Senior Thesis – Spring 2006

Capital One Lecture Hall Addition

Advisor: Dr. Michael Horman

McLean, VA
Capital One Lecture Hall Addition

Project Overview ~
Dates of Construction: May 2005 – Aug. 2005
Project Size: 20,400 SF
Overall Cost: $15,095,988 GMP
Project Delivery: CM/GC, design-bid-build

Project Team ~
Owner: Capital One Financial Corp.
Owner's Rep: Jones Lang LaSalle
Architect: Mancini Duffy
CM/GC: James G. Davis Construction
MEP Engineer: KTA Group
Structural Engineer: Rathgeber/Goss Assoc.

Building Description ~
- Auditorium will hold approx. 450 seats with tablet arms and wireless internet access
- Includes projectors and screens, audio-visual support, and multi-use stage
- Additional space includes a garden atrium, green room, catering pantry, and conference rooms

Garden Atrium ~
- Interior landscaping governs main lobby
- Small water features break up planters
- Increased available sunlight with 50' x 55' skylight in the lobby

Mechanical ~
- (3) air handling units: 4,800 CFM, 19,200 CFM and 10,725 CFM units
- (2) 4,100 lb boilers for heating and hot water
- Wet pipe sprinkler system for fire protection

Electrical ~
- Existing 3 phase – 400A breaker replaced with 3 phase – 1,200A breaker
- Two main 277/480V, 800A, 3 phase distribution panels
- 800 KW life-safety and 1,750 KW standby emergency generators

Lighting ~
- Lecture Hall: incandescent and halogen down-lights, as well as halogen wall-washers
- Stage: halogen ellipsoidal projectors with 19" lens barrel
- Lobby: recessed down-light, metal halide up-light fixtures, and gro-lights for garden

Structural ~
- Custom made structural steel system for large auditorium and atrium openings
- Concrete column footings with 14" thick cast-in-place shear walls
- Basement floor is slab-on-grade with 6x6 W2.0 x W2.0 WWF

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Executive Summary

Situated on a 29 acre site in McLean, Virginia, the 20,400 ft2 addition to the base building will eventually house Capital One's recruiting and educational events. From the start of the demolition phase on 13-May-2005 to the proposed project closeout on 23-August-2006, the Design-Bid-Build project will approach $15 million. Major project requirements include a Lecture Hall with approximately 400 seats, designed to accommodate large meetings, recruiting events, and educational sessions. In addition to the main hall, there will be support space including a green room, breakout space, a catering pantry, administrative space and two mid-size conference rooms.

Main construction research was aimed to reveal industry member concerns relating to current involvement within a construction project's value engineering process. This study came as a result of observations made from a lackluster debate at a Partnership for Achieving Construction Excellence conference in the Fall of 2005. Further investigations revealed agreement between designers and general contractors that VE process frequently began too late and unequal idea contributions created unsatisfied project teams. In order to resolve dissemination between key players, utilization of partnering activities may pose more beneficial VE results.

These deficiencies are then applied to the Capital One Lecture Hall Addition and its inefficient value engineering process. If project teams were given sufficient time and increased communication, foundation work and other interior building system costs could have been revised. Within the breadth analyses, more thorough evaluations of valuable products and processes are conducted. The central building components examined were the steel catwalk, boilers contained in a congested mechanical room, and foundation work. Main selection criteria dealt with cost, lead times, installation times, and other feasibility concerns.

Final recommendations and calculations of these three options revealed a total savings around $96,000. Not only would there have been reduced costs, but a cumulative 4-6 weeks in schedule savings was possible.

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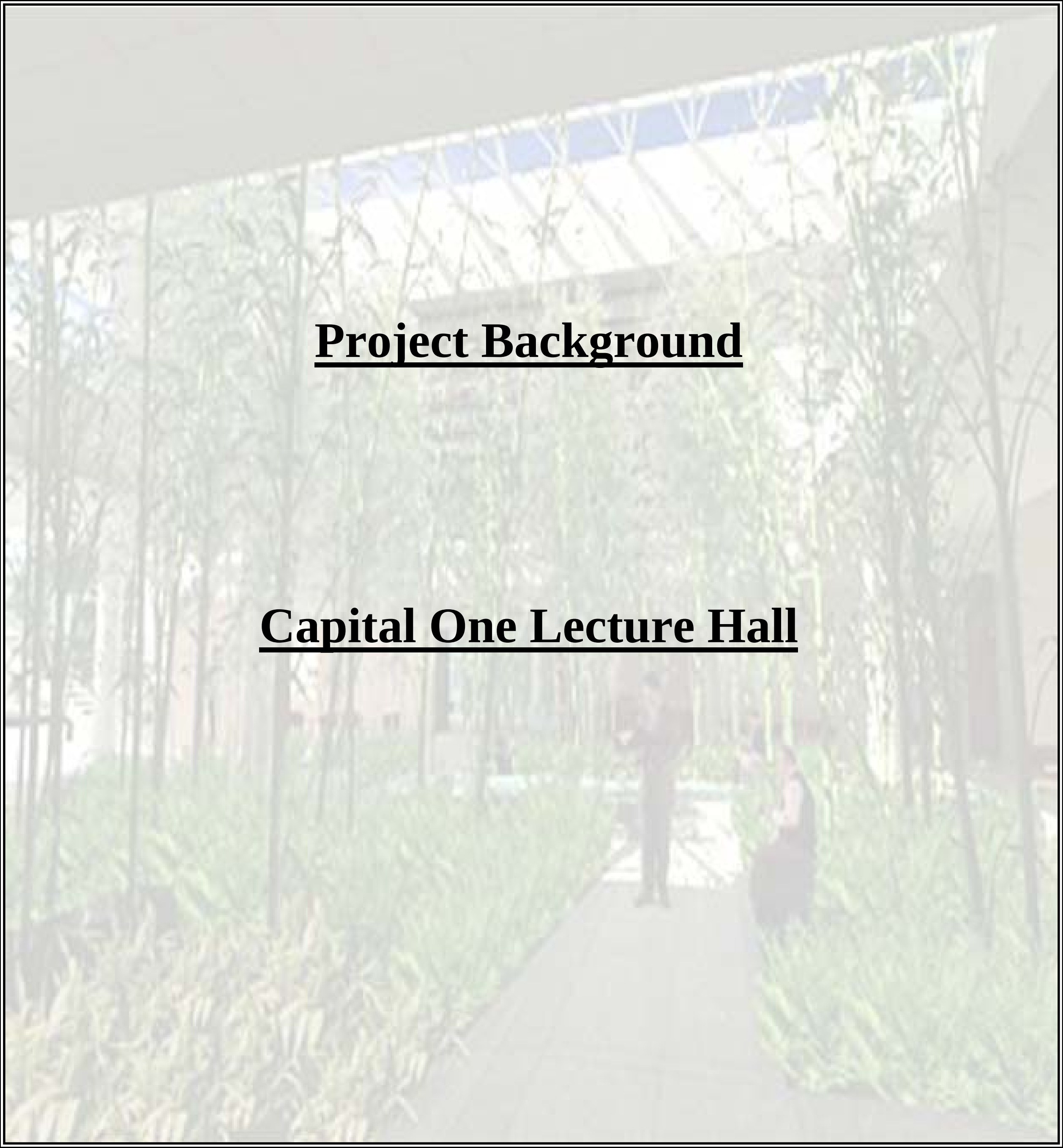


Project Background

Capital One Lecture Hall

Client Information

Introduction

Jones Lang LaSalle ("JLL") had been retained by Capital One to serve as its Development Manager to handle the day-to-day administration of the project and facilitate effective communication within the project team. It is in the role as Development Manager that JLL solicit proposals from qualified construction management firms. Due to the unique nature of the Lecture Hall project and the schedule requirements involved, JLL and Capital One desire to engage the services of the Consultant as early as possible in its planning and design process.

Project Overview

Purpose Statement

The primary drive for this project resides in the need to allow Capital One the ability to continue and expand its ongoing utilization of large meetings, currently held off-site at the University of Virginia Darden facility. The creation of an addition to the existing building is seen as an opportunity to create a flexible, multi-functional amenity that supports and facilitates the collaborative culture inherent within the organization. Locating a Lecture Hall facility on the headquarters' campus provides a local venue that offers opportunities for the CEO and other senior executives to meet with staff, both formally in the auditorium or informally in the Garden Atrium.

Summary of Project Program Requirements

Sizing of the new addition is the result of both program needs and the remaining square footage allowable based on the site's floor to area ratio (FAR). Phase I construction has an area of 479,622 ft^2. With an approved FAR of 500,000 ft^2, a 20,378 ft^2 addition to the existing structure is allowed. The level of design is based on a "business class" image that will complement and respect the architecture of the existing office tower.

Critical program requirements presented by Capital One to be incorporated within the new facility include:

- A Lecture Hall with approximately 400 seats, designed to accommodate large meetings, recruiting events, and educational sessions.
- A design that will allow the Lecture Hall to be divided to accommodate smaller meetings while providing a more intimate facility.
- A stage with front-screen projection as well as audio-visual support. Flexible lighting for both the audience chamber and stage that is appropriate for Capital One's methods of presentation, which can include two presenters at the same time.
- A Lecture Hall design with architectural, interior finish and structural properties that shelter the hall from unwanted outside noise while enhancing the acoustical experience within.
- Lecture Hall seating that is comfortable, stadium-style, uni-directional and on one level; seating will facilitate long meetings and a wide range of presentations by including tablet arms, power, and wireless internet access.
- Support space, including a green room, breakout space, a catering pantry, administrative space and two mid-size conference rooms.

Summary of Design Concepts

- Integrate the new structure into the existing headquarters structure and reinforce the strength of the total architectural experience.
- Create an autonomous identity for the Lecture Hall without detracting from the existing headquarters building.
- Provide a garden atrium to create a transitional link between the existing structure and the new facility.
- Create a structure that offers Capital One's staff a multi-functional facility that also reinforces the collaborative culture of the organization by enhancing face-to-face interaction.
- Incorporate sustainable design elements and efficiencies to create a high performance building.

Project Teams

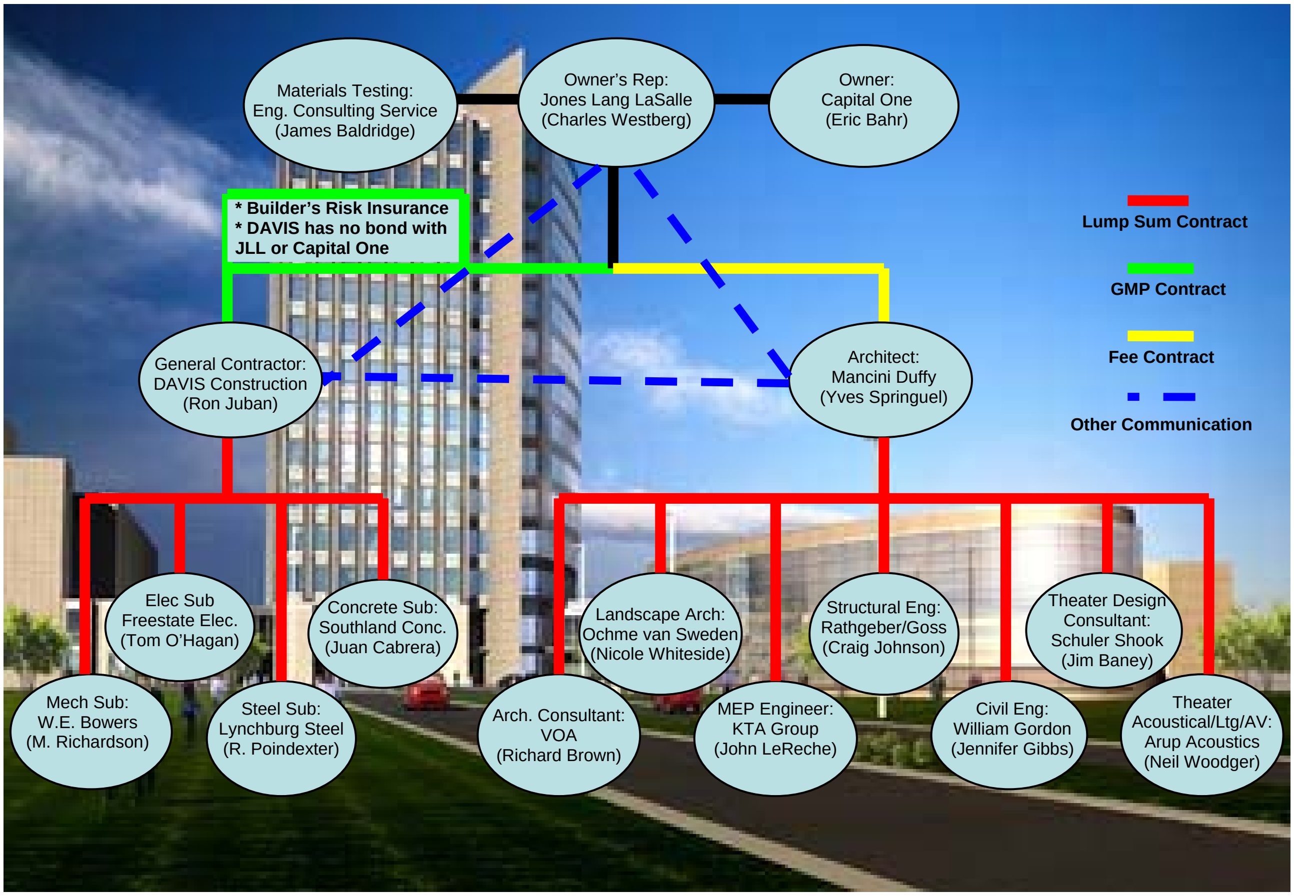


Figure 1. Lecture Hall Project Team Schematic

Delivery System

Starting at the earliest recorded actions of the Lecture Hall Addition project on June 23, 2004, Capital One has had countless decisions to make. During this time it was in their best interest to release a design team to further advance the development of the project and a civil engineer to develop a preliminary site plan. With the help of JLL and Engineering Consulting Services ("ECS") performing existing soils tests, project procurement was on the way. Mancini Duffy was awarded a "Fee" contract with JLL because of other smaller projects occurring on site and their involvement with them. Although the Lecture Hall is the main focus for Mancini Duffy, they can utilize their "Fee" capabilities since Capital One and JLL have had additional design requests affecting the overall site.

With the design phase in full swing, another consultant and landscape architect were assigned to the Lecture Hall with a lump sum because of their familiarity with the base building. Between mid-July and early September of 2004, the remaining portion of the Architectural and Engineering Team was mobilized. Rathgeber/Goss Associates came under a lump sum contract with Mancini Duffy during this time. An MEP Engineer was soon to follow and the KTA Group was awarded its own contract. Theater Design assistance from Schuler Shook and Arup Acoustics began once the two firms signed their lump sum agreement with Mancini Duffy.

These lump sum contracts between the architect, engineers, and designers are fairly standard in the industry when projects are not incredibly technical. The ability to maintain lump sum drawings make it more convenient for the architect in sustaining an accurate "Fee" with JLL.

As major design teams got involved in the Lecture Hall project, Capital One also needed to find itself a General Contractor. Following suit with the base building, James G. Davis Construction had a slight advantage over other GC's in obtaining the work.

With the relatively short project duration and cost in comparison to the base building, DAVIS does not hold a bond with JLL. Their minute chance of going out of business and their great reputation with Cap One has allowed them to do this. Although, DAVIS has purchased Builder's Risk Insurance to insure the Lecture Hall while it is under construction and decrease liability. This insurance is provided for loss resulting from accidental direct physical damage to the structure.

Key communication lines are also represented between the three major players involved in this project. The Owner holds weekly meetings with the Architect, GC, and Engineers. Any changes made by the Owner are passed onto Mancini Duffy, which then travel to the engineers for review and re-submission. Once resubmitted and approved by the Architect, the GC obtains the documents to be passed to the subcontractors for their review. In order to keep a well informed construction staff, the DAVIS holds weekly meetings with subcontractors. Any changes in cost or scope of work will be evaluated by DAVIS and sent to JLL and Mancini Duffy. Final submittals are always passed onto Capital One and JLL from DAVIS.

Given the fast-track of the project, JLL and Capital One entered into a Guaranteed Maximum Price (GMP) contract with a general contractor. Such a contract will be between Capital One and James G. Davis Construction Company.

Staffing Plan

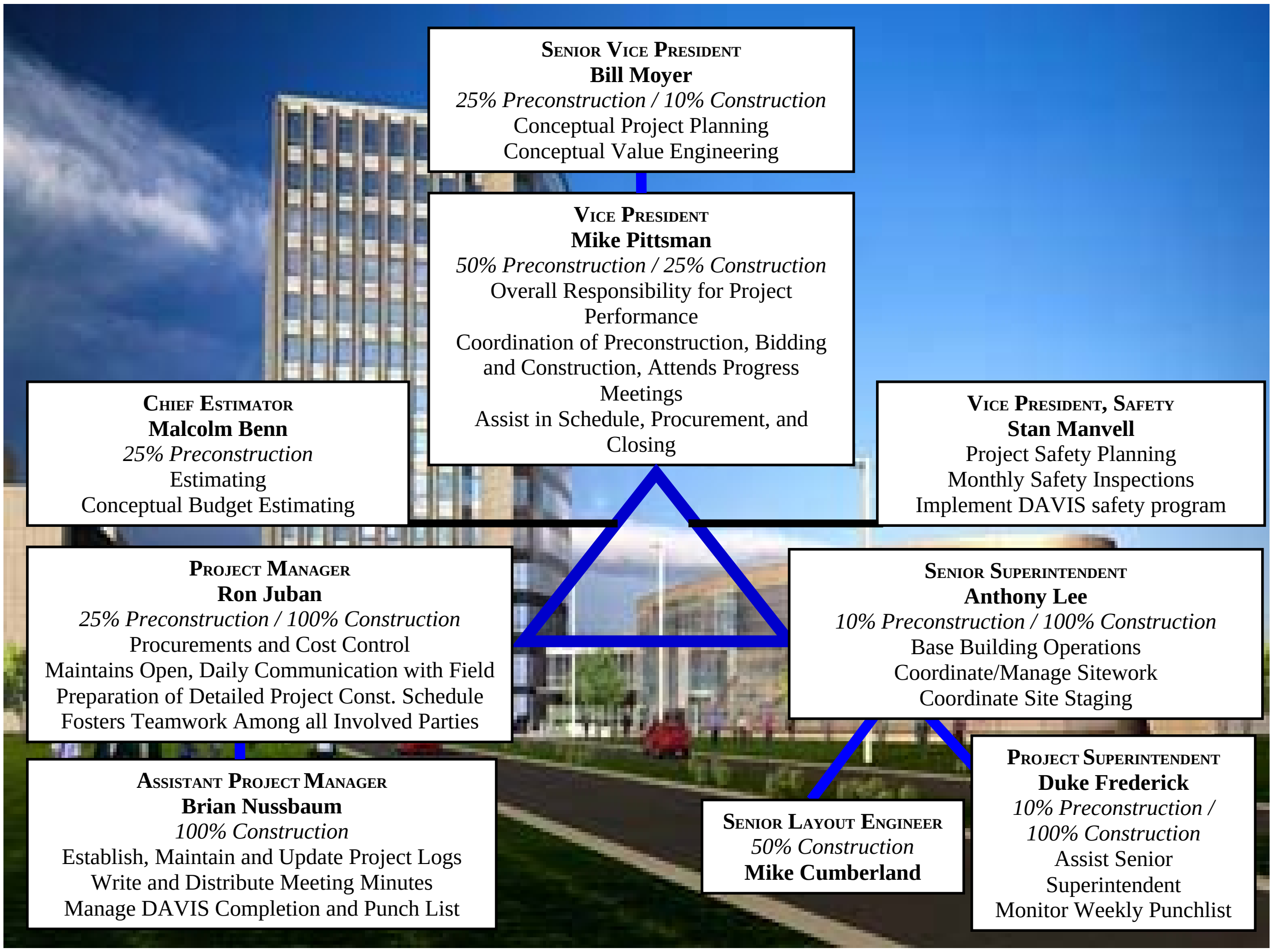


Figure 2. DAVIS Staffing Plan Schematic
*As of 23 September 2005

In order to maximize productivity and minimize excess General Conditions costs throughout the Lecture Hall Addition, DAVIS developed the employee organization chart that can be seen above. The percentages below each name, accompanying the preconstruction and construction processes, account for the amount of their time devoted to the project during that phase.

