Final Thesis Report

Army National Guard Readiness Center

Advisor: Jim Faust

4/7/2010

Army National Guard Readiness Center

Arlington, Virginia

Arne Kvinnesland | Construction Management

Project Team

Owner: Army National Guard
General Contractor: Tompkins Builders, Inc.
Architect: CH2M Hill, AECOM
Engineer: AECOM

Structural System

- Cast-In-Place Concrete and Structural Steel
- Shear Wall lateral bracing system
- Multi-layer mat slab foundation system
- Typical Bay Size: 20'x25' - 20'x30'
- Typical Column Size: 1'-10"x1'-10"
- Structural Steel: HSS Type

Project Overview

Function: Comm/Office/Federal
Size: 251,500 sf office building
435 space parking garage
Stories:
Office Building: 3 stories below grade
5 stories above grade
Parking Garage: 3.5 stories below grade
1.5 stories above grade
Cost: $100,000,000
Delivery Method: Design-Bid-Build

Mechanical System

- Hydronic four-pipe heating and chilled water
- AHUs and VAV terminal units on each floor
- Building Automation System controls individual FCUs throughout each floor
- Mechanical Room on each floor housing Air Handling Units
- Emergency generators and Energy Recovery Units in Mechanical Penthouse

Electrical System

- 35.4kV Total Utility Load
- (2) 15kV medium voltage feeders at building
- 480/277, 3 phase, 4 wire system in building
- 208/120, 3 phase, 4 wire lighting system
- (2) 1500 kW diesel-powered generators back-up power

E-portfolio: http://www.engr.psu.edu/ae/thesis/portfolios/2010/aik5011/

Special thanks to the Army National Guard and Tompkins Builders, Inc. for images and data.

Contents

Executive Summary

Presented in this Architectural Engineering Senior Thesis Final Report are the findings of a semester's worth of analysis and research on the Army National Guard Readiness Center project. The project is a $100,000,000 Federal office facility located in Arlington, VA.

The first analysis topic is a construction management analysis based on a critical industry issue: Building Information Modeling deliverables on a project. A series of interviews were conducted with owners and general contractors dealing with how Building Information Modeling deliverables are used on their projects and in the industry as a whole. A list of questions was sent out to owner and general contractor contacts within the industry and their responses are compiled in the following report, along with conclusions drawn from their responses on what can be done to further Building Information Modeling in the industry.

The second analysis deals with the emergency backup power supply to the facility. There are two diesel powered emergency backup generators located on the roof of the facility that will supply power to the facility during a blackout. This analysis replaces one of those backup generators with an array of photovoltaic solar panels which will supply the building with clean energy and help power the facility and reduce the energy impact on the local power grid. It will provide a large cost savings to the owner and help the project attain the goal of a LEED Silver rating.

The final analysis looks at a unique feature of the Army National Guard Readiness Center project: a permanent structural secant pile wall system. The installation of the secant pile wall system is expensive due to its uniqueness, difficulty of installation, and long schedule. For this analysis, an alternate system is designed to replace the secant pile wall while maintaining structural performance and reducing the cost and schedule of the project.

The results of these three analyses are based upon the research of Arne Kvinnesland and the ideas presented are those solely of Arne Kvinnesland. Sources of information are listed at the end of the report along with special thanks to all of those who aided Arne in his development as a senior student in the Architectural Engineering major.

Introduction

The Army National Guard Readiness Center (ArNGRC) is a Federal Office Building project located in Arlington, VA. There is an existing building on-site and the new project will connect to the existing building via a small, enclosed bridge. The project consists of a 251,444 square foot office building and a 435 space parking garage located on the north end of the site. The main office building is three stories below grade and five stories above grade. The parking garage is three and a half stories below grade and one and a half stories above grade. The project delivery method is lump sum/design-bid-build. Total cost is approximately $100,000,000 with a starting date of December 1, 2008 and ending on March 1, 2011.

The project is currently under construction and the general contractor is using Building Information Modeling (BIM) as a tool during the coordination phase of the mechanical, electrical, plumbing, fire suppression, and structural systems. For the general contractor and many of the subcontractors on the project, this is the first BIM project they have BIM involved with. The project has recently finished coordination of all of the building systems using BIM.

The Army National Guard Readiness Center is a cast-in-place concrete structure, which is fairly typical for the general area in Arlington, VA. Cast-in-place concrete and structural steel are the two most common structural types in the area. ArNGRC also employs a deep foundation system, which is not common for the immediate vicinity. The majority of local projects are shallow foundation projects. There are deep foundation systems on projects in the busier parts of Arlington, but ArNGRC is located near residential areas more so than near other large-scale construction projects.

Soil conditions in the area are a mixture of clay and sand. The mixture, when moist, creates almost a spongy soil type, which makes it difficult to achieve necessary bearing capacity for the building foundation systems. The site has an unknown source of water flowing into it from multiple sides, making it very difficult to keep the excavation dry. Research is being done into whether a local water main could be cracked. There is no history of an underground spring in the area, but the idea has not been ruled out as a possible source for the fairly constant flow of water coming into the site.

The owner of this project is the Army National Guard. They are building this facility as an expansion to an existing facility on site. It is going to function as an administrative office building. The capacity of the existing facility is currently being exceeded by a considerable amount. Most of the office spaces in the new building are going to be filled immediately once construction is complete.

As it is with most construction projects, safety is a primary concern for everyone involved. It is standard practice for construction projects to have safety plans on site and this project is no different. Safety is monitored by the general contractor on site.

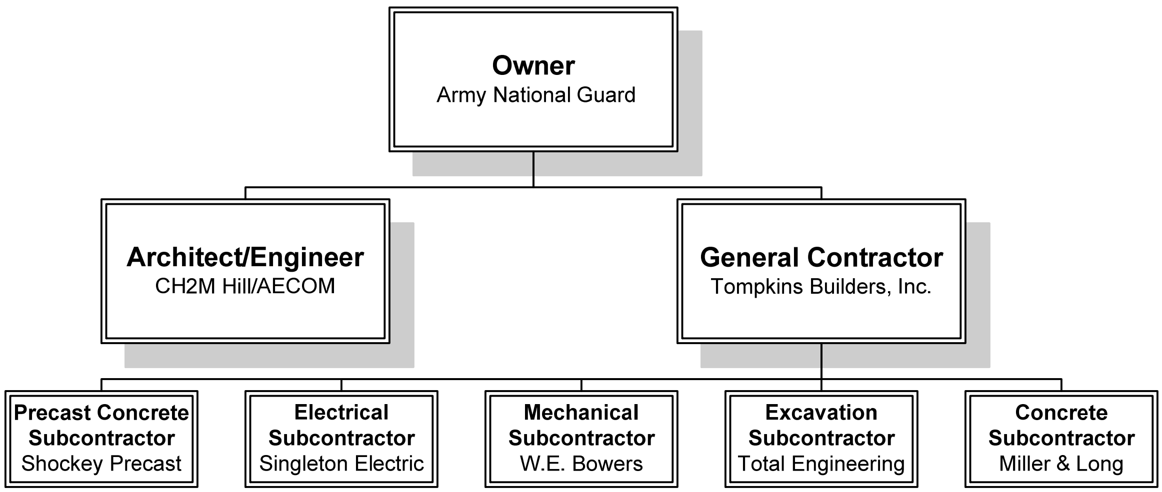
The Army National Guard is very concerned about the quality of construction of this project. There are many high-end security, audio-visual, and telecom systems built into this project. There are also blast radius and blast resistant material requirements for the façade of the building. As a federal organization, security is of utmost importance to the owner and the systems involved must be of the highest quality.

Note: Due to the project being a federal building and the owner being a military organization, not much can be revealed about the major concerns to the owner and all of their reasons to build the facility. Everything written above comes directly from assumptions and observations made by Arne Kvinnesland during his time spent working on site with the general contractor.

The Army National Guard holds a Design-Bid-Build contract with Tompkins Builders, the general contractor. As the owner, the Army National Guard mandated that this be the delivery system used. This is not Tompkins preferred method of project delivery, however. Tompkins prefers doing more Design-Build work because it is more efficient and effective. They prefer to manage the design team instead of having the owner perform this task. This makes communication even more vital between the design team and the general contractor to meet the owner's needs and deliver a successful project.

Tompkins Builders holds lump sum contracts with all of the subcontractors on the project except for the inspector, surveyor, schedule consultant, and utility locator. Subcontractors submit lump sum bids which Tompkins then review and evaluate prior to awarding the contract to the subcontractor for a specific area of the project. This allows Tompkins to mandate specific contractual items (such as Building Information Modeling capabilities) with each subcontractor. It also allows Tompkins to evaluate baseline bid cost vs. quality of work with each bid based on subcontractor past performance, giving them the opportunity to select the most appropriate subcontractor to perform the work.

The Design-Bid-Build delivery method, stipulated by the owner, carries with it several critical items to deliver a successful project. A complete and accurate set of drawings, provided by the design team, is needed to accurately bid the project. Any inconsistencies with the drawings that were originally bid by the general contractor can lead to design and cost changes later in the project. A good relationship between owner, architect/engineer, and general contractor is needed to successfully manage design and price changes throughout the project to eliminate or minimize conflict within the team. Any conflicts within the team can cause the project schedule to slip and needs to be managed efficiently. Below is the organizational chart for this project.



For this project, a Design-Build delivery method may have been more appropriate to deal with changes and drawing inaccuracies. This building has high-end security, electrical, and mechanical systems associated with it, much of which was changed during the coordination process early in the project, leading to cost changes. Since the project was bid based on the original set of contract documents, a price has already been set for individual systems and cost changes create issues with the owner.

Building Architecture Information

Architecture

This building will function as an administrative headquarters building being constructed as an addition to the existing building on site. The 3 largest stories of the building are below grade and hold open office space, a Joint Operations Center, fitness facilities, locker rooms, and an auditorium. Once above grade, the building footprint gets smaller and climbs 5 stories into the sky as a triangular tower. The tower floors function as general office space, conference rooms, and a small library. The transition between the 3 lower floors and the tower forms a large outdoor plaza area with seating, walking paths, and will double as a green roof.

A unique feature of the building, added as a bid option, is a large steel tricorn (see image on title page) sitting atop the southern point of the triangular tower. This architectural feature is purely aesthetic and is meant to give the appearance of an "eyebrow".

There is a new parking garage being built on another part of the site, as well. The garage consists of 3.5 stories below grade and 1.5 stories above. It will tie into the existing parking garage and the elevations of the new garage are being designed to match those of the existing garage.

Building Enclosure

The tower portion of the building is enclosed in a mixture of class, metal panels, and architectural precast panels. Glass type has not been finalized and has yet to be submitted. The rendering below shows the layout of the various types of enclosure materials.

The roofing system consists of a vapor barrier on top of the structural concrete slab, sloped rigid insulation, a single-ply roofing membrane, and topped by roof pavers in certain areas. The plaza roofing system, doubling as a green roof, consists of: structural concrete slab with a softer concrete topping sloped for drainage, roofing membrane with fabric reinforcement, root barrier, insulation, a drainage water retention element, filter fabric, and finally a planting element.

Sustainability Features

The plaza space that doubles as a green roof, as mentioned above, can be clearly seen in Figure 1 above. This is the most prominent sustainable feature for the project. There is no natural ventilation or solar shading associated with the building.

