ Ratio(w_{sa}) = w_{ra} - \frac{BTUH_{Latent}}{CFM \times 4{,}840} = 0.00836 - \frac{41{,}068}{2{,}823 \times 4840} = 0.00535\,\frac{lb_w}{lb_{da}}$$

The above humidity ratio corresponds to supply air of 55°F and 58% relative humidity, found from the chart in Appendix A.

The primary air will handle all of the latent loads and outdoor air supply. The sensible load will partly be handled by the primary air supply with the balance of the sensible load being handled by the secondary cooling of the chilled beam. Table 5 below shows the amount of sensible load controlled by the primary and secondary side of the chilled beam.

Floor	Total Sensible Load (BTUH)	Primary Air Sensible Capacity (BTUH)	Primary Air Sensible % of Total	Secondary Sensible Capacity (BTUH)	Secondary Sensible % of Total
1	174,420	28,729	16.5%	145,691	83.5%
2	220,320	50,142	22.8%	170,178	77.2%
3	220,320	51,838	23.5%	168,482	76.5%
4	220,320	51,838	23.5%	168,482	76.5%
5	220,320	51,838	23.5%	168,482	76.5%
6	220,320	51,838	23.5%	168,482	76.5%
7	220,320	51,838	23.5%	168,482	76.5%
8	220,320	51,838	23.5%	168,482	76.5%
9	220,320	51,838	23.5%	168,482	76.5%

Table 5 – Required Sensible Load Capacities of Chilled Beam

Below are the sample calculations to calculate the required sensible load capacities of the chilled beams for Floor 1. Similar calculations were used to calculate the values for the other floors.

$$Primary\ Air\ Sensible\ Capacity = 1.08 \times CFM \times (T_R - T_S) = 1.08 \times 1{,}565(72 - 55) = 28{,}729BTUH$$

$$Secondary\ Sensible\ Capacity = Total\ Sensilbe\ Load - \ Primary\ Air\ Sensible\ Capacity$$
$$= 174{,}420BUTH - 28{,}729BTUH = 145{,}691BUTH$$

For this analysis, an assumption of 1,000 BTUH of sensible cooling per linear foot of chilled beam and 6’ chilled beams will be used. Table 6 below shows the number of chilled beams that will be required per floor.

Floor	Secondary Sensible Capacity (BTUH)	Linear Feet of Chilled Beam Required	Number of 6' Chilled Beams
1	145,691	146	25
2	170,178	170	29
3	168,482	168	29
4	168,482	168	29
5	168,482	168	29
6	168,482	168	29
7	168,482	168	29
8	168,482	168	29
9	168,482	168	29
		Total Number of 6’ Beams	**257**

Table 6 – Number of Chilled Beams Required per Floor

Below are the sample calculations to calculate the number of 6’ chilled beams required for Floor 1. Similar calculations were used to calculate the values for the other floors.

$$Feet\ of\ Beam\ Required = \frac{Sensilbe\ Load}{1{,}000\frac{BTUH}{ft\ of\ beam}} = \frac{145{,}691 BTUH}{1{,}000\frac{BTUH}{ft\ of\ beam}} = 146'$$

$$Number\ of\ 6'Chilled\ Beams = \frac{Feet\ of\ Beam\ Required}{6\frac{ft}{beam}} = 24\ beams$$

13.7 Cost Impacts of Chilled Beams

According to TROX USA, Inc., active chilled beams cost $140 per linear foot to purchase the beam and $140 per linear foot for the labor to install the beam. Using $280 per linear foot cost, the 6' beams used on this project will cost $1,680 per beam. Table 7 below shows the material, labor, and total cost of the active chilled beams for each floor of Building II.

Floor	Number of 6' Chilled Beams	Material Cost	Labor Cost	Total Cost
1	25	$21,000	$21,000	$42,000
2	29	$24,360	$24,360	$48,720
3	29	$24,360	$24,360	$48,720
4	29	$24,360	$24,360	$48,720
5	29	$24,360	$24,360	$48,720
6	29	$24,360	$24,360	$48,720
7	29	$24,360	$24,360	$48,720
8	29	$24,360	$24,360	$48,720
9	29	$24,360	$24,360	$48,720
		Total Chilled Beam Cost		**$431,760**
		Chilled Beam Cost per SF		**$2.47**

Table 7 – Chilled Beam Costs per Floor

Material and labor costs for the different components of the VAV mechanical system of Building II are seen in Table 8 below.

Description	Material	Labor	Total	% of Total
Chilled Water Piping	$116,601	$66,159	$182,760	7.6%
Mechanical Insulation	$58,998	$76,002	$135,000	5.6%
Pumps	$20,004	$3,558	$23,562	1.0%
Cooling Towers	$205,775	$16,325	$222,100	9.2%
VAVs	$37,088	$8,212	$45,300	1.9%
Fans	$79,100	$7,413	$86,513	3.6%
Self Contained AHUs	$790,242	$38,183	$828,425	34.5%
Ductwork	$97,290	$607,710	$705,000	29.3%
Controls	$86,670	$48,330	$135,000	5.6%
Condensate Piping	$9,412	$13,488	$22,900	1.0%
Testing and Balancing	$0	$18,000	$18,000	0.7%
Totals	**$1,501,178**	**$903,382**	**$2,404,560**	**100.0%**
VAV Mechanical System Cost per SF = $11.44				

Table 8 – VAV Mechanical System Cost Breakdown

The cost impact for this analysis will use an add-deduct cost method. Each line item of the above cost summary will be analyzed for cost changes due to the chilled beam mechanical system.

The total CFM of the original VAV mechanical system is 112,900 CFM. Whenever the chilled beam system is implemented, only part of the original system will be converted to chilled beams. The spaces that remain supplied with air through the remaining VAVs account for 5,000 CFM on the first floor and another 300 CFM for each typical office floor adding up to 8,600 CFM. In areas where components are shared between the chilled beams and the remaining VAVs, a factor of 92% (chilled beam reduction portion of original airflow=(112,900-8,600)/112,900)will be used to calculate the savings by switching to the chilled beams. An area where this pertains is for ductwork, fans, and controls.

The primary air side of the chilled beam system is 24,060 CFM. With another 8,600 CFM for the remaining VAVs, the chilled beam mechanical system will need AHUs with a total CFM capacity of 32,660 CFM.

Chilled Water Piping

The chilled water piping that is already in the cost summary for the original system will remain (mostly for risers). The chilled beam system will need an additional 1,300 linear feet of 1-1/2" chilled water piping per floor to provide the chilled water to the chilled beams. 1,300 linear feet was estimated by running a two pipe loop system through the center of the open office space with an additional 20% for the branches off to the chilled beams. According to L.H. Cranston, 1-1/2" hydronic piping would cost $14 per linear foot of pipe.

Material Cost for Additional Chilled Water Piping = $8.94/lf *1,300lf/floor*9floors = $104,598
Labor Cost for Additional Chilled Water Piping = $5.06/lf *1,300lf/floor*9floors = $59,202
Total Cost for Additional Chilled Water Piping = $163,800

Mechanical Insulation

All of the supply piping for the chilled beam system will needed to be insulated in order to prevent condensation on the pipes. However, the cost of this added insulation will be offset by the cost reduction for the insulation used on the VAV system. L.H. Cranston estimated that the cost change would be negligible for the mechanical insulation.

Pumps

Water pumping capacity will need to be increased with the chilled beam system. META Engineers estimated that the additional pump capacity needed would double from the original amount of pump capacity provided by the original VAV system. The original system cost $23,562.

Material Cost for Additional Pump Capacity = $20,004*2 = $40,008
Labor Cost for Additional Pump Capacity = $3,558*2 = $7,116
Total Cost for Additional Pump Capacity = $47,124

Cooling Tower

The HVAC loads of the building are the same with both systems. Therefore, the capacity required of the cooling towers will remain the same.

VAVs

72 of the 84 VAVs in Building II will be deleted with the chilled beam system. Each VAV has a total cost of $539.

Material Savings for Reduced Number of VAVs = 72VAVs*$442/VAV = $31,824
Labor Savings for Reduced Number of VAVs = 72VAVs*$97/VAV = $6,984
Total Savings for Reduced Number of VAVs = $38,808

Fans

Total air flow rates for the chilled beam part of the building will be reduced by 77% with the chilled beam system. To be conservative, a 70% reduction will be used for this analysis. The original cost of the fans for Building 2 is $86,513. A 92% factor will be used to eliminate the remaining VAVs share of fan costs.

Material Savings for Reduced Fan Airflow = 0.7*0.92*$79,100 = $50,940
Labor Savings for Reduced Fan Airflow = 0.7*0.92*$7,413 = $4,774
Total Savings for Reduced Number of VAVs = $55,714

Self Contained AHUs (SCUs)

All of the self contained AHUs (one on each floor) will be deleted with the chilled beam system. This is due to the fact that the SCUs house everything needed for heating and cooling the building, including the heating coil and compressor for cooling. With the chilled beam system, electric heating coils will need to be added to the chilled beams to heat the building, a centrifugal chiller will be added in the mechanical penthouse to provide the chilled water, and AHUs will be added to provide the required primary outdoor air. See the cost estimate below for the added heating coils, centrifugal chiller, and AHUs.

Material Savings for Deleting SCUs = $790,242
Labor Savings for Deleting SCUs = $38,183
Total Savings for Reduced Number of VAVs = $828,425

Electric Heating Coils

In the original system, each SCU had 67KW heating coil built into it for a total heating capacity of 603KW. In order to achieve same amount of heat capacity with the heating coils on each chilled beam, a 3KW heating coil will be used for each beam. There are a total of 248 beams requiring the 3KW heating coil. With the additional heating coils throughout the building spaces, wiring will need to be added to power the heating coils. See below cost estimate for added wiring. Cost data for the heating coils was gathered from R.S. Means.

Material Cost for Heating Coils = 257coils*$620/coil = $159,340
Labor Cost for Heating Coils = 257coils*$59/coil = $15,163
Total Cost for Heating Coils = $174,503

Wiring and Conduit for Heating Coils

The 28 heating coils per floor will require 650 ft per floor of 3-wire #12 AWG to power the heating coils. EMT conduit will also need to be installed to house the wire. Cost data for the wiring and conduit was gathered from R.S. Means.

Material Cost for Wiring and Conduit = 3-wires*$0.81/LF*650LF/floor*9floors = $14,217
Labor Cost for Wiring and Conduit = $2.47/LF*650LF/floor*9floors = $14,450
Total Cost for Wiring and Conduit = $28,667

Centrifugal Chillers

A centrifugal chiller must be provided to cool the chilled water system. For Building II, all loads including the office areas, corridors, and lobby have a total load of 870-tons of cooling required. For this analysis, a 900-ton centrifugal chiller will be added to cost of the chilled beam system. Cost data for the centrifugal chiller was gathered from R.S. Means.

Material Cost for Centrifugal Chiller = $384,160
Labor Cost for Centrifugal Chiller = $18,032

Total Cost for Centrifugal Chiller = $402,192

Air Handling Units (AHUs)

The chilled beam system needs AHUs with a total CFM capacity of 32,660 CFM. To maximize efficiency and minimize mechanical room area, the chilled beam system will use two AHUs, one 15,000 CFM AHU on the first floor and one 20,000 CFM AHU in the mechanical penthouse at the roof level. Cost data for the AHUs was gathered from R.S. Means.

Material Cost for 15,000 CFM AHU = $20,272
Labor Cost for 15,000 CFM AHU = $2,968
Total Cost for 15,000 CFM AHU = $23,240

Material Cost for 20,000 CFM AHU = $26,320
Labor Cost for 20,000 CFM AHU = $4,088
Total Cost for 20,000 CFM AHU = $30,408

Material Cost for AHUs = $46,592
Labor Cost for AHUs = $7,056
Total Cost for AHUs = $53,648

Ductwork

Total air flow rate for the building is reduced by 77% with the chilled beam mechanical system. To be conservative, a 70% reduction in CFM will be used for this analysis. Ductwork cost is based on the weight of the duct installed. A 70% reduction in will not reduce the weight of the ductwork by 70%. A reasonably accurate method to determine reduction in ductwork weight is to reduce the cross-sectional area of a square duct and calculate the reduction in surface area of the reduced duct. Figure 12 below is a visual representation of how much the duct sizes will be reduced by using the chilled beam system.

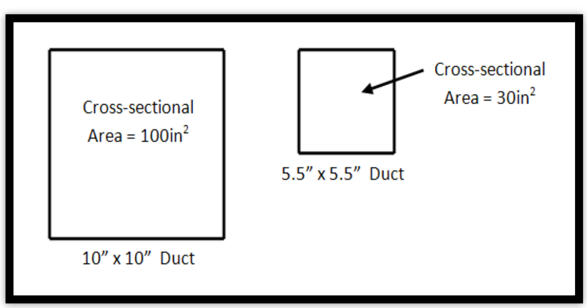


Figure 12 – Representation of the Reduction in Duct Size

1 linear foot of the original 10”x10” duct will have 3.33ft^2 of sheet metal. 1 linear foot of the reduced 5.5”x5.5” duct will have 1.83ft^2 of sheet metal. Therefore, a reduction of a duct’s flow rate by 70% will correspond to a reduction of 45% to the amount of sheet metal needed to fabricate the duct.

The duct work for the chilled beam system will follow the same approximate loop as the original system. It does not seem reasonable to reduce the labor cost by 45% because, while there will be less labor involved, the same basic steps will need to be taken to install the duct. L.H. Cranston estimated that the reduction of labor to install the ductwork for the chilled beam system would be around 25%. A 92% factor will be used to eliminate the remaining VAVs share of ductwork cost.

Material Savings for Ductwork = 0.45*0.92*$97,290 = $40,278
Labor Savings for Ductwork = 0.25*0.92*$607,710 = $137,773
Total Savings for Ductwork = $178,051

Controls

The controls used with the VAV system are much more complex than the controls used with the chilled beam system. The VAV system has thermostats for each zone of the building that must be individually wired, adding cost. The control system for the chilled beams is an automatic valve that adjusts the operation of the chilled beam according to the design. This valve is included in the cost of the chilled beam. Therefore, all the cost for control systems with the VAV system can be deleted from the cost forthe chilled beam estimate.

Material Savings for Deleted Control Systems = 0.92*$86,670 = $79,736
Labor Savings for Deleted Control Systems = 0.92*$48,330 = $44,464
Total Savings for Deleted Control Systems = $124,200

Condensate Piping

Because the cooling capacities of the Building II’s HVAC system did not change, the cost of the condensate piping will not change.

Testing and Balancing

The testing and balancing of the chilled beam system will cost less than the original VAV system. The VAV system had a substantial amount more ductwork that would take longer to commission. Paul Tseng of Advanced Building Performance, the third party testing and balancing agency, estimates the reduction in labor cost for the chilled beam part of the HVAC system will be reduced by switching to the chilled beam system would be 50%.

Material Savings for Testing and Balancing = $0
Labor Savings for Testing and Balancing = 0.5*0.92*$18,000 = $16,560
Total Savings for Testing and Balancing = $16,560

Material and labor costs for the different components of the chilled beam mechanical system of Building II are seen in Table 9 below.

Description	Material	Labor	Total	% of Total
Chilled Beams	$215,880	$215,880	$431,760	17.4%
Chilled Water Piping	$221,199	$125,361	$346,560	14.0%
Mechanical Insulation	$58,998	$76,002	$135,000	5.4%
Pumps	$60,012	$10,674	$70,686	2.9%
Cooling Towers	$205,775	$16,325	$222,100	9.0%
VAVs	$5,264	$1,228	$6,492	0.3%
Fans	$28,160	$2,639	$30,799	1.2%
Self Contained AHUs	$0	$0	$0	0.0%
Electric Heating Coils	$159,340	$15,163	$174,503	7.0%
Wiring and Conduit for Heating Coils	$14,217	$14,450	$28,667	1.2%
Centrifugal Chiller	$384,160	$18,032	$402,192	16.2%
AHUs	$46,592	$7,056	$53,648	2.2%
Ductwork	$57,012	$469,937	$526,949	21.3%
Controls	$6,934	$3,866	$10,800	0.4%
Condensate Piping	$9,412	$13,488	$22,900	0.9%
Testing and Balancing	$0	$16,560	$16,560	0.7%
Totals	**$1,472,954**	**$1,006,662**	**$2,479,616**	**100%**
Chilled Beam Mechanical System Cost per SF = $11.79				

Table 9 – Chilled Beam Mechanical System Cost Breakdown

Table 10 below shows the percent increase for the chilled beam mechanical system versus the original VAV system.

VAV Cost	Chilled Beam Cost	% Increase
$2,404,560	$2,479,616	1.03

Table 10 – Chilled Beam % Increase

Additional Office Leasing Space

Removing the 6 SCUs from floors 2-7 will provide an additional 2,160 SF of office space for the project. This amount of area will lease out for approximately $12/SF per month, resulting in an additional leasing income of $25,920/month.

13.7 SCHEDULE IMPACTS OF CHILLED BEAMS

The original schedule for the VAV mechanical system was obtained from the mechanical subcontractor and can be viewed on the following page. This schedule was analyzed for similarities and differences to build the chilled beam system schedule off of. The following activities have been added, deleted, or changed in duration for the chilled beam schedule. The chilled beam schedule is after the original VAV schedule.

- Pump installation time was doubled to account for the additional pumps in the chilled beam design.
- Centrifugal chiller installation time was estimated to take 10 days for the chilled beams.
- The outdoor air riser duration has been changed from 9 days to 6 days in order to account for the smaller size duct used.
- The chilled beam system deleted all the SCUs from the system and added chilled beams, a chilled water loop for each floor, and heating coils and wiring for each chilled beam.
- Control installation is now not needed for each floor; it only needs to be added into the schedule when that floor has an AHU.

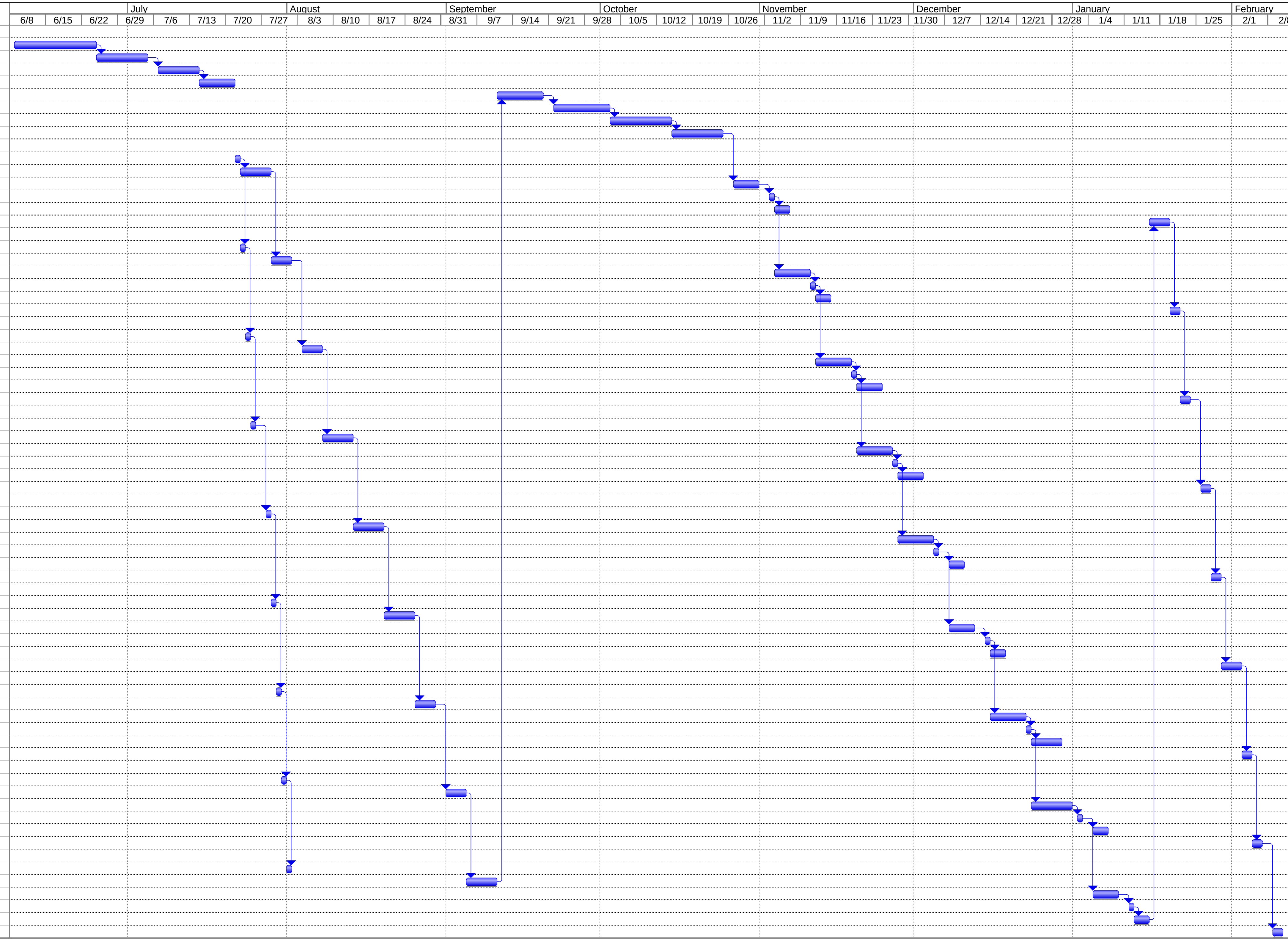
TROX USA, Inc., estimated that a contractor would be able to install 6 linear feet of beam per day with a standard crew. This duration was used for the calculations of the chilled beam schedule. The remaining durations used for the schedule were obtain from L.H. Cranston or R.S. Means.