A majority of the preconstruction work is to be split between 6 of the 9 team members listed. As the Senior Vice President and Vice President of DAVIS, it was the job of Bill Moyer and Mike Pittsman to do a majority of the initial project engineering and planning. Once DAVIS generated an appropriate cost estimate, the project manager and site superintendents needed to become more accustomed to the existing site conditions and the proposed design development.

With the construction phase of the Lecture Hall being in full swing, both superintendents and the two project managers have been spending all of their hours on this project. In order to keep everyone on this team at DAVIS up-to-date with construction progress, a free flow of information is required between the Vice President, Project Managers, and Superintendents. To lighten some of the tasks requested of the Senior Superintendent, the Senior Layout Engineer develops site layouts and helps to resolve some preliminary trade coordination issues. Throughout the entire project, Stan Manvell oversees the work being performed on site and executes safety checks to make sure everything is in order to reduce the chance of accidents.

Existing Construction Conditions

Local Conditions

With all of the construction going on in the Virginia and Washington, D.C. area, all work must follow local laws and zoning requirements. One point of interest is the height restriction law enacted by Congress in 1899 which ensures that no private structure in Washington, D.C., will extend higher than the Capitol. Although the Capital One Lecture Hall is in Virginia, this law is only for the District of Columbia and does not affect the surrounding counties.

The project site is located north of and adjacent to the existing Capital One Building in Tysons Corner, Fairfax County, Virginia. Within the 29 acre plot of land, construction parking and deliveries are not a concern. A separate access road has been constructed at the end of Scott's Crossing Road and contains around 20 temporary parking spaces.

A typical soil profile in this area consists of a thin layer of clayey silt or silty clay near the ground surface, where weathering is more advanced. The near surface clay soils transition to more granular, less weathered soil with depth. The density of the soils generally increases with depth as a result of the reduced extent of the weathering process. It is not unusual to find lenses and boulders of hard rock and zones of decomposed rock within the soil mantle well above the general bedrock level.

Fairfax County Soils Mapping indicates that the surface soils in the eastern half of the site are Glenelg soils, which occur in the high elevations or areas of the site. Meadowville soils, a type B soil, are mapped in the western half of the site, in the low, concave bottom slope and drainage areas. Both of these soils are described as silts and clays overlaying silty and sandy decomposed rock.

Site Layout and Utility Plan

Please view the Existing Site and Utility Plan within **Appendix A**.

Building Systems Summary

Demolition

Being an addition to Capital One's base building, the Lecture Hall project entailed demolition to the recently completed work. In total, two conference rooms and a coffee shop contained on the end of two separate floors had to be completely removed. The mechanical and electrical systems were cut and are to be re-routed in these spaces until the Lecture Hall is complete and can be tied back in. Structurally, all of the steel and post-tensioned slabs were knocked down. In order to maintain a structurally stable second floor slab, an additional beam was connected between an existing concrete column and steel column. The removal of lead paint or asbestos was not a problem in the demolition work of the new base building. Other than the countertops in the coffee shop, light fixtures, and concrete pavers in the patio, everything was eliminated.

Figure 3. Base Building Demolition

Structural Steel Frame

Due to the abnormally shaped building and large open spaces, the Lecture Hall had to be custom designed by the structural engineer. The elliptically shaped configuration prevents the use of repetitive steel sizes and typical bay dimensions. With the two large open spaces of the auditorium and garden atrium, the steel system had to be designed with moment connections. Cross bracing can only be found in the trusses for the roof. A 40-ton truck mounted crane from Link Belt has been used to place the regular steel pieces, but a larger undetermined crane will be needed for the roof trusses.

Figure 4. Garden Atrium Space

Cast-in-Place Concrete

The Lecture Hall is supported by a foundation with 14” thick shear walls and concrete column footings. Also, the facility utilizes slab on grade and concrete slabs on each floor level. The 5” slab on grade at the basement is reinforced with 6x6 – W2.0xW2.0 WWF on 6” No.57 stone. For the auditorium slab on grade, a similar system is used, except that it is a stepped concrete slab to conform to the seating elevation layout.

Figure 5. Ulma Forms in Staging Area

Figure 6. Ulma Forms

On this job there were multiple concrete placement methods as well as formwork types. Although all the shear walls were poured with the help of a 1.5 yard bucket attached to a 40-ton mobile crane, two different framing types were used. For the curved wall along the north end of the basement, special metal Ulma forms were used. A majority of the remaining shear walls were framed with wood forms constructed by hand on site. The wood forms allowed the concrete subcontractor to re-use them for multiple pours once the wall had set and forms taken down. All of concrete used for the slab on grade pours had been pumped.

Pre-cast Concrete

Besides the intricate glazing system designed and fabricated in Italy, the exterior of the Lecture Hall is mainly comprised of pre-cast concrete panels around the nose of the building. All of these panels which are to match the existing base building will be cast at the subcontractor's site in Virginia. Arban & Carosi will create the finished panels from their own concrete forms. Once they are complete, all of the pre-cast panels will be delivered to the site in sections 40' in height. One 70-ton hydraulic truck crane from Link Belt, model HTC-8670, will be used to maneuver the panels into place. The upper portions of the pre-cast have welded/bolted connections to the steel above to keep it from moving in and out. At the ground level, the panels are to be welded to plates on the concrete wall.

Figure 7. Installation of Pre-cast Panels

Mechanical System

The two mechanical rooms within the Lecture Hall are located in the basement. Mechanically, Capital One's lecture hall is supported by 3 air handling units and 2 boilers. While the air handing units supply the VAV boxes located throughout the building, the two 4,100 pound boilers will be utilized for heating and hot water. The base building supports the lecture hall system with a pair of 6" cold water supply and return runs. AHU-1,-2 and -3 respectively have 4,800 CFM, 19,200 CFM, and 10,725 CFM supply fans.

In the event of a fire, the Lecture Hall is equipped with a wet pipe sprinkler system with alarm indicators, check valve, tees, and all associated piping. Concealed sprinkler heads are located in all public areas, while pendent heads are in the storage and equipment rooms.

Electrical System

The Lecture Hall power distribution originates from the base building. By removing one existing 3 phase – 400A circuit breaker and replacing it with a new 3 phase – 1200A circuit breaker, the two main distribution panels can be supplied with power. Both main panel boards are specified to be 227/480V, 800A, 3 phase, 4 wire. MDP-A and MDP-B have a total connected/demand load of 464KVA / 397KVA and 280KVA / 280KVA respectively. The remaining secondary surface mounted panels are either 120/208V or 277/480V, 3 phase, 4 wire. In the event of an emergency, one 800KW life-safety generator and one 1750KW standby generator will supply power to the Lecture Hall.

Curtain Wall

Figure 8. Future Curtain Wall Location

At the front entrance of the building, it will be impossible not to notice the impressive glass screen wall spanning a width of around 180'. The entire glazing and support system, including the screen printed detailing, shall be manufactured in Italy. Steel rods that are to be anchored into the precast have four small wedges at the end of them to act as a sleeve for the corners of the class to be inserted in.

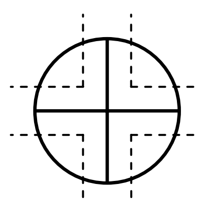


Figure 9. Glazing Sleeve on Rod

Project Schedule

The detailed project schedule included in **Appendix B** contains around 220 activities, each separated into its own respective portion of work. The construction phase of the Capital One Lecture Hall began on 03-May-05 and is projected to continue until 23-Aug-06. Seeing as though the proposed facility is only around 20,400 ft^2 and there is not an abundance of repetitive spaces, dividing the subcontracted work into short intervals would not be appropriate.

The breakdown in this schedule presented to Capital One and Jones Lang LaSalle consists of three major activities. These include base building construction from 5/3/05-4/11/06, site work from 3/21/06-6/6/06, interior construction from 8/23/05-8/3/06, owner occupancy between 7/14/06-7/31/06, and project closeout from 7/25/06-8/23/06. Since base building and interior construction are very large portions of this project, each of these activities is further broke down into smaller subdivisions.

Base building construction is separated into site preparation, demolition, concrete structure, waterproofing and backfill, steel structure, fire proofing, MEP rough-in, façade and roof, and elevators. Interiors are broken down into existing building, cellar, bathrooms, auditorium, 1st floor, 2nd floor, and planters and water fountain. Although not in chronological order, it is easier to track the work in each of these larger, non-repetitive spaces.

Project Cost Summary

Actual Project Summary

The table on the following page is a breakdown of the contracts awarded to each subcontractor and their respective work. These numbers were presented to the owner as a part of DAVIS' GMP proposal in August 2005. In reference to the FAR mentioned in the **Project Overview,** a building size of 20,400 ft^2 has been assumed for the Lecture Hall.

- Total Building Construction Cost (CC): **$13,270,291**
  - CC per ft^2: **$650.50/$ft^2$**
- Total Project Cost (TC): **$15,095,988**
  - TC per ft^2: **$740.00/$ft^2$**
- Mechanical System (HVAC & Plumbing): **$1,612,900**
  - Mechanical System per ft^2: **$79.06/$ft^2$**
- Electrical System: **$1,208,536**
  - Electrical System per ft^2: **$59.24/$ft^2$**
- Structural System (Concrete & Steel): **$2,012,944**
  - Structural System per ft^2: **$98.67/$ft^2$**
- Interior/Exterior Glass and Glazing: **$2,074,355**
  - Glass and Glazing System per ft^2: **$101.68/$ft^2$**

Parametric Estimate (Using D4 Cost 2005)

Using similar fine performing arts centers, the Lecture Hall was estimated to have a Total Building Cost of $4,782,000.

RS Means Square Foot Estimate

Considering the space is a lecture hall with a large garden atrium space in the lobby, comparable auditorium and commercial greenhouse rooms were used to calculate the square foot estimate. With a Fairfax, Virginia location factor of 0.91, the Lecture Hall was estimated to cost $3,123,000.

Total Project Bid Summary

CSI	Description	Recommended Subcontractor	IGMP
02200	General Excavation	PARRECO	$410,236
02250	Dewatering	DAVIS	$10,000
02510	Asphalt Paving	ALLOWANCE	$10,000
02560	Site Utilities	FRANK JOY	$71,415
02620	Site Concrete & Pavers	ALLOWANCE	$65,450
02815	Water Fountain System	DELTA FOUNTAIN	$72,220
02900	Landscaping & Irrigation	SUNSET HILLS	$158,179
02950	Site Development	DAVIS	$115,000
02951	Surveying	DAVIS	$0
02952	Demolition	NECO	$314,929
03300	Concrete	SOUTHLAND	$1,122,817
03450	Precast	ARBAN & CAROSI	$479,150
04200	Masonry	N/A	$0
04400	Stone	LORTON	$314,300
05120	Structural Steel	LYNCHBURG	$890,127
05500	Miscellaneous Metals	MISC. METALS	$359,728
06100	Carpentry	DAVIS	$103,035
06400	Millwork	PATELLA	$852,801
07100	Waterproofing	ADVANCED	$91,875
07250	Spray-on Fireproofing	DIAMOND	$86,700
07500	Roofing	PROSPECT	$147,661
07900	Caulking	CAULKING APPL.	$30,974
08110	Doors, Frames, & Hardware	ATLANTIC BUILDERS	$64,650
08800	Exterior Glass & Glazing	TSI / ARCHIGLAZE	$1,620,530
08801	Interior Glass & Glazing	TSI	$453,825
09250	Drywall & Ceilings	TRISTATE	$842,801
09310	Ceramic Tile & Stone Countertops	NICHOLAS TROIANO	$59,060
09680	Floor Finishes	EASTERN FLOORING	$136,500
09900	Painting & Wall covering	MILLER PAINTING	$62,300
09950	Stretched Fabric Panels	Z-BEST	$88,654
10160	Toilet Partitions & Accessories	ACCESSIBLE	$28,920
10200	Louvers	E.F. RODGERS	$2,100
10425	Interior Signage	ALLOWANCE	$10,000
10520	Fire Extinguishers	N/A	$0
10650	Operable Partition	SURFACE & SYSTEM	$15,280
11060	Lecture Hall Room Divider	AE MITCHELL	$125,000
11132	Projection Screens	MATERIAL DIST	$68,800
12000	Window Treatment	DIRECT PATH/SUN	$68,030
14200	Elevators	OTIS	$100,936
14430	Wheelchair Lift	ACCESS LIFTS	$20,000
15000	HVAC & Plumbing	W.E. BOWERS	$1,612,900
15300	Fire Protection	ECFP	$179,522
16000	Electrical	FREESTATE	$1,208,536
16720	Security	N/A	$0
18000	Auditorium Chairs	FIGUERAS	$795,350
	Expansion Joints	TBD	$0
	Total Direct Cost		**$13,270,291**
	General Conditions		$826,927
	Subtotal		**$14,097,218**
	Fee		$455,000
	Virginia Gross Receipts Tax (0.12%)		$17,463
	General Liability Insurance (0.40%)		$58,279
	Builder's Risk Insurance (0.25%)		$36,570
	Contingency (2%)		$431,458
	Performance % Payment Bond		$0
	GMP TOTAL		**$15,095,988**

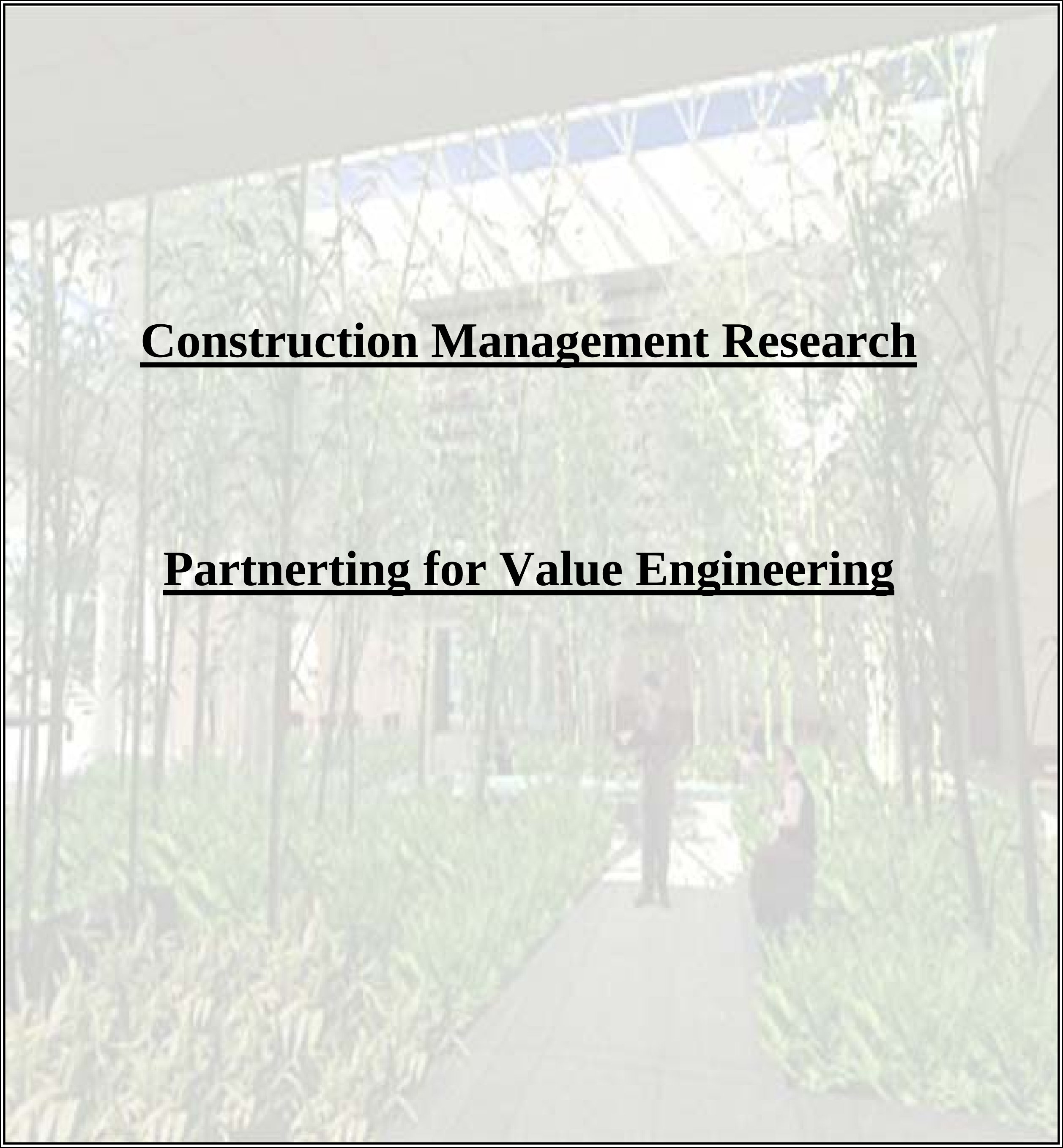
Table 1. Project Bid Summary

Cost Evaluation

As you can see, both estimates fail to grasp the numerous unique features contained within Capital One's Lecture Hall Addition design. This space was designed to be a high end "upper-class, white collar" facility. In addition to the auditorium space, other architectural and building systems contribute to the challenging task of accurately estimating from known averages. Some of these distinct spaces which are not normally found in an auditorium include; a garden atrium and water features inside the lobby, medium-size conference rooms with audio-visual support, wireless internet throughout the auditorium space, a large skylight, and a glass screen wall system from Italy.