This project is still in the early stages of construction and many of the materials and products used in the building have yet to be submitted and finalized.

Required Demolition

Prior to start of construction, the site needed to be cleared of shrubs and certain areas were covered in trees that needed to be removed. There was also an antenna tower on site which needed to be relocated to another part of the site.

The Army National Guard Readiness Center is being constructed as an expansion to an existing facility on site. The ArNGRC will be attached to the existing structure by a small enclosed bridge walkway. To make this connection, a portion of the façade of the existing building needs to be demolished. The existing façade is architectural precast concrete with small portions of strip windows. On the interior of the existing building, where the bridge will connect, drywall partitions along with existing carpet floor need to be removed and demolished to create a hallway approaching the bridge.

Structural Steel Frame

Structural steel at the main stair tower in the tower portion of the project is a mixture of HSS type beams and columns. Rectangular beams are either HSS12x8x.625 or HSS14x4x.625 while columns are composite round HSS8.625x.322 or HSS11.25x.500. These steel beams tie into the cast-in-place concrete structure at each floor and must be erected at the same time as the concrete systems are poured all the way up the building.

Cast-In-Place Concrete

Other than at the main stair tower of the upper five floors of the building, the entire structure is cast-in-place concrete. The walls are designed to be laterally braced by the floor and roof systems and shear walls located throughout the building provide extra lateral support. Typical bay size varies from 20’x25’ to 20’x30’. Typical column size is 1’-10”x1’-10” with (8) #8 vertical reinforcement bars and #3 horizontal ties at 12” on-center.

Column and wall formwork are pre-constructed metal forms that are stripped and re-used all the way up the building. Horizontal slab formwork consists of plywood sheets with standard re-shores.

Concrete slabs are poured via pump. The concrete subcontractor has 2-3 pump trucks located on site at all times which are mobile and can be relocated around the perimeter of the building to efficiently reach all slab areas. Columns and walls are being poured via crane and bucket.

Precast Concrete

There is architectural precast concrete located throughout the façade of the main building. The garage has precast concrete structural columns and slabs with cast-in-place exterior walls and slab-on-grade. There is a tower crane located at the parking garage site to place the structural precast members. There are also two tower cranes located at the main building site. These will be used to place the architectural precast panels but are located on-site throughout the entire project to place concrete and perform lifts for any trades necessary.

The structural precast concrete members are being cast in Winchester, VA. The architectural precast has not been awarded so no casting location is known currently.

Mechanical System

A hydronic HVAC system, consisting of a four-pipe heating and chilled water systems, distribute water to the air handling units (AHU) and variable air volume (VAV) terminal units on each floor and the energy recovery units in the mechanical penthouse. AHUs and VAVs are supplied by outdoor air and individual units are regulated by a Building Automation System (BAS). The BAS controls individual units, monitors temperatures in each space, and controls the fan coil units (FCU) around the building, as well.

Each floor has a mechanical room where AHUs are located with individual VAVs and FCUs spaced throughout the floors. On the roof there is also a mechanical penthouse that houses emergency backup generators and the energy recover units.

The sprinkler system is supplied by two hydrants providing a 1520 GPM flow rate. These hydrants are supplied by waterlines that are tapped into the existing water main on the nearby street. The building will employ both a Light Hazard, providing 0.10 GPM over 3000 square feet, and an Ordinary Hazard system, providing 0.20 GPM over 3000 square feet.

The main server room in the building employs a FM-200 system. FM-200 is a colorless, nontoxic gas that is stored in two 300 gallon cylinders which will release into the room and extinguish a fire within 10 seconds of detection. It is a clean product that will only minimally damage the equipment in the server room compared to a sprinkler system employing water, which will destroy the electrical components.

Electrical system

Power comes into the site at 35.4kV, supplied by the local power company. ArNG has a switchgear which steps it down and feeds power into the building with 2 medium voltage feeders at 15kV each. These feeders connect to substations within the main building, where power is stepped down again to a 480/277, 3 phase, 4 wire system. Lighting systems are fed by 208/120, 3 phase, 4 wire panel boards.

Two 1500 kW diesel-powered generators located on the roof penthouse level supply emergency power to the substations located on the lower level. A large conduit riser goes down 7 stories through the building and cuts east-west across the second story to connect to the substation room.

Lighting: ArNG will be lit by fluorescent lamps (277V) and incandescent lamps (120V). Programmable lighting relay systems will control all of the open office areas. Dimmable lighting fixtures are provided in some of the smaller offices around the perimeter of the Operations Center. Automatic controls will cover the rest of the lighting.

Curtain Wall

The curtain wall consists of aluminum framing with multiple glazing types. The glazing for this project has not been submitted yet so exact types are unknown currently, but there are both LEED and blast resistance requirements built into the specifications for the project that make it a fairly unique and complex curtain wall system. Due to security issues, the Army National Guard does not want the blast requirements for the glazing revealed so those features will not be reported here.

Support of Excavation

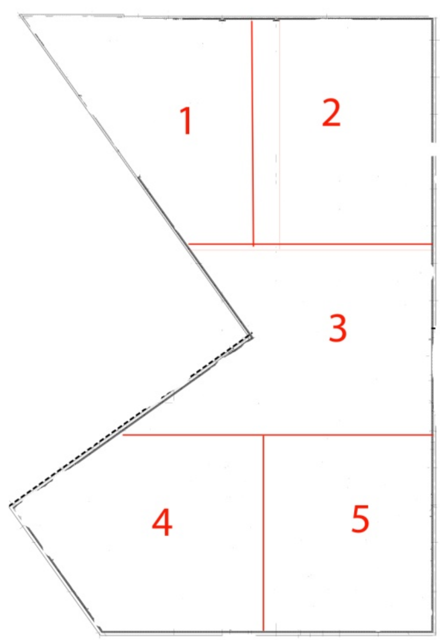
Only small portions of the utility installation on-site for the project require any shoring. Both the main building and the parking garage have multiple below-grade stories and large amounts of excavation are needed. The excavation support systems consist of soldier piles with lagging boards placed as the site is excavated. Grouted tie-backs are drilled and installed every 10-12’ of excavation.

A unique feature of this project appears at the garage: a secant-pile wall permanent excavation support. The secant-pile wall is placed between the new garage and the garage existing on site. Due to the close proximity of these two structures to each other and the depth of the excavation for the new garage, a more advanced excavation support system was needed than the standard lagging.

An extensive temporary dewatering system was needed both at the main building and the garage. Due to the depth of excavation at both sites, the water table needed to be lowered a considerable amount. There was an extensive amount of water coming into the site and approximately 20 dewatering pumps were installed around the perimeter of the main building site to deal with the water.

Construction Sequence

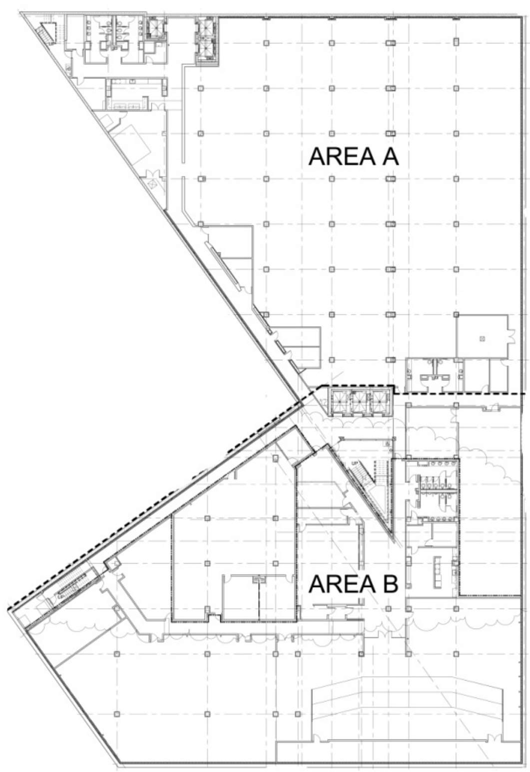
Foundation Sequence: The foundation is a mat slab foundation system. The building footprint is divided up into five areas and all work will progress along the same five-step sequence (see diagram below) throughout the entire project for all systems. Once excavation was completed through area 4 and the necessary compressive soil strength was achieved, foundation construction began. Concrete pours started once the crushed stone base was laid one area ahead and the pours were sequenced starting in area 1 through area 5.



Superstructure Construction Sequence: The Army National Guard Readiness Center uses a cast-in-place concrete structural system with steel being used only for the major stair tower in the upper five floors of the building. The cast-in-place columns, beams, and walls supporting the floor above are poured prior to the floor slab of the current floor being poured. This is due to the fact that the rebar in all columns and walls is tied into the rebar of the floor slab and the floor slab concrete butts against the previously poured column concrete.

The most difficult part of the structure sequence comes when the upper five floors, referred to as the tower, are being constructed. For the tower, the steel ties into the concrete floor slabs and columns so steel for each floor must be erected just prior to the concrete for that floor being poured. Steel in concrete crews must work hand-in-hand in the same areas to ensure that this phase of the project goes smoothly.

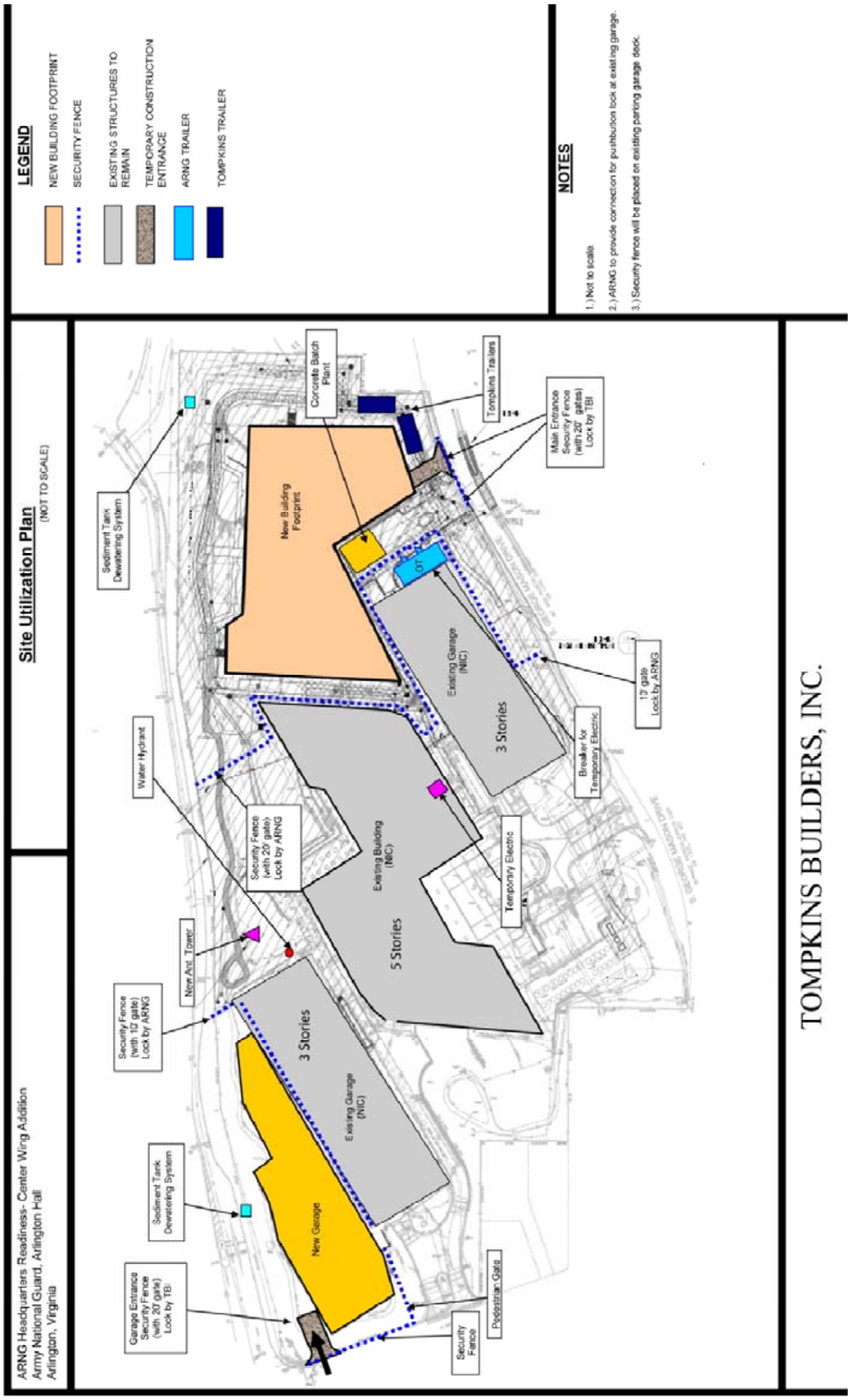
Finish Construction Sequence: Interior fit-out is divided up into two major sections on each of the three lower floors: Area A and Area B (see diagram below). On these three lower floors, interior work will begin in the southern Area B and progress into Area A. This is due to the tower being located above Area A so it gives structural crews time to work through the tower floors prior to interiors crews coming into the space below while still allowing Tompkins to manage interior work on the lower floors during tower structure construction.