The original schedule for the VAV system started on June 9, 2009, and finished on February 10, 2009, a total duration of 246 days. The schedule developed for the chilled beam system (on the following page) has construction starting on June 9, 2009, and finishing on March 19, 2009, a total duration of 283 days.

It is not surprising that the chilled beam system increased the duration of the construction schedule. The chilled beam system has more components to install in the building, from the actual chilled beams, 29 beams per floor versus 8 VAVs per floor, to the heating coil and electric wire to power the coil, and also the increased amount of chilled water piping.

The increased schedule duration for the chilled beam system will not affect the completion date of the overall project. The area where the chilled beam schedule is further behind the original VAV schedule is in the open office space area where the chilled beams, ductwork, and chilled water piping are being installed. Because the building is a core and shell project, the project team doesn't have to work around finishes in the open office space.

ID	Task Name	Duration	Start	Finish	Predecessors
1	**Original VAV Schedule**	**175 days**	**Mon 6/9/08**	**Tue 2/10/09**	
2	Install Pipe CWS&R	12 days	Mon 6/9/08	Tue 6/24/08	
3	Install Pipe 2" Make-up CT-1	8 days	Wed 6/25/08	Fri 7/4/08	2
4	Install Cooling Towers	6 days	Mon 7/7/08	Mon 7/14/08	3
5	Install Chilled Water Pumps	5 days	Tue 7/15/08	Mon 7/21/08	4
6	Install Toilet Exhaust Duct Riser	7 days	Thu 9/11/08	Fri 9/19/08	68
7	Install OAI Riser Ductwork	9 days	Mon 9/22/08	Thu 10/2/08	6
8	Install Duct Riser SP-1	8 days	Fri 10/3/08	Tue 10/14/08	7
9	Install Duct Riser SP-2	8 days	Wed 10/15/08	Fri 10/24/08	8
10	**1st Floor**	**128 days**	**Tue 7/22/08**	**Mon 1/19/09**	
11	Set SCU-1	1 day	Tue 7/22/08	Tue 7/22/08	
12	Pipe SCU-1	4 days	Wed 7/23/08	Mon 7/28/08	11
13	Install Duct Loop	5 days	Mon 10/27/08	Fri 10/31/08	9
14	Install VAVs	1 day	Mon 11/3/08	Mon 11/3/08	13
15	Install Controls	3 days	Tue 11/4/08	Thu 11/6/08	14
16	Testing and Balancing	2 days	Fri 1/16/09	Mon 1/19/09	71
17	**2nd Floor**	**129 days**	**Wed 7/23/08**	**Wed 1/21/09**	
18	Set SCU-2	1 day	Wed 7/23/08	Wed 7/23/08	11
19	Pipe SCU-2	4 days	Tue 7/29/08	Fri 8/1/08	12
20	Install Duct Loop	5 days	Tue 11/4/08	Mon 11/10/08	14
21	Install VAVs	1 day	Tue 11/11/08	Tue 11/11/08	20
22	Install Controls	3 days	Wed 11/12/08	Fri 11/14/08	21
23	Testing and Balancing	2 days	Tue 1/20/09	Wed 1/21/09	16
24	**3rd Floor**	**130 days**	**Thu 7/24/08**	**Fri 1/23/09**	
25	Set SCU-3	1 day	Thu 7/24/08	Thu 7/24/08	18
26	Pipe SCU-3	4 days	Mon 8/4/08	Thu 8/7/08	19
27	Install Duct Loop	5 days	Wed 11/12/08	Tue 11/18/08	21
28	Install VAVs	1 day	Wed 11/19/08	Wed 11/19/08	27
29	Install Controls	3 days	Thu 11/20/08	Mon 11/24/08	28
30	Testing and Balancing	2 days	Thu 1/22/09	Fri 1/23/09	23
31	**4th Floor**	**131 days**	**Fri 7/25/08**	**Tue 1/27/09**	
32	Set SCU-4	1 day	Fri 7/25/08	Fri 7/25/08	25
33	Pipe SCU-4	4 days	Fri 8/8/08	Wed 8/13/08	26
34	Install Duct Loop	5 days	Thu 11/20/08	Wed 11/26/08	28
35	Install VAVs	1 day	Thu 11/27/08	Thu 11/27/08	34
36	Install Controls	3 days	Fri 11/28/08	Tue 12/2/08	35
37	Testing and Balancing	2 days	Mon 1/26/09	Tue 1/27/09	30
38	**5th Floor**	**132 days**	**Mon 7/28/08**	**Thu 1/29/09**	
39	Set SCU-4	1 day	Mon 7/28/08	Mon 7/28/08	32
40	Pipe SCU-4	4 days	Thu 8/14/08	Tue 8/19/08	33
41	Install Duct Loop	5 days	Fri 11/28/08	Thu 12/4/08	35
42	Install VAVs	1 day	Fri 12/5/08	Fri 12/5/08	41
43	Install Controls	3 days	Mon 12/8/08	Wed 12/10/08	42
44	Testing and Balancing	2 days	Wed 1/28/09	Thu 1/29/09	37
45	**6th Floor**	**133 days**	**Tue 7/29/08**	**Mon 2/2/09**	
46	Set SCU-6	1 day	Tue 7/29/08	Tue 7/29/08	39
47	Pipe SCU-6	4 days	Wed 8/20/08	Mon 8/25/08	40
48	Install Duct Loop	5 days	Mon 12/8/08	Fri 12/12/08	42
49	Install VAVs	1 day	Mon 12/15/08	Mon 12/15/08	48
50	Install Controls	3 days	Tue 12/16/08	Thu 12/18/08	49
51	Testing and Balancing	2 days	Fri 1/30/09	Mon 2/2/09	44
52	**7th Floor**	**134 days**	**Wed 7/30/08**	**Wed 2/4/09**	
53	Set SCU-7	1 day	Wed 7/30/08	Wed 7/30/08	46
54	Pipe SCU-7	4 days	Tue 8/26/08	Fri 8/29/08	47
55	Install Duct Loop	5 days	Tue 12/16/08	Mon 12/22/08	49
56	Install VAVs	1 day	Tue 12/23/08	Tue 12/23/08	55
57	Install Controls	3 days	Wed 12/24/08	Mon 12/29/08	56
58	Testing and Balancing	2 days	Tue 2/3/09	Wed 2/4/09	51
59	**8th Floor**	**135 days**	**Thu 7/31/08**	**Fri 2/6/09**	
60	Set SCU-8 (in Penthouse)	1 day	Thu 7/31/08	Thu 7/31/08	53
61	Pipe SCU-8	4 days	Mon 9/1/08	Thu 9/4/08	54
62	Install Duct Loop	5 days	Wed 12/24/08	Wed 12/31/08	56
63	Install VAVs	1 day	Fri 1/2/09	Fri 1/2/09	62
64	Install Controls	3 days	Mon 1/5/09	Wed 1/7/09	63
65	Testing and Balancing	2 days	Thu 2/5/09	Fri 2/6/09	58
66	**9th Floor**	**136 days**	**Fri 8/1/08**	**Tue 2/10/09**	
67	Set SCU-9 (in Penthouse)	1 day	Fri 8/1/08	Fri 8/1/08	60
68	Pipe SCU-9	4 days	Fri 9/5/08	Wed 9/10/08	61
69	Install Duct Loop	5 days	Mon 1/5/09	Fri 1/9/09	63
70	Install VAVs	1 day	Mon 1/12/09	Mon 1/12/09	69
71	Install Controls	3 days	Tue 1/13/09	Thu 1/15/09	70
72	Testing and Balancing	2 days	Mon 2/9/09	Tue 2/10/09	65



Project: Original VAV Schedule
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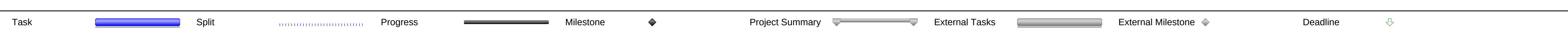

ID	Task Name	Duration	Start	Finish	Predecessors
1	**Chilled Beam Schedule**	**202 days**	**Mon 6/9/08**	**Thu 3/19/09**	
2	Install Pipe CWS&R	12 days	Mon 6/9/08	Tue 6/24/08	
3	Install Pipe 2" Make-up CT-1	8 days	Wed 6/25/08	Fri 7/4/08	2
4	Install Cooling Towers	6 days	Mon 7/7/08	Mon 7/14/08	3
5	Install Chilled Water Pumps	10 days	Tue 7/15/08	Mon 7/28/08	4
6	Install Centrifugal Chiller	10 days	Tue 7/29/08	Mon 8/11/08	5
7	Install Toilet Exhaust Duct Riser	7 days	Tue 8/12/08	Wed 8/20/08	6
8	Install OAI Riser Ductwork	6 days	Thu 8/21/08	Thu 8/28/08	7
9	Install Duct Riser SP-1	8 days	Fri 8/29/08	Tue 9/9/08	8
10	Install Duct Riser SP-2	8 days	Wed 9/10/08	Fri 9/19/08	9
11	**1st Floor**	**118 days**	**Mon 9/22/08**	**Fri 3/6/09**	
12	Set AHU-1	1 day	Mon 9/22/08	Mon 9/22/08	10
13	Pipe AHU-1	4 days	Tue 9/23/08	Fri 9/26/08	12
14	Install Chilled Beams	5 days	Mon 10/6/08	Fri 10/10/08	80
15	Install Duct Loop	5 days	Mon 10/13/08	Fri 10/17/08	14
16	Install Chilled Water Loop	3 days	Mon 10/20/08	Wed 10/22/08	15
17	Install Heating Coils	2 days	Thu 10/23/08	Fri 10/24/08	16
18	Wire Heating Coils	2 days	Mon 10/27/08	Tue 10/28/08	17
19	Install VAVs	3 days	Wed 10/29/08	Fri 10/31/08	18
20	Install Controls	3 days	Mon 11/3/08	Wed 11/5/08	19
21	Testing and Balancing	2 days	Thu 3/5/09	Fri 3/6/09	74
22	**2nd Floor**	**96 days**	**Thu 10/23/08**	**Mon 3/9/09**	
23	Install Chilled Beams	5 days	Thu 10/23/08	Wed 10/29/08	16
24	Install Duct Loop	4 days	Thu 10/30/08	Tue 11/4/08	23
25	Install Chilled Water Loop	3 days	Wed 11/5/08	Fri 11/7/08	24
26	Install Heating Coils	2 days	Mon 11/10/08	Tue 11/11/08	25
27	Wire Heating Coils	2 days	Wed 11/12/08	Thu 11/13/08	26
28	Testing and Balancing	1 day	Mon 3/9/09	Mon 3/9/09	21
29	**3rd Floor**	**85 days**	**Mon 11/10/08**	**Tue 3/10/09**	
30	Install Chilled Beams	5 days	Mon 11/10/08	Fri 11/14/08	25
31	Install Duct Loop	4 days	Mon 11/17/08	Thu 11/20/08	30
32	Install Chilled Water Loop	3 days	Fri 11/21/08	Tue 11/25/08	31
33	Install Heating Coils	2 days	Wed 11/26/08	Thu 11/27/08	32
34	Wire Heating Coils	2 days	Fri 11/28/08	Mon 12/1/08	33
35	Testing and Balancing	1 day	Tue 3/10/09	Tue 3/10/09	28
36	**4th Floor**	**77 days**	**Fri 11/21/08**	**Wed 3/11/09**	
37	Install Chilled Beams	5 days	Fri 11/21/08	Thu 11/27/08	31
38	Install Duct Loop	4 days	Fri 11/28/08	Wed 12/3/08	37
39	Install Chilled Water Loop	3 days	Thu 12/4/08	Mon 12/8/08	38
40	Install Heating Coils	2 days	Tue 12/9/08	Wed 12/10/08	39
41	Wire Heating Coils	2 days	Thu 12/11/08	Fri 12/12/08	40
42	Testing and Balancing	1 day	Wed 3/11/09	Wed 3/11/09	35
43	**5th Floor**	**66 days**	**Tue 12/9/08**	**Thu 3/12/09**	
44	Install Chilled Beams	5 days	Tue 12/9/08	Mon 12/15/08	39
45	Install Duct Loop	4 days	Tue 12/16/08	Fri 12/19/08	44
46	Install Chilled Water Loop	3 days	Mon 12/22/08	Wed 12/24/08	45
47	Install Heating Coils	2 days	Fri 12/26/08	Mon 12/29/08	46
48	Wire Heating Coils	2 days	Tue 12/30/08	Wed 12/31/08	47
49	Testing and Balancing	1 day	Thu 3/12/09	Thu 3/12/09	42
50	**6th Floor**	**55 days**	**Fri 12/26/08**	**Fri 3/13/09**	
51	Install Chilled Beams	5 days	Fri 12/26/08	Fri 1/2/09	46
52	Install Duct Loop	4 days	Mon 1/5/09	Thu 1/8/09	51
53	Install Chilled Water Loop	3 days	Fri 1/9/09	Tue 1/13/09	52
54	Install Heating Coils	2 days	Wed 1/14/09	Thu 1/15/09	53
55	Wire Heating Coils	2 days	Fri 1/16/09	Mon 1/19/09	54
56	Testing and Balancing	1 day	Fri 3/13/09	Fri 3/13/09	49
57	**7th Floor**	**44 days**	**Wed 1/14/09**	**Mon 3/16/09**	
58	Install Chilled Beams	5 days	Wed 1/14/09	Tue 1/20/09	53
59	Install Duct Loop	4 days	Wed 1/21/09	Mon 1/26/09	58
60	Install Chilled Water Loop	3 days	Tue 1/27/09	Thu 1/29/09	59
61	Install Heating Coils	2 days	Fri 1/30/09	Mon 2/2/09	60
62	Wire Heating Coils	2 days	Tue 2/3/09	Wed 2/4/09	61
63	Testing and Balancing	1 day	Mon 3/16/09	Mon 3/16/09	56
64	**8th Floor**	**33 days**	**Fri 1/30/09**	**Tue 3/17/09**	
65	Install Chilled Beams	5 days	Fri 1/30/09	Thu 2/5/09	60
66	Install Duct Loop	4 days	Fri 2/6/09	Wed 2/11/09	65
67	Install Chilled Water Loop	3 days	Thu 2/12/09	Mon 2/16/09	66
68	Install Heating Coils	2 days	Tue 2/17/09	Wed 2/18/09	67
69	Wire Heating Coils	2 days	Thu 2/19/09	Fri 2/20/09	68
70	Testing and Balancing	1 day	Tue 3/17/09	Tue 3/17/09	63
71	**9th Floor**	**22 days**	**Tue 2/17/09**	**Wed 3/18/09**	
72	Install Chilled Beams	5 days	Tue 2/17/09	Mon 2/23/09	67
73	Install Duct Loop	4 days	Tue 2/24/09	Fri 2/27/09	72
74	Install Chilled Water Loop	3 days	Mon 3/2/09	Wed 3/4/09	73
75	Install Heating Coils	2 days	Thu 3/5/09	Fri 3/6/09	74
76	Wire Heating Coils	2 days	Mon 3/9/09	Tue 3/10/09	75
77	Testing and Balancing	1 day	Wed 3/18/09	Wed 3/18/09	70
78	**Penthouse**	**122 days**	**Mon 9/29/08**	**Thu 3/19/09**	
79	Set AHU-2	1 day	Mon 9/29/08	Mon 9/29/08	13
80	Pipe AHU-2	4 days	Tue 9/30/08	Fri 10/3/08	79
81	Testing and Balancing	1 day	Thu 3/19/09	Thu 3/19/09	77

Project: Chilled Beam Schedule
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Task | Split | Progress | Milestone | Project Summary | External Tasks | External Milestone | Deadline

13.8 Energy Savings

The Environmental Protection Agency (EPA) has a calculator to determine the average energy costs throughout the United States. For this analysis, we will use this estimated average use as our baseline energy consumption for the original VAV system.

Average Annual Energy Cost/SF for Mid-Atlantic Area Office Building = $1.59/SF
= $1.59/SF*210,240SF = $334,282 per year

Without designing the chilled beam system using sophisticated design software, it is not possible to accurately predict the energy savings of the chilled beam system versus the VAV system. Therefore, for this analysis, a range of possible savings in energy will be used. Table 11 below shows the energy cost savings for 20%, 30%, and 40% reductions in HVAC system energy consumption for chilled beams.

Energy Reduction	Energy Costs per Year
20%	$267,426
30%	$233,997
40%	$200,569

Table 11 – Energy Costs per Year for Various Possible Energy Reductions

13.9 Payback Period

The payback period for switching the HVAC system to chilled beams will be less than one year. The initial cost of the chilled beams is higher by $75,056, or an increase of 1.03%. Operating costs are much more in favor of the chilled beams than the VAV system. The chilled beam system will save between $66,856 and $133,713 versus the VAV system. In addition to lower operating costs, the chilled beam system will have increased revenue of $25,920/month or $311,040/year for the additional office area available for leasing.

13.10 Conclusion and Recommendation

Chilled beams were shown to have many advantages over VAV systems in this analysis. The chilled beam system equivalent to the original VAV system designed for the Redland Tech Center had an increased initial cost by $75,056. Even though the chilled beam system was more expensive initially, the operating costs are much lower and then revenues are higher whenever the chilled beam system is used.

The construction schedule increased in duration for the chilled beam system when compared to the original VAV system. This increase is mainly due to the additional number of components that a chilled beam system uses to control the building spaces.

Chilled beams have shown promise that they are capable of exceeding the best all air HVAC systems. Industry professionals in the United Stated need to continue working with chilled beams to expand their knowledge of these HVAC systems. Only then will the true costs, schedule, and energy savings be known.

14.0 NEC Wire Sizing (Electrical Breadth)

14.1 Background Information

Like the chilled beam analysis, this analysis will also look at different building systems for energy efficiency improvements. Specifically, this analysis will research upsizing wire size beyond the minimum size requirement set by the National Electric Code for different loads. There are many different articles on the World Wide Web and talk in the building industry about the benefits to upsizing conductors. This notion is based upon the principle that even wire conductors have some amount of resistance.

14.2 Goal

The goal of this analysis is determine the feasibility of upsizing wire to save in energy costs. If it is in fact true that actual savings in energy are realized, a payback period will be calculated for the different areas studied. Also, this analysis will determine the areas of a building that this technique would be most beneficial to.

14.3 Method

- Conduct literature reviews and interviews of electrical engineers
- Consult with faculty members about the feasibility of upsizing wire to improve the energy efficiency of a building
- Refer to the National Electric Code
- Conduct calculations as necessary to determine energy efficiency gains and payback periods
- Determine areas of buildings or specific building types that would be most appropriate for wire upsizing

14.4 Resources

- Case studies
- Electrical faculty and L/E students
- Mike Prinkey, Penn State Electrical Engineer
- META Engineers
- National Electric Code
- R.S. Means

14.5 Expected Outcome

A guide to upsizing wire for energy efficiency gains will be established and payback periods will be determined. This analysis will determine the areas of buildings and/or specific building types that would be most appropriate for wire upsizing.

14.6 Findings

Speaking to several different electrical engineers has made it clear that upsizing wires beyond the NEC minimum has issues that are not typically addressed in articles on the subject. The main flaw in the theory of upsizing wires is the assumption that the current flowing on the conductor is the maximum allowable by the National Electric Code. The maximum allowable current for a particular conductor size is usually larger than average load on the circuit in most all cases. Mike Prinkey, an electrical engineer for Penn State's Office of Physical Plant, said the University finds that the main service energy capacities of the buildings on campus are often twice the peak loads and 3 to 4 times the average loads. When comparing the average load to the rated capacity, the wiring is usually already upsized several times.