Afterword

The purpose of this background section was to familiarize the reader of Capital One's Lecture Hall project. As you proceed to read through this document, please consider the owner's desire to have a highly valuable Lecture Hall with a reasonably priced contract. With a better understanding of the client, general contractor, and the building systems, hopefully you may agree with the recommendations and analyses to follow.



Construction Management Research

Partnerting for Value Engineering

Advisor: Dr. Michael Horman

Executive Summary

This research study begins with an overview of two commonly used terms within the construction industry. Separately, value engineering is commonly known as a process in which product value and accompanying services are increased, where as partnering is thought to be a management tool to improve project quality within an open environment to reduce confrontation. Together these construction management tools can be implemented to reveal the most advantageous products available in an environment that is full of integrity and communication.

After evaluation of a Partnership for Achieving Construction Excellence conference last fall, research in this depth section was aimed at revealing detached perceptions of design teams from general contractors and construction managers. A survey included in **Appendix C** was used to reveal the opinions portrayed by engineers and general contractors concerning their current involvement within a construction project's value engineering process. Response investigations reveal common flaws encountered within VE. Whether a lack of communication for achieving common goals or poor timing during the design development phase, project teams need to work more cooperatively. Doing so will create a trusting environment where valuable suggestions can be discussed in order to improve the overall worth of any project.

Later, this is related to the VE procedure implemented on the Capital One Lecture Hall Addition. Although a number of cost cutting suggestions were accepted in hopes of lowering the budget, additional measures could have been taken. Had project groups looked at alternative solutions before 75% construction documents and formed an open discussion forum, additional ventures could have been accomplished.

Background

Value Engineering (VE)

The term “value engineering” or “value analysis” and their accompanying methodology have been used over half a century. This commonly misused expression in the construction industry is a methodical advance to improve the overall value of a product and accompanying services. As stated by Lawrence Miles, “value is the ratio of Function to Cost.” In order to increase value, one can either improve a products function or reduce its cost. Most importantly, VE is not to be used to reduce overall quality at the expense of pursuing valuable improvements. Proper methods should use instinctive judgment and an examination of a product or sequence’s function to identify relationships that increase value.

Partnering

As we all know, the construction industry involves a large number of participants with different interests. In some cases, this type of an environment may create an uncooperative and blaming culture. The most common causes of construction problems are adversarial relationships between project participants and unbalanced risk allocation creating a “blame game.” Results may lead to project delays, inflated costs, and an overall uninviting atmosphere.

Over the past dozen years, the term “partnering” has been used as a “management tool to improve quality and program, to reduce confrontations between parties, thus enabling an open and non-adversarial contracting environment”[5]. The key themes behind partnering are teamwork, collaboration, trust, openness, and mutual respect. Mechanisms typically used to formulate partnering are project team building sessions, formulation of a joint project charter, periodic assessment to adherence to partnering principles, guidelines for resolving disputes in a timely and effective manner, and requirements for procedure enhancement and risk sharing. Collectively, preliminary claims have been made indicating that partnered projects have achieved superior results in controlling costs, improved technical performance, and better satisfying customers.

Introduction

PACE Seminar

Given the opportunity to attend the Partnership for Achieving Construction Excellence conference last fall, one would have been able to notice a severe lack of enthusiasm during a "Project Level Team Development" conversation. This topic was geared to discuss owner and design team motivations and issues related to outside parties within a construction project. Within the allotted hour and a half time slot, questions like "how do team members learn what motivates owners," "what leadership skills and traits are needed to manage design teams," and "what motivates design professions?" were debated. Unlike an earlier enthusiastic discussion about In-House Teams, this debate did not create the same eager atmosphere and began to fade within 45 minutes. The observations made during the PACE conference leads us to believe that there may be predicaments created between project teams, disallowing each other to understand what drives the other.

Proposal

A detached perception of design teams noticed during the debate mentioned above, may be widespread through the construction industry. The first step to develop these relationships and open communication between teams is to identify that there is a dilemma. A survey included in **Appendix C** and discussed in the following section will be used as a tool to get a better understanding of design team and GC/CM opinions on the process of value engineering.

As projects and teams working on them get larger, open communication and integrity often seem to be put to the side. If design teams and contractors do not accept each other as working for the same cause, many problems may arise during preconstruction and construction phases. Due to the increased flow of communication between project teams during value engineering, it is imperative to have team building and partnering exercises put into place.

Survey

The survey included as **Appendix C**, was intended to pick into the minds of both construction and design teams alike. Its specific purpose was to reveal the opinions portrayed by each side concerning their involvement within a current construction project's value engineering process.

Warming up the subjected industry members to further value engineering discussion, they were requested to verify a date for phases of design documents with a notation of value engineering beginning. Before revealing the purpose of VE and the entities which were the source of suggestions, their judgment towards the timing of VE is exposed. Next, a brief explanation of steps taken to identify the owner's needs and priorities was asked for.

The second section of the questionnaire consists of statements to which industry members are to agree or disagree with, revealing their satisfaction or displeasure on the project. Lastly, the final section is an inquiry of specific project team's opinion of success on a job and triumphant VE processes.

Results and Conclusions

The chart to the right is a representation of the percentage of project team members that feel their value engineering phase began at an appropriate time. Of the surveys collected from design team members, 22% of them felt value engineering occurred at a fitting time, where 78% believed it was inappropriate timing. In addition to this, 60% of general contractors and construction managers thought VE happened too late in the design and 40% were content with its position. Collectively, a small percentage of industry members agreed with their situation compared to the 71% who did not.

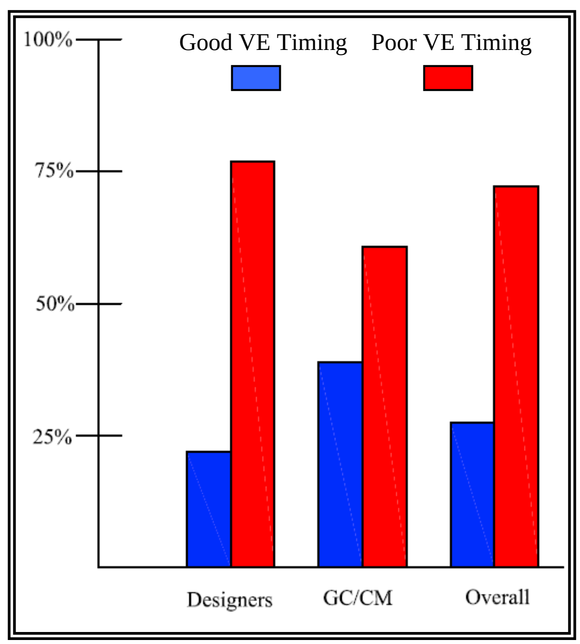


Chart 1. % of Project Teams in Timely VE Processes

Results such as these make you wonder what could be wrong with the VE process. Whether it is strictly timing with design, other project team issues, or a combination of both shall be further investigated. If the case was that either the designers or constructors felt value engineering occurred at a more appropriate time over the other, particular flags may be raised. In this scenario, both sides of the construction spectrum agree that typically VE begins at a bad time, suggesting overall project planning may be at fault. To get a better look into the issue of design and construction phase sequencing, it would be a good idea to look at the addition of value during particular deadlines.

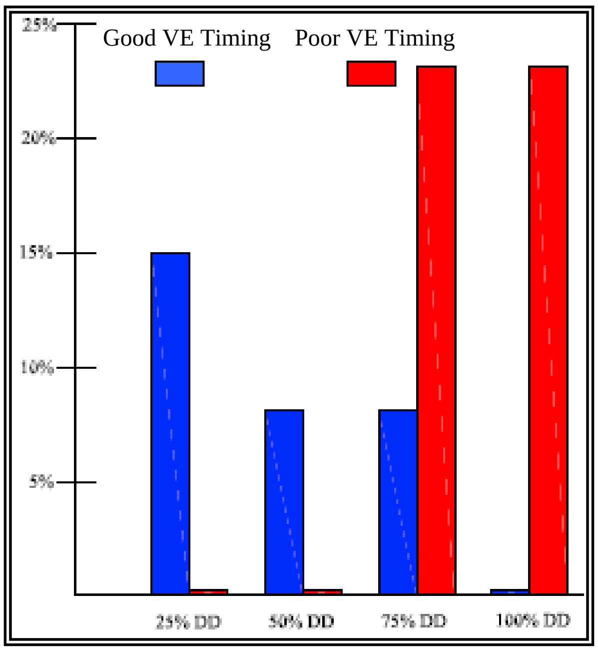


Chart 2. Timely VE of Design Document Progression

In most processes, projects go through the review of 50%, 75%, and 100% design documents. The accompanying table depicts opinions of the industry members concerning their VE procedures. Within this representation, the appropriate sequence is compared to the progression of design documents. A majority of optimistic agreement between the two parties exist for 25% and 50% design documents. Once design documents progress to 75% and above, value engineering tends to be inefficient or too late. Due to the fast paced nature of construction, general contractors and construction managers are often forced to procure major trades such as steel, glass, and concrete by 75% design.

This makes us believe that the most opportune duration to begin suggestions of adding value in design is around 25% and just after the completion of 50% documents. Some may argue that plans are not sufficiently developed to get a realistic understanding of the structure at 25%, but an honest effort as soon as possible can be very advantageous. Conversely, poor communication between the owner, engineers, and general contractor will result in unsuccessful value adding suggestions. If project teams are aware of future strategies, they will have time to prepare the most beneficial options to an owner.

Now that frequent a deficiency within the procurement of VE activities has been exposed, it is best to examine the actual process itself. As stated earlier, this practice is an advance to improve the overall value of a product and accompanying services, without sacrificing quality. More often than not, today's construction industry promotes cost cutting in order to get projects back under budget. This statement can be seen in the table below. For this study, it was revealed that over three quarters of the time, designers and contractors experience cost cutting tactics.

Although there is an agreement that these steps occur, utilizing "value engineering" to lower project budget can cause dissemination. Common comments made by designers in the survey suggest that GC/CM's frequently propose cheaper building components at the cost of quality. As stated by Chris Mellinger of Innovative Electrical Systems, Inc. "a successful VE process is one where the engineers are given the chance to evaluate their own design and offer valid changes that would help save money without degrading their design. Too often engineers are not given the chance to "value" engineer their own design." Actions such as these may percolate untrusting project atmospheres.

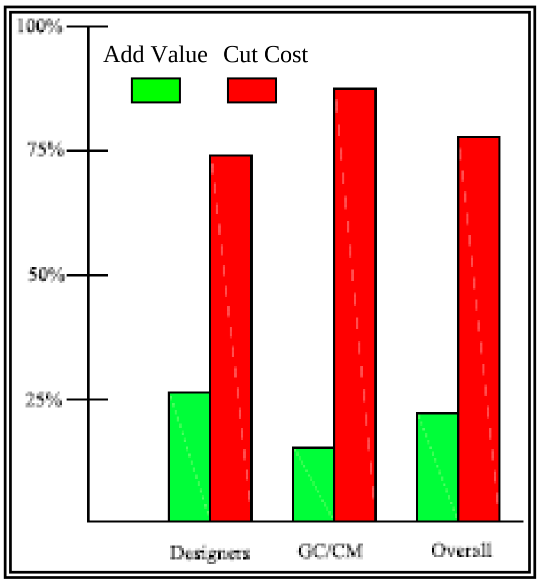


Chart 3. VE Cost Cutting vs. Adding Value

A dissimilar response from a structural engineer has an indirect reference promoting the beneficial nature of close and communicative project teams. For his project, the owner, developer, and general contractor are all from the same company. As a result, he claims that a formal value engineering process was never performed, but 95% of their decisions were made with the point of adding value to their project.

Further investigation of survey responses may prove additional dissemination between design teams and constructors. In the chart below, you can see that designers have a notion that owners and architects may have a slightly smaller influence in the VE process than engineers and GC/CM's. On the other hand, constructors believe they have a far greater influence on suggestions provided during VE. This evaluation only strengthens the validity of the electrical engineer's statement about their inability to properly re-evaluate their designs and maintain system quality. Above all, both project teams agree that owners typically present the fewest options of value.

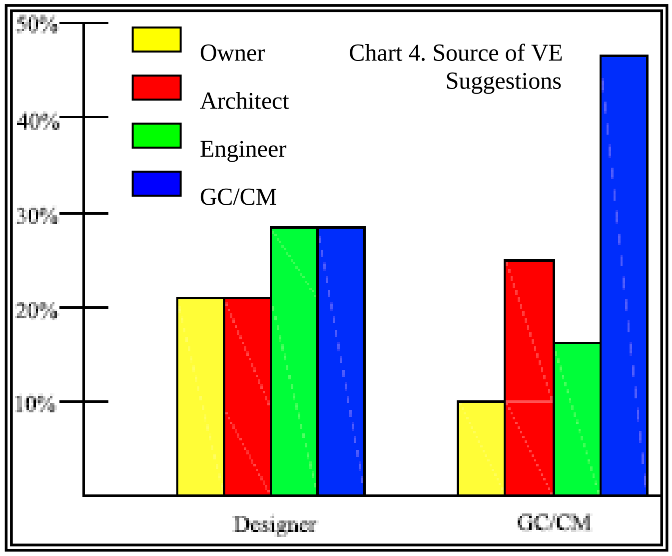


Chart 4. Source of VE Suggestions

The final figure represents data compiled from industry member's responses referencing positive statements of team characteristics. Dealing with their current projects, engineers and contractors agree that they feel less involved in a team atmosphere with no exclusions. Moreover, both parties suggest that every party involved is not attempting to minimize waste from design and construction. On the contrary, trusting and respectful atmospheres have been created, but with room for improvement.

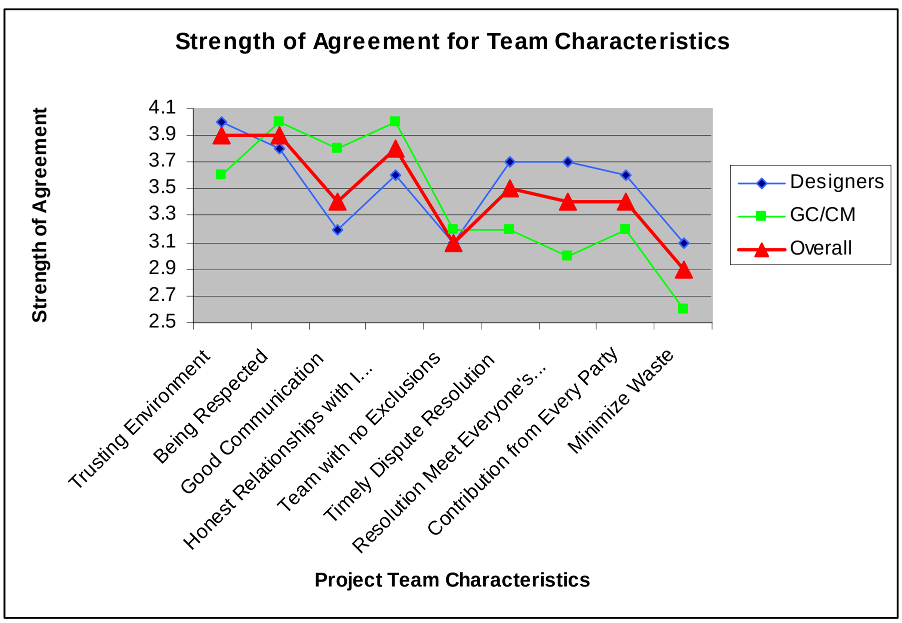


Chart 5. Strength Agreement for Team Characteristics

Recommendations

The research conducted in this study reveals the presence of controversy between project teams during the period of value engineering. Although it does not prove a detached perception of design teams from constructors as initially believed from the PACE seminar, it does however show that their shared motivations for owner/client satisfaction can be different. The major drive in this satisfaction comes from a desire to do repeat work in the future. Where a general contractor's goal may be to hand over a cost efficient and timely project, an engineer's may be to provide the most efficient and functional design.