The MEP systems in this building are extensive so the rough-in construction sequence will take detailed coordination to plan and execute. Rough-in work will take place in the standard sequence of ductwork first, plumbing piping next, finishing with mechanical piping, electrical conduit, and fire suppression systems last. Aside from conduit inside of the drywall partitions all of this work is located in the ceiling on each floor. Partitions locations will be laid out prior to MEP rough-in and then framed up, along with the grid ceiling, after the MEP systems have been installed.

As partitions are framed up, the drywall crew can come through each area of the building and hang drywall. Finally the painter can come through each space and paint the walls, the grid ceiling tiles can be installed, and the raised floor system tiles can be dropped into place.

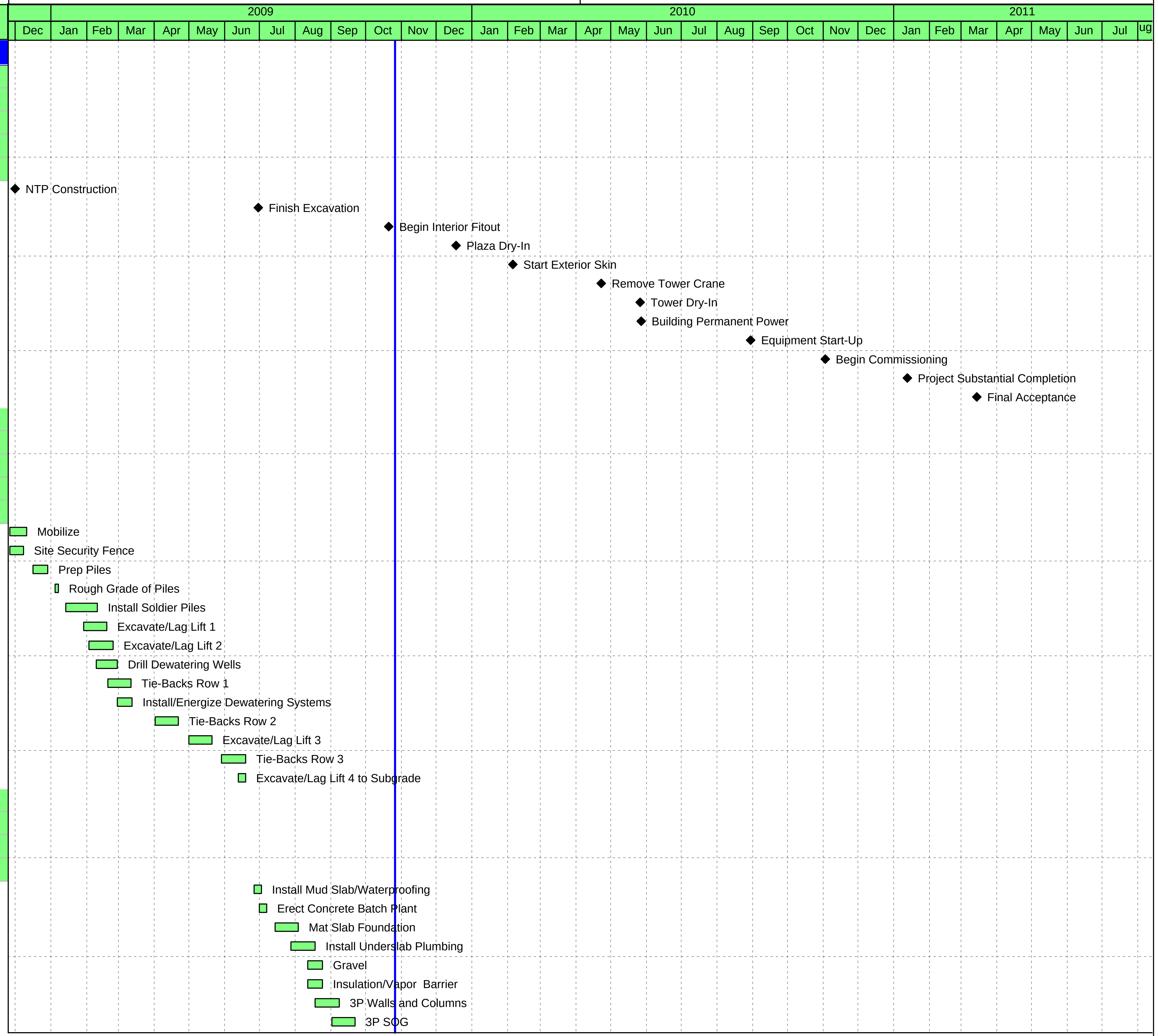
Site Plan


Site Utilization Plan
(NOT TO SCALE)
LEGEND
NEW BUILDING FOOTPRINT
SECURITY FENCE
EXISTING STRUCTURES TO REMAIN
TEMPORARY CONSTRUCTION ENTRANCE
ARNG TRAILER
TOMPKINS TRAILER
NOTES
1.) Not to scale.
2.) ARNG to provide connection for pushbutton lock at existing garage.
3.) Security fence will be placed on existing parking garage deck.
ARNG Headquarters Readiness- Center Wing Addition
Army National Guard, Arlington Hall
Arlington, Virginia
New Building Footprint
Concrete Batch Plant
Tompkins Trailers
Main Entrance Security Fence (with 20' gates) Lock by TBI
Sediment Tank Dewatering System
Existing Garage (NIC)
3 Stories
Existing Building (NIC)
5 Stories
New Garage
Water Hydrant
Security Fence (with 20' gate) Lock by ARNG
Security Fence (with 10' gate) Lock by ARNG
New Ant. Tower
Temporary Electric
Breaker for Temporary Electric
10' gate Lock by ARNG
Garage Entrance Security Fence (with 20' gate) Lock by TBI
Pedestrian Gate
Security Fence
TOMPKINS BUILDERS, INC.

Project Schedule

The project schedule for the Army National Guard Readiness Center can be seen on the following pages.

Activity ID	Activity Name	Original Duration	Start	Finish
	Army National Guard Readiness Center	598	26-Nov-08	14-Mar-11
	Milestone	595	01-Dec-08	14-Mar-11
	Excavation	595	01-Dec-08	14-Mar-11
	Concrete Frame	595	01-Dec-08	14-Mar-11
	Exterior Curtainwall	595	01-Dec-08	14-Mar-11
	3Pb	595	01-Dec-08	14-Mar-11
A1020	NTP Construction	0	01-Dec-08	
A1070	Finish Excavation	0		29-Jun-09
A1110	Begin Interior Fitout	0	21-Oct-09	
A1150	Plaza Dry-In	0		18-Dec-09
A1190	Start Exterior Skin	0	05-Feb-10	
A1810	Remove Tower Crane	0		23-Apr-10
A1200	Tower Dry-In	0		26-May-10
A1210	Building Permanent Power	0	27-May-10	
A1220	Equipment Start-Up	0	30-Aug-10	
A1230	Begin Commissioning	0	03-Nov-10	
A1250	Project Substantial Completion	0		13-Jan-11
A1260	Final Acceptance	0		14-Mar-11
	No Project Milestone	568	26-Nov-08	28-Jan-11
	Excavation	147	26-Nov-08	18-Jun-09
	No Concrete Frame	147	26-Nov-08	18-Jun-09
	No Exterior	147	26-Nov-08	18-Jun-09
	No Interior	147	26-Nov-08	18-Jun-09
A1000	Mobilize	12	26-Nov-08	11-Dec-08
A1010	Site Security Fence	9	26-Nov-08	08-Dec-08
A1030	Prep Piles	10	16-Dec-08	29-Dec-08
A1270	Rough Grade of Piles	3	05-Jan-09	07-Jan-09
A1280	Install Soldier Piles	20	14-Jan-09	10-Feb-09
A1290	Excavate/Lag Lift 1	15	29-Jan-09	18-Feb-09
A1300	Excavate/Lag Lift 2	15	03-Feb-09	23-Feb-09
A1310	Drill Dewatering Wells	15	09-Feb-09	27-Feb-09
A1320	Tie-Backs Row 1	15	19-Feb-09	11-Mar-09
A1330	Install/Energize Dewatering Systems	10	27-Feb-09	12-Mar-09
A1340	Tie-Backs Row 2	15	01-Apr-09	21-Apr-09
A1350	Excavate/Lag Lift 3	15	30-Apr-09	20-May-09
A1360	Tie-Backs Row 3	15	29-May-09	18-Jun-09
A1370	Excavate/Lag Lift 4 to Subgrade	5	12-Jun-09	18-Jun-09
	No Shoring and Excavation	416	26-Jun-09	28-Jan-11
	Concrete Frame	211	26-Jun-09	16-Apr-10
	No Exterior	211	26-Jun-09	16-Apr-10
	No Interior	211	26-Jun-09	16-Apr-10
A1380	Install Mud Slab/Waterproofing	5	26-Jun-09	02-Jul-09
A1390	Erect Concrete Batch Plant	5	30-Jun-09	06-Jul-09
A1400	Mat Slab Foundation	15	14-Jul-09	03-Aug-09
A1410	Install Underslab Plumbing	15	28-Jul-09	17-Aug-09
A1420	Gravel	10	11-Aug-09	24-Aug-09
A1430	Insulation/Vapor Barrier	10	11-Aug-09	24-Aug-09
A1440	3P Walls and Columns	15	18-Aug-09	07-Sep-09
A1450	3P SOG	15	01-Sep-09	21-Sep-09