Calculating the energy loss associated with the resistance of the wiring can be approached much in the same way as voltage drop calculations usually preformed to check wiring size. For this analysis, the No. 2 circuit for the lighting panel LP-H will be used as an example of how to calculate the power loss. Once the power loss is known for the actual circuit, the wire will be upsized one size and the calculations will be performed again for the larger wire size. The results summarized in energy savings and a payback period calculation will be performed.

Circuit No. 12 on the lighting panel LP-H provides power to 2'x4' parabolic troffer luminaire. The 277V circuit's connected Volt-Amps is 5,000VA. The circuit uses two #12 wires with a #12 wire for the ground. The current in the wires is 5,000VA/277V = 18.1 amps. The luminaire are approximately 100' from the panelboard.

The first step is to calculate the resistance of the wire:

For #12 THHN @ 75^{o}C (From NEC Chapter 9, Table 9):

$R = 2\Omega/kFT$

To correct resistance to 30^{o}C, use NEC Table 8 footnote:

$R_2 = 2\ [1+0.00323(30-75)] = 1.71\ \Omega/kFT$

The second step is to calculate the power loss:

Power Loss = $I^2 * R = (18.1)^2 * 1.71 * 0.1 = 56.0$ W

The third step is to calculate energy loss per year:

Energy Loss = 56.0 W / 1000W/kW * 12hrs/day * 365days/year = 245 kWh/yr

Now repeat the steps for the upsized wire:

For #10 THHN @ 75°C (From NEC Chapter 9, Table 9):

$R = 1.2\ \Omega/kFT$

To correct resistance to 30°C, use NEC Table 8 footnote:

$R_2 = 1.2\ [1+0.00323(30\text{-}75)] = 1.03\ \Omega/kFT$

Calculate the power loss:

Power Loss = $I^2 * R = (18.1)^2 * 1.03 * 0.1 = 33.7$ W

Calculate the energy loss per year:

Energy Loss = 33.7 W / 1000W/kW * 12hrs/day * 365days/year = 147 kWh/yr

Savings due to upsizing the wiring:

245-147 = 98 kWh/yr

Dollar Savings at $0.09 per kWh:

$8.82/year

Dollar Savings at $0.14 per kWh:

$13.72/year

Initial Cost Increase:

Cost of #12 wire & conduit = $2.85LF*100' = $285

Cost of #10 wire = $3.03LF*100' = $303

Cost difference = $18

Discounted Payback Period (assume MARR=15%):

Period	Cash Flow	Cost of Funds (15%)	Cumulative Cash Flow
0	($18)	$0	($18)
1	$13	($3)	($8)
2	$13	($1)	$4

Payback period is within two years.

The above strategy may work for specific applications, but the wiring is already oversized for most applications, so there would be little efficiency gains and therefore payback.
Locations where this may work are locations with constant high loads. Data center equipment, large constant speed motors, and possibly HVAC chillers are all applications where this strategy may work.

14.7 Conclusion and Recommendation

The above calculations prove that upsizing wire from the NEC minimum can have a payback in efficiency saving within a few years. The savings for each circuit may not be drastic, but if you applied this principle to more building areas, overall operating savings could be substantial. One major flaw with the principle of upsizing the wire conductors is that most circuits never operate at their full design capacity. This would lead to the wires being oversized in most instances and not provide the calculated cost benefits.

Upsizing wires have the most potential for savings when used in conjunction with circuits that have large, constant loads. Data centers, large constant speed motors, and possibly even HVAC chillers are potential areas that would work well for upsizing wires beyond the NEC minimum.

15.0 PARKING GARAGE CONSTRUCTION SEQUENCE

15.1 BACKGROUND INFORMATION

The parking garage for the Redland Tech project was constructed in two phases. The first phase included 90% of the foundation work, excluding the southeast corner of the garage. This corner was constructed in the second phase; it was left out because this allowed an access point to the basement of the garage for structural precast member deliveries and crane movement. Figure 13 below shows the dirt access ramp and the area of the CIP foundation walls that were left out of the first phase. The crane erected the first phase of precast members from the basement of the garage. After the crane was finished erecting the precast members of the first phase, it was dismantled and taken offsite to another project. Whenever the first phase was complete, the foundation crew finished constructing the last 10% of the garage foundation. Once the foundation was finished, the precast erectors brought another crane back to the site and erected the remaining 10% of precast members. There was a 46 day gap in the erection of precast panels.

Figure 13 – Above picture shows the dirt access ramp and the area where the CIP foundation walls were left out for precast member delivery.

15.2 GOAL

The goal of this analysis is to determine if there was a more efficient method to construct the parking garage. The garage was finished before the end of the project but the sequencing method used was not ideal and caused many problems for the entire project team.

15.3 METHODS

- Consult with Precast Erectors (the erection company) to determine other possible methods to construct garage.
- Consult with Tindall Corporation (designer and precast panel fabricator) to determine other possible methods to construct garage.
- Consult with Clark Construction to determine the feasibility of recommended techniques.
- Develop plan and size crane as necessary.
- Develop 4D BIM model to assist in planning construction
- Determine schedule impacts and cost savings with new sequencing method.

15.4 RESOURCES

- Precast Erectors
- Tindall Corporation
- Clark Construction
- Manitowoc Crane Guide
- Revit Architecture
- NavisWorks
- Microsoft Project

15.5 EXPECTED OUTCOME

An alternative construction sequencing will be established for the parking garage that will eliminate the 46 day gap in the erection of the precast panels. This alternative method will be more efficient and save money for the project team.

15.6 ACTUAL CONSTRUCTION SEQUENCE

The parking garage at Redland Tech Center could not be constructed with the crane located outside the building foot print. There were two reasons for this, the first being the close proximity to the other buildings and a sedimentation pond which did not enough room for crane travel on the perimeter of the building. Second, even if there was enough room for crane travel, due to the size of the parking garage precast members and spans, it would have been cost prohibitive to use a crane with enough capacity to make the picks across the garage footprint. It was determined by the construction team the best way to erect the parking garage was in two sequences.

Each phase of construction included the footings, foundation walls, and erection of the precast panels. The first phase included all of the building except the southeast corner of the garage.

The area included is depicted in Figure 14 below. The scope in Phase One, shown in red, excluded column lines D-F/1-4. Phase Two, shown in purple, finished the remaining footings, foundation walls, and erection of the precast panels. All six floors were erected in each sequence.

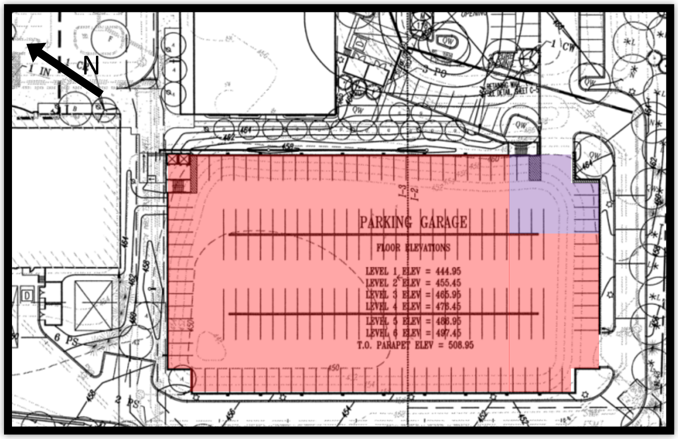


Figure 14 – Parking Garage Sequencing: Phase One shown in red, Phase Two shown in Purple

Figures 15-18 below show the 4D BIM model of the actual construction sequence. See Appendix B for more screenshots of the 4D BIM model created for this analysis.

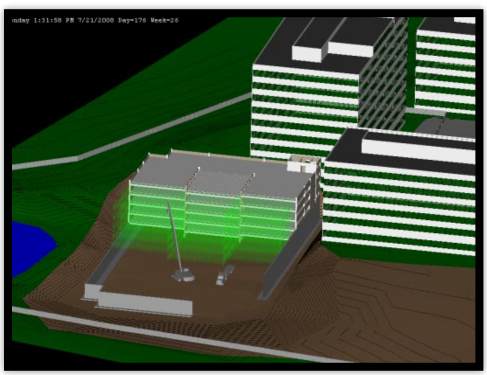


Figure 15 – Phase 1, Precast Sequence 3

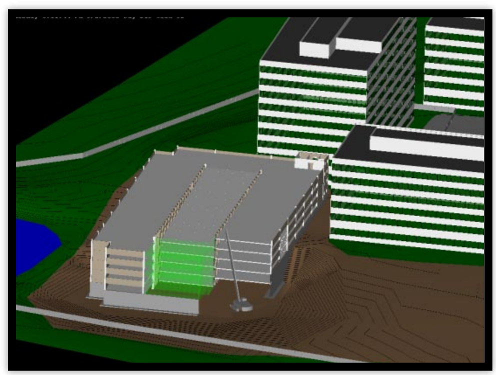


Figure 16 – Phase 1, Precast Sequence 6

Figure 17 – Phase 2, Foundation

Figure 18 – Phase 2, Precast Sequence 7

Table 12 below is a summary of the actual schedule for the parking garage. For the complete detailed schedule of the parking garage construction, see Appendix C.

Activity	Duration	Start	Finish
NTP	0 days	6-Feb-08	6-Feb-08
Mobilization	2 days	6-Feb-08	7-Feb-08
Excavation	25 days	8-Feb-08	12-Mar-08
Footings	138 days	13-Mar-08	19-Sep-08
Under Slab MEP	19 days	12-Sep-08	8-Oct-08
Foundation Walls	108 days	2-May-08	29-Sep-08
Slab	22 days	16-Sep-08	15-Oct-08
Precast Panels	116 days	2-Jun-08	7-Nov-08
Mobilize	5 days	2-Jun-08	6-Jun-08
Sequence 1: A- F/10-12	10 days	23-Jun-08	4-Jul-08
Sequence 2: A- F/8-10	10 days	7-Jul-08	18-Jul-08
Sequence 3: A- F/6-8	10 days	19-Jul-08	31-Jul-08
Sequence 4: A- F/4-6	10 days	1-Aug-08	14-Aug-08
Sequence 5: A-C/1-4	10 days	15-Aug-08	28-Aug-08
Sequence 6: C-D/1-4	10 days	29-Aug-08	11-Sep-08
Remobilize	5 days	20-Oct-08	24-Oct-08
Sequence 7: D-F/1-4	10 days	27-Oct-08	7-Nov-08
Top Out	0 days	7-Nov-08	7-Nov-08
MEP Rough Ins	70 days	10-Nov-08	13-Feb-09
Garage Finishes	70 days	1-Dec-08	6-Mar-09
Site Work	65 days	10-Nov-08	6-Feb-09
Elevators	58 days	8-Dec-08	25-Feb-09
M.E.P. Systems	45 days	10-Nov-08	9-Jan-09
Exterior Hardscape	30 days	24-Nov-08	2-Jan-09
Landscaping	40 days	15-Dec-08	6-Feb-09
Parking Striping	15 days	15-Dec-08	2-Jan-09
System Testing	5 days	26-Feb-09	4-Mar-09
Final Inspections	20 days	5-Mar-09	1-Apr-09
Substantial Completion	0 days	1-Apr-09	1-Apr-09

Table 12 – Actual Garage Construction Schedule

Notice in the above schedule summary, there is a 46 day gap in the erection of the precast panels. This gap was cause by the sequencing used for the construction of the parking garage. Some of this delay was caused by the time needed for the concrete foundation crew to come back to site and finish the foundation work in Phase Two. But most of the time was due to project specifications stating minimum cure time for the concrete foundations before the precast panels could be erected and place load on the foundation. The specifications stated that the concrete must cure to 28 day strength before any load can be placed on the foundation. Due to this time delay, the erection crew disassembled the crane and moved it to another project.

Whenever the Phase Two foundation work reached strength, Clark notified Precast Erectors to remobilize and finish erecting the Phase Two precast panels. Precast Erectors brought a different crane to site and finished the last sequence of work in 10 days. Precast Erectors was not paid for the remobilization charges, approx. $70,000, as there was only one mobilization fee provided in the subcontract.

15.7 Proposed Construction Sequence

For this analysis, interviews were conducted with Precast Erectors, Clark Construction, and the Tindall Corporation (designer and fabricator) to understand the sequencing method used and to determine other possible construction sequence methods. It was determined that during the coordination meetings conducted at the Clark Construction trailers between the projects teams, the remobilization plans for the crane was never discussed. Precast Erectors and Clark Construction had different sequencing methods and they were never communicated to the other party. While this was neither parties fault, both noted that the coordination could have been better and a agreed upon plan been made.

The engineer of record, Jeff Lepard of Tindall Corporation, recommended using the same basic sequencing method except, to avoid having to wait for the concrete to cure, leave out the non-load bearing foundation wall on column line C-D/1. In this scenario, the crane would be able to erect all of the building from the basement of the garage up until the last sequence. Whenever the next-to-last sequence is finished being erected, move the crane through the opening in the foundation and erect the last sequence from outside the building perimeter. Once the last sequence is finished, the crane would be dismantled and the foundation crew returns to cast the final foundation wall. The superintendent for Clark Construction agreed that this sequencing method would work and does improve the process of constructing the parking garage.

Figures 19 and 20 below show the 4D BIM model of the revised construction sequence. See Appendix D for more screenshots of the 4D BIM model created for this analysis.

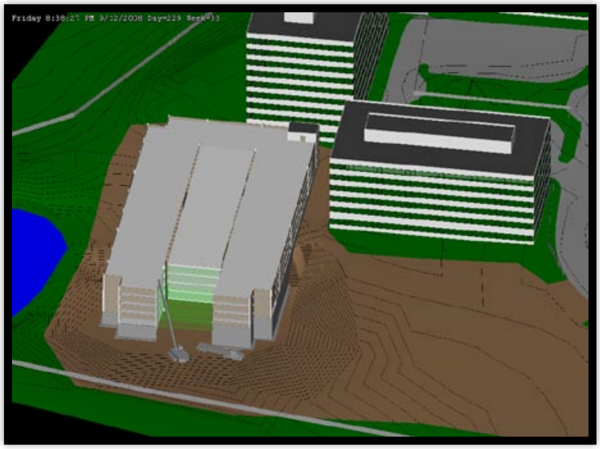


Figure 19 – Precast Sequence 7

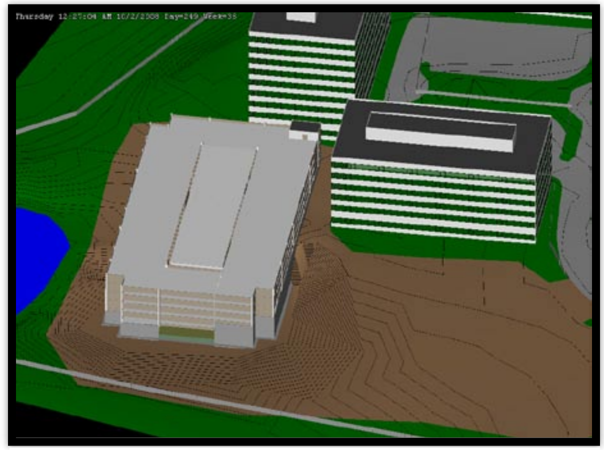


Figure 20 – Phase 2 Footing and Foundation Wall Construction

Table 13 below is a summary of the proposed schedule for the parking garage. For the complete detailed proposed schedule of the parking garage construction, see Appendix E.

Activity	Duration	Start	Finish
NTP	0 days	6-Feb-08	6-Feb-08
Mobilization	2 days	6-Feb-08	7-Feb-08
Excavation	25 days	8-Feb-08	12-Mar-08
Footings	145 days	13-Mar-08	30-Sep-08
Under Slab MEP	19 days	26-Sep-08	22-Oct-08
Foundation Walls	112 days	2-May-08	3-Oct-08
Slab	22 days	30-Sep-08	29-Oct-08
Precast Panels	85 days	2-Jun-08	25-Sep-08
Mobilize	5 days	2-Jun-08	6-Jun-08
Sequence 1: A- F/10-12	10 days	23-Jun-08	4-Jul-08
Sequence 2: A- F/8-10	10 days	7-Jul-08	18-Jul-08
Sequence 3: A- F/6-8	10 days	19-Jul-08	31-Jul-08
Sequence 4: A- F/4-6	10 days	1-Aug-08	14-Aug-08
Sequence 5: A-C/1-4	10 days	15-Aug-08	28-Aug-08
Sequence 6: D-F/1-4	10 days	29-Aug-08	11-Sep-08
Sequence 7: C-D/1-4	10 days	12-Sep-08	25-Sep-08
Top Out	0 days	25-Sep-08	25-Sep-08
MEP Rough Ins	70 days	26-Sep-08	1-Jan-09
Garage Finishes	70 days	17-Oct-08	22-Jan-09
Site Work	65 days	26-Sep-08	25-Dec-08
Elevators	58 days	24-Oct-08	13-Jan-09
M.E.P. Systems	44 days	26-Sep-08	26-Nov-08
Exterior Hardscape	30 days	10-Oct-08	20-Nov-08
Landscaping	40 days	31-Oct-08	25-Dec-08
Parking Striping	15 days	31-Oct-08	20-Nov-08
System Testing	5 days	14-Jan-09	20-Jan-09
Final Inspections	20 days	21-Jan-09	17-Feb-09
Substantial Completion	0 days	17-Feb-09	17-Feb-09

Table 13 – Proposed Garage Construction Schedule

15.8 Schedule Impact

A comparison of the substantial completion dates for the actual construction sequence and the proposed sequence reveals a substantial savings in construction duration for the parking garage. The proposed sequence has a completion date of February 17, 2009, versus April 4, 2009, for the actual construction sequence, a difference of 43 days. In both scenarios, the parking garage will be finished before the completion of the entire Redland Tech Center project, which is May 18, 2009. Being finished early may not seem beneficial at first, but it is very important for two reasons, efficiency of construction and weather delays.

Optimizing the construction process is one of the best ways for a construction company to minimize risk on a project. Shortening the duration of a project limits the amount of time people will have access to the site and the possibility of having an accident. In the case of this project, Precast Erectors will have had to erect and take down their crawler crane twice to construct the garage in the actual sequence. In the proposed sequence, the crawler crane would only be erected once.

Also, it didn't happen on this project, but a potential delay that could have been costly would be if Precast Erectors couldn't was unable to bring a crane back to the site on time for the second phase of precast erection. Redland's completion date could have been impacted if they were unable to bring the crane back within 6 weeks of the foundations being up to strength. It's best to use the equipment while it is on site versus having to bring it back later.

Reviewing the schedules for each sequencing scenario shows that the proposed sequence is less likely to have weather delays than the actual construction sequence. In the actual construction sequence, the site work, including hardscape and landscaping, is started in November and finished in February whereas the proposed sequence starts in September and finishes in December. While the Washington D.C. area usually does not get much snow, the actual construction sequence has a much higher risk of weather delays than the proposed sequence, possibly affecting Redland's completion date.

15.9 Cost Impacts

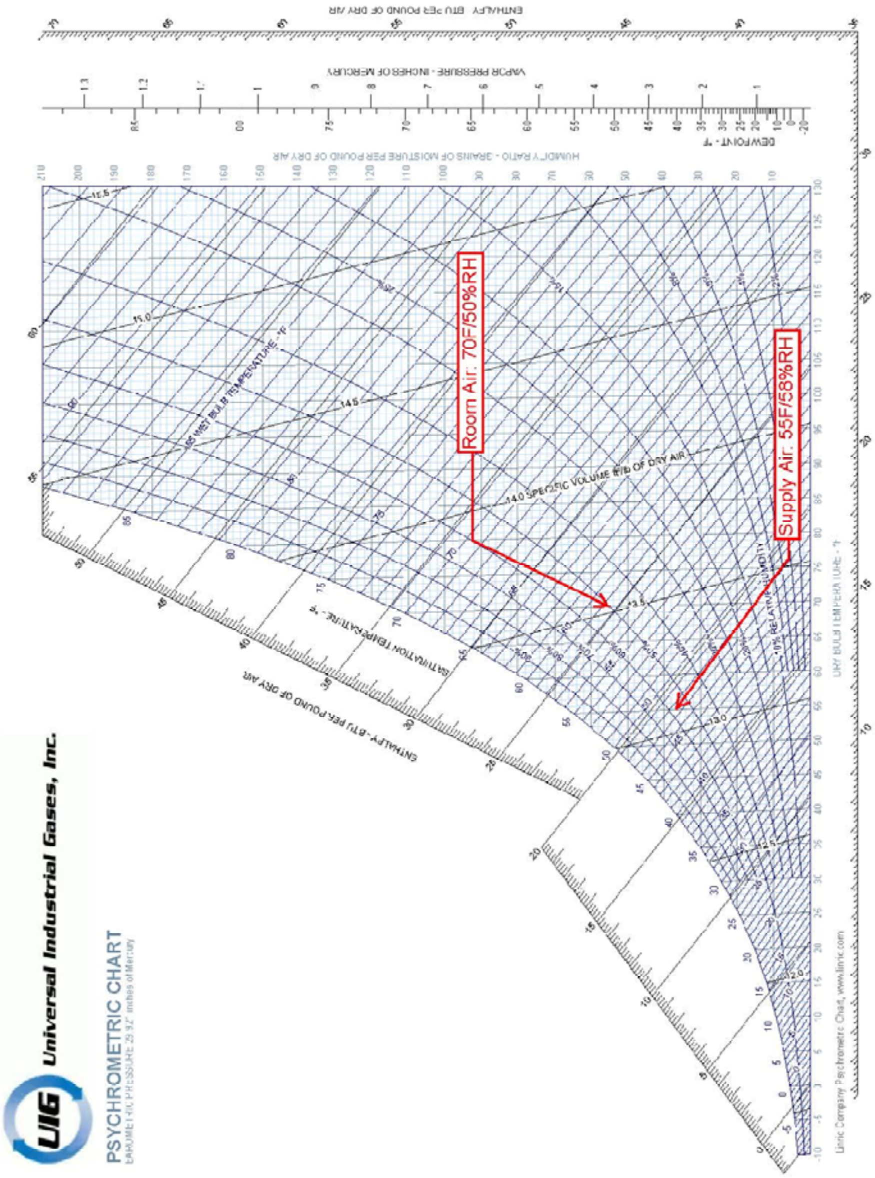
Using the proposed construction sequencing will not reduce the cost of constructing the parking garage. The shorter duration will not reduce the General Condition's cost to build the job because the GC's are built into the construction cost of the entire project. Clark Construction is not able to reduce their staffing or jobsite utilities by finishing the parking garage earlier.