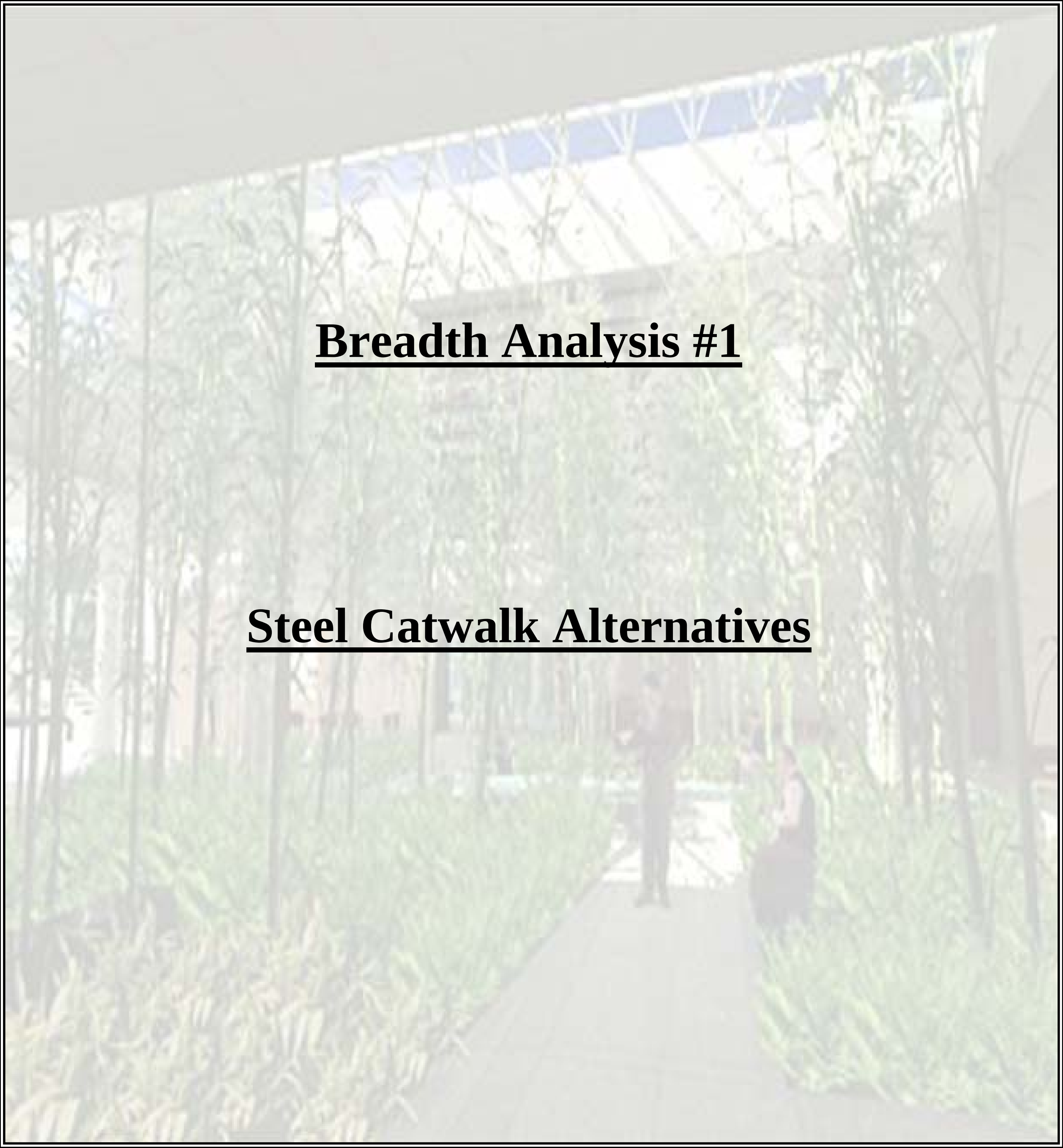
You may feel that deficiencies created during pre-construction and construction phases are caused by countless things beyond the control of project teams. This may be true, but as long as owners, engineers, and contractors work together at the earliest instant permitted, more solutions may be created. Working as one collaborative team for a common goal, with mutual trust and respect for others, VE can be an invaluable process.

Application to Lecture Hall

Each year, as the owner, Capital One puts aside a set amount of money to be allocated towards particular improvements on their property. Being such a large company, the preliminary maximum figures are expected to be spent, unless additional costs can be saved. Where projects are funded with money and they do not occur over a given time span, these funds will be distributed elsewhere. The final result may even be that the previous project is not pursued for years to come, or never thought of again.

Preliminary budgets were being created throughout the schematic design phase. As the contract documents progressed towards completion, subcontract estimates rose. DAVIS' Interim GMP eventually grew much larger than the maximum pre-determined amount in the 75% Construction Documents. From that point, it was imperative that building systems and site logistics be re-evaluated. While the value engineering process began for the Lecture Hall project, DAVIS was requested by Capital One to create a preliminary list of VE items to be discussed. By that stage in pre-construction, major trades containing long lead items had already been procured. With pre-cast concrete, steel, and glazing contracts already signed, DAVIS had to look into interior savings and other site characteristics.

Although replacing initial wood ceiling tile and wall finishes with less expensive alternatives saved money, it was viewed to be a cost cutting activity. An especially large savings came with DAVIS' recommendation to keep soil excavations on site, to be later used for backfill, instead of removing it. These recommendations were effective at reducing the budget, but additional suggestions could also have been achieved. The analyses to follow will represent a few items DAVIS and Capital One could have profited from had they taken a few extra measures during their VE process.



Breadth Analysis #1

Steel Catwalk Alternatives

Executive Summary

The Capital One Lecture Hall has been designed with a costly and heavy steel catwalk. With the project teams' inability to discuss appropriate design issues and value engineering options in a timely manner, the structural engineer, Rathgeber/Goss and Associates was responsible for producing a properly planned structure. Having little or no experience in such designs, they created a formation that would in no way feel unstable. As a result, large steel members were used for strength and constructability issues.

In order to devise an accurate schematic of which to compare alternative structural materials, three main construction management concerns were considered. Between the proposed steel; aluminum, fiberglass reinforced polymer (FRP), and wood members are analyzed for acceptable catwalk designs.

When looking at cost, lead time, and assembly duration, the FRP option is the most advantageous to the project. With an estimated savings of almost $14,000 and 3 weeks of assembly, FRP can add a significant amount of value to the Lecture Hall over steel.

The structural breadth evaluated in this analysis consists of load calculations for the critical steel hangers and girders. In turn, these results are used to analyze aluminum design adequacy for the specified dead and live loads.

Background

Like any hectic work week in the construction industry, the deadline for complete design documents creates a sense of urgency and long hours in the office. For Rathgeber/Goss and Associates, finishing the design of the Lecture Hall structural system was no exception. Within a few days of the design document due date, the architect requested that they design the auditorium catwalk. With no experience or prior knowledge of what catwalk design and serviceability requirements entail, RGA began their experimentation. To be 100% confident in their design, they made sure the catwalk did not vibrate, sway, or feel unstable in any way. As a result, the catwalk within the auditorium consists of large steel members that will support the 40 PSF live load and 20 PSF dead load requirements. This system is quite expensive due to the ever increasing market price of steel and contributes to a large portion of the subcontractor's scope of work.

As stated by the general contractor, the catwalk was always intended to be pre-engineered and prefabricated. A supplier of catwalks would have had a much better understanding of how much deflection, vibration, and sway is acceptable. In turn, this would result in a structure with more slim members of steel and a decreased cost in materials and labor. Due to time restraints and not considering this option at an earlier stage in design, the structural engineer was stuck with its creation.

In the 100% Construction Documents, the catwalk is in the shape representing an "H." The two main strips span a length of around 70', with a middle connection at 60'. There are also 3 small 15'segments branching off the side. No fireproofing is required for the catwalk since it is not considered structural steel. As shown in the accompanying picture, the catwalk will be fastened to the steel trusses being put in place.

Figure 10. Placement of Steel Trusses

Proposal

If the project teams in this venture would have been able to devote more time into choosing other valuable catwalk options, they might have been able discover the possibility of saving both time and money. Once a number of key construction concerns have been presented for the erection of the steel catwalk, alternate structural systems and materials will be taken into consideration. Topics such as cost, lead and construction times, system strength capabilities, and other miscellaneous specifications will be reviewed to better determine an appropriate catwalk structure.

System Comparisons

The following materials shall be investigated as a few of numerous possibilities that may satisfy the Lecture Hall catwalk structure. These results have been obtained through conversations with the general contractor, specialty subcontractors, and *RS Means 2006* analyses.

Steel

As previously stated, the 2 foot wide Lecture Hall catwalk is designed with structural steel members that are specified to support the 40 PSF live and 20 PSF dead loads. Before going into further research, it is important to first consider the load calculations for the steel. From this we will have a basis to which the alternate systems can be compared. For brevity purposes, only the critical members will be analyzed.

In order to hang the catwalk from the steel trusses, pairs of HSS 5x5x5/16 members have been utilized and are only subject to tensile forces. As long as the end stress result is below 50 ksi (1,000lbs/in^2), the design is adequate. After a tributary area of 25 was calculated, the total force per square foot was used with the live and dead load factors. The overall stress within the HSS hangers was calculated to be 0.27 ksi, much less than the maximum.

Likewise, it is imperative to check the W8x28 girders used to span lengths between 10-25 feet. First we must convert the already determined 88 pounds per square foot (PSF) into pounds per linear feet (PLF), and then use that to check the shear, moment, and deflection in the member. As a final check, look at the L/480 and L/360 deflection constraints. Respectively, if they are smaller than 0.625 inches and 0.833 inches, the members are good. For a more thorough numeric evaluation, please view **Appendix D**.

Now that there is an understanding of the structural aspects of the catwalk, we can dive into discussion of other criteria to assist our decision. Like many construction projects, steel is one of the most critical long lead items. For the Lecture Hall project, a lead time of around 8 weeks was expected for steel delivery. Once the steel arrived on site, pieces were individually lifted into the building by crane due to their heavy nature and bolted into place. Furthermore, in the Detailed Schedule included in **Appendix B**, an estimated construction time of 3 weeks was included for "A8000 Install Catwalk." In actuality, the assembly lasted 4 weeks. Since the installation of these steel members takes up a significant about of space on the scaffolding platform, this extension of time could end up setting predeceasing trades from starting their work on time. Lastly, concerning cost, a detailed estimate produced a cost around $75,850. The table below is a summary of the costs of each section. To view the detailed estimate, please turn to **Appendix E**.

Table 2. Steel Catwalk Cost Summary

	Total Weight (tons)	Material Cost	Labor Cost	Total Cost
Main Strip (2)	10.98	$21,951	$15,554	$37,505
Middle Wing (2)	1.85	$3,706	$2,627	$6,333
Middle Connection	5.21	$10,418	$6,903	$17,321
Top Tail	0.54	$1,074	$961	$2,036
Metal Grating	-	$4,800	$960	$5,760
			Total	$68,954
			Sub Profit	+10%
			Final Total	$75,850

Aluminum

For years, industry members have been arguing about the most advantageous material being either steel or aluminum. For argument sake, when looking at aluminum systems, the overall weight of aluminum structures can be roughly 30-40% less than that of steel. In this scenario, if it wasn't for the controlling 10" concrete slab poured above the steel trusses, a lighter designed catwalk may allow for a slimmer and less expensive truss system. Besides the inability of sizing down the steel trusses, a lighter aluminum system may permit larger pre-assembled sections to be inserted into the auditorium ceiling at a time. In turn, this will result in a shorter duration for construction and allow proceeding trades to begin their work earlier. With the ability to pre-assemble sections on site before installation, the previous 4 week allotment for steel could result in a shorter 3 week duration. Concerning aluminum lead times, a 6-7 week span for delivery after placement of the order can be expected. Corrosion concerns between steel and aluminum contact will be eliminated because of final cleaning and final painting of the members.

In order to obtain a comparable aluminum catwalk system to that of the steel, geometric properties were analyzed. Looking in "Stock Components for Architectural Metal Work," a Julius Blum & Co. text, similar sized aluminum shapes were found and substituted. Structurally, the same load analyses were considered. The different properties that need to be considered when analyzing aluminum are its yield strength of 35 ksi and modulus of elasticity of 10e3 ksi. Like the steel calculations, critical aluminum members used for this analysis include HSS 4x4x3/16 hangers and W10x10 girders. Stress in the hangers was calculated to be around 0.77 ksi, smaller than the 35 ksi limit. Deflection of the aluminum girder with the same dead and live load requirements end up being 0.5 inches, which is still less than the L/480 limits. These calculations can be found in **Appendix D**.

A detailed estimate for an aluminum system cost around $62,155. The table on the following page is a summary of the costs of each section. To view the detailed estimate, please turn to **Appendix E**.

Table 3. Aluminum Catwalk Cost Summary

	Material Cost	Labor Cost	Total Cost
Main Strip (2)	$17,440	$13,060	$30,500
Middle Wing (2)	$2,659	$1,991	$4,651
Middle Connection	$8,197	$6,138	$14,336
Top Tail	$720	$539	$1,259
Metal Grating	$4,800	$960	$5,760
		Total	$56,505
		Sub Profit	+10%
		Final Total	$62,155

Fiber Reinforced Polymer (FRP)

Fiber reinforced polymer composites are increasingly being used in civil infrastructure applications ranging from reinforcing rods and tendons, to all-composite bridge decks, and even hybrid and all-composite structural systems. Anecdotal evidence has provided substantial reason to believe that, if appropriately designed and fabricated, FRP composite materials can provide longer lifetimes and lower maintenance than equivalent structures fabricated from conventional materials. Further investigations and communication with FRP manufacturers will pose as an interesting venture in the determination to implement this system into the Lecture Hall.

Recommended by DAVIS' Project Manager; E.T. Techtonics is one of many reliable suppliers of engineered fiberglass bridges and building systems. Quoted by their website, "these high-strength FRP materials provide bridge systems with a strength-to-weight ratio greater than steel, offering design and erection advantages over traditional materials. E.T. Techtonics feature two basic design approaches referred to as truss spans and post-tensioned cable spans.

After brief discussions with G. Eric Johansen of E.T. Techtonics, Inc. the Lecture Hall catwalk was estimated to cost $62,000. All of the pieces are lightweight and can withstand a maximum weight of approximately 60 lbs. The 2' wide path consists of a solid FRP composite deck which can hinder objects from falling to the acoustic paneling below. Delivery of the catwalk would be no more than 6 weeks from the order placement date. According to the company's claims, 2 workers can construct a typical 25'x 2' section on the ground in 4 hours. Bringing these 25' pre-assembled sections could then be fastened to the steel trusses in 2 hours. Totaling about 6 hours per 25' section, a construction time of only 45 man-hours each for the nine segments is expected.

Table 4. FRP Cost Summary

Quantity	Span	Unit Weight (lbs)	Price($)/Unit	Total Cost
5	20'	750	6,000	30,000
4	25'	1,000	8000	32,000
			Total	$62,000

Wood

As a final alternative, pre-fabricated wood I-beams can be considered. The critical steel girders shall be substituted with acceptable Georgia-Pacific I-beams. To keep a consistent member depth throughout the system, 14" GPI 40 and GPI 65 elements will be used. Georgia-Pacific wood I-beams resist shrinking and twisting, and have consistent strength characteristics. Being composed of wood, members are much lighter than steel and can be cut easily on site if alterations need to be made. For durability and strength purposes, the steel HSS hangers in the initial design were kept and metal chairs will be used for the wood system to sit on.

40 PSF Live Load + 20 PSF Dead Load

Joist	Joist Depth	Spacing (Simple Span) 12" o.c.	16" o.c.	19.2" o.c.	24" o.c.
GPI 20	11⅞"	20'-05"	18'-08"	17'-08"	15'-11"
GPI 40	9½"	18'-00"	16'-06"	15'-07"	14'-02"
	11⅞"	21'-06"	19'-08"	18'-01"	16'-02"
	14"	24'-04"	21'-09"	19'-10"	17'-09"
GPI 65	11⅞"	23'-03"	21'-03"	20'-00"	18'-08"
	14"	26'-05"	24'-02"	22'-09"	21'-03"
	16"	29'-04"	26'-09"	25'-03"	22'-03"

Table 5. GPI Series Joists-Floor Spans

Like that of the FRP system, lead times for pre-fabricated wood I-beams can be around 6 weeks. Construction times will again be less than steel due to the ability to pre-assemble sections on site. In order to obtain a rough estimate, 50 PSF structural I-joists with wood flanges were considered from RS Means 2006 to substitute the GPI beams. Since the specified loadings are so small and the I-beam girders would be critical, equivalent wood members were also estimated to substitute steel railings and floor supports. On the down side, although steel was not required to be fireproofed, the flammability of wood is much greater than the previously mentioned material. For a detailed wood estimate for the catwalk, please view **Appendix E**.

	Material Cost	Labor Cost	Total Cost
Main Strip (2)	$1,554	$779	$2,333
Middle Wing (2)	$288	$116	$404
Middle Connection	$748	$350	$1,098
Top Tail	$62	$30	$92
Misc Steel	$9,250	$12,989	$22,239
Metal Grating	$4,800	$960	$5,760
		Total	$31,927
		Sub Profit	+10%
		Final Total	$35,119

Table 6. GP I-Beam Cost Summary

Recommendation

Now that all of the proposed structural systems and alternate materials have been considered, compiling the information into an easy to read chart is necessary before final suggestions can be made. The table below depicts three main construction management concerns of cost, lead and construction times, and an additional section for system downfalls.

Table 7. Catwalk Summary Table

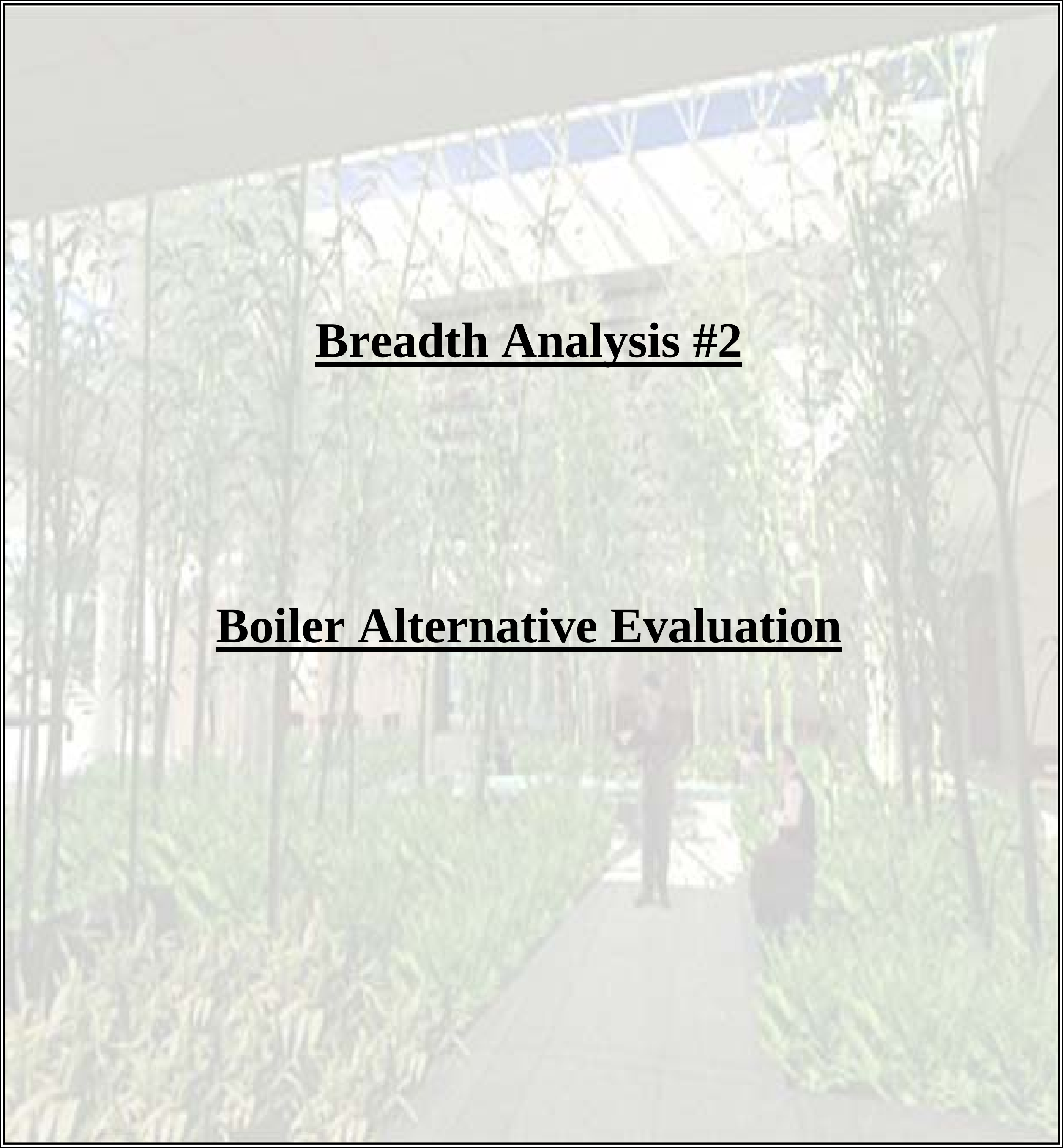
System Material	Cost	Lead Time	Construction Time	Other
Steel	75,850	8-9 weeks	4 weeks	Heavy
Aluminum	62,155	6 weeks	2 weeks	Corrosion
FRP	**62,000**	**6 weeks**	**6 days**	**-**
Wood	35,119	5-6 weeks	2 weeks	Flammability

Not surprising, the wood structure costs the least amount compared to the other three. Although cost is a big motivator to an owner and general contractor, other characteristics need to be looked into. Being a much more flammable material, wood can be a greater fire hazard liability than an owner would want to risk, despite cost. In addition to this, although the construction time for a wood system would be less than steel, it is still lengthier than FRP.