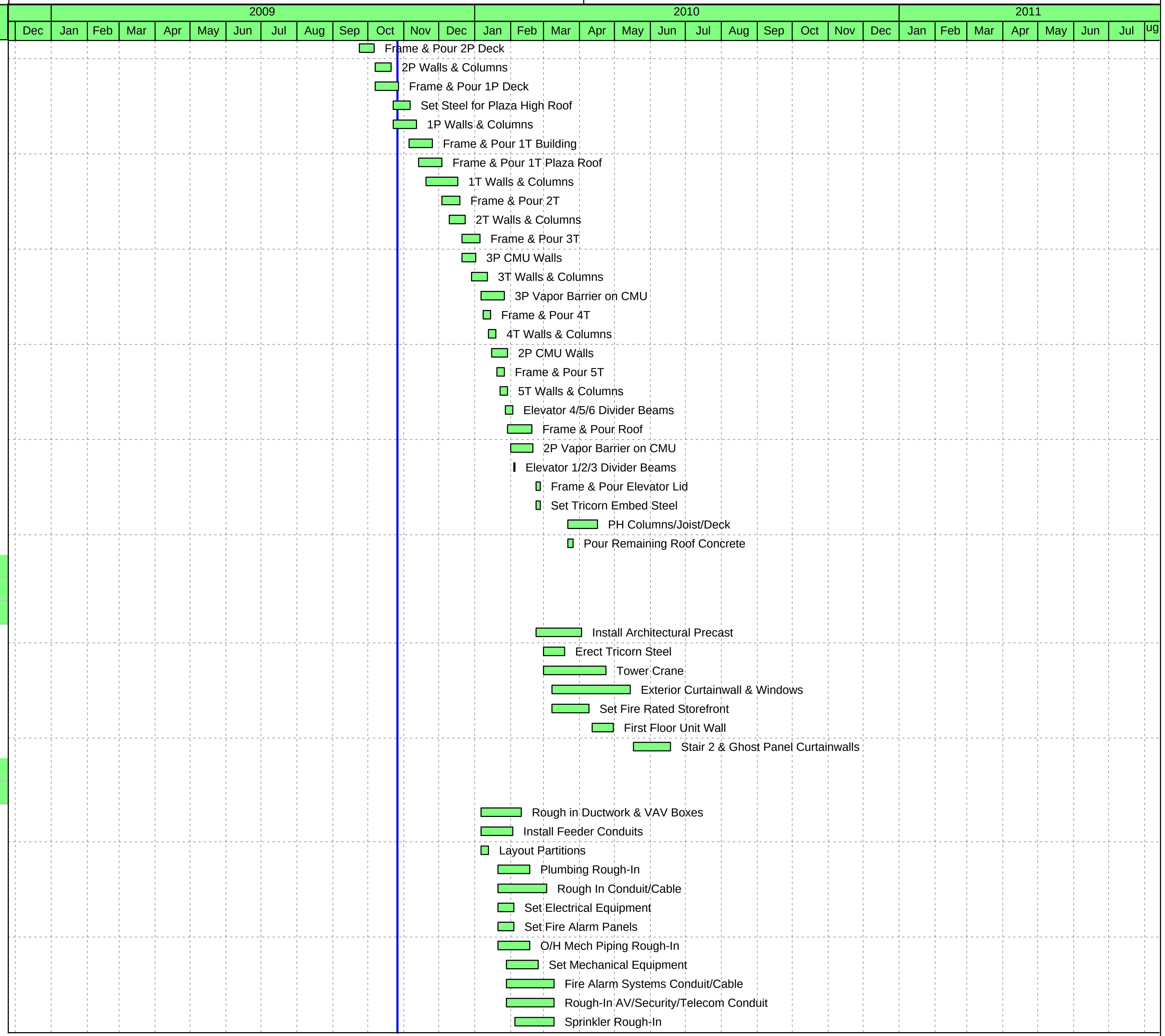


Actual Work | Critical Remaining Work
Remaining Work | Milestone

Arne Kvinnesland

Schedule supplied by Tompkins Builders, Inc. Edited by Arne Kvinnesland

Activity ID	Activity Name	Original Duration	Start	Finish
A1460	Frame & Pour 2P Deck	10	23-Sep-09	06-Oct-09
A1470	2P Walls & Columns	10	07-Oct-09	20-Oct-09
A1490	Frame & Pour 1P Deck	15	07-Oct-09	27-Oct-09
A1480	Set Steel for Plaza High Roof	12	22-Oct-09	06-Nov-09
A1500	1P Walls & Columns	15	22-Oct-09	11-Nov-09
A1510	Frame & Pour 1T Building	15	05-Nov-09	25-Nov-09
A1520	Frame & Pour 1T Plaza Roof	15	13-Nov-09	03-Dec-09
A1530	1T Walls & Columns	20	20-Nov-09	17-Dec-09
A1540	Frame & Pour 2T	12	03-Dec-09	18-Dec-09
A1550	2T Walls & Columns	10	10-Dec-09	23-Dec-09
A1560	Frame & Pour 3T	12	21-Dec-09	05-Jan-10
A1570	3P CMU Walls	10	21-Dec-09	01-Jan-10
A1580	3T Walls & Columns	10	29-Dec-09	11-Jan-10
A1590	3P Vapor Barrier on CMU	15	06-Jan-10	26-Jan-10
A1600	Frame & Pour 4T	5	08-Jan-10	14-Jan-10
A1610	4T Walls & Columns	5	12-Jan-10	18-Jan-10
A1620	2P CMU Walls	10	15-Jan-10	28-Jan-10
A1630	Frame & Pour 5T	5	20-Jan-10	26-Jan-10
A1640	5T Walls & Columns	5	22-Jan-10	28-Jan-10
A1650	Elevator 4/5/6 Divider Beams	5	27-Jan-10	02-Feb-10
A1660	Frame & Pour Roof	15	29-Jan-10	18-Feb-10
A1670	2P Vapor Barrier on CMU	15	01-Feb-10	19-Feb-10
A1680	Elevator 1/2/3 Divider Beams	2	03-Feb-10	04-Feb-10
A1690	Frame & Pour Elevator Lid	5	22-Feb-10	26-Feb-10
A1700	Set Tricorn Embed Steel	5	22-Feb-10	26-Feb-10
A1720	PH Columns/Joist/Deck	20	22-Mar-10	16-Apr-10
A1730	Pour Remaining Roof Concrete	5	22-Mar-10	26-Mar-10
No Concrete Frame		278	06-Jan-10	28-Jan-11
Exterior Curtainwall		85	22-Feb-10	18-Jun-10
No Interior		85	22-Feb-10	18-Jun-10
A1740	Install Architectural Precast	30	22-Feb-10*	02-Apr-10
A1710	Erect Tricorn Steel	15	01-Mar-10	19-Mar-10
A1750	Tower Crane	40	01-Mar-10*	23-Apr-10
A1760	Exterior Curtainwall & Windows	50	08-Mar-10	14-May-10
A1770	Set Fire Rated Storefront	25	08-Mar-10	09-Apr-10
A1780	First Floor Unit Wall	15	12-Apr-10	30-Apr-10
A1800	Stair 2 & Ghost Panel Curtainwalls	25	17-May-10	18-Jun-10
No Exterior		278	06-Jan-10	28-Jan-11
3Pb		205	06-Jan-10	19-Oct-10
A1790	Rough in Ductwork & VAV Boxes	25	06-Jan-10	09-Feb-10
A1820	Install Feeder Conduits	20	06-Jan-10	02-Feb-10
A1830	Layout Partitions	5	06-Jan-10	12-Jan-10
A1840	Plumbing Rough-In	20	21-Jan-10	17-Feb-10
A1850	Rough In Conduit/Cable	30	21-Jan-10	03-Mar-10
A1860	Set Electrical Equipment	10	21-Jan-10	03-Feb-10
A1870	Set Fire Alarm Panels	10	21-Jan-10	03-Feb-10
A1880	O/H Mech Piping Rough-In	20	21-Jan-10	17-Feb-10
A1890	Set Mechanical Equipment	20	28-Jan-10	24-Feb-10
A1900	Fire Alarm Systems Conduit/Cable	30	28-Jan-10	10-Mar-10
A1910	Rough-In AV/Security/Telecom Con...	30	28-Jan-10	10-Mar-10
A1920	Sprinkler Rough-In	25	04-Feb-10	10-Mar-10