In the actual construction of the garage, Clark did not have to pay Precast Erectors for the second mobilization costs due to contractual reasons. However, Precast Erectors did pay approximately $70,000 for the second mobilization. This cost could have been avoided for the erectors if they used the proposed sequence for construction.

15.10 Conclusion and Recommendation

The proposed construction sequence has several distinct advantages over the actual construction sequence. First, reducing the project duration reduces Clark Construction's risk on the project, both risk of accidents and construction delays. Second, the proposed sequence allows the site work to be completed by December versus completing the site work in the cold winter months of January and February in the actual construction sequence. Third, the proposed sequence will not reduce the construction costs of the parking garage for the owner; it will allow Precast Erectors to save on the second mobilization charge. All of these reasons would deliver better value to the project team.

APPENDIX A – CHILLED BEAM PSYCHOMETRIC CHARTS



APPENDIX B – ORIGINAL PARKING GARAGE CONSTRUCTION SEQUENCE 4D MODEL

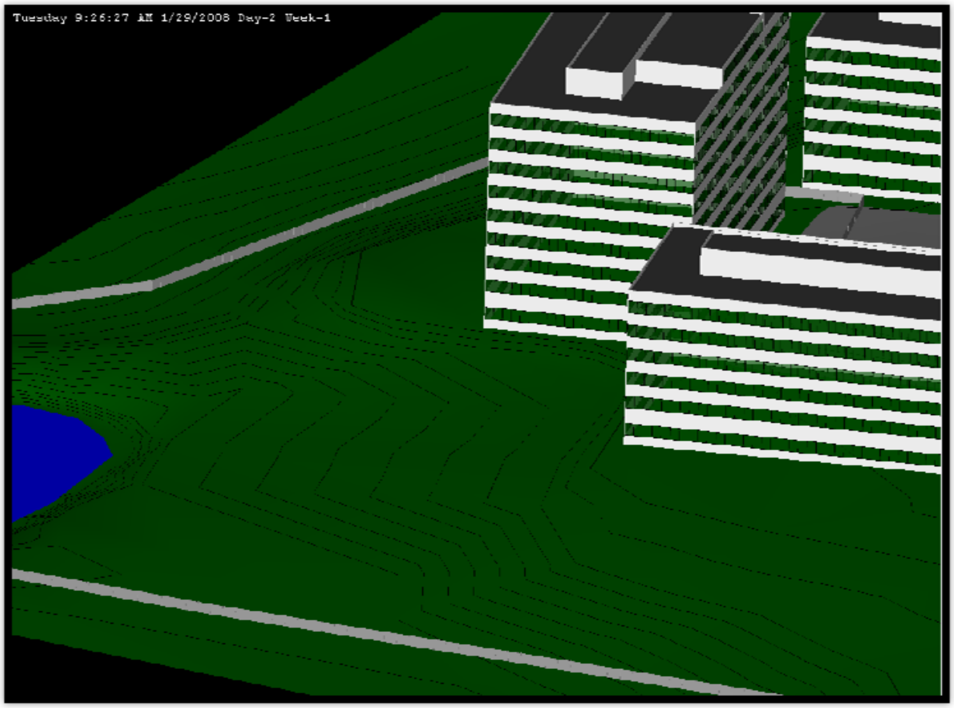


Figure 1 – Site Before Construction

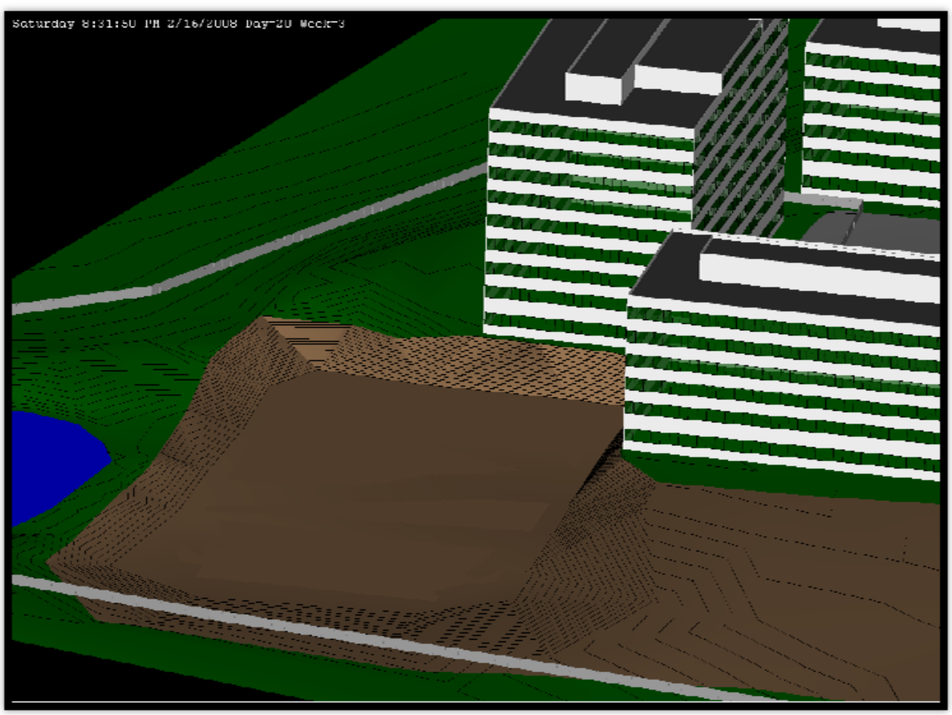


Figure 2 – Site During Excavation

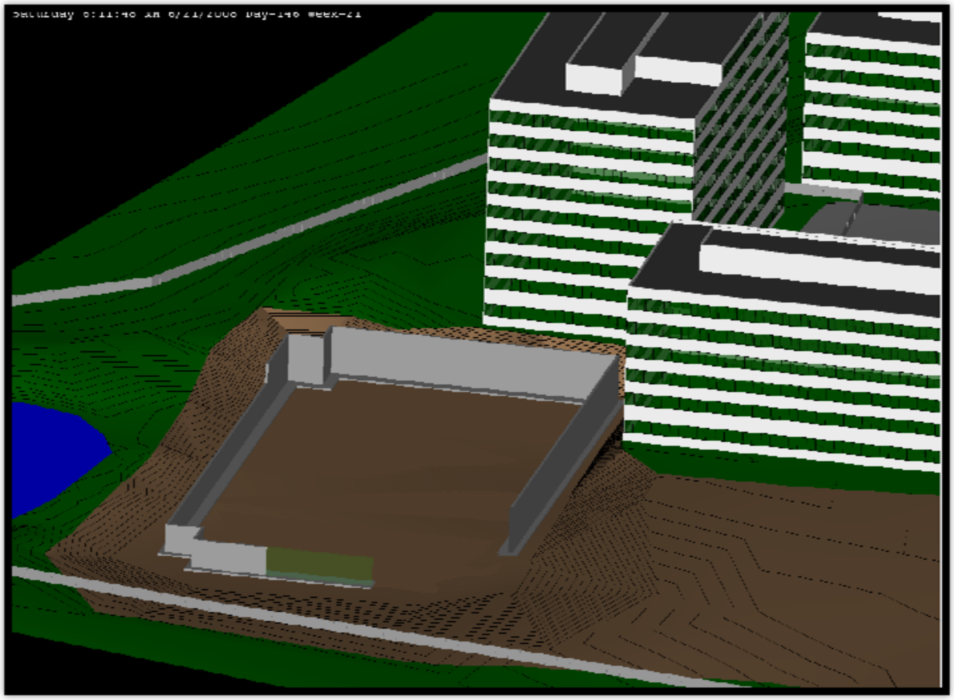


Figure 3 – Phase 1 Footing and Foundation Wall Construction

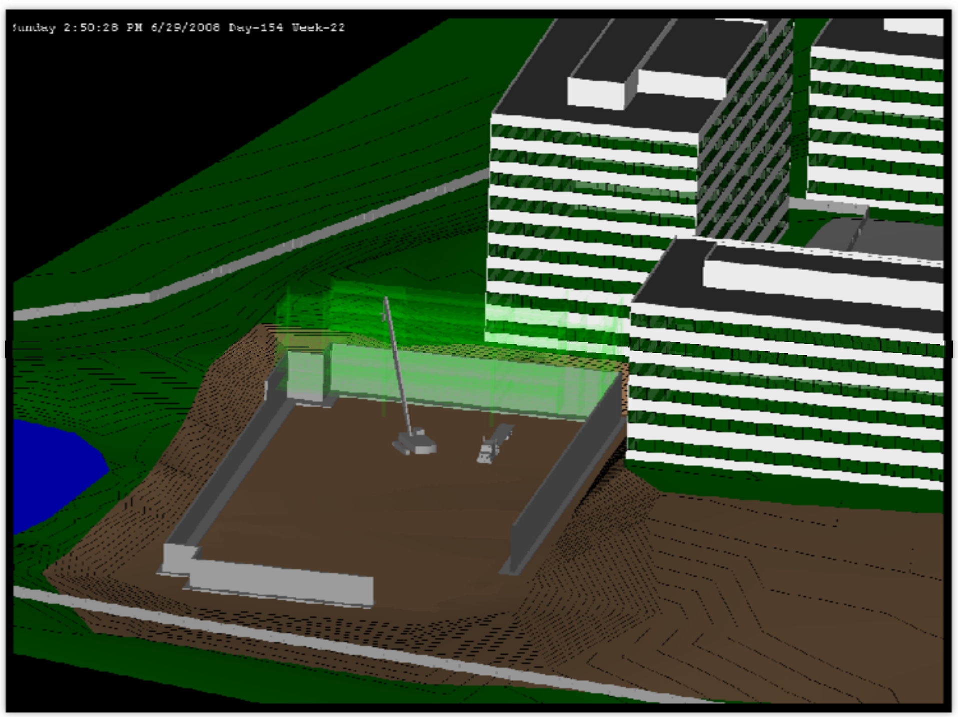


Figure 4 – Phase 1, Precast Sequence 1

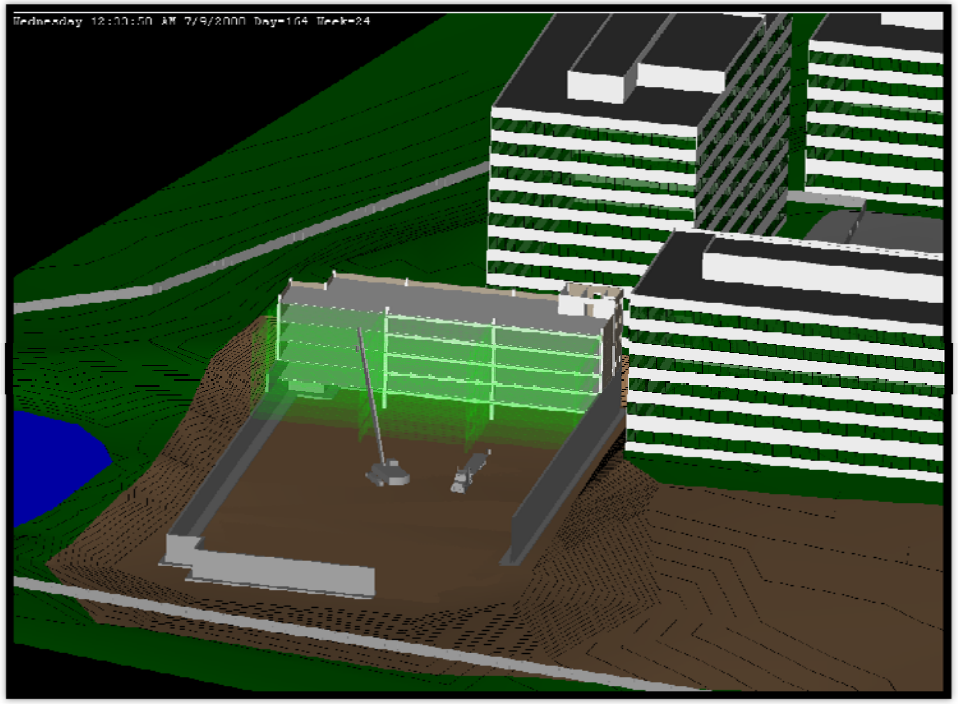


Figure 5 – Phase 1, Precast Sequence 2

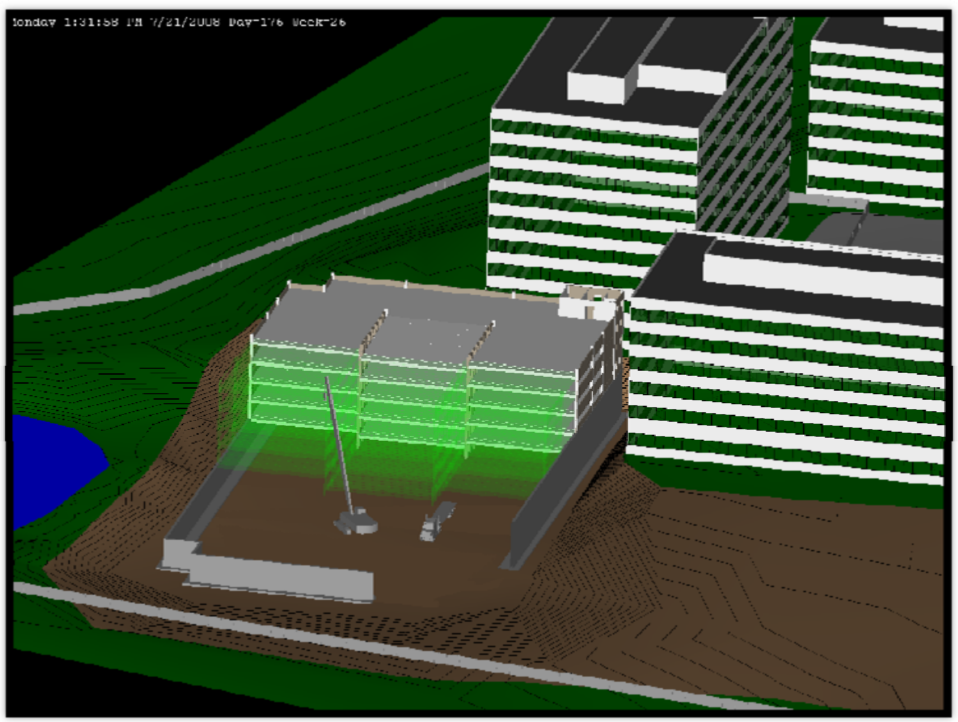


Figure 6 – Phase 1, Precast Sequence 3

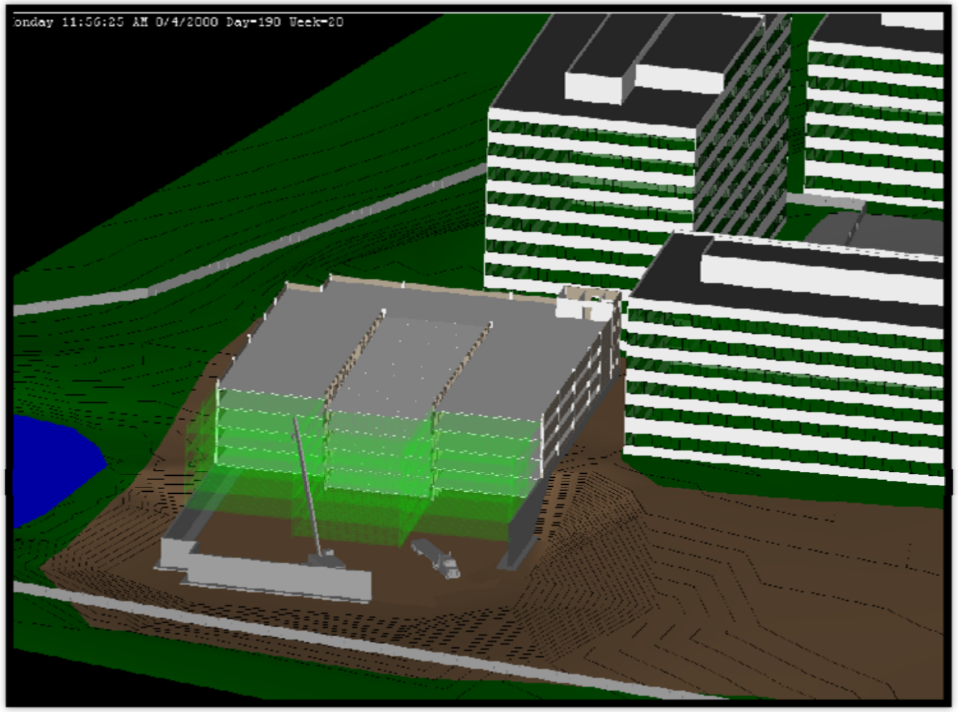


Figure 7 – Phase 1, Precast Sequence 4

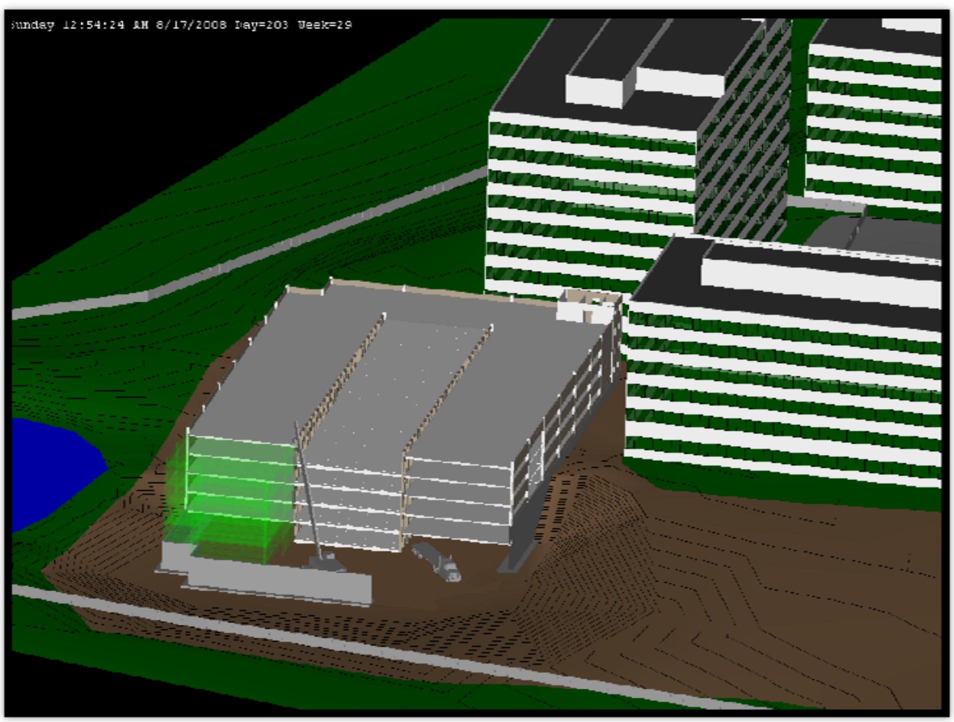


Figure 8 – Phase 1,Precast Sequence 5

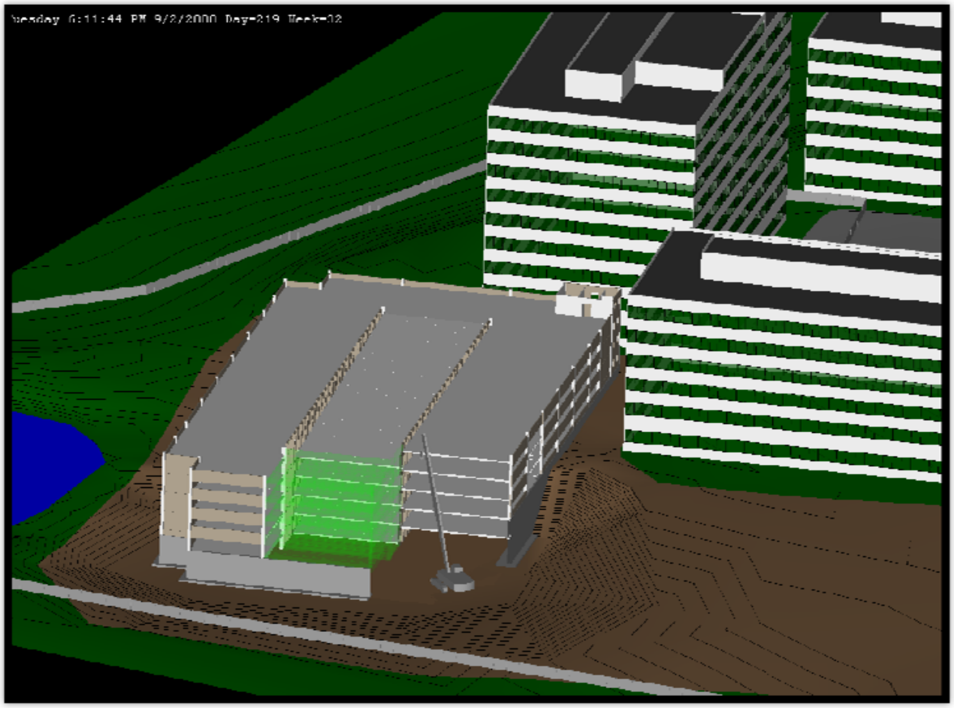


Figure 9 – Phase 1, Precast Sequence 6

Figure 10 – Phase 2 Footing and Foundation Wall Construction

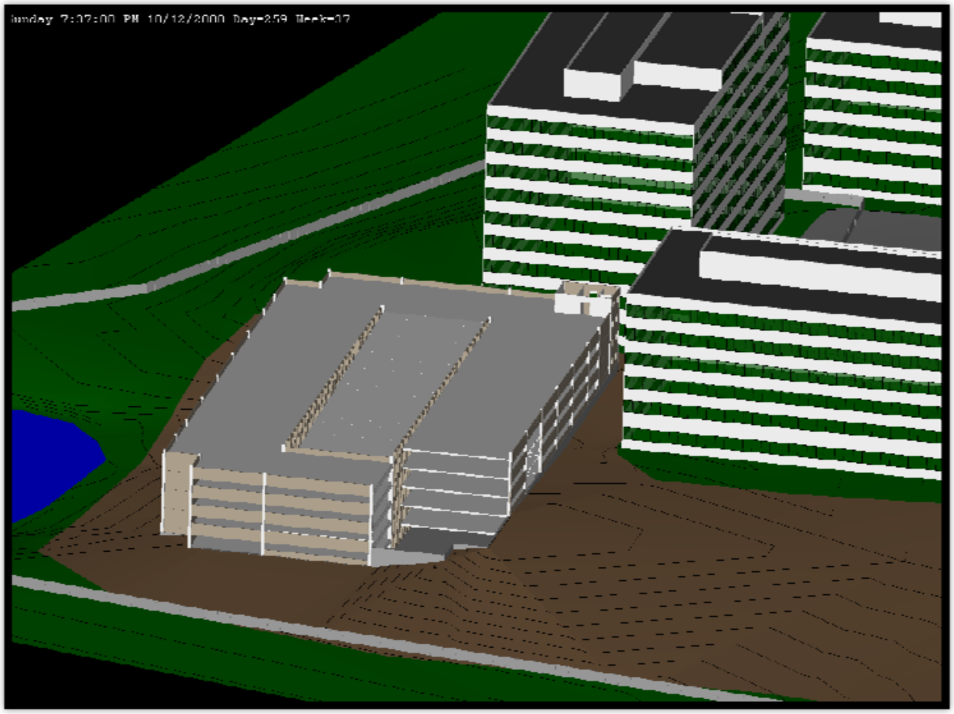


Figure 11 – Foundation Complete, Backfill Complete, Waiting on Crane

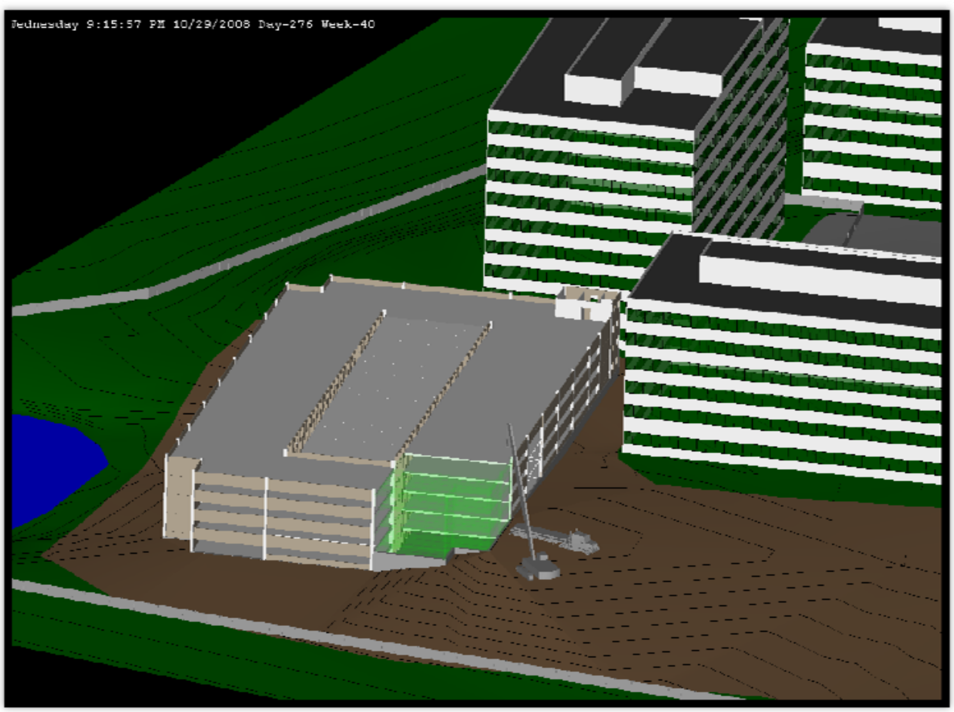


Figure 12 – Phase 2, Precast Sequence 7

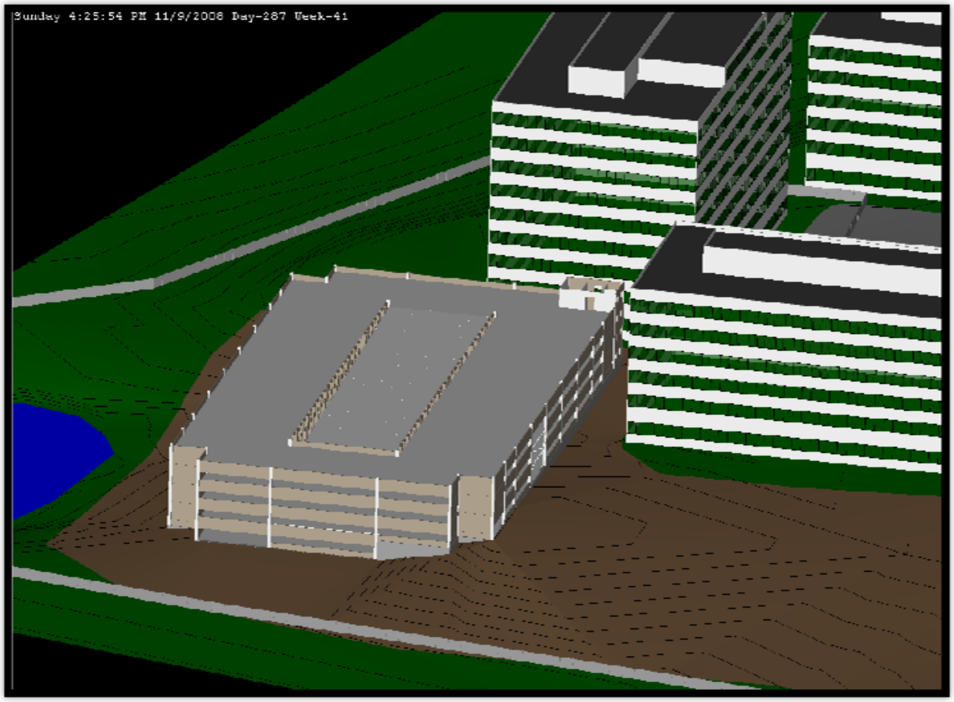