The currently installed steel system also does not seem to be a valuable option. Compared to the other three, steel is more costly and takes up a considerable amount of time.

Without much analysis, it is easy to see the aluminum and FRP systems are pretty similar. With comparable estimates and lead times, the main advantage of fiberglass reinforced members over aluminum is the 6 days of construction time.

In conclusion, switching from steel members to FRP would be in the best interest of every construction entity on the job, especially Capital One and DAVIS. An up front cost of almost $14,000 can be saved, not to mention 2 weeks lead time and roughly 3 weeks in construction time. The shorter FRP durations will allow more freedom for other trades to do work above the auditorium and also benefit delivery deadlines from the smaller lead time.



Breadth Analysis #2

Boiler Alternative Evaluation

Advisor: Dr. Michael Horman

Executive Summary

As the general contractor's Interim GMP was reaching numbers far exceeding Capital One's budget, a look at the buildings large mechanical system seemed beneficial. The current system is contained within two separate rooms of much different size. Two boilers located in a small mechanical room are creating space and access issues towards electrical equipment also located in the same room.

In order to alleviate these spatial problems, two additional mechanical considerations are analyzed to supplement the need for heating and hot water provided by the boilers. The supplied 67 gallons of water per minute was used to help estimate overall requirements for the alternate systems of an electric resistance heater or geothermal heat pumps.

After extended analyses, it was determined that the electric heat coils would save space and $48,000. The ground source heat pumps would also save on space, but cost Capital One an additional $400,000 and increase construction time by months. Despite the poor efficiency of electric heat coils and large energy costs, it was determined that this system is the best option of the three. The owner would be more content with dropping initial project costs than saving money 10 years down the road.

The mechanical breadth for this analysis is included within **Appendix F** and is primarily used to find a cumulative sensible cooling load. This load can then be used to help formulate an approximate size for the alternate mechanical systems. Further calculations divide the total load into smaller quantities used for each coil and its equivalent amount of kW power.

Background

With DAVIS' Interim GMP increasing as the 75% Construction Documents became more complete, it was imperative that the building systems be looked at in depth. Estimated project costs were amounting to much more than Capital One funded for. While the value engineering process began for the Lecture Hall project, DAVIS was requested by Capital One to create a preliminary list of VE items to be discussed.

As currently planned, there are two separate mechanical rooms. Besides the three air handling units, two boilers were designed in a congested area distant from the main mechanical space. With the sole purpose of supplying the AHU's with hot water, these two 4,100 lb pieces of equipment and their accompanying pumps do not seem like the most space efficient systems. In addition to the boilers, the Lecture Hall's two 800A main distribution panels are located within the second mechanical room.

Concerning chilled water for the Lecture Hall, all of the supply and return runs are connected to a chiller already existing inside the base building. Besides the supply and return of hot water, the air handling units exist as an independent system connected to an outside source. Lastly, localized heating on the variable air volume (VAV) boxes are located throughout the space and would be able to handle a large portion of the heating load during a warm winter.

In order to bring the boilers and air handling units into the building, pieces will be hoisted down to the basement through a shaft along the west wall. Once this is done, the individual sections will be assembled in place.

Proposal

In order to conserve space and possibly decrease the overall mechanical scope of work, removing the boilers and all associated piping would have numerous benefits. Alternative solutions such as electric heat coils and geothermal heat pumps are viable options. Within this analysis, these three schemes will be compared based on estimated costs, construction times, and other general system requirements. After further review, a smaller and less expensive source for hot water shall be obtained.

System Comparisons

The following mechanical systems will be investigated as only a few of multiple possibilities to provide a need for hot water in the building. These results have been obtained through research and conversations with a MEP engineer.

Boilers

Within the current mechanical system, two 4,100 pound boilers are provided for heating and hot water to three air handling units. In addition to the boilers, their accompanying 250 pound pumps are also contained in the small secondary mechanical room. Separate from the weight, respective dimensional sizes pose as a space concern. According to a Burnham Industrial cut sheet, the two boilers consume a space of approximately 5' in length, 8' in width, and 5' in height. Not to forget, there are also the Lecture Hall's main distribution panels located in the secondary mechanical room, causing possible inconveniences for access.

Getting back to the system in which further mechanical comparisons can be made to determine appropriate substitutions, the boilers are fueled by natural gas and are estimated to have an 80% efficiency. Over the past few years the cost of natural gas has skyrocketed. For this analysis an estimate of $0.40/ kWh[1] (kilo-watt hour) will be used. Considering its demand of 67 gallons per minute (gpm) with an entering water temperature of 140°F and a leaving water temperature of 180°F, an equivalent 1,336 MBtu/hour (1,000 Btu/hr) is provided. The conversion can be viewed within **Appendix F**. As quoted by W.E. Bowers, the installation and furnish price of the boilers alone should be around $85,000. Typical lead and construction time for the units, including installation and piping, are both 8-10 weeks.

Since the alternate mechanical system to follow has an effect on the air handling unites, it is important to also take a look at their characteristics. AHU-1, -2, and -3 have total cfm of 4,800, 19,200, and 10,725 respectively. Like any typical AHU, its main components include a supply fan, cooling coil, heating coil, and return fan. Without piping and additional duct work, AHU's of this size run about $150,000 combined. Lastly, its lead time is also around 8-10 weeks, but installation can take up to 20 weeks to complete. Installation of these pieces of equipment may occur simultaneously if space and labor permit, not creating a combined time of 28-30 weeks.

Electric Heat Coil

Within this analysis, our previously design boilers will be eliminated. The inclusion of electric heat coils within Capital One's existing AHU's could possibly be an adequate substitute. Instead of having boilers present to supply the units with hot water, these heat coil sections could produce the appropriate heat themselves.

A benefit of this electrical resistance heating is that it converts nearly 100% of the energy in the electricity to heat. However, most electricity is produced from oil, gas, or coal generators that convert only about 30% of the fuel's energy into electricity. Because of electricity's generation and transmission losses, electric heat is often more expensive than heat produced with combustion. The lower $0.06/kWh for electric is deceptive. As stated before, since electric resistance is so much more inefficient than the boilers, having to fulfill the same load requirements often results in higher fuel costs for electricity.

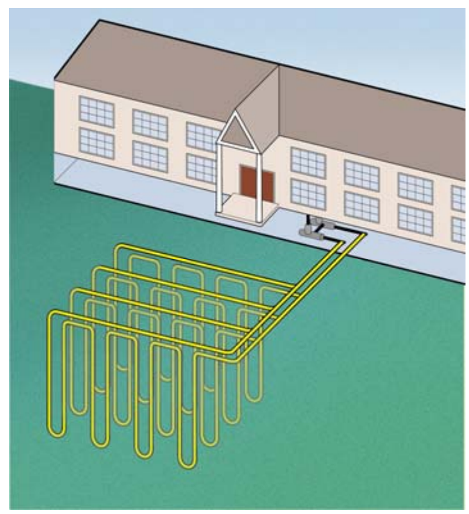
In terms of the air handling unit, the addition of an electric heat coil shall include another 3' of length to each. Dealing with this extra volume of occupied space is not a concern in the main mechanical room as it is with the secondary. Lead times for the modified AHU's are still between 8-10 weeks. Considering installation times, inserting an additional heat coil section would not be that difficult for the mechanical subcontractor. Around 20 weeks for installation is expected and can cost up to $158,000.

Although there are a few electrical considerations for removing boilers and adding electrical heat coils, these calculations were not assessed as part of the analysis. Despite the specific fused switch and feeder alterations, a $29,000 electrical scope increase can be expected.

Geothermal Heat Pump

Although this next mechanical system has been well established in residential construction, geothermal heat pumps (aka ground-source heat pumps or GSHP's) have been increasing in popularity in the commercial and Federal sector. While there may a significant difference between air and ground temperatures, temperatures of the earth and its waters are very stable. In order to tap this energy source, heat pumps have external piping buried in the earth or submerged in a body of water. In our case, a GSHP would use the ground as a heat source during the winter months and as a heat sink during the summer cooling month. These ground coupled types can be placed either vertically or horizontally near the surface. According to John Lund, as a rule of thumb, 150-200 feet/ton is associated with vertical loops and approximately 30-50% longer for horizontal loops under the same condition.

Figure 11. Commercial Vertical Loop



*http://www.geoexchange.org

Being on a site where future high rise buildings will be constructed, adjacent to the I-495 Capital Beltway, open land is at a minimum. This will automatically eliminate any horizontal GSHP configuration. To better understand the cost of the geothermal system, vertical earth coils will be evaluated.

As calculated in **Appendix F**, the total load required for our space is 1,336 MBtu/hr. Looking further into *RS Means 2006* to estimate the cumulative amount of heat pumps necessary to fulfill this need, (16) 20 ton heat pumps would be used. With an 85 MBtu/hr heat capacity at 0°F, these 20 ton pieces of equipment would cost $20,400 each. Being able to install one heat pump every 5 working days would result in a 16 week installation time. Assisted by a fellow student, an estimated $4.40/ft for drilling was obtained from the Royal Electric Company. Accumulating a 320 ton system and a 160 ft deep hole per ton, will result in soil work around $225,280.

Recommendation

In order to come up with a final proposal, many things need to be taken into consideration. Especially within this scenario, although an overall price is appealing; outside factors need to be examined. The summary table below will help guide our decision making process.

Table 8. Mechanical Summary Table

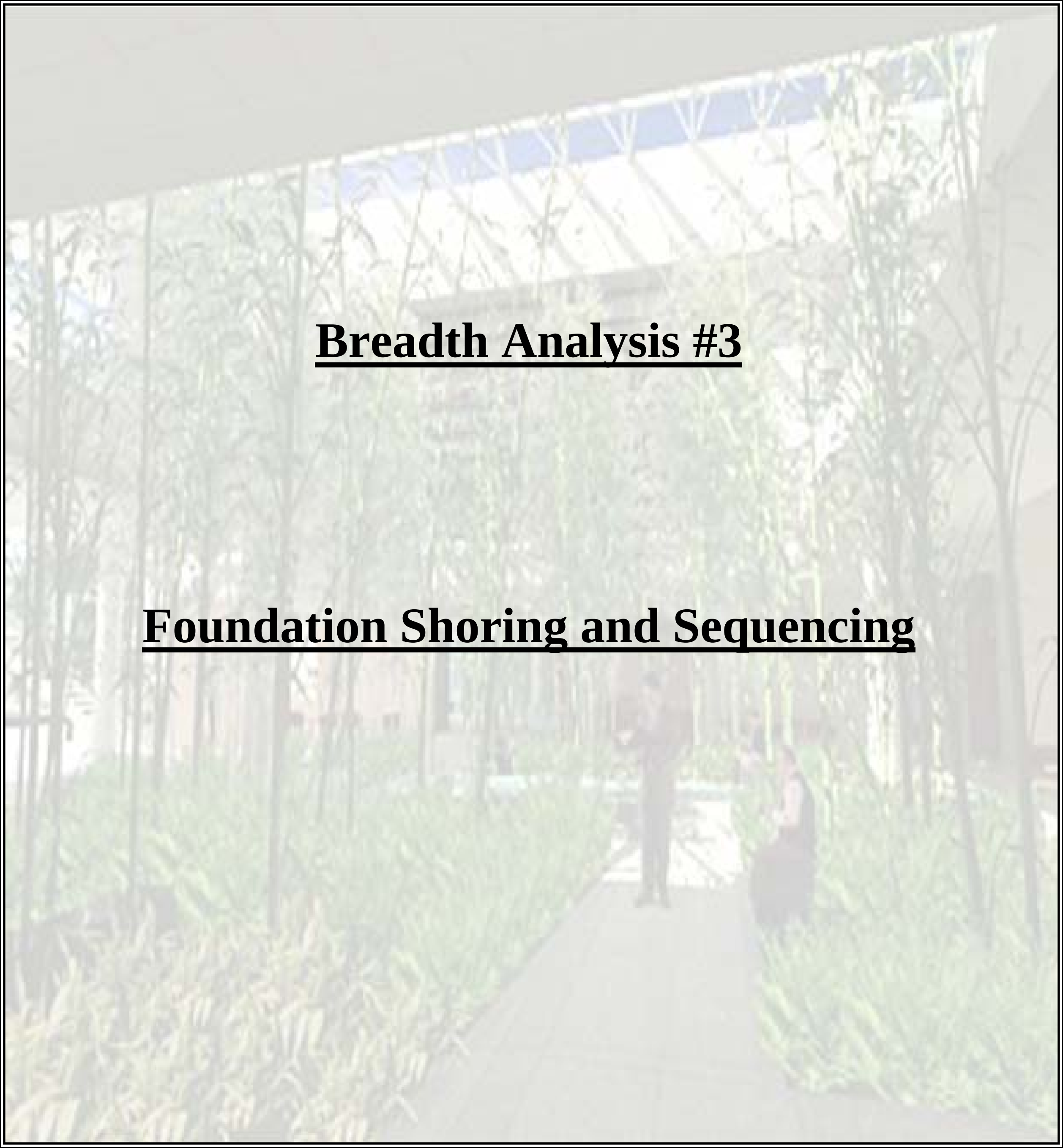
System	Lead Time	Installation Time	Energy Cost	Cost	Other
Current					
+Boilers (2)	8-10 wks	8-10 wks	gas - $0.40/kWh	$85,000	tight mechanical space
+AHU-1,-2,-3	8-10 wks	20 wks	*elec - $0.06/kWh	$150,000	
			Total	$235,000	
Alt. #1 - Electric Heat					
+AHU-1,-2,-3	8-10 wks	20 wks	*elec - $0.06/kWh	$158,000	+$29,000 for electrical work
+Electric Heat Coil	incl.	incl.	incl.	incl.	
			Total	$187,000	
Alt. #2 - GSHP					
+Heat Pumps (16)	-	16 wks	N/A	$408,000	land area not available
+Earth Coil System	-	64 wks	N/A	$225,280	
			Total	$633,280	

The biggest concern with the Lecture Hall's current mechanical system is the overall size, consuming two separate rooms. Lead and installation times of 8-10 and 20 weeks are typical and won't have a large impact on its outcome. Comparatively, the $235,000 cumulative cost of the two boilers and three air handling units is fairly larger than alternative #1.

When looking at the geothermal heat pump option, numerous figures stand out. Although there are a lot of benefits with an environmentally friendly mechanical system and a cheap source of energy, its installation time and costs are expensive. Thinking back to Capital One and their influence as an owner, setting aside fixed sums of money for projects, adding $400,000+ dollars to an already tight budget is in the best interest of no party on this project. Not to mention, the large amount of land required for pursuit of a geothermal heat pump system does not exist. Their property is filled with recently completed soccer fields, baseball fields, basketball courts, security booths, a 14 story high rise building, and is the future site of an additional multi-story structure. Digging up these fields and possibly rupturing the geothermal piping when excavations occur during future expansion would not please Capital One. Lastly, the current cooling system is already supported by the base building chiller. If GSHP's are put in place, they will only be used for heating purposes only. Utilizing only half of their intended purpose would be absurd considering the large additional cost.

That brings us to our final electric resistance heat coil option. First, the additional 8-10 weeks of installation time for the boilers will be cut and allow for other mechanical work to take place. Despite the additional electrical work needed to support this alternate system, there can still be a savings of $48,000. Bringing ourselves back to our initial goal of saving space, the addition of these coil units will have little effect on the available space within the main mechanical room. Alternatively, an estimated 300ft^3 of space will become available for access to the main distribution panels and similar equipment.

An argument over the poor efficiency and overall cost of its energy is a viable point. In time, this mechanical system will eventually cost the owner more money than its current system. But looking at the owner and their objectives, we aren't dealing with an environmental engineering firm or government body that wants their new building looking as energy efficient as possible. Capital One only wants to know "what's in your wallet?" and theirs, not "what's in our mechanical room?" At the end of the day, as a general contractor, final value engineering ideas are decided by the owner. If they are happy with the older and reliable mechanical systems that don't cost a fortune, that is their decision.



Breadth Analysis #3

Foundation Shoring and Sequencing

Advisor: Dr. Michael Horman

Executive Summary

Two months into excavation and foundation construction, Capital One began to have desires to obtain their future Lecture Hall a few months prior to the previously agreed upon date noted in the contract. Without adequate notification of the owner's project intentions, DAVIS Construction was unable to adjust work sequencing and other methods which may cut down on the overall duration for foundation completion. Whatever time that could have been saved, would almost have had to wait until interior activities began.

In this analysis, we will take a look at the actual foundation schedule created by photo observations and note the possible room for improvement. A more efficiently sequenced schedule is then produced and its duration is compared to that of the original. With the assistance of *NavisWorks JetStream*, construction activities and their accompanying construction images, schedule differences are noticed. Overall, 23 working days can be saved had the general contractor been given sufficient time in preparing a foundation schedule.