Actual Work | Critical Remaining Work | Remaining Work | ◆ Milestone

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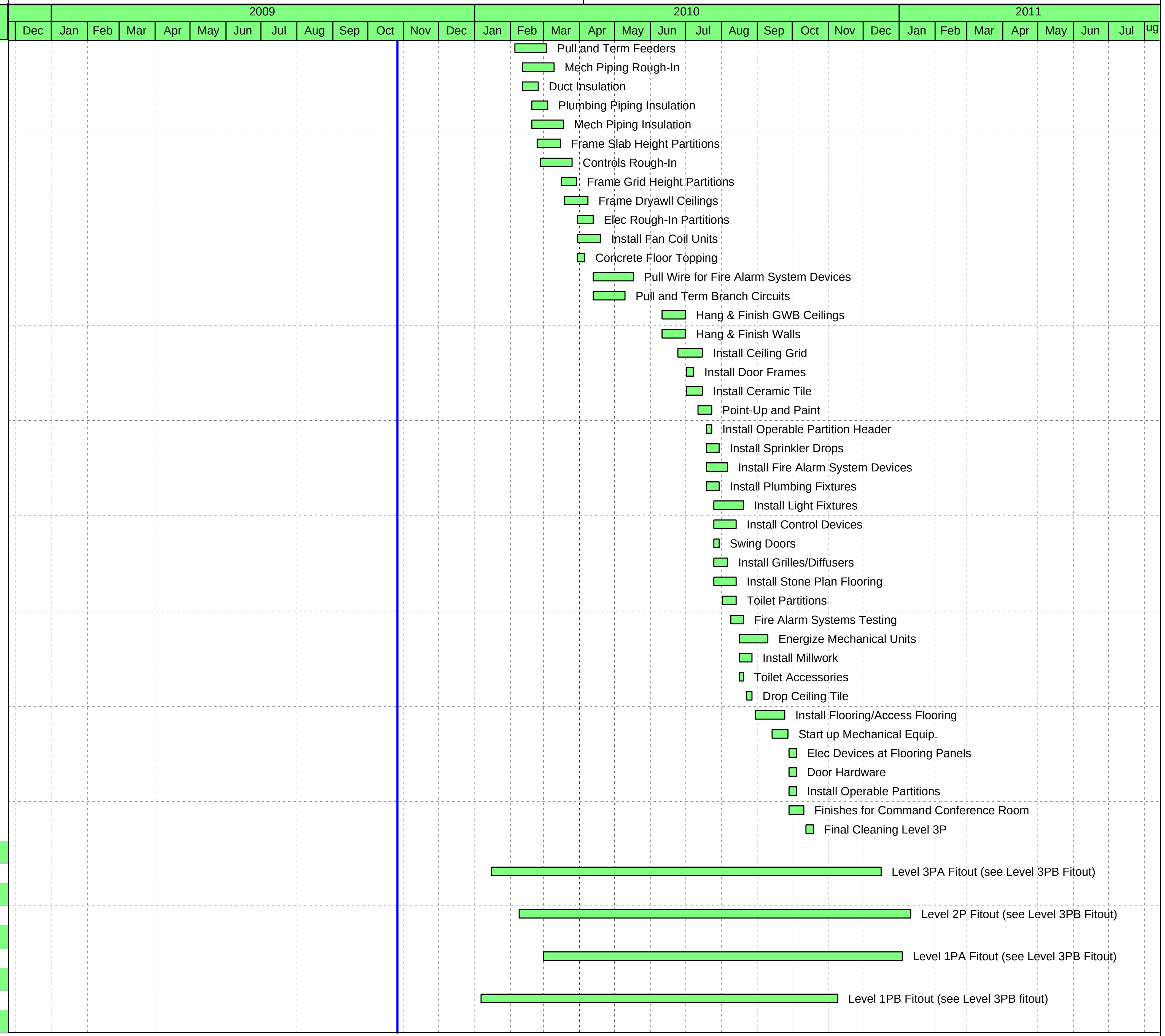
Activity ID	Activity Name	Original Duration	Start	Finish
A1930	Pull and Term Feeders	20	04-Feb-10	03-Mar-10
A1940	Mech Piping Rough-In	20	11-Feb-10	10-Mar-10
A1950	Duct Insulation	10	11-Feb-10	24-Feb-10
A1960	Plumbing Piping Insulation	10	19-Feb-10	04-Mar-10
A1970	Mech Piping Insulation	20	19-Feb-10	18-Mar-10
A1980	Frame Slab Height Partitions	15	23-Feb-10	15-Mar-10
A1990	Controls Rough-In	20	26-Feb-10	25-Mar-10
A2000	Frame Grid Height Partitions	10	16-Mar-10	29-Mar-10
A2010	Frame Drywall Ceilings	15	19-Mar-10	08-Apr-10
A2020	Elec Rough-In Partitions	10	30-Mar-10	12-Apr-10
A2030	Install Fan Coil Units	15	30-Mar-10	19-Apr-10
A2040	Concrete Floor Topping	5	30-Mar-10	05-Apr-10
A2050	Pull Wire for Fire Alarm System De...	25	13-Apr-10	17-May-10
A2060	Pull and Term Branch Circuits	20	13-Apr-10	10-May-10
A2070	Hang & Finish GWB Ceilings	15	11-Jun-10	01-Jul-10
A2080	Hang & Finish Walls	15	11-Jun-10	01-Jul-10
A2090	Install Ceiling Grid	15	25-Jun-10	15-Jul-10
A2100	Install Door Frames	5	02-Jul-10	08-Jul-10
A2110	Install Ceramic Tile	10	02-Jul-10	15-Jul-10
A2120	Point-Up and Paint	10	12-Jul-10	23-Jul-10
A2130	Install Operable Partition Header	5	19-Jul-10	23-Jul-10
A2140	Install Sprinkler Drops	10	19-Jul-10	30-Jul-10
A2150	Install Fire Alarm System Devices	15	19-Jul-10	06-Aug-10
A2160	Install Plumbing Fixtures	10	19-Jul-10	30-Jul-10
A2170	Install Light Fixtures	20	26-Jul-10	20-Aug-10
A2180	Install Control Devices	15	26-Jul-10	13-Aug-10
A2190	Swing Doors	5	26-Jul-10	30-Jul-10
A2200	Install Grilles/Diffusers	10	26-Jul-10	06-Aug-10
A2210	Install Stone Plan Flooring	15	26-Jul-10	13-Aug-10
A2220	Toilet Partitions	10	02-Aug-10	13-Aug-10
A2230	Fire Alarm Systems Testing	10	09-Aug-10	20-Aug-10
A2240	Energize Mechanical Units	20	16-Aug-10	10-Sep-10
A2250	Install Millwork	10	16-Aug-10	27-Aug-10
A2260	Toilet Accessories	5	16-Aug-10	20-Aug-10
A2270	Drop Ceiling Tile	5	23-Aug-10	27-Aug-10
A2280	Install Flooring/Access Flooring	20	30-Aug-10	24-Sep-10
A2290	Start up Mechanical Equip.	10	14-Sep-10	27-Sep-10
A2300	Elec Devices at Flooring Panels	5	28-Sep-10	04-Oct-10
A2310	Door Hardware	5	28-Sep-10	04-Oct-10
A2320	Install Operable Partitions	5	28-Sep-10	04-Oct-10
A2330	Finishes for Command Conference ...	10	28-Sep-10	11-Oct-10
A2340	Final Cleaning Level 3P	5	13-Oct-10	19-Oct-10
3Pa		240	15-Jan-10	16-Dec-10
A2350	Level 3PA Fitout (see Level 3PB Fit...	240	15-Jan-10	16-Dec-10
2P		242	08-Feb-10	11-Jan-11
A2360	Level 2P Fitout (see Level 3PB Fitout)	242	08-Feb-10	11-Jan-11
1Pa		221	01-Mar-10	03-Jan-11
A2380	Level 1PA Fitout (see Level 3PB Fit...	221	01-Mar-10	03-Jan-11
1Pb		220	06-Jan-10	09-Nov-10
A2370	Level 1PB Fitout (see Level 3PB fit...	220	06-Jan-10	09-Nov-10
1T		206	29-Mar-10	10-Jan-11



Actual Work | Critical Remaining Work | Remaining Work | Milestone

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Activity ID	Activity Name	Original Duration	Start	Finish
A2390	Rough-In Ductwork & VAV Boxes	30	29-Mar-10	07-May-10
A2400	Plumbing Rough-In	20	12-Apr-10	07-May-10
A2410	OH/Mech Piping Rough-In	20	12-Apr-10	07-May-10
A2420	Mech Piping Rough-In	20	12-Apr-10	07-May-10
A2430	Install Feeder Conduit	20	13-Apr-10	10-May-10
A2440	Rough-In Conduit/Cable	30	27-Apr-10	07-Jun-10
A2450	Sprinkler Rough-In	20	18-May-10	14-Jun-10
A2460	Layout Partitions	5	18-Jun-10	24-Jun-10
A2470	Set AHU	5	25-Jun-10	01-Jul-10
A2480	Duct Insulation	20	25-Jun-10	22-Jul-10
A2490	Plumbing Piping Insulation	10	25-Jun-10	08-Jul-10
A2500	Set Electrical Equipment	10	25-Jun-10	08-Jul-10
A2510	Mech Piping Insulation	20	25-Jun-10	22-Jul-10
A2520	Frame Slab Height Partitions	10	12-Jul-10	23-Jul-10
A2530	Pull and term Feeders	20	12-Jul-10	06-Aug-10
A2540	Set Mech. Equipment	20	26-Jul-10	20-Aug-10
A2550	Set Fire Alarm Panels	10	26-Jul-10	06-Aug-10
A2560	Fire Alarm Systems Conduit/Cable	30	26-Jul-10	03-Sep-10
A2570	Rough-In AV/Security/Telecom Con...	30	26-Jul-10	03-Sep-10
A2580	Frame Grid Height Partitions	10	26-Jul-10	06-Aug-10
A2590	Frame Drywall Ceilings	15	26-Jul-10	13-Aug-10
A2600	Elec. Rough-In Partitions	10	09-Aug-10	20-Aug-10
A2610	Install Fan Coil Units	15	09-Aug-10	27-Aug-10
A2620	Concrete Floor Topping	1	09-Aug-10	09-Aug-10
A2630	Hang & Finish GWB Ceilings	15	16-Aug-10	03-Sep-10
A2640	Pull Wire for Fire Alarm System De...	25	23-Aug-10	24-Sep-10
A2650	Controls Rough-In	20	23-Aug-10	17-Sep-10
A2660	Pull and Term Branch Circuits	20	23-Aug-10	17-Sep-10
A2670	Hang & Finish Walls	15	07-Sep-10	27-Sep-10
A2680	Energize Mech. Units	20	21-Sep-10	18-Oct-10
A2690	Install Ceiling Grid	15	28-Sep-10	18-Oct-10
A2700	Install Door Frames	5	28-Sep-10	04-Oct-10
A2710	Install Ceramic Tile	10	28-Sep-10	11-Oct-10
A2720	Install Plumbing Fixtures	10	13-Oct-10	26-Oct-10
A2730	Point Up and Paint	10	20-Oct-10	02-Nov-10
A2740	Install Sprinkler Drops	10	20-Oct-10	02-Nov-10
A2750	Install Fire Alarm System Devices	15	27-Oct-10	16-Nov-10
A2760	Toilet Partitions	10	27-Oct-10	09-Nov-10
A2770	Toilet Accessories	5	27-Oct-10	02-Nov-10
A2780	Swing Doors	5	03-Nov-10	09-Nov-10
A2790	Install Light Fixtures	10	03-Nov-10	16-Nov-10
A2800	Install Control Devices	15	03-Nov-10	23-Nov-10
A2810	Install Grilles/Diffusers	10	03-Nov-10	16-Nov-10
A2820	Install Stone Plank Flooring	15	03-Nov-10	23-Nov-10
A2830	Install Glass Walls @ Lobby	15	03-Nov-10	23-Nov-10
A2840	Fire Alarm Systems Testing	10	18-Nov-10	01-Dec-10
A2850	Drop Ceiling Tile	5	18-Nov-10	24-Nov-10
A2860	Start Up Mech. Equipment	10	26-Nov-10	09-Dec-10
A2870	Install Millwork	10	26-Nov-10	09-Dec-10
A2880	Install Flooring/Access Flooring	20	26-Nov-10	23-Dec-10
A2890	Controls Testing	5	10-Dec-10	16-Dec-10
A2900	Testing and Balance	5	17-Dec-10	23-Dec-10

Actual Work · Critical Remaining Work · Remaining Work · Milestone

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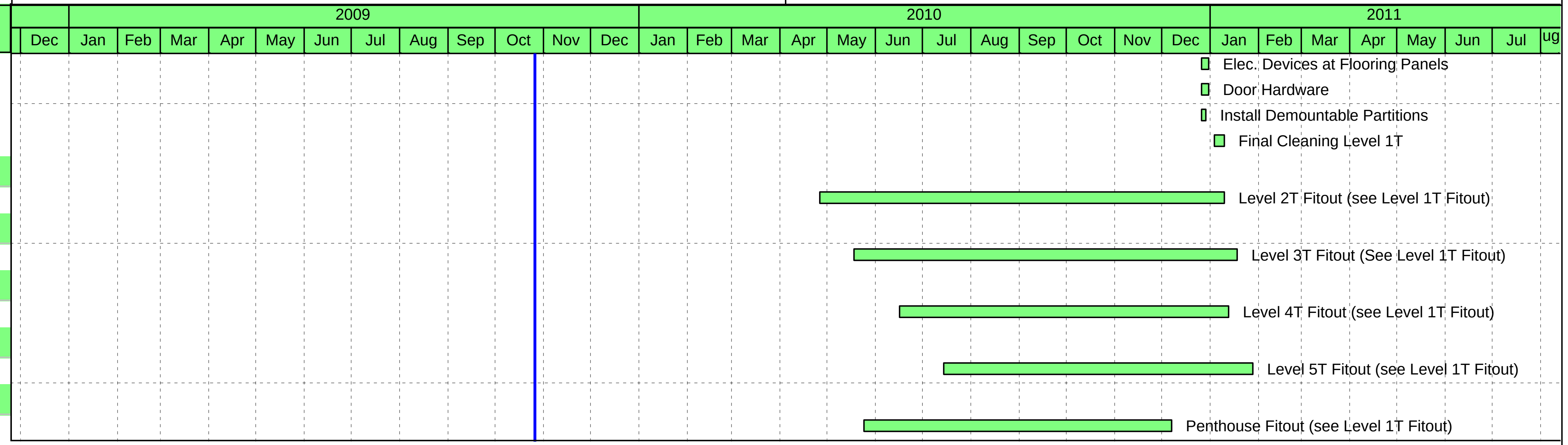
Activity ID	Activity Name	Original Duration	Start	Finish
A2910	Elec. Devices at Flooring Panels	5	27-Dec-10	31-Dec-10
A2920	Door Hardware	5	27-Dec-10	31-Dec-10
A2930	Install Demountable Partitions	3	27-Dec-10	29-Dec-10
A2940	Final Cleaning Level 1T	5	04-Jan-11	10-Jan-11
2T		186	26-Apr-10	10-Jan-11
A2950	Level 2T Fitout (see Level 1T Fitout)	186	26-Apr-10	10-Jan-11
3T		176	18-May-10	18-Jan-11
A2960	Level 3T Fitout (See Level 1T Fitout)	176	18-May-10	18-Jan-11
4T		152	16-Jun-10	13-Jan-11
A2970	Level 4T Fitout (see Level 1T Fitout)	152	16-Jun-10	13-Jan-11
5T		142	15-Jul-10	28-Jan-11
A2980	Level 5T Fitout (see Level 1T Fitout)	142	15-Jul-10	28-Jan-11
Penthouse		141	25-May-10	07-Dec-10
A2990	Penthouse Fitout (see Level 1T Fito...	141	25-May-10	07-Dec-10