Figure 13 – Parking Garage Construction Complete

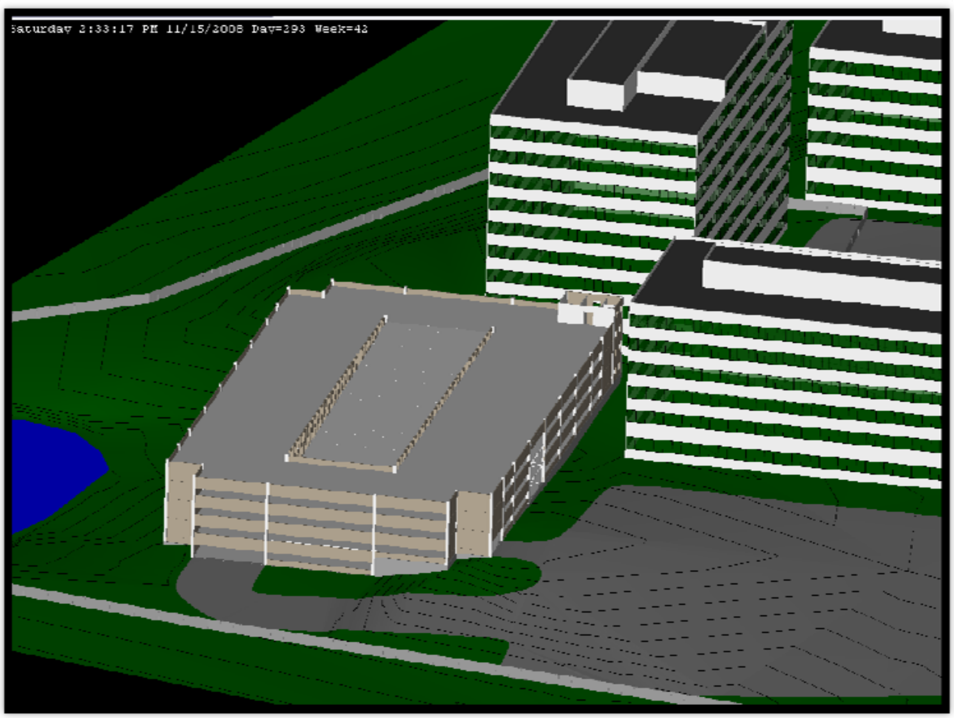
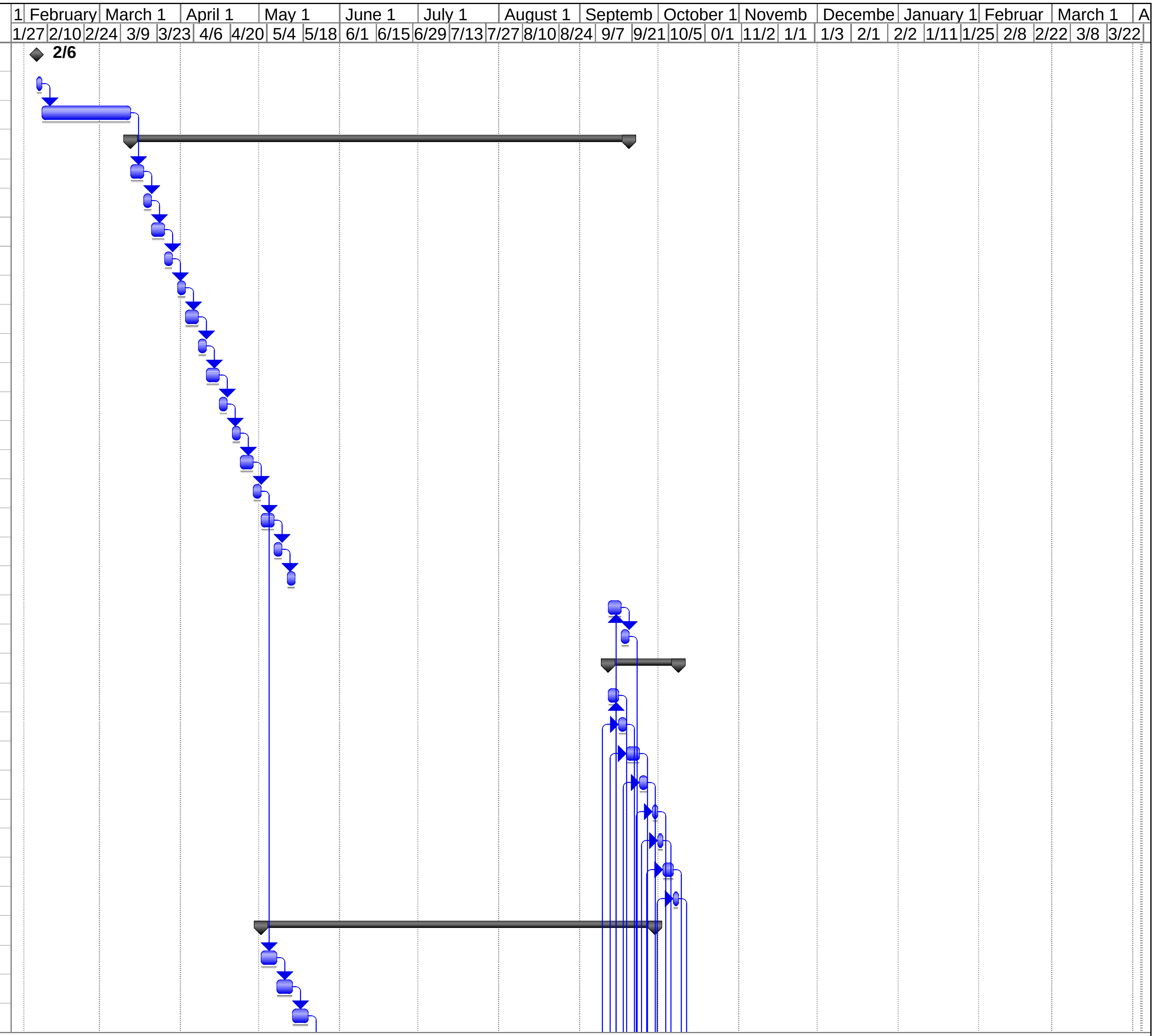


Figure 14 – Final Site

Appendix C – Original Parking Garage Construction Schedule

** Please See Next Page **

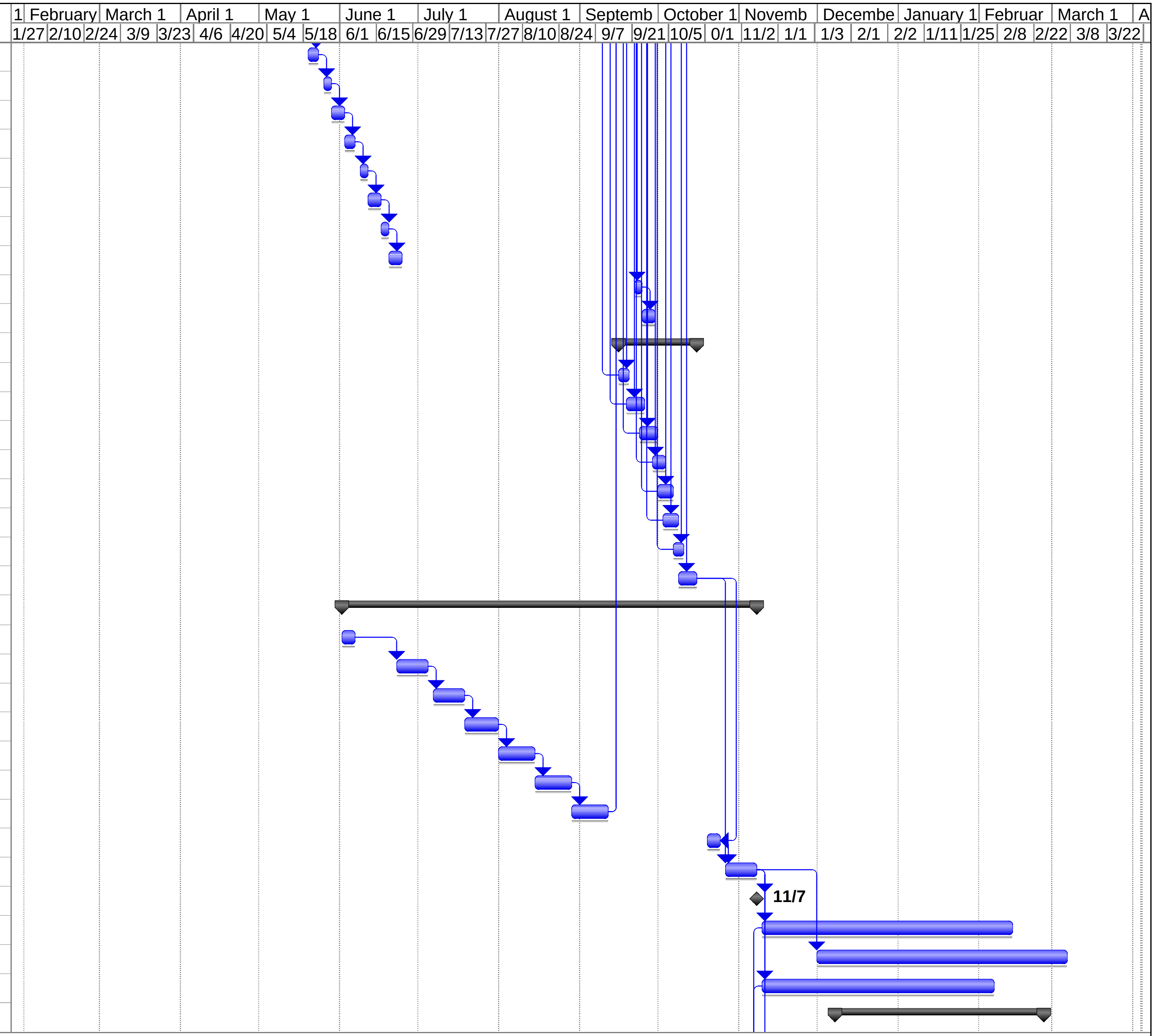
ID		Task Name	Duration	Start	Finish	Predecessors
1		NTP	0 days	Wed 2/6/08	Wed 2/6/08	
2		MOBILIZATION	2 days	Wed 2/6/08	Thu 2/7/08	
3		EXCAVATION	25 days	Fri 2/8/08	Wed 3/12/08	2
4		**FOOTINGS**	**138 days**	**Thu 3/13/08**	**Fri 9/19/08**	
5		SEQUENCE 1: F/9-12	3 days	Thu 3/13/08	Mon 3/17/08	3
6		SEQUENCE 2: C.5-F/12	3 days	Tue 3/18/08	Thu 3/20/08	5
7		SEQUENCE 3: A-C.5/12	3 days	Fri 3/21/08	Tue 3/25/08	6
8		SEQUENCE 4: F/7-9	3 days	Wed 3/26/08	Fri 3/28/08	7
9		SEQUENCE 5: D/7-10	3 days	Mon 3/31/08	Wed 4/2/08	8
10		SEQUENCE 6: C/7-10	3 days	Thu 4/3/08	Mon 4/7/08	9
11		SEQUENCE 7: A/9-12	3 days	Tue 4/8/08	Thu 4/10/08	10
12		SEQUENCE 8: A/7-9	3 days	Fri 4/11/08	Tue 4/15/08	11
13		SEQUENCE 9: C/3-7	3 days	Wed 4/16/08	Fri 4/18/08	12
14		SEQUENCE 10: D/3-7	3 days	Mon 4/21/08	Wed 4/23/08	13
15		SEQUENCE 11: F/4-7	3 days	Thu 4/24/08	Mon 4/28/08	14
16		SEQUENCE 12: A/3-7	3 days	Tue 4/29/08	Thu 5/1/08	15
17		SEQUENCE 13: A/1-3	3 days	Fri 5/2/08	Tue 5/6/08	16
18		SEQUENCE 14: A-B.5/1	3 days	Wed 5/7/08	Fri 5/9/08	17
19		SEQUENCE 15: B.5-D/1	3 days	Mon 5/12/08	Wed 5/14/08	18
20		SEQUENCE 16: D-F/1	3 days	Fri 9/12/08	Tue 9/16/08	61
21		SEQUENCE 17: F/1-4	3 days	Wed 9/17/08	Fri 9/19/08	20
22		**UNDERSLAB MEP**	**19 days**	**Fri 9/12/08**	**Wed 10/8/08**	
23		SEQUENCE 1: A-F/10-12	2 days	Fri 9/12/08	Mon 9/15/08	61
24		SEQUENCE 2: A-C/6-10	3 days	Tue 9/16/08	Thu 9/18/08	46SS
25		SEQUENCE 3: C-D/6-10	3 days	Fri 9/19/08	Tue 9/23/08	47SS
26		SEQUENCE 4: D-F/6-10	3 days	Wed 9/24/08	Fri 9/26/08	48SS
27		SEQUENCE 5: A-C/3-6	2 days	Mon 9/29/08	Tue 9/30/08	49SS
28		SEQUENCE 6: C-D/3-6	2 days	Wed 10/1/08	Thu 10/2/08	50SS
29		SEQUENCE 7: D-F/3-6	2 days	Fri 10/3/08	Mon 10/6/08	51SS
30		SEQUENCE 8: A-F/1-3	2 days	Tue 10/7/08	Wed 10/8/08	52SS
31		**FOUNDATION WALLS**	**108 days**	**Fri 5/2/08**	**Mon 9/29/08**	
32		SEQUENCE 1: F/9-12	4 days	Fri 5/2/08	Wed 5/7/08	16
33		SEQUENCE 2: C.5-F/12	4 days	Thu 5/8/08	Tue 5/13/08	32
34		SEQUENCE 3: A-C.5/12	4 days	Wed 5/14/08	Mon 5/19/08	33