The structural breadth work within this analysis includes soil calculations necessary to determine proper shoring forces. Additional costs of the rakers are included and compared to that of DAVIS' liquidated damage of $1,000/day in the event of late building turnover. With an estimated shoring cost of $11,258 and the 23 day schedule savings, execution of the Ulma rakers seems to be a valuable activity. Moreover, this 4 week reduction can save approximately $45,437 in General Conditions costs.

Background

As with every base building project, excavation and foundation work are two of the most crucial aspects in construction. Although they are the most distant activities from building turnover, they can set an initial trend for months to follow. Jobs that get behind from the beginning may end up being quite stressful and force project teams to play catch up all the way till the end. On the other hand, when days, weeks, and even months of schedule time are saved due to careful planning, projects tend to run more smoothly.

In the case of the Lecture Hall, Capital One neglected to inform the general contractor of their premature ideas of an early project turnover, one that was nearly two months prior to the contract date. About 14 weeks into construction, after the basement excavation was complete and cast-in-place walls were in progress, Capital One approached DAVIS with its proposal to hand over the building early.

At that point in time, DAVIS was left with few options to accelerate or re-sequence the core and shell schedule. The only thing they could do was hope to make up time within the Lecture Hall's interior work. If the project teams had created a more open path of communication at an earlier stage, additional schedule considerations may have been discussed.

In the case where an early completion is brought to the attention of the Project Manager sooner, the most feasible and least costly option they would have is to re-sequence work. Secondly, with sufficient notice, it might have been possible to implement sheeting and shoring techniques that would save both time and money. In the worst case scenario, if project turnover was in fact late, Capital One will charge DAVIS $1,000 dollars every day after the July 31st contract date.

Proposal

To obtain a better understanding of typical sequencing and location of trades, a 3-dimensional model and its accompanying schedule will be linked in *NavisWorks JetStream*. After an evaluation of possible time saving work arrangements are considered, an alternate schedule will be proposed. In addition to sequencing, the use of shoring rakers shall be included as a possible time saving device. After each schedule ha been discussed, a direct visual comparison of the two scenarios will be provided. Assuming the foundation directly affects the critical path, a cost analysis will confirm the valuable nature of this shoring consideration.

Actual Foundation Schedule

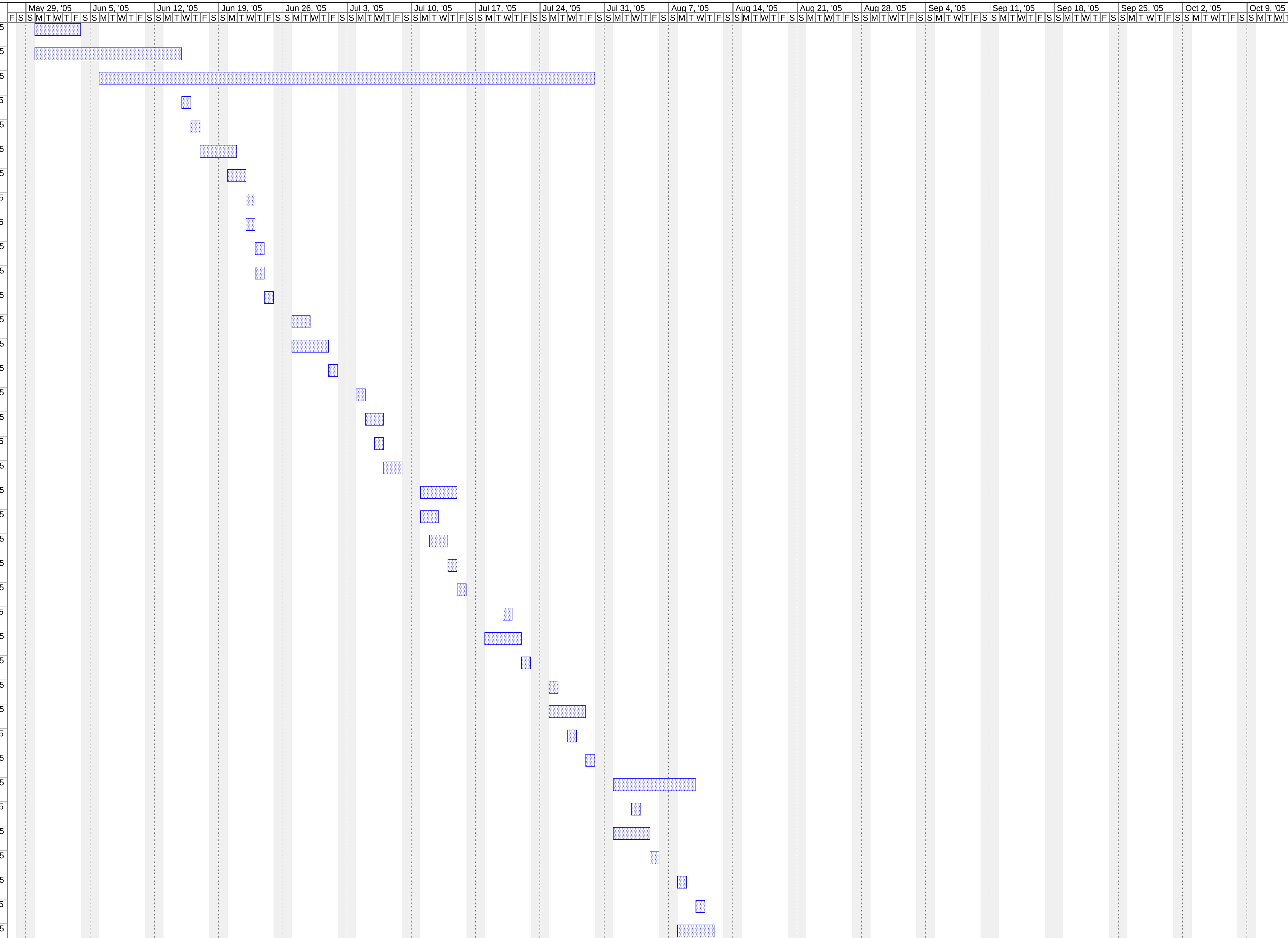
The detailed schedule provided on the following two pages was obtained through the evaluation of hundreds of carefully dated construction photographs. Key elements for completion of the Lecture Hall foundation were noted and later organized into a rational order with proper time durations. Since no detailed schedule was created by the general contractor, as shown in the "Demolition" and "Concrete Structure" phases of **Appendix B**, this revised timetable was created.

With site mobilization and excavations beginning at the end of May, base building demolition was able to commence in the first week of June. Come April 15, 2005, the basement excavations were complete and drilling began for the hydraulic elevator. As footing excavations progressed over the next two weeks, framing of the first wall pour along the south facing wall was complete by April 30th. While Wall #1 was poured on the first day of May, footing excavations continued in a clockwise manner through "Pour #2, 3, and 4," catching up to the Shear Wall Pour #2 on the west wall. Over the next two weeks, the outer curved wall's continuous footings were poured and Wall #5 was framed. The final three concrete pours continued in a clockwise manner, ending by August 31st. The cast-in-place basement floors were staged in three sections, occurring on the 15th and 16th of August and completed on September 6th. Work within the adjacent garden atrium and auditorium nose sections did not begin until mid-September, once steel began to be set in place. This backfilling delay was due to the need for the walls being tied in place with the first floor steel. Without any type of support system, backfilling too early would have caused the basement walls to fail. Foundation construction within the atrium and auditorium progressed over the next month and did not conclude until October 12th.

Although the schedule seemed to develop in a sequential manner, an outsider's intuitive predictions of wall locations would not be correct. As shown on the final page of this analysis section, walls #1 and 2 are not neighboring each other. Without diving into the sequencing shortcomings, the process in which the curved walls were framed and poured arose as a concern. With only a few foot gap between the walls, adequate space for workers to frame and shore hardly existed. Just as Capital One was late on properly informing the general contractor of their early completion ideas, DAVIS could not properly implement a more demanding timeline of trades in the most efficient manner. Subcontractor workings were somewhat sporadic and did not shoot for the goal of foundation completion, leading into further construction on the first and second floors.

Lecture Hall Foundation Schedule - Actual

ID	Indicators	Task Name	Duration	Start
1		Site Mobilization	5 days	Mon 5/30/05
2		Site Grating, Excavation, Layout	12 days	Mon 5/30/05
3		Base Building Demolition	40 days	Mon 6/6/05
4		Drill for Elevator Hydraulic	1 day	Wed 6/15/05
5		Excavate/Frame Elevator Pit	1 day	Thu 6/16/05
6		Excavate/Frame Line 26-27 Footings	2 days	Fri 6/17/05
7		Excavate/Frame Wall #1 Continuous Foc	2 days	Mon 6/20/05
8		Pour Elevator Pit	1 day	Wed 6/22/05
9		Pour Wall #1 Continuous Footing	1 day	Wed 6/22/05
10		Layout Curved Walls and Shear Wall #2	1 day	Thu 6/23/05
11		Strip Pit	1 day	Thu 6/23/05
12		Pour Line 26-27 Ftgs	1 day	Fri 6/24/05
13		Excavate Curved Wall Ftg	2 days	Mon 6/27/05
14		Frame/Shore Wall #1	4 days	Mon 6/27/05
15		Pour Wall #1	1 day	Fri 7/1/05
16		Pour Curved Wall Ftg	1 day	Mon 7/4/05
17		Excavate Shear Wall Continuous Ftg	2 days	Tue 7/5/05
18		Strip Forms Wall #1	1 day	Wed 7/6/05
19		Pour Shear Wall Continuous Ftg	2 days	Thu 7/7/05
20		Frame/Shore Wall #2	4 days	Mon 7/11/05
21		Excavate/Frame Wall #3 Continuous Ftg	2 days	Mon 7/11/05
22		Excavate/Frame Wall #4 Continuous Ftg	2 days	Tue 7/12/05
23		Pour Wall #3/4 Continuous Ftg	1 day	Thu 7/14/05
24		Pour Wall #2	1 day	Fri 7/15/05
25		Strip Forms Wall #2	1 day	Wed 7/20/05
26		Frame/Shore Wall #3	4 days	Mon 7/18/05
27		Pour Wall #3	1 day	Fri 7/22/05
28		Pour Outer Curved Wall Continuous Ftg	1 day	Mon 7/25/05
29		Frame/Shore Wall #4	4 days	Mon 7/25/05
30		Strip Forms Wall #3	1 day	Wed 7/27/05
31		Pour Wall #4	1 day	Fri 7/29/05
32		Run PVC/Conduit Cellar Grade	7 days	Mon 8/1/05
33		Strip Forms Wall #4	1 day	Wed 8/3/05
34		Frame/Shore Wall #5	4 days	Mon 8/1/05
35		Pour Wall #5	1 day	Fri 8/5/05
36		Pour Inner Curved Wall Continuous Ftg	1 day	Mon 8/8/05
37		Strip Forms Wall #5	1 day	Wed 8/10/05
38		Frame/Shore Wall #6	4 days	Mon 8/8/05

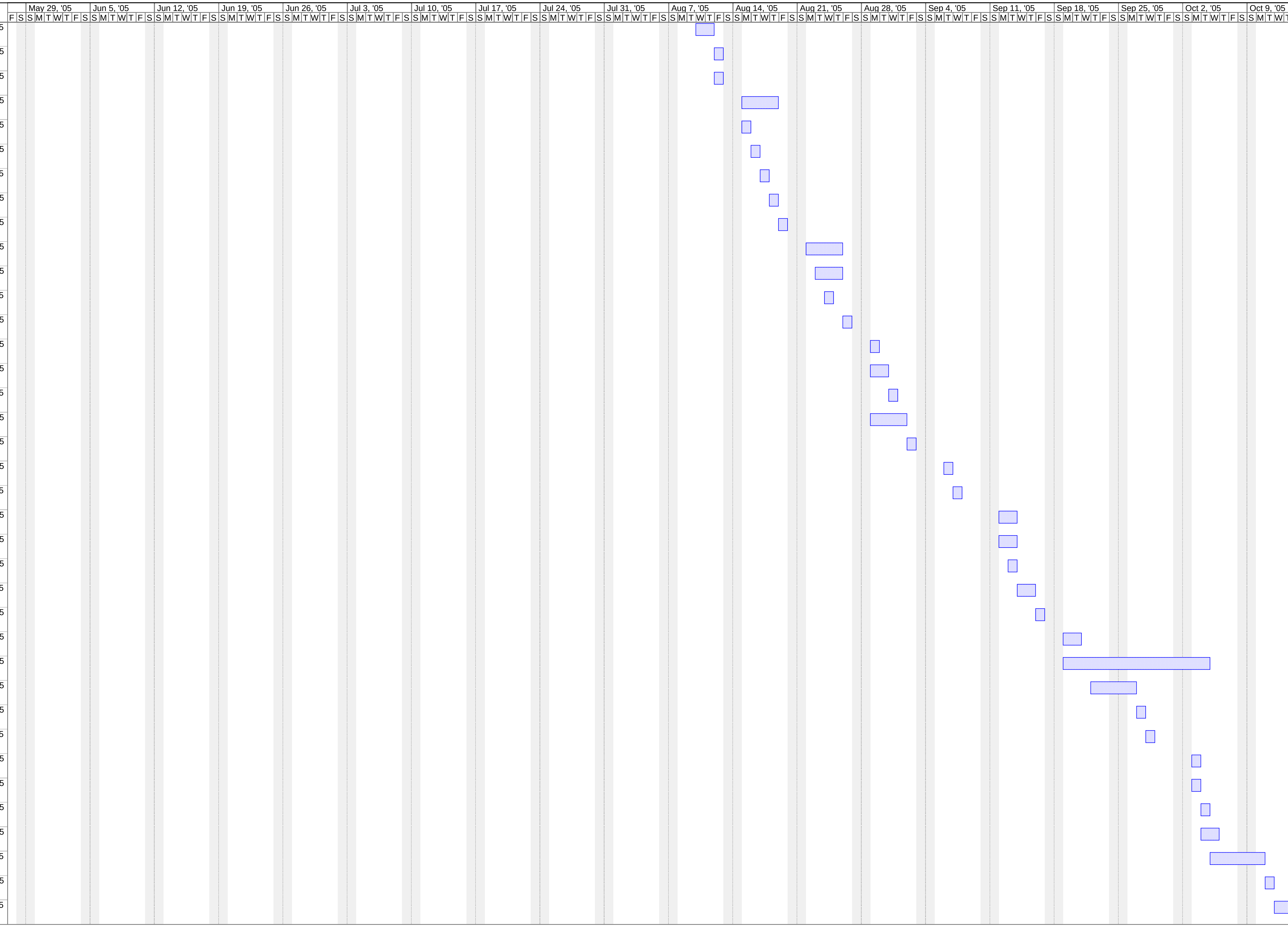


Project: Lecture Hall Foundation~534
Date: Tue 4/4/06

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

Lecture Hall Foundation Schedule - Actual

ID	Task Name	Duration	Start
39	Gravel Fill and WWF Cellar Slab #1/2	2 days	Wed 8/10/05
40	Pour Wall #6	1 day	Fri 8/12/05
41	Excavate/Frame Wall #8 Ftgs	1 day	Fri 8/12/05
42	Frame/Shore Wall #7	4 days	Mon 8/15/05
43	Pour Cellar Slab #1	1 day	Mon 8/15/05
44	Pour Cellar Slab #2	1 day	Tue 8/16/05
45	Strip Forms Wall #6	1 day	Wed 8/17/05
46	Pour Wall #8 Ftgs	1 day	Thu 8/18/05
47	Pour Wall #7	1 day	Fri 8/19/05
48	Frame/Shore Wall #8	4 days	Mon 8/22/05
49	Set Steel Lines A-A.7	3 days	Tue 8/23/05
50	Strip Forms Wall #7	1 day	Wed 8/24/05
51	Pour Wall #8	1 day	Fri 8/26/05
52	Backfill West Side	1 day	Mon 8/29/05
53	Set Steel Lines BB-C	2 days	Mon 8/29/05
54	Strip Forms Wall #8	1 day	Wed 8/31/05
55	Frame/Shore Wall #9	4 days	Mon 8/29/05
56	Pour Wall #9	1 day	Fri 9/2/05
57	Pour Cellar Slab #3	1 day	Tue 9/6/05
58	Strip Forms Wall #9	1 day	Wed 9/7/05
59	Set Steel Lines C-DD	2 days	Mon 9/12/05
60	Backfill Atrium and East Side	2 days	Mon 9/12/05
61	Backfill and Level Nose	1 day	Tue 9/13/05
62	Excavate/Frame Nose Foundation	2 days	Wed 9/14/05
63	Pour Nose Foundation	1 day	Fri 9/16/05
64	Excavate/Frame Atrium Ftgs	2 days	Mon 9/19/05
65	Run PVC/Conduit Atrium Grade	12 days	Mon 9/19/05
66	Frame Nose Wall	3 days	Thu 9/22/05
67	Pour Nose Wall	1 day	Tue 9/27/05
68	Pour Atrium Footings	1 day	Wed 9/28/05
69	Set Atrium Steel	1 day	Mon 10/3/05
70	Strip Nose Forms	1 day	Mon 10/3/05
71	Backfill Atrium	1 day	Tue 10/4/05
72	Backfill Auditorium Nose	2 days	Tue 10/4/05
73	Frame Foundation Atrium	4 days	Wed 10/5/05
74	Set Nose Steel	1 day	Tue 10/11/05
75	Pour Atrium Slab	2 days	Wed 10/12/05



Project: Lecture Hall Foundation~534
Date: Wed 4/5/06

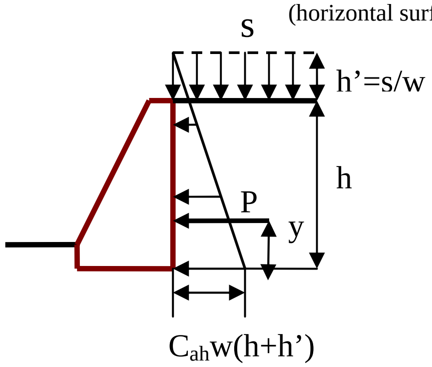
Task		Progress		Summary		External Tasks		Deadline	
Split		Milestone		Project Summary		External Milestone			

Proposed Shoring

Load Analysis

In order to calculate approximate loadings caused by backfilling, a Professional Engineer at Rathgeber/Goss and Associates suggested examples present in the "Design of Concrete Structures" text. From the diagram and equations to follow, an estimated force per horizontal foot of soil can be calculated. In turn, this force will be supported by rakers strategically placed to withhold the load for the largest possible on-center spans. For a better understanding of this process, please view **Appendix G**.