Actual Work | Critical Remaining Work
Remaining Work | Milestone

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Proposal Information

The first research topic proposed in this document deals with Building Information Modeling. It is a research topic dealing with BIM and project deliverables, specifically deliverables that benefit the owner once the project is complete. Many owners are unaware of the capabilities of Building Information Modeling and the benefits that they can reap by paying for and requiring BIM on their projects. My first analysis topic will consist of a series of interviews of current owners and contractors using BIM and comparing that with a comprehensive list of deliverables that BIM is capable of.

The final two analysis topics presented in this document will cover the breadth topics for my thesis requirements: design of a battery back-up and photovoltaic array system to replace the diesel powered generators incorporated into the building currently and structural redesign of a soil retention system. With the photovoltaic analysis, I hope to reduce the Army National Guard's reliance on local power companies to supply this project with power and to increase energy efficiency of the project. The structural redesign of the soil retention system, currently in the form of a secant pile wall, will have major cost and schedule impacts. These will be the main focus of this final analysis.

Construction Management Analysis – Industry Issue

This analysis consists of a series of owner and contractor interviews regarding Building Information Modeling deliverables used on their projects as well as in the industry as a whole. A list of questions was presented to a number of owners and contractors and their answers were compared to a predetermined list of known BIM deliverables. The predetermined list was compiled from my own research, as well as the research provided by the BIM Project Execution Planning Guide team. The goal was to determine common deliverables asked for by owners and provided by contractors, as well as some of the not-so-common features of Building Information Modeling that were used. I wanted to gauge the knowledge level within the industry currently of owners and contractors and see if there were options easily provided but not usually asked for that can help progress BIM within the industry. The more informed people are about this new technology, the faster it will grow in the industry.

The use of BIM provides the opportunity to take advantage of many unique and useful features in the form of deliverables at the end of a project. The first part of this analysis was to research a list of these features to provide a comparison point to the answers received after conducting the industry member interviews. None of this research was presented to the industry members prior to or during any part of the interview process. The goal was to obtain an honest, overall perspective of where BIM stands in the industry.

Below is a list of features and deliverables BIM can provide on a project if the management team and owner are informed and educated about the possibilities of BIM on their project.

Credit is given to the BIM Project Execution Planning Guide Team for the official labels and many of the explanations of the below information.

- Asset Management – The use of a record model to help aid in the operation and maintenance of the physical building, building systems, and equipment. Asset management can be used to determine the cost of operating and maintaining a building and its systems and help find the most efficient way to deal with these costs.
- Building Maintenance Scheduling – Developing a maintenance program can reduce maintenance costs and improve building performance. The schedule includes the building structure and equipment serving the building.
- Building System Analysis – Analyses can be run using BIM software to determine whether or not a building’s performance is meeting the originally specified design. This can include mechanical and electrical systems, energy usage, airflow, ventilation, lighting, and heat gain.

- Cost Estimation – Typically a feature used during the design phases of a project to estimate total cost for the project, but can be adapted to a completed project. Using existing building models to estimate costs of renovations and additions to a building can save time and money in the estimation process.
- Disaster Planning – Gives emergency responders access to digital building information to plan recovery and rescue tactics. Can provide interactive 3D modeling along with 2D floor plans and elevations where needed, all in electronic format. Allows rescue teams to plan their strategies much more quickly and efficiently, being able to see a 3D version of what the building looks like instead of having to read just from 2D plans.
- Existing Condition Modeling – A 3D model is developed of an existing building which can be used to help plan expansion or renovation of the existing facility. Ties into the cost estimation feature listed above.
- Phase Planning (4D Modeling) – Used to effectively plan phased occupancy of a building during renovation and addition. Provides a visual for spacing requirements of a building.
- Record Model – A 3D model of the building and all of its systems, including mechanical, electrical, plumbing, fire suppression, and structural. Product information, maintenance history, and warranty information of all of the equipment and building components can also be stored in a 3D BIM model.
- Space Management and Tracking – A feature of the record model, space management and tracking allows the facility management team to effectively track and allocate workspaces and resources.
- Sustainability (LEED) Evaluation – These evaluations can be performed throughout the life-cycle of the facility being modeled. If energy analysis capabilities are built into the model during the design and construction phases, energy analysis throughout the life of the building are easily obtained.

After researching various deliverable options and coming up with the above list as the most likely to be asked for and most easily provided BIM deliverables, a series of interview questions were developed to be presented to owners, contractors, and other industry members to determine which, if any, of these options were readily used in the industry today.

Below is the comprehensive list of questions which were asked of various members of the industry. Not all questions were asked of every interviewee, some questions applying only to owners and others only to contractors.

- What are some of the BIM deliverables most commonly asked for by owners?
- What are some options you do not often see required by owners but that you feel are easily provided and can be helpful to the owner after project completion?
- Is it due to general lack of awareness of other options or the expense of other options that causes owners not to required BIM deliverables in less common forms?
- What are some of the more unique deliverables items that you have come across and seen requested by owners?
- I feel that contractors are responsible for furthering BIM in the industry and educating owners on each of their projects about the capabilities of this new technology. Is this generally the case or are owners researching on their own and requiring more and more from BIM on their projects?
- As an owner, what are some common BIM deliverables that you request on your projects? Is it usually just the standard MEP as built files or are there specific, unique items that you feel are especially useful in the everyday running of a building?
- Are there any specific, detailed deliverables that you have requested from contractors in the past that they have had trouble providing or requested more money to be able to provide them?
- BIM is a relatively new technology in the industry. As an owner, how much experience have you had with BIM and how has that helped you continue to develop your knowledge about what BIM is able to provide you? Have you asked for more and more out of BIM on successive projects?
- Do you encounter contractors offering up information about what BIM is capable of and do you feel that the more detailed deliverables are worth the extra cost (if there is any)?

Contractors were much more responsive than owners to the interviews which were sent out so the majority of the information provided below is from a contractor's perspective and from contractor representatives working with owners early in the planning phases of the project. Sources are listed in Appendix 1.

Most commonly right now owners are not asking for specific BIM deliverables to be turned over at the end of a job. They are just asking for the use of BIM for MEP coordination or for the project team's "BIM Implementation Plan" for the project to be used during the construction phase of the project, but with no real deliverables at the end of the project. 3D modeling is helpful for visualization of certain building elements, particularly in confusing or congested situations to help plan the work. At the end of the project the models will not be 100% accurate, but they will serve as a decent set of MEP as built drawings. On the Army National Guard Readiness Center the owner may be interested in pursuing loading warranty, service, and other O&M data into the files as a resource for the facility operators.

Government groups such as the USACE (United States Army Corp of Engineers), GSA (General Services Administration), and NIH (National Institute of Health) are asking for more robust BIM deliverables. Some of these deliverables include a master BIM file in a platform such as Revit or Bentley with all of the information included in one master file, specific levels of detail in certain areas and systems, specific inherent data included within the model, and the linking of files to the model in certain ways, but it is a small group of owners asking for this level of detail. Currently, it seems that the majority of owners are not requesting specific deliverables but more proactive government owners are asking for very detailed, robust models and deliverables. To date, there has not been much in between these two. As BIM moves past its infancy in the industry, owners are expected to become more knowledgeable and more deliverables are expected to emerge.

There are multiple deliverables that are not too difficult for general contractors to provide for owners that would benefit the owner during the operation of the building upon completion of the project. At a basic level of detail (LOD 200), an as built BIM model of the MEP systems, quantities extracted from the model, and electronic Operation and Maintenance data linked to the model are not difficult to provide for the owner. Having the discussion with the owner early and knowing exactly what they are looking for early on in the process will make these easier to deliver.

It is a combination of the lack of knowledge of what is available, the expense as well as funding source of some of the deliverables, and also the lack of interoperability between systems that lead to owners not asking for some of the less common deliverable options. The majority of owners do not know the full capabilities of Building Information Modeling and do not know how it can help benefit their project or the end use of the facility. The expense of some of the options as well as the funding source (either via construction budget or facilities budget) is sometimes an issue. Sometimes the owner's construction team feels that it should be funded by the owner's facilities team and visa versa. If there is something to get value engineered out of the project, the extra BIM items are often the first to go because their value during operation of the facilities is underestimated. Also, the lack of interoperability between the modeling platforms and the end user's systems can cause hesitation to not go too far with BIM for the end user's use. The owner general does not want to spend time and money training facility managers on a new, complex system.

It is apparent that the debate over whether or not BIM deliverables are worth the cost of developing these items on a project. Currently, BIM does provide viable deliverable options that are worth the cost. There are many different levels of deliverables that can be turned over to an owner at all different price ranges. Contractors will normally lay out all of the different levels of detail and development that they can provide the owner. When the deliverables are of an average level of detail and part of the normal construction process, these deliverables are typically of very low cost to the owner whereas other deliverables can cost tens or hundreds of thousands of dollars if there is a very detailed level of integrating the inherent model data, detailed linking of external files, and tie-in to end user software. The key is having the discussion early on in the project with the owner to understand their needs as well as explain to them what is available and coming to an agreement on scope, level of detail, and cost that works for all parties. By having the discussion early, the BIM deliverables can be made part of the construction process and it will typically cost less if contractors have a plan to incorporate it as a part of the process from the beginning of the project.

The development and progression of Building Information Modeling in the industry has moved ahead rapidly in the past few years. Two years ago, general contractors were barely being asked for anything BIM relate as part of a construction project. It was more of a “value added” type of service that companies with the capabilities could provide. Today, most owners are at least mentioning BIM and asking about how the construction management team plans to use it and many owners are requiring its use for the coordination process. Still, very few are asking for specific deliverables at the end of the project. An even fewer number of owners like those listed above are asking for very specific and highly detailed deliverables.