Project: PG Original Schedule
Date: Sat 4/4/09

Task	Progress	Summary	External Tasks	Deadline
Split	Milestone	Project Summary	External Milestone	

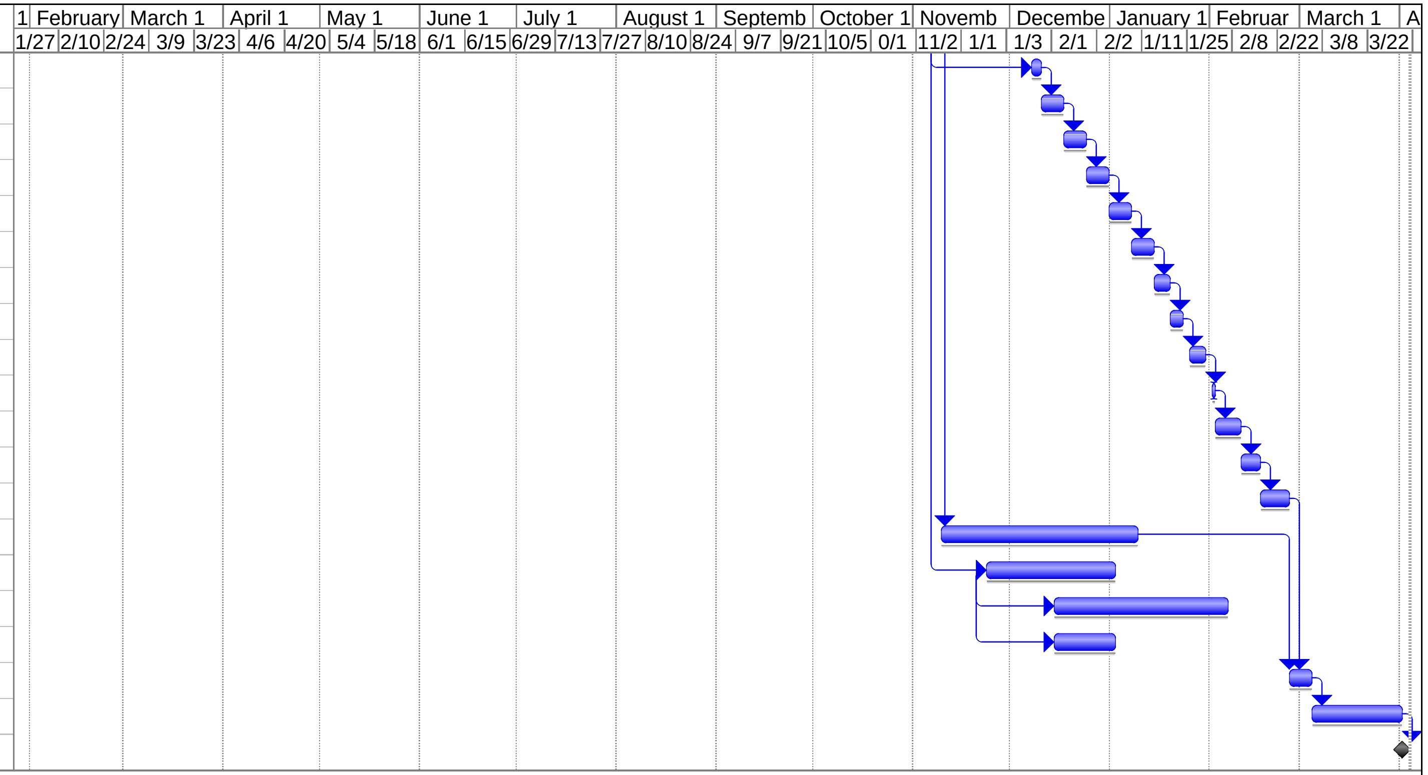
ID		Task Name	Duration	Start	Finish	Predecessors
35		SEQUENCE 4: F/7-9	4 days	Tue 5/20/08	Fri 5/23/08	34
36		SEQUENCE 5: A/9-12	3 days	Mon 5/26/08	Wed 5/28/08	35
37		SEQUENCE 6: A/7-9	3 days	Thu 5/29/08	Mon 6/2/08	36
38		SEQUENCE 7: F/4-7	4 days	Tue 6/3/08	Fri 6/6/08	37
39		SEQUENCE 8: A/3-7	3 days	Mon 6/9/08	Wed 6/11/08	38
40		SEQUENCE 9: A/1-3	3 days	Thu 6/12/08	Mon 6/16/08	39
41		SEQUENCE 10: A-B.5/1	3 days	Tue 6/17/08	Thu 6/19/08	40
42		SEQUENCE 11: B.5-D/1	3 days	Fri 6/20/08	Tue 6/24/08	41
43		SEQUENCE 12: D-F/1	3 days	Mon 9/22/08	Wed 9/24/08	21
44		SEQUENCE 13: F/1-4	3 days	Thu 9/25/08	Mon 9/29/08	43
45		**SLAB**	**22 days**	**Tue 9/16/08**	**Wed 10/15/08**	
46		SEQUENCE 1: A-F/10-12	4 days	Tue 9/16/08	Fri 9/19/08	23
47		SEQUENCE 2: A-C/6-10	5 days	Fri 9/19/08	Thu 9/25/08	24
48		SEQUENCE 3: C-D/6-10	5 days	Wed 9/24/08	Tue 9/30/08	25
49		SEQUENCE 4: D-F/6-10	5 days	Mon 9/29/08	Fri 10/3/08	26
50		SEQUENCE 5: A-C/3-6	4 days	Wed 10/1/08	Mon 10/6/08	27
51		SEQUENCE 6: C-D/3-6	4 days	Fri 10/3/08	Wed 10/8/08	28
52		SEQUENCE 7: D-F/3-6	4 days	Tue 10/7/08	Fri 10/10/08	29
53		SEQUENCE 8: A-F/1-3	5 days	Thu 10/9/08	Wed 10/15/08	30
54		**PRECAST PANELS**	**116 days**	**Mon 6/2/08**	**Fri 11/7/08**	
55		MOBILIZE	5 days	Mon 6/2/08	Fri 6/6/08	
56		SEQUENCE 1: A- F/10-12	10 days	Mon 6/23/08	Fri 7/4/08	55
57		SEQUENCE 2: A- F/8-10	10 days	Mon 7/7/08	Fri 7/18/08	56
58		SEQUENCE 3: A- F/6-8	10 days	Sat 7/19/08	Thu 7/31/08	57
59		SEQUENCE 4: A- F/4-6	10 days	Fri 8/1/08	Thu 8/14/08	58
60		SEQUENCE 5: A-C/1-4	10 days	Fri 8/15/08	Thu 8/28/08	59
61		SEQUENCE 6: C-D/1-4	10 days	Fri 8/29/08	Thu 9/11/08	60
62		REMOBILIZE	5 days	Mon 10/20/08	Fri 10/24/08	53FF
63		SEQUENCE 7: D-F/1-4	10 days	Mon 10/27/08	Fri 11/7/08	53,62
64		TOP OUT	0 days	Fri 11/7/08	Fri 11/7/08	63
65		MEP ROUGH INS	70 days	Mon 11/10/08	Fri 2/13/09	63
66		GARAGE FINISHES	70 days	Mon 12/1/08	Fri 3/6/09	63FS+15 days
67		SITEWORK	65 days	Mon 11/10/08	Fri 2/6/09	63
68		**ELEVATORS**	**58 days**	**Mon 12/8/08**	**Wed 2/25/09**	



Project: PG Original Schedule
Date: Sat 4/4/09

Task	Progress	Summary	External Tasks
Split	Milestone	Project Summary	External Milestone
Deadline			

ID		Task Name	Duration	Start	Finish	Predecessors
69		MOBILIZE	3 days	Mon 12/8/08	Wed 12/10/08	65SS+20 days
70		INSTALL CYLINDER	5 days	Thu 12/11/08	Wed 12/17/08	69
71		INSTALL RAILS	5 days	Thu 12/18/08	Wed 12/24/08	70
72		INSTALL PIT EQUIPMENT & C.	5 days	Thu 12/25/08	Wed 12/31/08	71
73		INSTALL MACHINE RM EQUIP	5 days	Thu 1/1/09	Wed 1/7/09	72
74		ENTRANCES, DOORS, HDW, I	5 days	Thu 1/8/09	Wed 1/14/09	73
75		COMPLETE HOISTWAY WALL	3 days	Thu 1/15/09	Mon 1/19/09	74
76		INSTALL HOISTWAY EQUIPMI	4 days	Tue 1/20/09	Fri 1/23/09	75
77		CABS, WIRING & DOOR OPER	5 days	Mon 1/26/09	Fri 1/30/09	76
78		PRE-ADJUSTMENT TKE CHEC	1 day	Mon 2/2/09	Mon 2/2/09	77
79		ADJUST	6 days	Tue 2/3/09	Tue 2/10/09	78
80		CLEAN, PAINT, PUNCHLIST	4 days	Wed 2/11/09	Mon 2/16/09	79
81		INSPECTIONS	7 days	Tue 2/17/09	Wed 2/25/09	80
82		M.E.P. SYSTEMS	45 days	Mon 11/10/08	Fri 1/9/09	63
83		EXTERIOR HARDSCAPE	30 days	Mon 11/24/08	Fri 1/2/09	67SS+10 days
84		LANDSCAPING	40 days	Mon 12/15/08	Fri 2/6/09	83SS+15 days
85		PARKING STRIPING	15 days	Mon 12/15/08	Fri 1/2/09	83SS+15 days
86		SYSTEM TESTING	5 days	Thu 2/26/09	Wed 3/4/09	81,82
87		FINAL INSPECTIONS	20 days	Thu 3/5/09	Wed 4/1/09	86
88		SUBSTANTIAL COMPLETION	0 days	Wed 4/1/09	Wed 4/1/09	87



Project: PG Original Schedule
Date: Sat 4/4/09

Task	Progress	Summary	External Tasks	Deadline
Split	Milestone	Project Summary	External Milestone	