Figure 12. Earth Pressure
(horizontal surface with surcharge)



$$y = \frac{h^2 + 3hh'}{3(h + 2h')}$$

$$P = 1/2C_{ah}wh(h+2h')$$

Figure 13. Ulma Raker Support

With an estimated equipment surcharge to be 115 lb/ft2, a modified load height was figured to be around 3.28' above the footing. Our pressure per horizontal foot can be calculated at 2,997 lbs/ft. A resulting axial load in the shores would be around 1,546 lbs. With a maximum strength of 8,500 lbs, the proposed Ulma posts need to be placed every 5.5 feet on-center. Similar braces can be seen in the above photograph.

Cost Analysis

As quoted by Southland Concrete, a concrete subcontractor, the overall shoring work should cost around $11,258. The table to follow breaks down the estimate into labor, tools, and material costs.

	Unit Rate	Units	8/8/2005	8/9/2005	8/29/2005	8/30/2005	9/12/2005	9/13/2005	
Labor									
Carpenter	$36.00	HR	8	8	8	8	0	0	$1,152.00
Helper	$30.00	HR	8	8	8	8	8	8	$1,440.00
Laborer	$26.00	HR	0	0	0	0	8	8	$416.00
								Sub Total	$3,008.00
Misc Tools									
Bit	$5.00	DAY	1	1	1	1			$20.00
Hammer Drill	$25.00	DAY	1	1	1	1			$100.00
Cut Off Saw	$45.00	DAY					1	1	$90.00
								Sub Total	$210.00
Materials									
Ulma Shores	$15.00	EA	40						$600.00
Bolts (4/anchor)	$7.00	EA	320						$2,240.00
Bracing Anchors	$65.00	EA	80						$5,200.00
								Sub Total	$8,040.00
								Total	$11,258.00

Table 9. Ulma Shoring Estimate

Proposed Schedule

A revised schedule may be observed on the two pages prior to the final foundation analyses.

Preliminary Considerations

After careful scrutiny of the actual foundation schedule, one would be able to create a more efficient timetable of construction activities. In order to create such a schedule, a Project Manager should set some initial goals and requirements in which to achieve these goals.

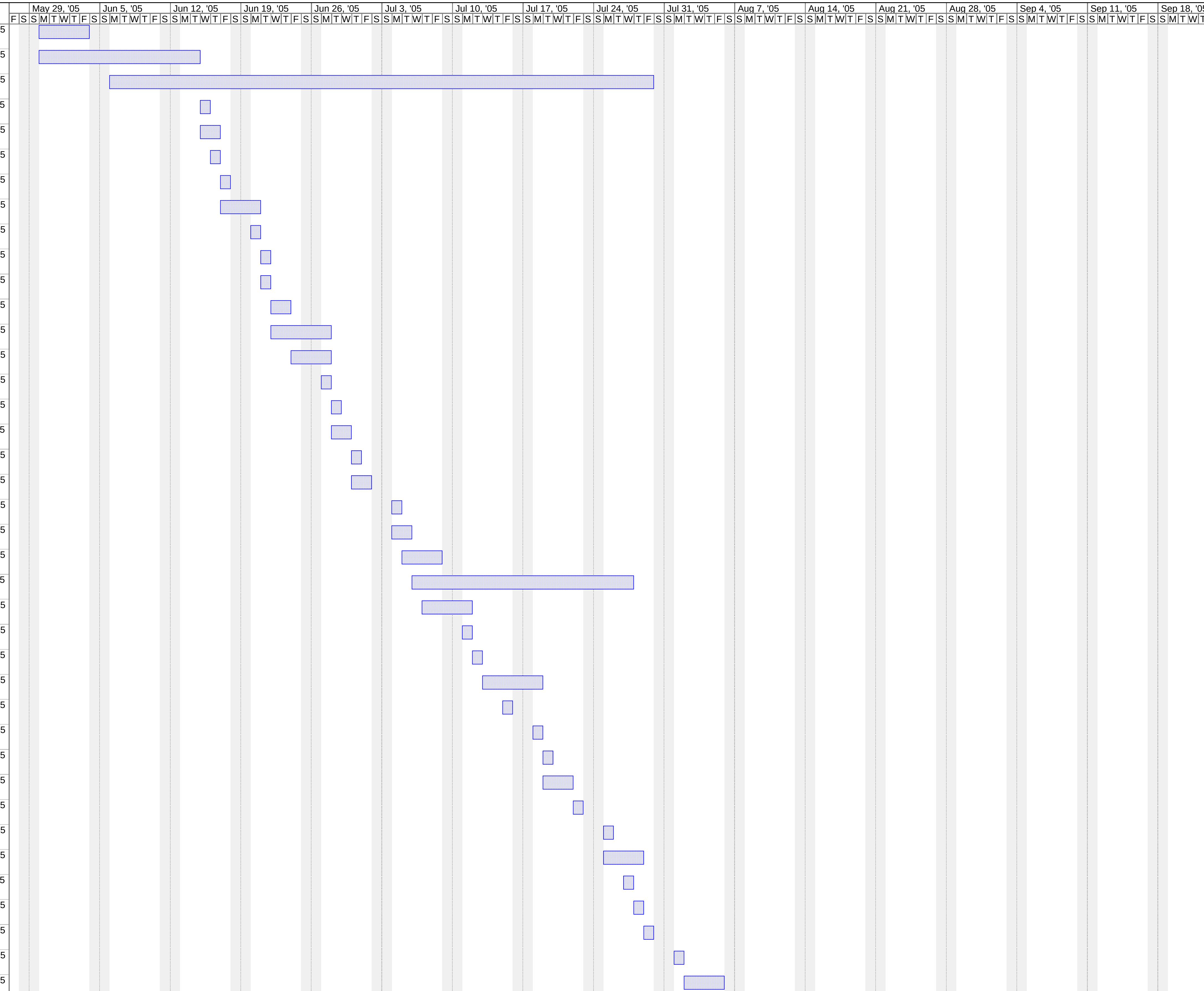
As stated in the proposal, the overall goal of this analysis is to obtain an earlier foundation completion date. For brevity purposes and a distinct finish line, the final activities shall include a slab-on-grade atrium pour and backfill within the auditorium nose. A secondary goal of this analysis is the implementation of a raker shoring system, which may further shorten the overall project duration for foundation work.

With these goals in mind, it was necessary to finish slab-on-grade basement pours in a sequential manner. By completing the first two floor pours, rakers could be installed and backfilling start in the Garden Atrium Space. Once the third and final floor pour is complete, shoring on the adjacent walls can go in. Soon after, the auditorium nose backfilling and foundation work can begin.

Revised Schedule

With construction beginning on the same June 15th date, activity durations and estimated space concerns were taken into consideration. Elevator pit and footing excavations began immediately. As framing is going up along Wall #1, adjacent continuous footing digging occurred. To better utilize space needs, curved wall footing work took place on the opposite side of the foundation while Wall #3 was being started around the 24th. Moving along swiftly, shear wall excavations begin by June 30th and connect up with the curved wall footings already poured. With the creation of continuous footings, framing and pouring of walls progressed right behind. To better plan work for the curved walls, each was framed at separate time. As soon as the inner curved wall pour was complete on July 18th, framing was stripped and placed on the parallel outer wall. Following placement of conduit along the basement grade and sufficient footings and walls were poured, the first cellar slab transpired on August 1st. Shortly after floor section #2 was filled with gravel, another slab-on-grade pour was expected. Come the 8th of August, the first two floor pours had adequate time to cure and the Ulma raker supports could be installed. Once shoring along Wall #1 and #3 was complete, work within the Garden Atrium could commence.

ID		Task Name	Duration	Start	Finish
1		Site Mobilization	5 days	Mon 5/30/05	Fri 6/3/05
2		Site Grating, Excavation, Layout	12 days	Mon 5/30/05	Tue 6/14/05
3		Base Building Demolition	40 days	Mon 6/6/05	Fri 7/29/05
4		Drill for Elevator Hydraulic	1 day	Wed 6/15/05	Wed 6/15/05
5		Excavate/Frame Line 26-27 Footings	2 days	Wed 6/15/05	Thu 6/16/05
6		Excavate/Frame Elevator Pit	1 day	Thu 6/16/05	Thu 6/16/05
7		Pour Elevator Pit and Line 26-27 Footings	1 day	Fri 6/17/05	Fri 6/17/05
8		Excavate/Frame Wall #1 Continuous Footing	2 days	Fri 6/17/05	Mon 6/20/05
9		Layout Curved and Shear Wall #2 Footings	1 day	Mon 6/20/05	Mon 6/20/05
10		Pour Wall #1 Continuous Footing	1 day	Tue 6/21/05	Tue 6/21/05
11		Strip Pit	1 day	Tue 6/21/05	Tue 6/21/05
12		Excavate Curved Wall Footing	2 days	Wed 6/22/05	Thu 6/23/05
13		Frame/Shore Wall #1	4 days	Wed 6/22/05	Mon 6/27/05
14		Excavate/Frame Wall #3 Continuous Ftg	2 days	Fri 6/24/05	Mon 6/27/05
15		Pour Curved Wall Continuous Footings	1 day	Mon 6/27/05	Mon 6/27/05
16		Pour Wall #1	1 day	Tue 6/28/05	Tue 6/28/05
17		Excavate/Frame Wall #4 Continuous Ftg	2 days	Tue 6/28/05	Wed 6/29/05
18		Pour Wall #3/4 Continuous Ftg	1 day	Thu 6/30/05	Thu 6/30/05
19		Excavate Shear Wall Continuous Ftg	2 days	Thu 6/30/05	Fri 7/1/05
20		Strip Forms Wall #1	1 day	Mon 7/4/05	Mon 7/4/05
21		Pour Shear Wall Continuous Ftg	2 days	Mon 7/4/05	Tue 7/5/05
22		Frame/Shore Wall #3	4 days	Tue 7/5/05	Fri 7/8/05
23		Run PVC/Conduit Cellar Grade	16 days	Wed 7/6/05	Wed 7/27/05
24		Frame/Shore Inner Curved Wall	3 days	Thu 7/7/05	Mon 7/11/05
25		Pour Wall #3	1 day	Mon 7/11/05	Mon 7/11/05
26		Pour Inner Curved Wall	1 day	Tue 7/12/05	Tue 7/12/05
27		Frame/Shore Wall #4	4 days	Wed 7/13/05	Mon 7/18/05
28		Strip Forms Wall #3	1 day	Fri 7/15/05	Fri 7/15/05
29		Strip Inner Curved Wall Forms	1 day	Mon 7/18/05	Mon 7/18/05
30		Pour Wall #4	1 day	Tue 7/19/05	Tue 7/19/05
31		Frame/Shore Outer Curved Wall	3 days	Tue 7/19/05	Thu 7/21/05
32		Pour Outer Curved Wall	1 day	Fri 7/22/05	Fri 7/22/05
33		Strip Forms Wall #4	1 day	Mon 7/25/05	Mon 7/25/05
34		Frame/Shore Wall #5	4 days	Mon 7/25/05	Thu 7/28/05
35		Strip Outer Curved Wall	1 day	Wed 7/27/05	Wed 7/27/05
36		Gravel Fill and WWF Cellar Slab 1	1 day	Thu 7/28/05	Thu 7/28/05
37		Pour Wall #5	1 day	Fri 7/29/05	Fri 7/29/05
38		Pour Cellar Slab 1	1 day	Mon 8/1/05	Mon 8/1/05
39		Frame/Shore Wall #2	4 days	Tue 8/2/05	Fri 8/5/05

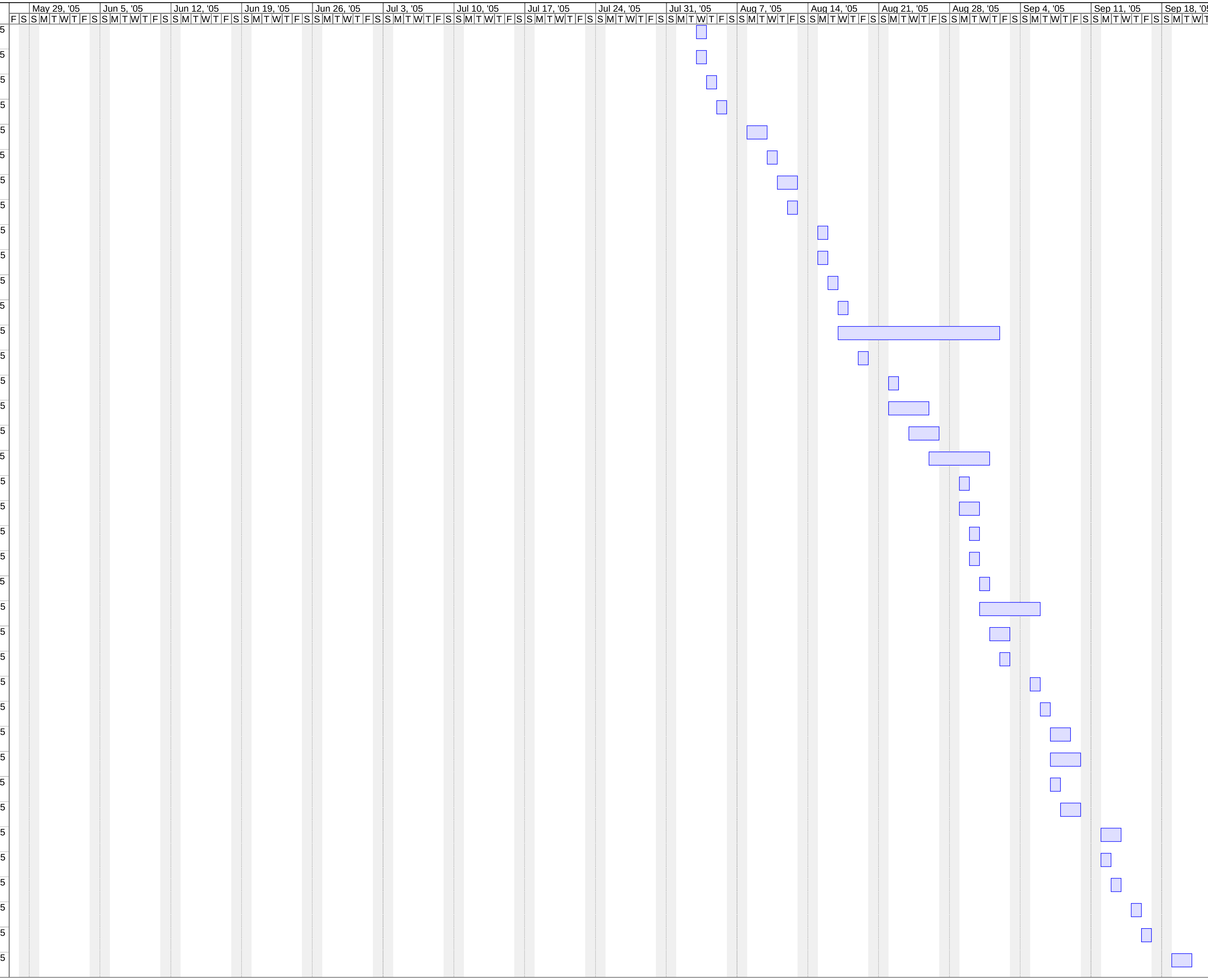


Project: Lecture Hall Foundation
Date: Tue 4/4/06

Task		Progress		Summary		External Tasks	
Split		Milestone		Project Summary		External Milestone	

Deadline

ID		Task Name	Duration	Start	Finish
40		Gravel Fill and WWF Cellar Slab 2	1 day	Wed 8/3/05	Wed 8/3/05
41		Strip Forms Wall #5	1 day	Wed 8/3/05	Wed 8/3/05
42		Pour Cellar Slab 2	1 day	Thu 8/4/05	Thu 8/4/05
43		Pour Wall #2	1 day	Fri 8/5/05	Fri 8/5/05
44		Fasten Ulma Shores Walls 1/3	2 days	Mon 8/8/05	Tue 8/9/05
45		Backfill Atrium	1 day	Wed 8/10/05	Wed 8/10/05
46		Excavate/Frame Atrium Footings	2 days	Thu 8/11/05	Fri 8/12/05
47		Excavate/Frame Wall #8 Ftgs	1 day	Fri 8/12/05	Fri 8/12/05
48		Pour Atrium Footings	1 day	Mon 8/15/05	Mon 8/15/05
49		Strip Forms Wall #2	1 day	Mon 8/15/05	Mon 8/15/05
50		Backfill Atrium	1 day	Tue 8/16/05	Tue 8/16/05
51		Pour Wall #8 Ftgs	1 day	Wed 8/17/05	Wed 8/17/05
52		Run PVC/Conduit Atrium Grade	12 days	Wed 8/17/05	Thu 9/1/05
53		Gravel Fill and WWF Cellar Slab 3	1 day	Fri 8/19/05	Fri 8/19/05
54		Pour Cellar Slab #3	1 day	Mon 8/22/05	Mon 8/22/05
55		Frame/Shore Wall #9	4 days	Mon 8/22/05	Thu 8/25/05
56		Set Steel Lines A-A.7	3 days	Wed 8/24/05	Fri 8/26/05
57		Frame/Shore Wall #8	4 days	Fri 8/26/05	Wed 8/31/05
58		Pour Wall #9	1 day	Mon 8/29/05	Mon 8/29/05
59		Fasten Ulma Shores Wall 5/Curved	2 days	Mon 8/29/05	Tue 8/30/05
60		Strip Forms Wall #9	1 day	Tue 8/30/05	Tue 8/30/05
61		Backfill Atrium	1 day	Tue 8/30/05	Tue 8/30/05
62		Backfill and Level Nose	1 day	Wed 8/31/05	Wed 8/31/05
63		Frame Atrium Foundation	4 days	Wed 8/31/05	Mon 9/5/05
64		Excavate/Frame Nose Foundation	2 days	Thu 9/1/05	Fri 9/2/05
65		Pour Wall #8	1 day	Fri 9/2/05	Fri 9/2/05
66		Pour Nose Foundation	1 day	Mon 9/5/05	Mon 9/5/05
67		Pour Atrium Slab	1 day	Tue 9/6/05	Tue 9/6/05
68		Set Steel Lines BB-C	2 days	Wed 9/7/05	Thu 9/8/05
69		Frame Nose Wall	3 days	Wed 9/7/05	Fri 9/9/05
70		Strip Forms Wall #8	1 day	Wed 9/7/05	Wed 9/7/05
71		Set Steel Lines C-DD	2 days	Thu 9/8/05	Fri 9/9/05
72		Remove Ulma Shores	2 days	Mon 9/12/05	Tue 9/13/05
73		Pour Nose Wall	1 day	Mon 9/12/05	Mon 9/12/05
74		Set Atrium Steel	1 day	Tue 9/13/05	Tue 9/13/05
75		Set Nose Steel	1 day	Thu 9/15/05	Thu 9/15/05
76		Strip Nose Forms	1 day	Fri 9/16/05	Fri 9/16/05
77		Backfill Auditorium Nose	2 days	Mon 9/19/05	Tue 9/20/05



Project: Lecture Hall Foundation
Date: Tue 4/4/06

Task		Progress		Summary		External Tasks	
Split		Milestone		Project Summary		External Milestone	

Deadline

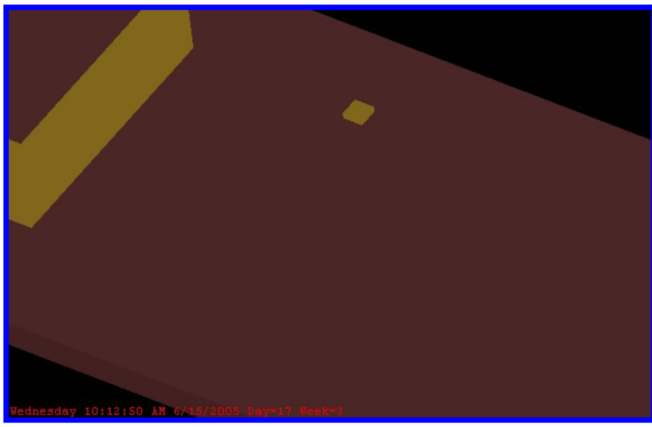
Foundation Schedule Analysis

The following images are provided to help visualize and compare the actual schedule enforced by DAVIS and a revised, more stringent timeline. With the objective of completing the basement floor pours and their surrounding walls as soon as possible, Ulma rakers could be inserted to provide support for backfilling. This backfilling would allow work to progress within the elevated garden atrium and auditorium nose areas. Additional subcontractor work sequencing is implemented to decrease the original leniency of activities.