Conclusion: Building Information Modeling is still in its infancy in the construction industry. Industry members are making it fairly clear that things are just getting kicked off with BIM as a technology accepted industry-wide and that the capabilities of BIM are wide but fairly underexploited by both general contractors and owners. The technology is so new and changing that many members of the industry are still unaware of the capabilities. Technical expertise and requirements should come from the engineering and design side and be written into project specifications. Some general contractors are just beginning to incorporate 3D modeling language into their subcontracts, which is a huge step in the right direction. Once there are solid deliverables and requirements that are supported contractually, the change and shift in the industry will begin to occur.

Electrical Analysis – Photovoltaic and Battery System Design

The goal of this analysis is to design a photovoltaic system that can be used to replace one of the diesel back-up generators on the Army National Guard project. This will provide additional points for the LEED Silver rating that the team is working for, as well as provide a small amount of energy independence for the Army National Guard. There is a large conduit riser that drops from the generators on the roof all the way through to the second floor and cuts across the floor above the ceiling to connect to the substation room. The amount of MEP coordination that went into working around this conduit bank and making room for it as it cuts across the second story was immense. By replacing at least one of the generators, the size of this conduit rack will be reduced significantly and help with the coordination process.

The first step was to find an appropriate photovoltaic (PV) panel to use for the analysis. To produce enough power to run any specific system there needed to be space to create an array of panels to place in the same area where the generator is located. This space is approximately 22'x50'. The panel chosen for this analysis is a BP Solar product, Model: BP SX 170B. The product data and specifications for this panel can be seen in Appendix 3.

The diesel powered generators are 1500 kW generators. Each generator costs $512,000. With these numbers in mind a calculation was run on cost and space occupied vs. power produced by a solar panel array of the above listed panels. These calculations can be seen in Appendix 2. By removing one generator, 1100 square feet is left unoccupied, providing space for two 30 panel arrays with a walkway in between. Each panel and the associated wiring costs $850 and takes up 15 square feet. The run from the roof to the substation is approximately 123 feet. Using AWG #12 wire at a run of 123 feet, for 60 PV panels, total wiring cost comes to $2,217.70. The total cost of the 60 PV panel array is $51,000. This means that the total cost of the system is $53,217.70.

Replacing one generator with a PV solar panel array is a total savings of roughly $450,000. There is a large power loss due to this substitution. As can be seen in Appendix 2, the photovoltaic array produces 51 kW of power over the course of 5-6 hours during full solar exposure. This means that during a power outage or an emergency of some kind, only one 1500 kW generator would be left to power the building. However, the 51 kW of power from the solar panel array can be used continuously throughout the day, as long as there is solar exposure. According to www.worldfactsandfigures.com there are, on average, 96 sunny days in the Washington, DC area. This means that, per year, the solar panel array will produce almost 5000 kW of power that can be used by the Army National Guard to run the everyday functions of their facility.

The photovoltaic panel array can also be attached to a battery system to store power in 24V batteries for use in emergencies. At 24V per battery, however, to store a significant amount of power would require a huge amount of space and would not be cost effective.

Conclusion: Removing one of the diesel powered backup generators from the roof of the facility and replacing it with a photovoltaic panel array provides three distinct advantages: extra LEED points for the project to secure a LEED Silver rating, a strong source of clean solar energy that can be used to supplement the grid power being supplied to the facility, and a large cost savings of approximately $450,000. There is also one major drawback to this substitution: the emergency backup power for the building is practically cut in half due to the loss of one generator.

Another option that the owner has is keeping the second diesel generator and adding solar panel arrays to the project for extra clean energy. The cost would be another $53,000 (roughly) and the owner would have the benefit of extra LEED points to achieve their LEED Silver rating and the facility would have another 5000 kW of power per year to help power any of the facilities energy needs. This would guarantee that the facility would have the necessary emergency backup power. One negative impact this would have, aside from the extra cost, is the required coordination of the extra conduit for the solar array.

If the owner is willing to spend the extra money, the second option would be the stronger of the two. Adding a solar array to the project provides extra energy that is clean and reduces the need for power directly from the local power grid, reducing the negative impact of energy on the environment.

Structural Analysis – Secant Pile Wall Replacement System Design

The goal of this analysis was to develop an alternative permanent soil retention system to replace the secant pile wall used on this project for that purpose. This project has a secant pile wall being constructed at the new parking garage site, in between the new garage and the existing garage. It is meant to be a permanent structural support for the existing parking garage and a soil retention system. There are three bench heights along the length of the western wall of the parking garage, roughly 34 feet, 42 feet, and 50 feet. Each bench is approximately 105 feet in length. The construction sequence of the secant pile wall is as follows:

- Construction of a concrete guide wall with foam inserts for secant piles.
- Drilling of female piles (every other pile), grouting, with reinforcement added after grout has been poured.
- Drilling of male piles (every other pile) which cut into female piles, grouting, and vibrating steel I-beams into poured grout to reinforce pile.
- Excavating down in front of secant pile wall drilling tie-backs through steel I-beams in the male piles every 8-10 feet of depth.
- Shotcrete finish on the front of the secant pile wall to make a smooth, flat surface.

There are many challenges to building a system as complex as a secant pile wall. Sequencing and timing are extremely important. Perfect alignment of the drill rig is also critical, especially at depths as large as 34, 42, and 50 feet. Even a 1-2 degree angle on the bit at depths of 50 feet could mean a 1-2 foot misalignment from top to bottom of the secant pile. This meant that the accuracy of the guide wall had to be perfect.

Grout timing proved to be one of the largest issues on the Army National Guard project. A special grout mix was used, with admixtures to retard the set time of the grout. The construction team had roughly an hour and a half from the time the grout left the batch plant in a truck to get it into the hole and vibrate reinforcement through it. A drill rig with a grout pump was used which pumped grout as the drill bit was lifted out of the drilled pile. This guaranteed a steady flow of grout into the pile, reducing any air pockets or poorly compacted areas in the pile. As soon as the drill bit was out of the way and the pile was grouted, a crane moved into place and dropped reinforcement into the pile. Female piles each have a small rebar cage, while male piles each have a steel I-beam. If the construction team was too slow drilling a pile and grouting it, the reinforcement would not go all the way down into the pile. This lead to increased amounts of vibrating and hydrolic hammering of the steel members to get them into the piles. With an existing structure so close by, there were strict guidelines on the amount of vibratory force that could be used. This meant that if the team was too slow they could not increase the force beyond a certain point to get a reinforcing member into a pile.

Early on in the construction of the secant pile wall, a number of piles needed to be re-drilled because the grout set too quickly and the construction crew could not get the reinforcement into the pile. However, now the drill bit had to drill through grout and twice drill bits were broken. The subcontractor had a welder on site full time for 2 weeks repairing drill bits which broke.

Another key to grout timing was the cure time. Female piles were poured first in sets of 8-16, with male piles drilled afterward. This was usually a 4-5 day process to get all of them down. The grout in the female piles could not cure too fast or it would be impossible to drill through them with the male piles.

Secant pile walls are not a common system and for the Army National Guard project team, it was the first secant pile wall they had managed. The subcontractor hired to construct the secant pile wall had no experience constructing a system like this either. Extensive planning, sequencing, scheduling, and training went into the preparation for the construction phase of this structure. The original schedule had approximately three months allotted for the construction of the secant pile wall, starting with the guide wall installation and running through demobilization by the shoring contractor from the garage site. The secant pile wall was originally bid out at approximately $2.2 million. This analysis is meant to find a more common system to be used that will cut overhead planning costs as well as lower the construction cost of the system.

The first analysis idea came in the form of using a temporary soil retention system. A sheeting and shoring system and a temporary sheet pile system were looked at. However, they could not provide the structural support needed for the existing parking garage adjacent to the construction site. Next, the idea of a permanent pre-cast sheet pile system or a thicker slurry wall was considered, but again the structural support for the existing building would not be met by these systems.

Finally, a simple cast in place concrete retaining wall, thickened to the proportions of the secant pile wall diameter was analyzed. It is also a very simple system that is very common in the industry. Extensive preconstruction planning and training would not be required for a concrete retaining wall system, saving general conditions costs and project overhead. Labor costs, general conditions costs, and overhead would all be saved. The construction cost of the system itself would be lower.

The first step was to design a concrete retaining wall system that would perform at the same minimum requirements of the secant pile wall. Embedment depth and shear capacity of the wall were calculated and designed to match the secant pile wall minimum capacity requirements. These calculations can be seen in Appendix 4. Embedment depth was calculated as 15 feet after a factor of safety of 1.5 was applied. The wall is also 4 inches narrower that the secant pile wall, saving on material costs.

After it was proven that the concrete retaining wall could meet the structural requirements a cost analysis of the construction of the concrete wall was run and compared with the total cost of the secant pile wall construction. The takeoffs and cost calculations can be seen in Appendix 5. Total cost of the concrete retaining wall came out to approximately $458,000. As stated above, the initial cost of the secant pile wall was roughly $2.2 million. This is a savings of $1,753,158 just in construction costs for this line item.

Conclusion: The use of a concrete retaining wall system to replace the current secant pile wall system as a permanent structural support and soil retention system could save the project team roughly $1.75 million. After consulting with the management team on Army National Guard, however, it seems that a retaining wall structure could not be constructed in place of the secant pile wall system. They were forced to use a secant pile wall system due to the close proximity to the existing parking garage structure. There is not enough room between the two buildings to excavate and pour a retaining wall structure to the required depths while still supporting the existing structure. The 42 feet and 50 feet depths are too large to excavate and pour into without supporting the existing parking garage. The guide wall for the secant piles was only excavated and poured to a depth of approximately 10 feet. A temporary soil retention and building support system would need to be used at an even closer proximity to the structure than the secant pile wall is already located and it would not be possible to drill and lag temporary support in that space.

After witnessing the construction process of the secant pile wall during my time on-site as an intern with Tompkins Builders and seeing some of the sequencing and construction issues of building a secant pile wall, it would have been beneficial to possibly investigate sequencing and timing methods to help make the construction process of this difficult system go more smoothly. With more time in the semester this would have been a possible further analysis.

Conclusion

Building Information Modeling has come a long way in the past few years, but it is still in its infancy in the construction industry. The key to furthering the progress of BIM is education and research of its capabilities and all of the benefits that it can provide to a project and to the running of a facility upon completion. The best place for this information to come from is through the technical training of engineers working with this technology on an everyday basis and then bringing that expertise with them to their projects. Educating owners early on in the phases of planning of a project and allowing them to see the vast potentials of using Building Information Modeling during the construction phase of the project as well as the possible deliverables that BIM can provide for them to use during the day to day running of their facility is the key to BIM growing in the industry. If people become aware of the capabilities and begin to take advantage of these benefits, BIM will continue to grow and the technology will continue to expand.

The electrical analysis of the diesel generator and photovoltaic panel array provided the owner with three options: replace the generator with a solar panel array to provide power to the building throughout the year, keep the backup generator in case of emergencies and add the solar array to the scope of the project for an additional cost, or keep the system the way it is and not take advantage of a relatively cheap, but clean and renewable source of energy. The additional cost of $53,000 to add a solar panel array to the building while keeping the diesel backup generator is the best possible option for this facility. It guarantees that the vast amount of electronics in the building can be powered during an emergency, as well as provides roughly 5000 kW of power per year to the building in the form of renewable solar energy.