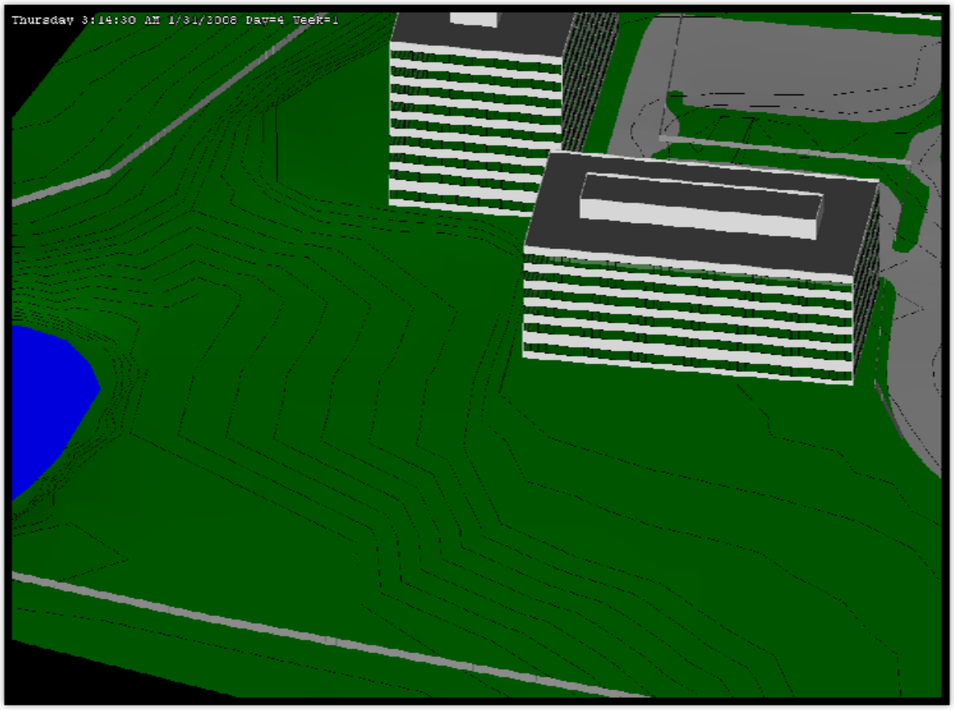


Figure 15 – Site Before Construction

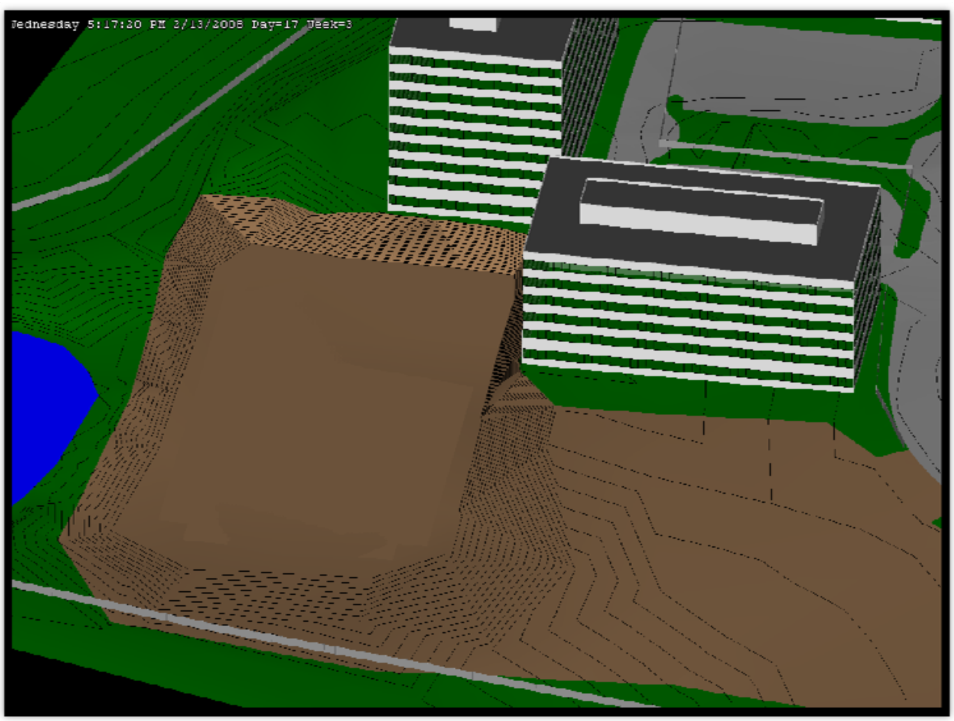


Figure 16 – Site During Excavation

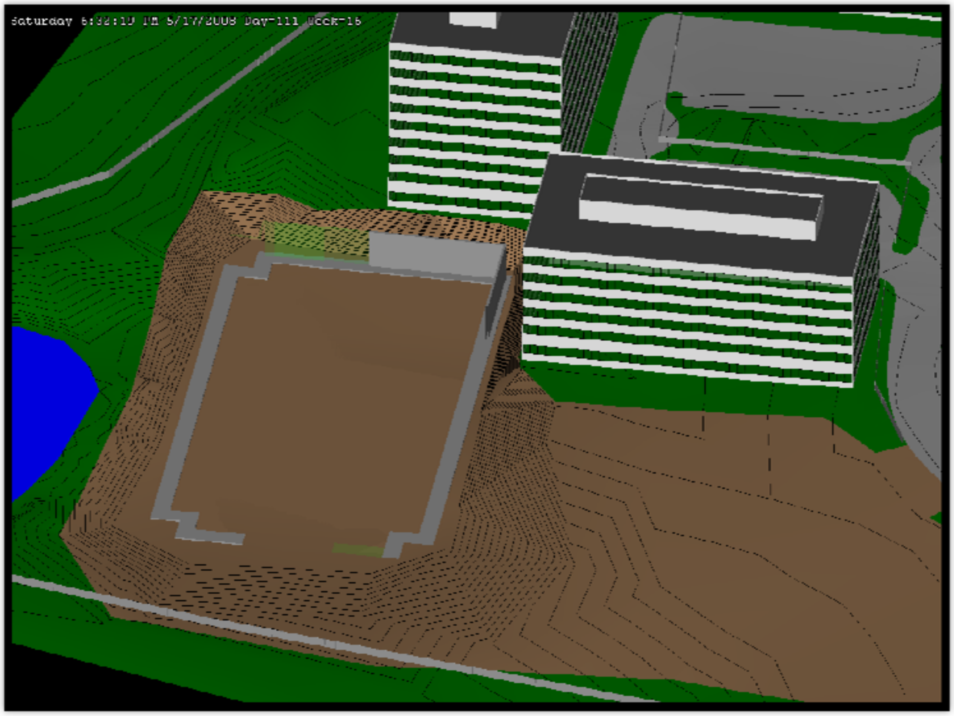


Figure 17 – Phase 1 Footing and Foundation Wall Construction

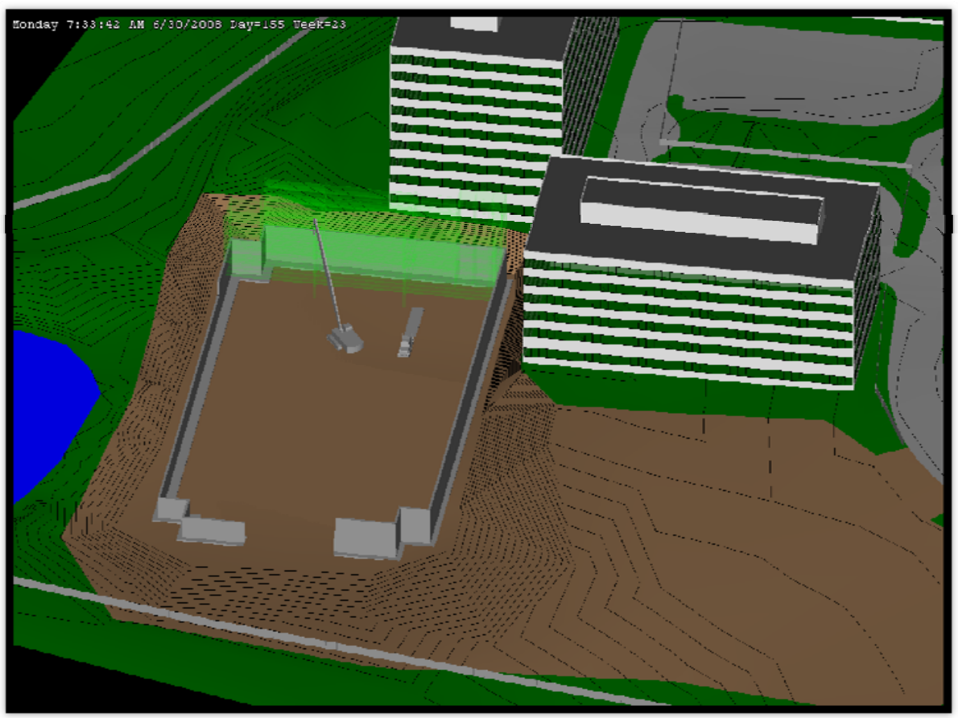


Figure 18 – Precast Sequence 1

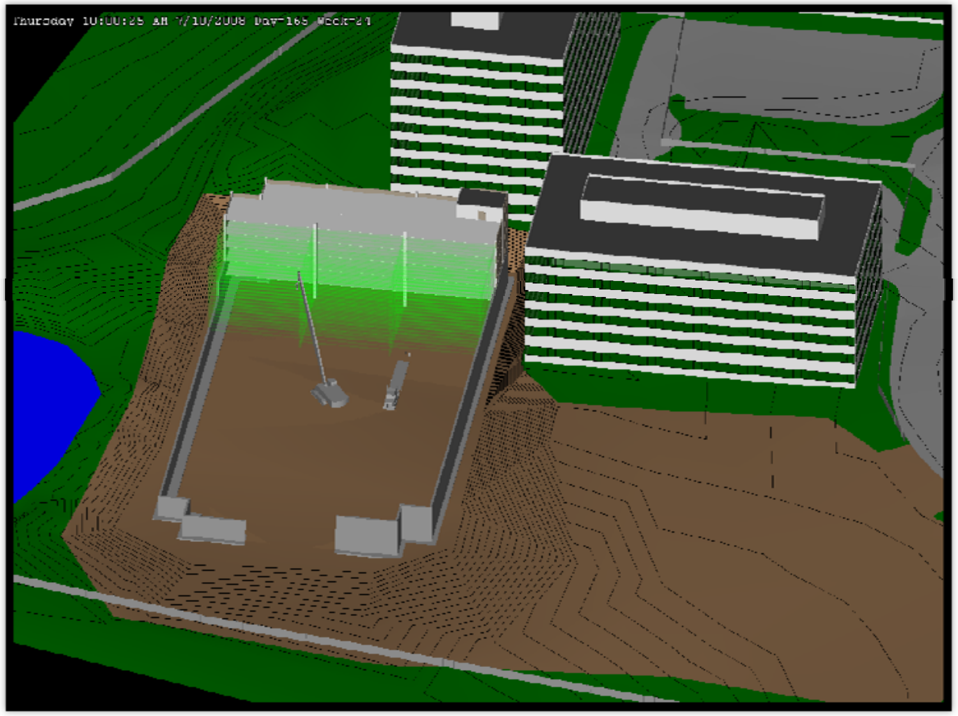


Figure 19 – Precast Sequence 2

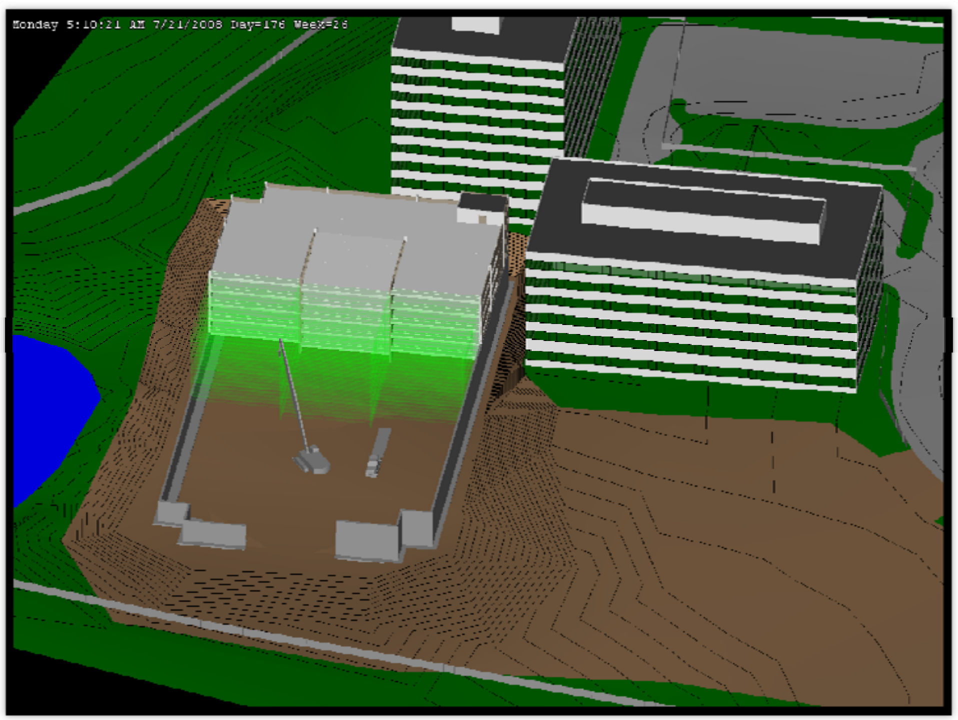


Figure 20 – Precast Sequence 3

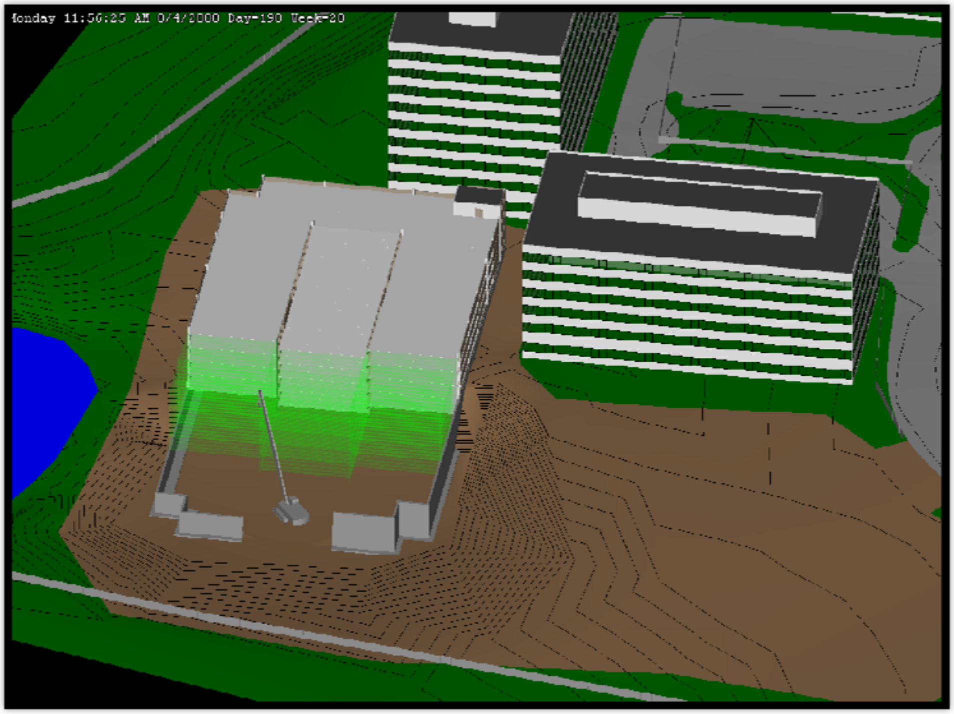


Figure 21 – Precast Sequence 4

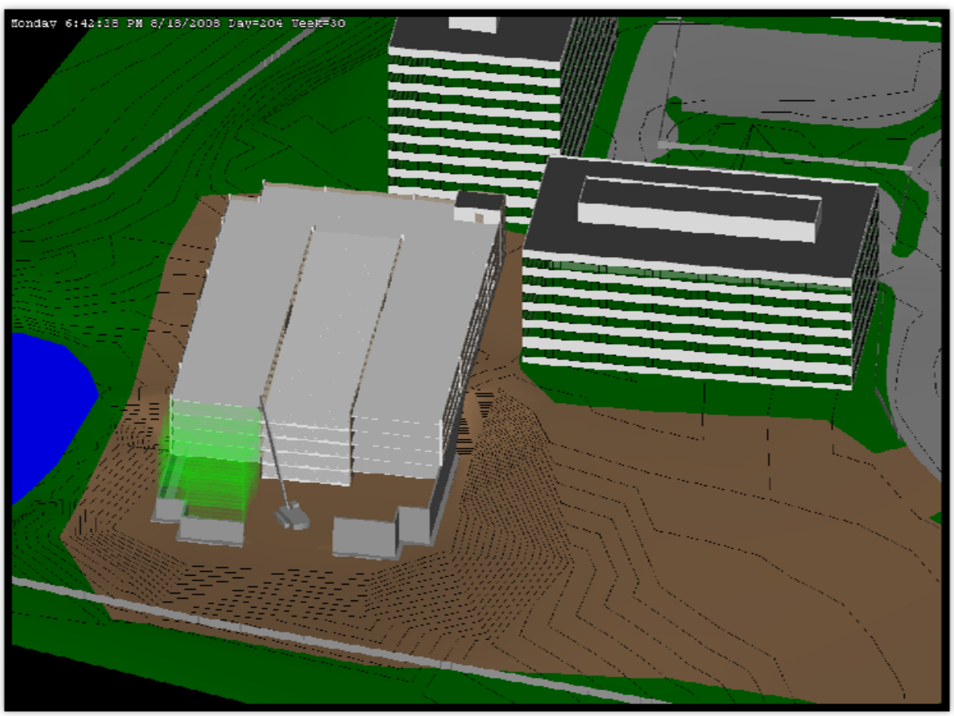


Figure 22 – Precast Sequence 5

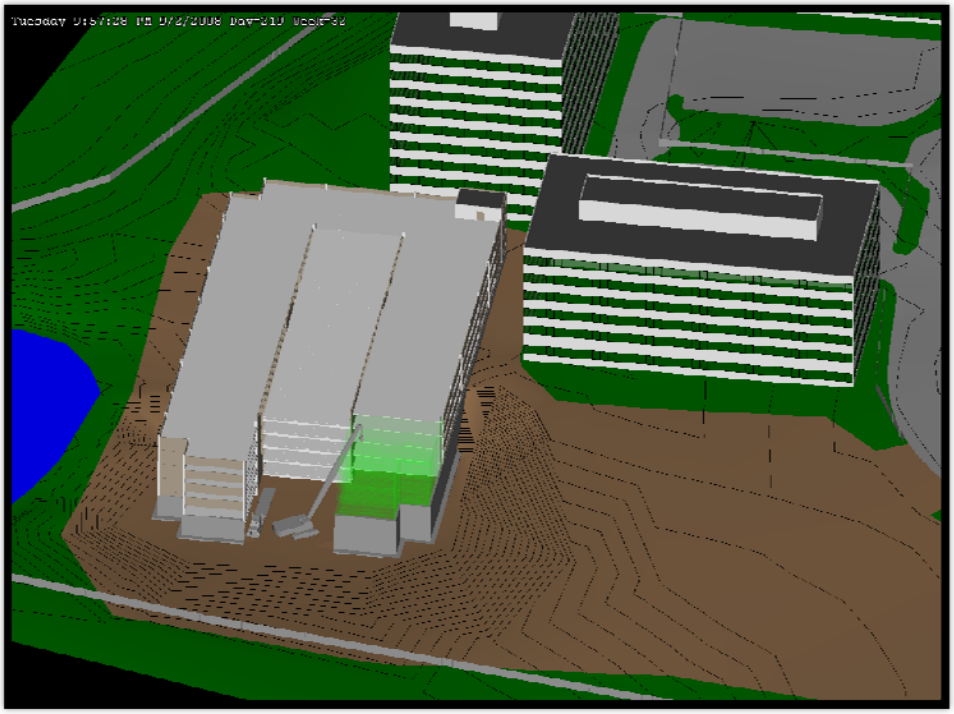


Figure 23 – Precast Sequence 6

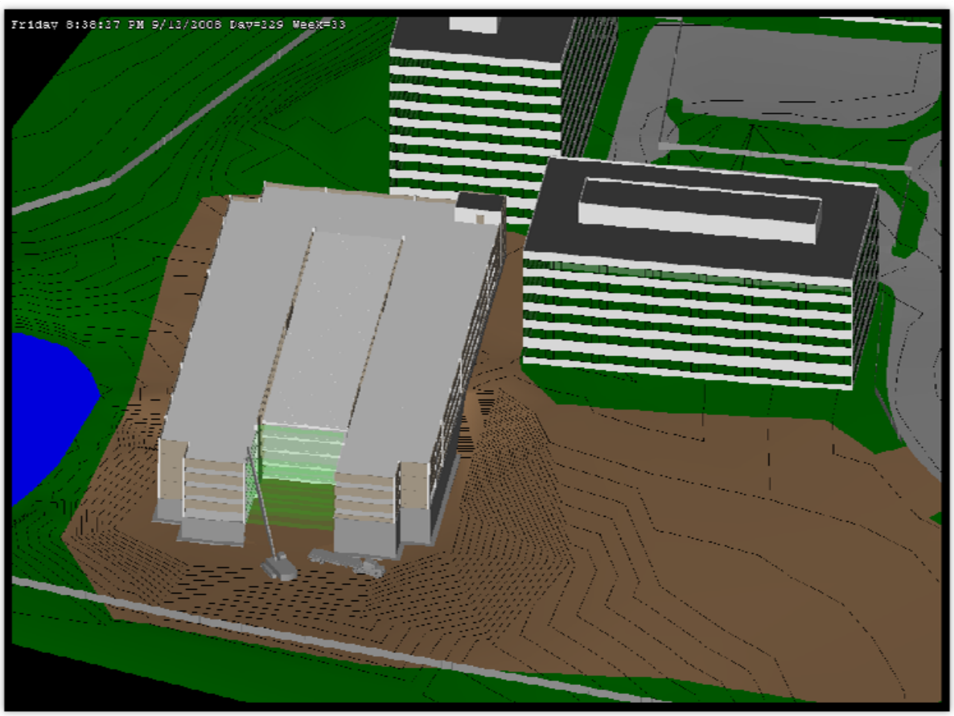


Figure 24 – Precast Sequence 7

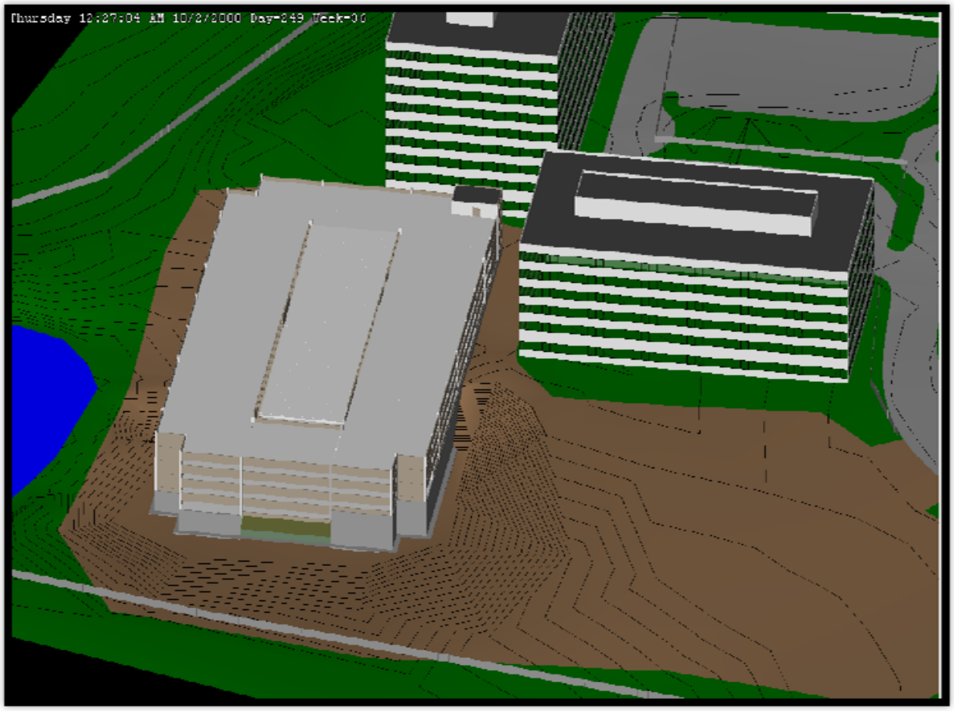


Figure 25 – Phase 2 Footing and Foundation Wall Construction

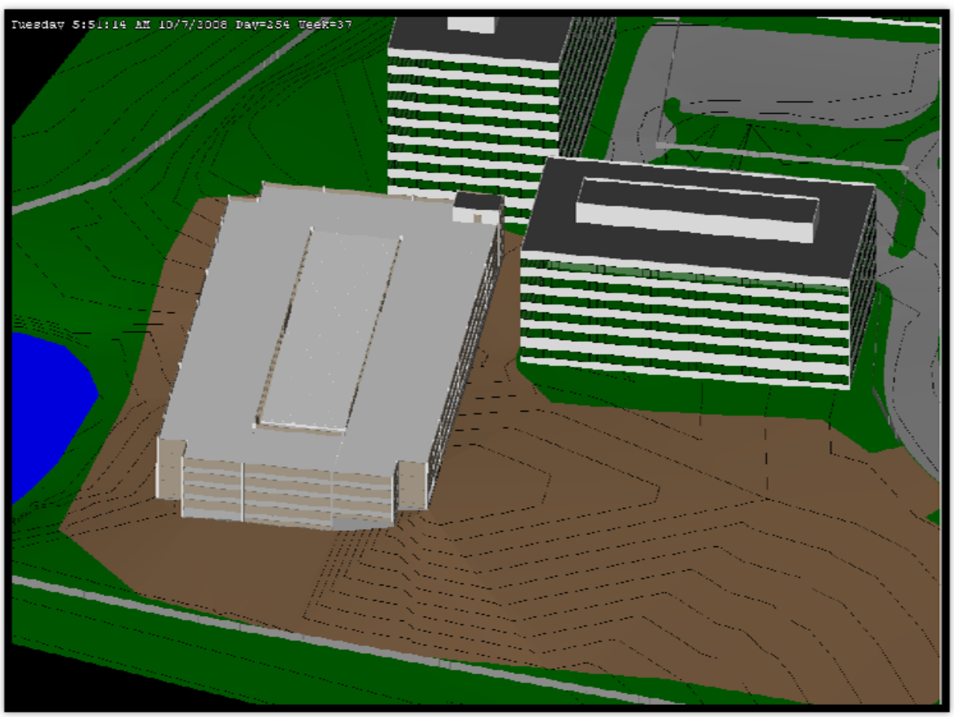


Figure 26 – Parking Garage Construction Complete

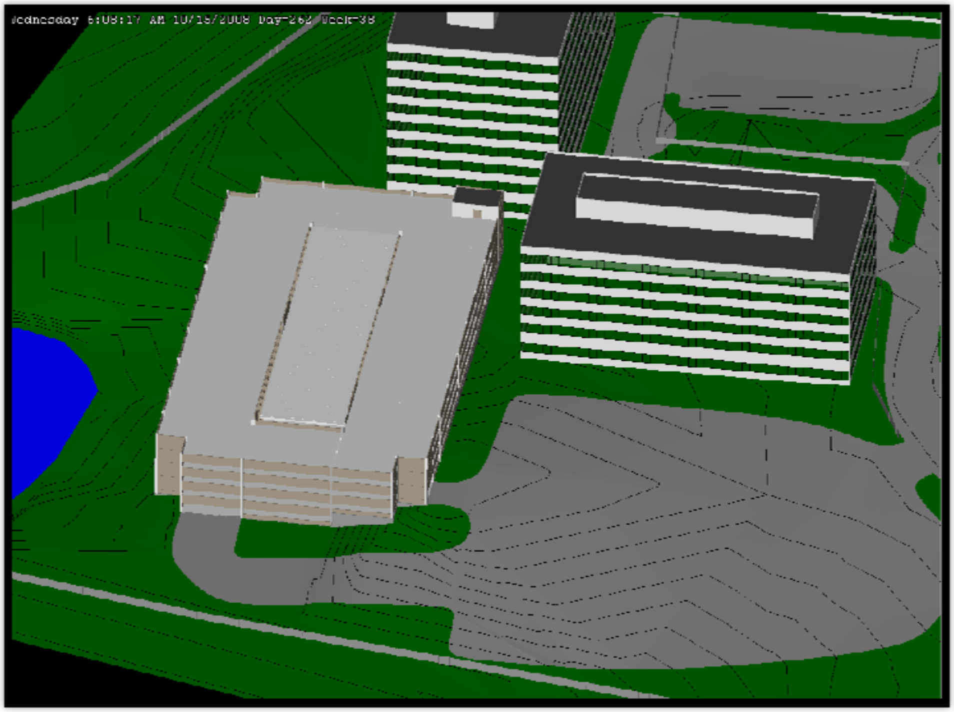
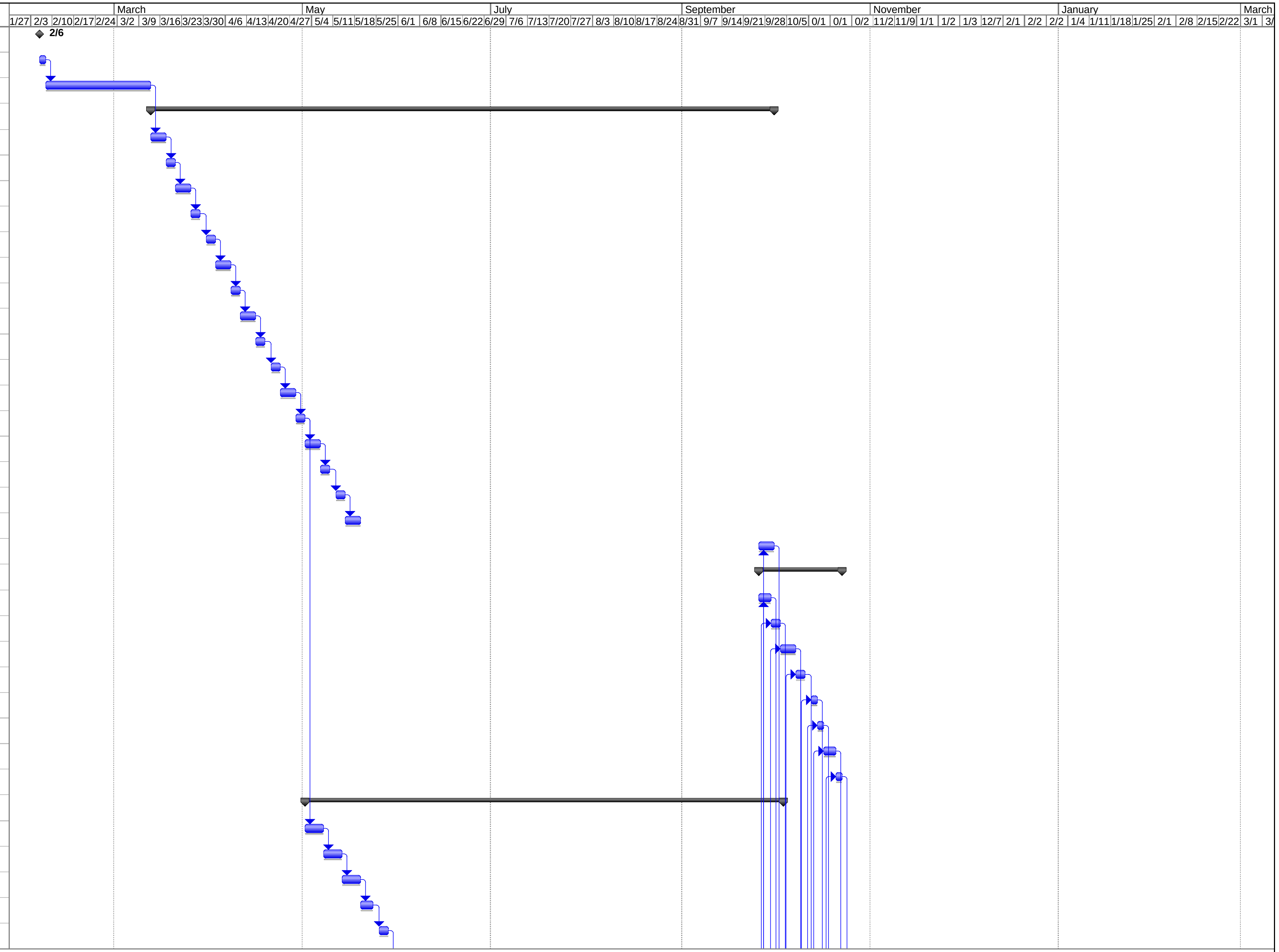


Figure 27 – Final Site

APPENDIX D – REVISED PARKING GARAGE CONSTRUCTION SCHEDULE

** PLEASE SEE NEXT PAGE **

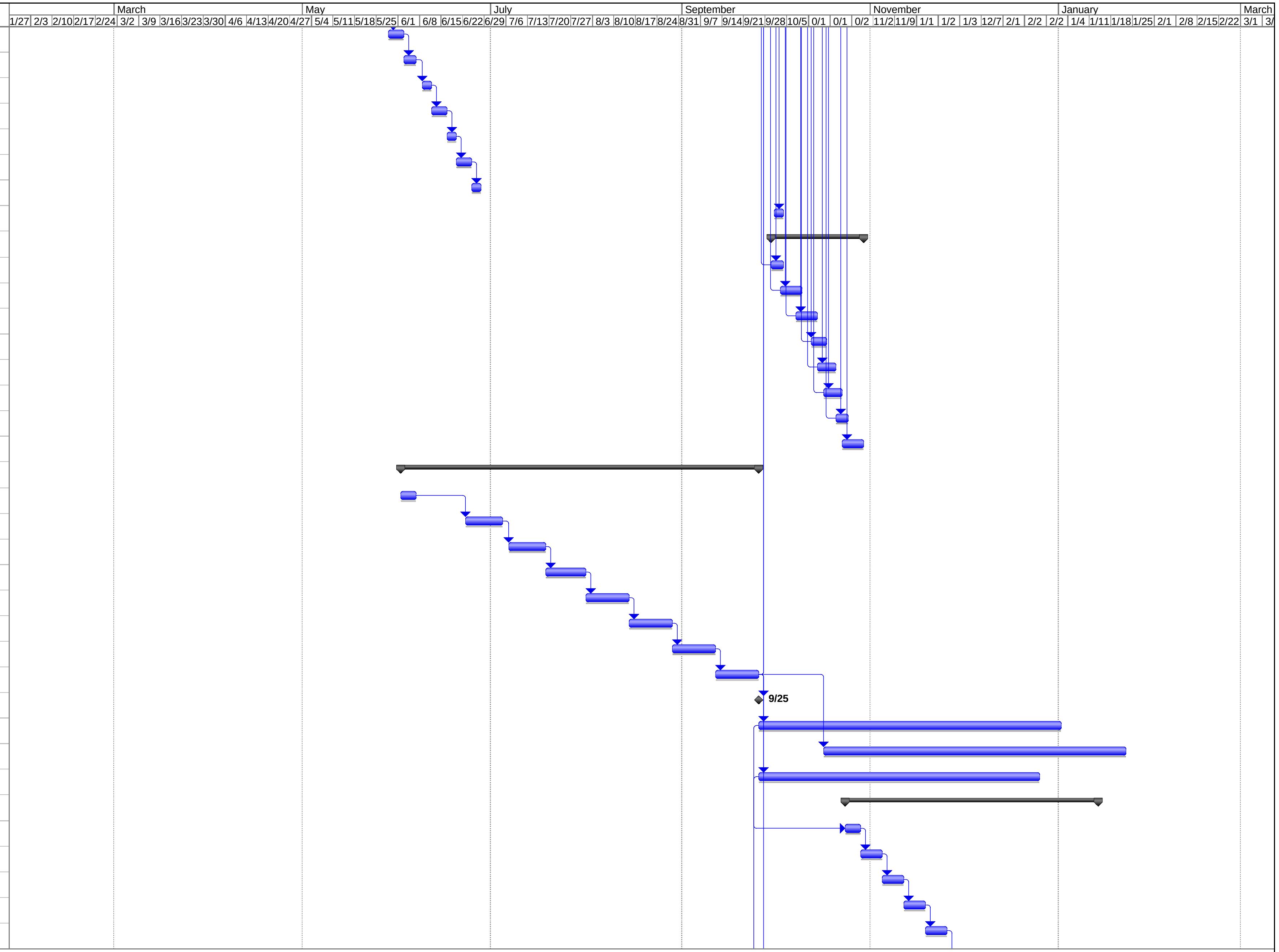
ID	Task Name	Duration	Start	Finish	Predecessors
1	NTP	0 days	Wed 2/6/08	Wed 2/6/08	
2	MOBILIZATION	2 days	Wed 2/6/08	Thu 2/7/08	
3	EXCAVATION	25 days	Fri 2/8/08	Wed 3/12/08	2
4	**FOOTINGS**	**145 days**	**Thu 3/13/08**	**Tue 9/30/08**	
5	SEQUENCE 1: F/9-12	3 days	Thu 3/13/08	Mon 3/17/08	3
6	SEQUENCE 2: C.5-F/12	3 days	Tue 3/18/08	Thu 3/20/08	5
7	SEQUENCE 3: A-C.5/12	3 days	Fri 3/21/08	Tue 3/25/08	6
8	SEQUENCE 4: F/7-9	3 days	Wed 3/26/08	Fri 3/28/08	7
9	SEQUENCE 5: D/7-10	3 days	Mon 3/31/08	Wed 4/2/08	8
10	SEQUENCE 6: C/7-10	3 days	Thu 4/3/08	Mon 4/7/08	9
11	SEQUENCE 7: A/9-12	3 days	Tue 4/8/08	Thu 4/10/08	10
12	SEQUENCE 8: A/7-9	3 days	Fri 4/11/08	Tue 4/15/08	11
13	SEQUENCE 9: C/3-7	3 days	Wed 4/16/08	Fri 4/18/08	12
14	SEQUENCE 10: D/3-7	3 days	Mon 4/21/08	Wed 4/23/08	13
15	SEQUENCE 11: F/3-7	3 days	Thu 4/24/08	Mon 4/28/08	14
16	SEQUENCE 12: A/3-7	3 days	Tue 4/29/08	Thu 5/1/08	15
17	SEQUENCE 13: A/1-3	3 days	Fri 5/2/08	Tue 5/6/08	16
18	SEQUENCE 14: A-C.1/1	3 days	Wed 5/7/08	Fri 5/9/08	17
19	SEQUENCE 15: F/1-3	3 days	Mon 5/12/08	Wed 5/14/08	18
20	SEQUENCE 16: C.9-F/1	3 days	Thu 5/15/08	Mon 5/19/08	19
21	SEQUENCE 17: C.1-C.9/1	3 days	Fri 9/26/08	Tue 9/30/08	62
22	**UNDERSLAB MEP**	**19 days**	**Fri 9/26/08**	**Wed 10/22/08**	
23	SEQUENCE 1: A-F/10-12	2 days	Fri 9/26/08	Mon 9/29/08	62
24	SEQUENCE 2: A-C/6-10	3 days	Tue 9/30/08	Thu 10/2/08	46SS
25	SEQUENCE 3: C-D/6-10	3 days	Fri 10/3/08	Tue 10/7/08	47SS
26	SEQUENCE 4: D-F/6-10	3 days	Wed 10/8/08	Fri 10/10/08	48SS
27	SEQUENCE 5: A-C/3-6	2 days	Mon 10/13/08	Tue 10/14/08	49SS
28	SEQUENCE 6: C-D/3-6	2 days	Wed 10/15/08	Thu 10/16/08	50SS
29	SEQUENCE 7: D-F/3-6	2 days	Fri 10/17/08	Mon 10/20/08	51SS
30	SEQUENCE 8: A-F/1-3	2 days	Tue 10/21/08	Wed 10/22/08	52SS
31	**FOUNDATION WALLS**	**112 days**	**Fri 5/2/08**	**Fri 10/3/08**	
32	SEQUENCE 1: F/9-12	4 days	Fri 5/2/08	Wed 5/7/08	16
33	SEQUENCE 2: C.5-F/12	4 days	Thu 5/8/08	Tue 5/13/08	32
34	SEQUENCE 3: A-C.5/12	4 days	Wed 5/14/08	Mon 5/19/08	33
35	SEQUENCE 4: F/7-9	4 days	Tue 5/20/08	Fri 5/23/08	34
36	SEQUENCE 5: A/9-12	3 days	Mon 5/26/08	Wed 5/28/08	35



Project: PG Revised Schedule
Date: Sun 4/5/09

Task | Split | Progress | Milestone | Summary | Project Summary | External Tasks | External Milestone | Deadline

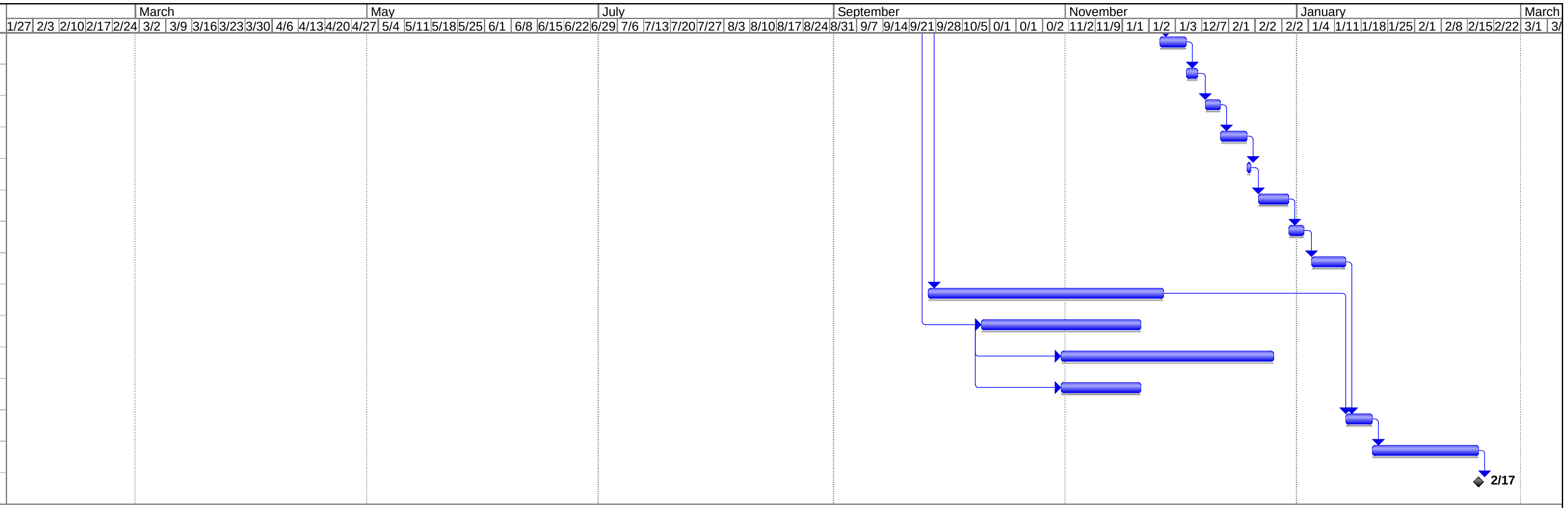
ID	Indicators	Task Name	Duration	Start	Finish	Predecessors
37		SEQUENCE 6: A/7-9	3 days	Thu 5/29/08	Mon 6/2/08	36
38		SEQUENCE 7: F/3-7	4 days	Tue 6/3/08	Fri 6/6/08	37
39		SEQUENCE 8: F/1-3	3 days	Mon 6/9/08	Wed 6/11/08	38
40		SEQUENCE 9: A/3-7	3 days	Thu 6/12/08	Mon 6/16/08	39
41		SEQUENCE 10: A/1-3	3 days	Tue 6/17/08	Thu 6/19/08	40
42		SEQUENCE 11: A-C.1/1	3 days	Fri 6/20/08	Tue 6/24/08	41
43		SEQUENCE 12: C.9-F/1	3 days	Wed 6/25/08	Fri 6/27/08	42
44		SEQUENCE 13: C.1-C.9/1	3 days	Wed 10/1/08	Fri 10/3/08	21
45		**SLAB**	**22 days**	**Tue 9/30/08**	**Wed 10/29/08**	
46		SEQUENCE 1: A-F/10-12	4 days	Tue 9/30/08	Fri 10/3/08	23
47		SEQUENCE 2: A-C/6-10	5 days	Fri 10/3/08	Thu 10/9/08	24
48		SEQUENCE 3: C-D/6-10	5 days	Wed 10/8/08	Tue 10/14/08	25
49		SEQUENCE 4: D-F/6-10	5 days	Mon 10/13/08	Fri 10/17/08	26
50		SEQUENCE 5: A-C/3-6	4 days	Wed 10/15/08	Mon 10/20/08	27
51		SEQUENCE 6: C-D/3-6	4 days	Fri 10/17/08	Wed 10/22/08	28
52		SEQUENCE 7: D-F/3-6	4 days	Tue 10/21/08	Fri 10/24/08	29
53		SEQUENCE 8: A-F/1-3	5 days	Thu 10/23/08	Wed 10/29/08	30
54		**PRECAST PANELS**	**85 days**	**Mon 6/2/08**	**Thu 9/25/08**	
55		MOBILIZE	5 days	Mon 6/2/08	Fri 6/6/08	
56		SEQUENCE 1: A- F/10-12	10 days	Mon 6/23/08	Fri 7/4/08	55
57		SEQUENCE 2: A- F/8-10	10 days	Mon 7/7/08	Fri 7/18/08	56
58		SEQUENCE 3: A- F/6-8	10 days	Sat 7/19/08	Thu 7/31/08	57
59		SEQUENCE 4: A- F/4-6	10 days	Fri 8/1/08	Thu 8/14/08	58
60		SEQUENCE 5: A-C/1-4	10 days	Fri 8/15/08	Thu 8/28/08	59
61		SEQUENCE 6: D-F/1-4	10 days	Fri 8/29/08	Thu 9/11/08	60
62		SEQUENCE 7: C-D/1-4	10 days	Fri 9/12/08	Thu 9/25/08	61
63		TOP OUT	0 days	Thu 9/25/08	Thu 9/25/08	62
64		MEP ROUGH INS	70 days	Fri 9/26/08	Thu 1/1/09	62
65		GARAGE FINISHES	70 days	Fri 10/17/08	Thu 1/22/09	62FS+15 days
66		SITEWORK	65 days	Fri 9/26/08	Thu 12/25/08	62
67		**ELEVATORS**	**58 days**	**Fri 10/24/08**	**Tue 1/13/09**	
68		MOBILIZE	3 days	Fri 10/24/08	Tue 10/28/08	64SS+20 days
69		INSTALL CYLINDER	5 days	Wed 10/29/08	Tue 11/4/08	68
70		INSTALL RAILS	5 days	Wed 11/5/08	Tue 11/11/08	69
71		INSTALL PIT EQUIPMENT & C.	5 days	Wed 11/12/08	Tue 11/18/08	70
72		INSTALL MACHINE RM EQUIP	5 days	Wed 11/19/08	Tue 11/25/08	71



Project: PG Revised Schedule
Date: Sun 4/5/09

Task		Progress		Summary		External Tasks		Deadline	
Split		Milestone		Project Summary		External Milestone			

ID		Task Name	Duration	Start	Finish	Predecessors
73		ENTRANCES, DOORS, HDW, I	5 days	Wed 11/26/08	Tue 12/2/08	72
74		COMPLETE HOISTWAY WALL	3 days	Wed 12/3/08	Fri 12/5/08	73
75		INSTALL HOISTWAY EQUIPMI	4 days	Mon 12/8/08	Thu 12/11/08	74
76		CABS, WIRING & DOOR OPEF	5 days	Fri 12/12/08	Thu 12/18/08	75
77		PRE-ADJUSTMENT TKE CHEC	1 day	Fri 12/19/08	Fri 12/19/08	76
78		ADJUST	6 days	Mon 12/22/08	Mon 12/29/08	77
79		CLEAN, PAINT, PUNCHLIST	4 days	Tue 12/30/08	Fri 1/2/09	78
80		INSPECTIONS	7 days	Mon 1/5/09	Tue 1/13/09	79
81		M.E.P. SYSTEMS	44 days	Fri 9/26/08	Wed 11/26/08	62
82		EXTERIOR HARDSCAPE	30 days	Fri 10/10/08	Thu 11/20/08	66SS+10 days
83		LANDSCAPING	40 days	Fri 10/31/08	Thu 12/25/08	82SS+15 days
84		PARKING STRIPING	15 days	Fri 10/31/08	Thu 11/20/08	82SS+15 days
85		SYSTEM TESTING	5 days	Wed 1/14/09	Tue 1/20/09	80,81
86		FINAL INSPECTIONS	20 days	Wed 1/21/09	Tue 2/17/09	85
87		SUBSTANTIAL COMPLETION	0 days	Tue 2/17/09	Tue 2/17/09	86



Project: PG Revised Schedule
Date: Sun 4/5/09

Task		Progress		Summary		External Tasks		Deadline	
Split		Milestone		Project Summary		External Milestone			