The alternative design to replace the secant pile wall with a concrete retaining wall proved to be a huge cost savings for the project, but turned out to not be a viable option due to its constructability. The existing parking garage facility is located too closely to new parking garage to provide enough space to excavate and pour a concrete retaining wall while using temporary excavation support systems. With more time, a strong analysis would be the sequencing and timing of the construction of the secant pile wall on-site to help deal with the numerous construction issues that presented during the project.

Special Thanks

Arne Kvinnesland would like to thank his professors in the Architectural Engineering department and the Pennsylvania State University as a whole for providing him with the opportunity to achieve one of the best educations available to young adults in the United States. All of the AE faculty at Penn State have provided Arne with a vast amount of knowledge that he is thankful to be carrying with him into the construction industry and furthering the legacy of Penn State University.

Thank you to all of the industry members who responded to email interviews and assisted Arne with the collection of information for this Building Information Modeling analysis.

Thank you to Turner Construction for providing a project to be used for Senior Thesis, as well as an internship on the Army National Guard Readiness Center job site. The knowledge and experience that came from being on site working hands on with this project gave Arne not only a great head start for his year of thesis but also practical industry experience that he will always carry with him.

Finally, a huge thank you goes out to Tompkins Builders, Inc. who is the general contractor for the Army National Guard Readiness Center project. The time spent with Tompkins on site as an intern gave Arne a great basis to build from for his year of Senior Thesis. Tompkins also provided Arne with information throughout the year and was incredibly helpful whenever he had questions or needed clarification or advice on a subject. Thank you so much, Tompkins.

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Appendix 2 – Electrical Calculations

ELECTRICAL ANALYSIS

ROOM TO PLACE PANELS AFTER GENERATOR IS GON

22' x 50' = 1100 ft²

BP SX 170B PANEL DIMENSIONS:

5.25' x 2.58' = 13.5 ft²

USE 15' TO ALLOW FOR RACKS.

1100 ft² / 15 ft² = 73 PANELS

USE 60 PANELS TO ALLOW FOR WALKWAY,

TWO ARRAYS OF 30.

TOTAL POWER OUTPUT:

170 WATTS / PANEL

60 x 170 W = 10,200 W / 1000 = 10.2 KW

STRONG SOLAR EXPOSURE: 10 am - 3 pm

5 hrs x 10.2 KW = 51 KW DAILY ON AVERAGE

TOTAL COST OF SYSTEM:

60 PANELS x $850 / PANEL = $51,000

123' RUN / 100' = 1.23 x $30.05 / CLF

= $36.96 / PANEL WIRING x 60 PANELS

= $2,217.70

TOTAL COST: $53,217.70

Appendix 3 – Solar Panel Product Data

Appendix 4 – Structural Calculations

The structural calculations for the concrete retaining wall structure, being used to replace the current secant pile wall designed for the project, are shown on the following pages.

STRUCTURAL RETAINING WALL CALCULATIONS

FROM STRUCTURAL ENGINEER:

SECANT PILE WALL BENDING AND SHEAR CAPACITIES:

$M_s = 356$ ft·K

$V_{REQ} = 131^K$

FROM SOIL REPORT, USING LOWER END VALUES:

$\phi = 28°$

$\delta = 17°$ (CONCRETE TO SOIL)

$\gamma = 120$ PCF

$\gamma_{SAT} = 60$ PCF

$K_P = 4.50$

$K_a = 0.32$

$c = 300$ PSF

$F'_c = 4000$ PSI

#10 REBAR

3" CLEAR

CALCULATE SHEAR CAPACITY

$d = 30" - 6" - .5" - 1.5" = 22"$

$b_w = 30"$

$\phi V_c = .75(2)(30)(22)\sqrt{4000}/1000 = 62.6^K$

* MUST MEET 68.3^K TO MATCH SECANT PILE WA[LL] CAPACITY. INCREASE THICKNESS.

$d = 32" - 6" - .5" - 1.5" = 24"$

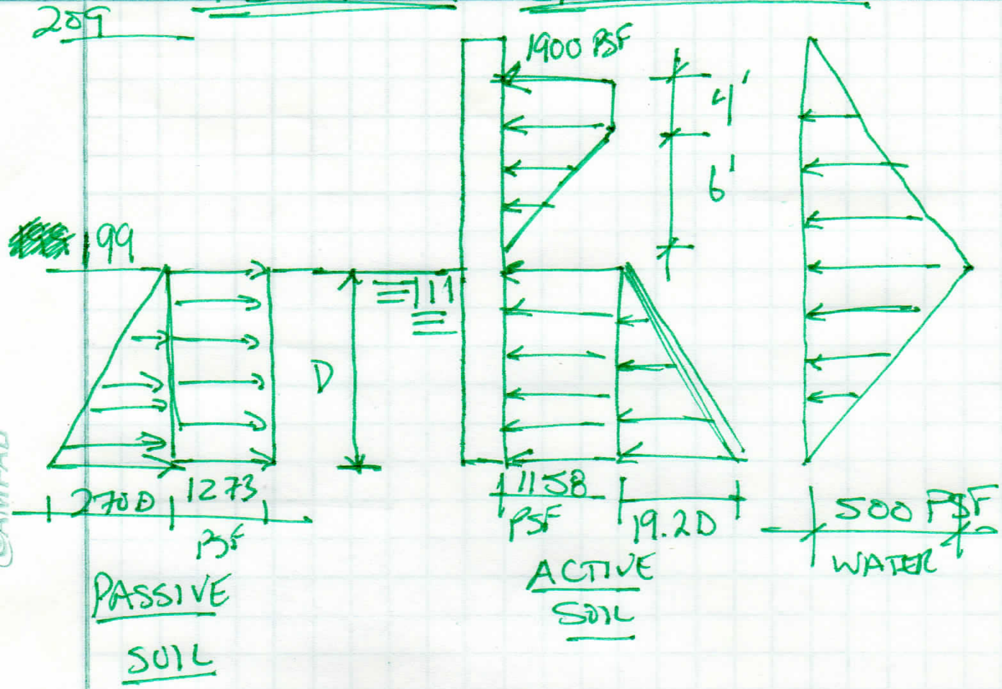
$b_w = 30"$

$\phi V_c = .75(2)(30)(24)\sqrt{4000}/1000 = 68.3^K$

$\phi V_s = .75(60)(.4)(24/12) = 36^K$

TOTAL SHEAR CAPACITY $= 36^K + 68.3^K = \boxed{104.3^K}$

EMBEDMENT CALCULATION



FROM SOIL REPORT, USING LOWER END VALUES:

$\phi = 28°$

$\delta = 17°$ (CONCRETE TO SOIL)

$\gamma = 120$ PCF

$\gamma_{SAT} = 60$ PCF

$K_p = 4.50$

$K_a = 0.32$

$C = 300$ PSF

THE EFFECTIVE SOIL PRESSURE (VERTICAL) AT ELEVATION 199:

$\bar{q} = 120(35) + 60(8) = 4680$ PSF

THE LATERAL PRESSURE IS $P_H = \bar{q} K_a - 2c\sqrt{K_a}$

$P_H = 4680(.32) - 2(300)\sqrt{.32}$

$P_H = 1158$ PSF

THE ADDITIONAL ACTIVE PRESSURE WILL BE:

$P_{H_1} = 60(.32)D = 19.2D$

THE PASSIVE PRESSURE IS:

$P_P = qK_P + 2C\sqrt{K_P} = \bar{q}(4.5) + 2(300)\sqrt{4.5}$

$= q(4.5) + 1273$

$\therefore \quad q = 60D$

THE RESISTING FORCE IS:

$F_R = 1273D + \frac{270D^2}{2}$

THE DRIVING FORCE IS:

$F_D = 1900(4) + 1900(6/2) + 500(8/2) + 500(D/2)$

$+ 1158D + 19.2D^2/2$

$F_D = 15,300 + 1408D + 9.6D^2$

* ASSUME HINGE FORMS AT LOWEST TIE AND SUM MOMENTS ABOUT THE HINGE TO DETERMIN D. THIS WILL BE CONSERVATIVE.

$1900(4)(2) + 1900(6)(6/2) + 500(8/2)(7.33) + 500(D/2)(D/3 + 10)$

$+ 1158D(D/2 + 10) + 19.2D(D/2)(2D/3 + 10)$

$= 1273D(D/2 + 10) + 270D(D/2)(2D/3 + 10)$

$64067 + 2500D + 83.3D^2 + 579D^2 + 11,580D + 6.4D^3 + 96D^2 =$

$64067 + 14080D + 758D^2 + 6.4D^3 = 1986D^2 + 12,730D + 90D^3$

$D = 6.5'$

INCREASE D BY 20% $\therefore$ $D_{MIN} = 6.5(1.2) = 7.8'$

ALTERNATE DESIGN

* INSTEAD OF INCREASING THE CALCULATED EMBEDMENT BY 20%, DIVIDE THE PASSIVE PRESSURE BY A FACTOR OF SAFETY OF 1.50.

$$64067 + 14080D + 758D^2 + 6.4D^3 = \frac{1986D^2 + 12{,}730D + 90D^3}{1.5}$$

$$= 1327D^2 + 8487D + 60D^3$$

$D = 10.5'$

$X/10.5 = 1.5$

$X = 15'$ WILL BE USED.

THIS IS $15/10.5 = 1.43$ TIMES THE EMBEDMENT CALCULATED USING A 1.5 FOS

Appendix 5 – Cost Calculations for Retaining Wall

The material and construction cost calculations for the permanent concrete retaining wall structure, being used to replace the secant pile wall designed on the project, are listed on the following pages.

TAKEOFFS FOR RETAINING WALL

CONCRETE

3 BENCH MARK HEIGHTS : 34', 42', 50'

* EACH 105' IN LENGTH

34' X 105' X 32"/12" = 9520 CF /27 = 352.6 CY

42' X 105' X 32"/12" = 11760 CF/27 = 435.6 CY

50' X 105' X 32"/12" = 14000 CF/27 = 518.5 CY

TOTAL = 1306.7 C

USE : 1310 CY

FORMWORK

34' X 105' + 42' X 105' + 50' X 105' = 13230 SF

13,230 SF X 2 SIDES = **26,460 SF**

REINFORCEMENT

FROM STRUCTURAL CALCULATIONS: 8 #10'S EVERY

105'/2.5' = 42 X 8 BARS = 336 #10'S PER BENCH

336 X 34' = 11,424 LF X 4.303 lbs/ft

= 49,157 /2000 = 24.6 ⇒ 25 TONS

336 X 42' = 14,112 LF X 4.303 lbs/ft

= 60,723 /2000 = 30 TONS

336 X 50' = 16,800 LF X 4.303 lbs/ft

= 72,290 /2000 = 36 TONS

TOTAL REBAR (TONS) = **91 TONS**

TOTAL COST FOR RETAINING WALL

FORMWORK (2 USE)

26,460 SF X $5.86 /SF = $155,055

CONCRETE

MATERIAL COST:

1310 CY X $158.15 = $207,176

PLACEMENT COST:

1310 CY X $18.85 = $24,695

REINFORCEMENT

91 TONS X $782/TON = $71,162

TOTAL COST OF ALTERNATIVE RETAINING WALL

$458,088

TOTAL COST OF SECANT PILE WALL:

* TAKEN FROM CONTRACTOR BID FOR PROJECT

$2,211,246

TOTAL SAVINGS:

$1,753,158