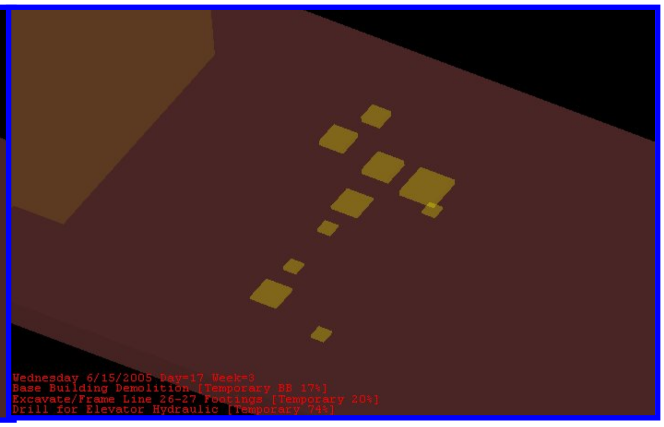
For reference purposes, South is to the left and North is to the right of the images. Two of the revised illustrations have been switched so proper foundation elements can be seen.

6 June 2005

Actual



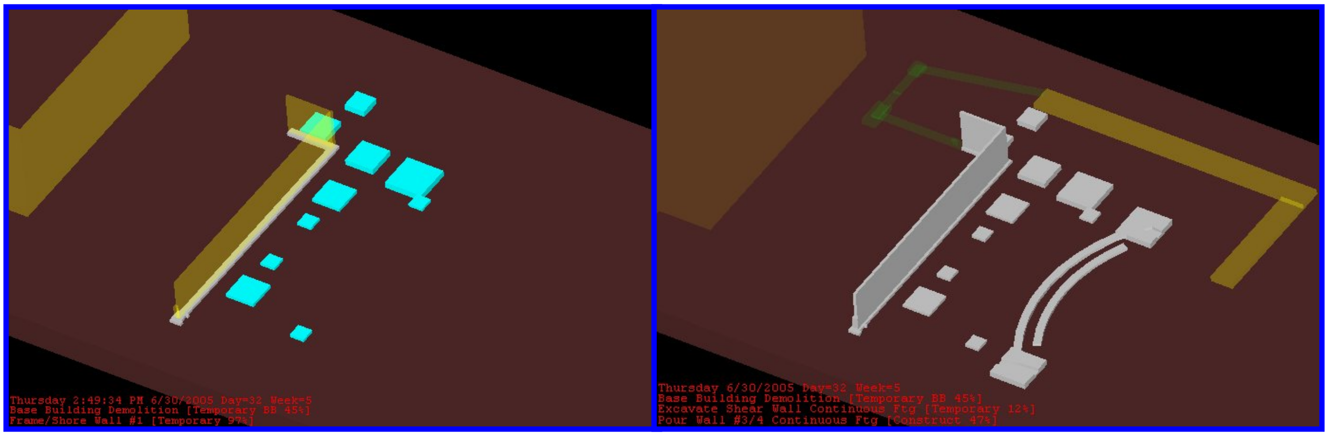
Revised



As depicted in the images above, foundation work began on the 6th in both scenarios. In the original schedule, only drilling for the hydraulic elevator was planned. If beginning in the morning, drilling should not extend much past lunch. This would allow excavation of the 26-27 line footings to begin, which is shown in the revised process. Within in the first two days of work, additional progress can already be visualized.

27 June 2005

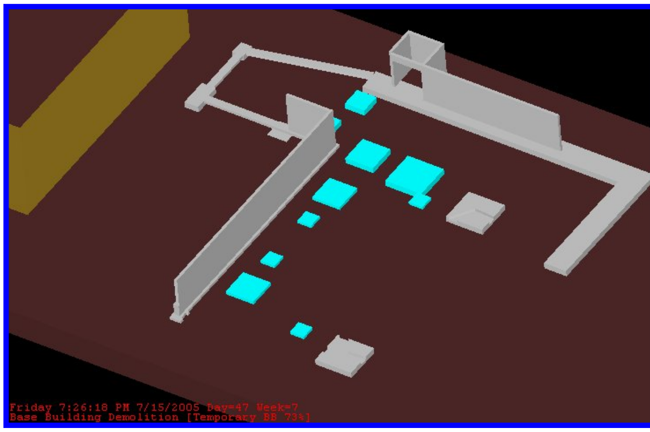
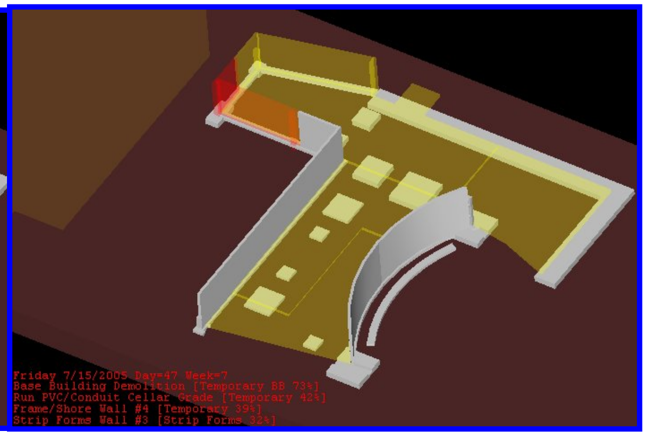
Actual | **Revised**



Three weeks later, the original schedule had accomplished the pouring of Line 26-27 footings and framing of Wall #1 was in progress. Although not shown in the photograph, excavations for the curved wall footings began later that day.

In order to accomplish the need for the wall footing pours, excavations were planned to happen simultaneously, on opposite sides of the foundation where ample space is provided and could be performed efficiently. This created an opportunity to bring cement trucks on site for three of four neighboring days, completing “Wall Pour #1,” “Curved Wall Footing,” and the green “Wall #3/4 Continuous Footing” shown on the right, in a short amount of time. Excavation of the large shear wall footing was also in the process to be completed the following day.

15 July 2005

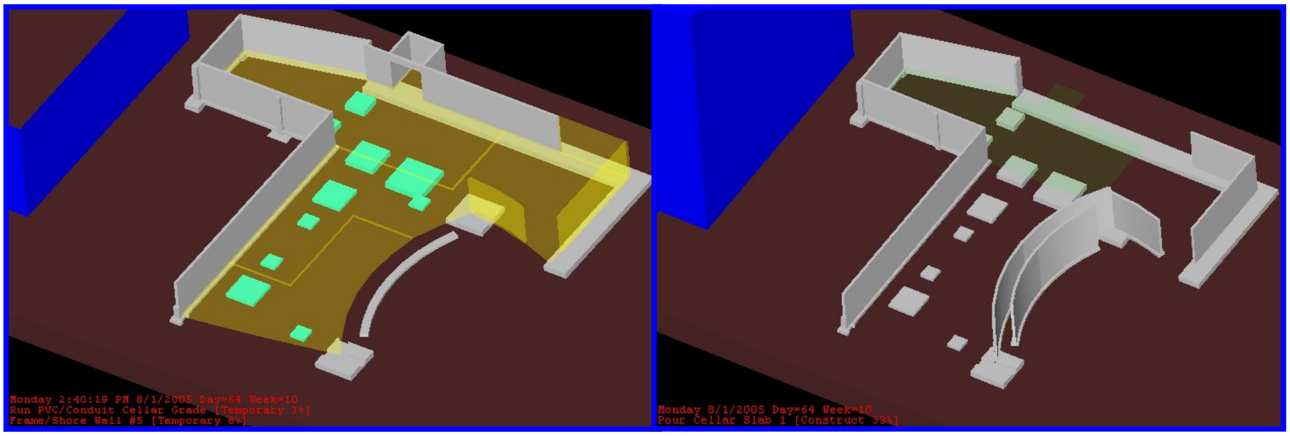
Actual	**Revised**
	

According to the schedule provided by DAVIS, 10-12 work days later, continuous footings wrapped all the way around to Wall #5. As the formwork from the first wall was removed, days later the large shear wall framing and shoring took place. Although the footing progress continued from Wall #1 to Wall #2, these two separate sections are located below the only standing walls. Transitioning from location to location did not seem efficient. Footings for the curved wall had also been poured come the 15th of July.

For the modified process, framing of the third and fourth walls continued, with the addition of the Inner Curved Wall. Since different materials were used for the curved walls, framing and pouring of Wall #3 and the curved wall could be done simultaneously on opposite sides of the foundation. As shown in the revised image, the red third wall was being stripped, allowing for the adjacent fourth wall to be framed. At this time, the Inner Curved Wall has already been poured and stripped. Running of conduit along the basement floor grade is also in progress where space is available.

1 August 2005

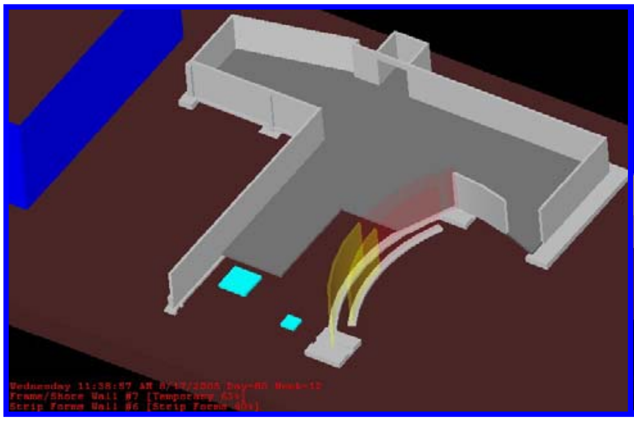
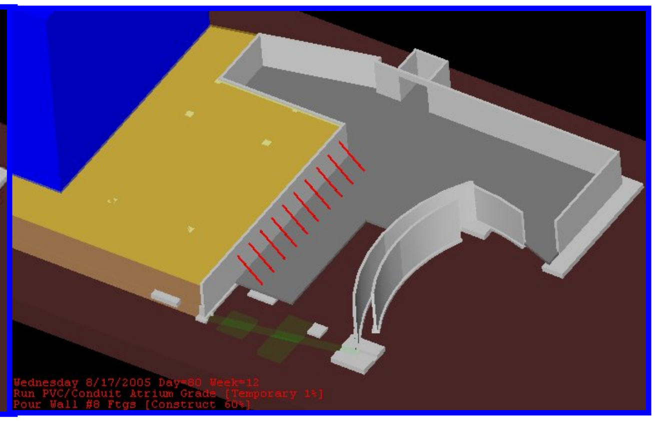
Actual | **Revised**



Since the last original schedule iteration, the concrete subcontractor had to back-track to Walls #3 and #*4*. Completion of these two sections occurred earlier today, August 1st. Framing of the fifth wall began while the fourth was being stripped. Running of conduit along the basement grade has begun and is to continue over the next week.

Over the past two weeks in the adjusted timeline, both the fifth and outer curved walls have been poured and stripped. Once Wall #4 was complete and conduit work had a few days to develop, the first slab section could be filled with gravel and welded wire fabric laid. At this point, “Gravel Fill and WWF Cellar Slab 1” were not expected to commence for almost another two weeks in the early schedule.

17 August 2005

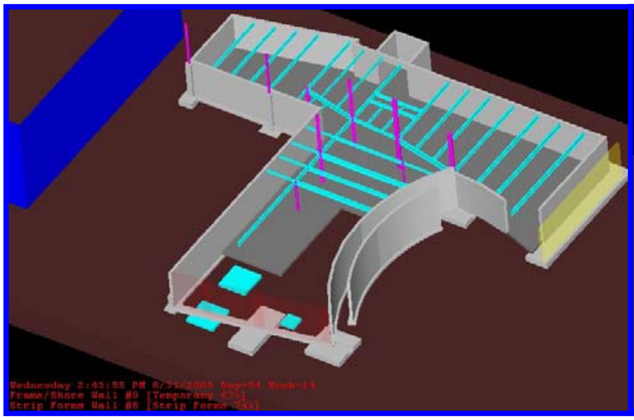
Actual	**Revised**
	

In the above illustration, you can see one of the concerns raised earlier about sequencing of the nearby curved walls. Instead of doing sections of the Inner and Outer Curved Walls at differing time periods, they did them simultaneously in two parts. By framing the inner wall and then attempting the other, workers were restricted to hardly enough free space to frame the outer wall efficiently. On a more positive note, at the period when framing was stripped from one portion, the same sections were used to frame the adjoining wall. Over the past few weeks, slab on grade activities for sections 1 and 2 were also accomplished.

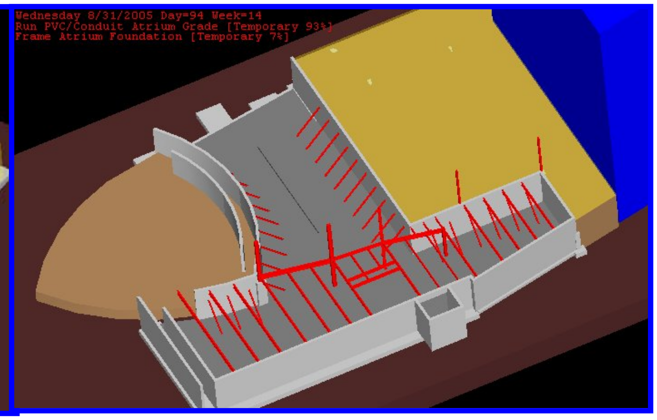
From the time of the revised observation, the south and west foundation sections were accomplished. More specifically, on August 1st, the second wall was poured and before the end of the week, the first two basement slabs were completed. At this point in the new foundation schedule, further advancement could be made with the help of shoring rakers. With the first two slabs poured, rakers could be fastened to the floor and support the walls against backfilling. Over the course of 6-7 working days, the Garden Atrium is backfilled and footings are finished. Compared to the original timetable, atrium work was not scheduled for another 2-3 weeks.

31 August 2005

Actual



Revised

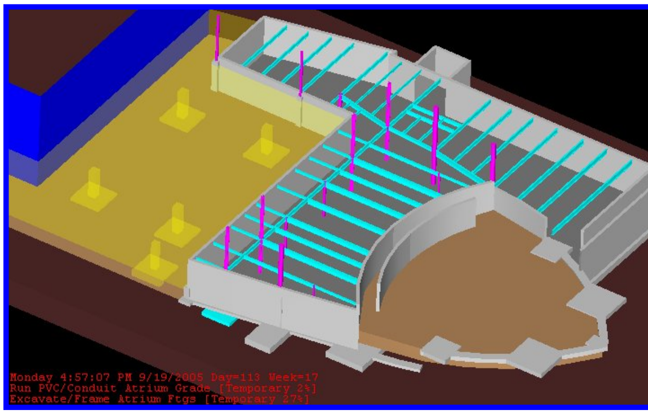


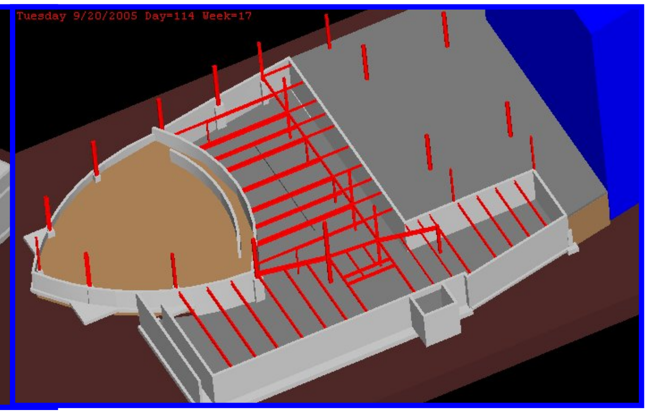
Two weeks later, the curved walls had been finished and close-up of the foundation was nearing completion. While Wall #8 was stripped, the last wall was being framed, excluding the auditorium nose section. Two phases of steel were also set along the A-A.7 Line and between Line BB and C. No work within the Garden Atrium or Auditorium Nose has yet to begin.

By August 31st, the modified schedule would be on the final stretch. Rakers along the curved wall would be in place and Auditorium Nose backfill progressing. Besides for the "Atrium Slab Pour," work in this area is complete and additional focus can transfer to the nose. Our main objective of basement slab pours and installation of shoring is quite evident in these visuals. Besides for a re-sequencing of activities to shorten the overall foundation schedule, it is easy to see the benefits provided by shoring to continue work in adjacent areas. Instead of waiting for steel to be set and tie in the walls for backfilling to occur, rakers can supplement the added steel function. As noted in the **Proposed Shoring** section, due to savings in schedule time, this system is cost effective as well.

19 September 2005

Actual **Revised**



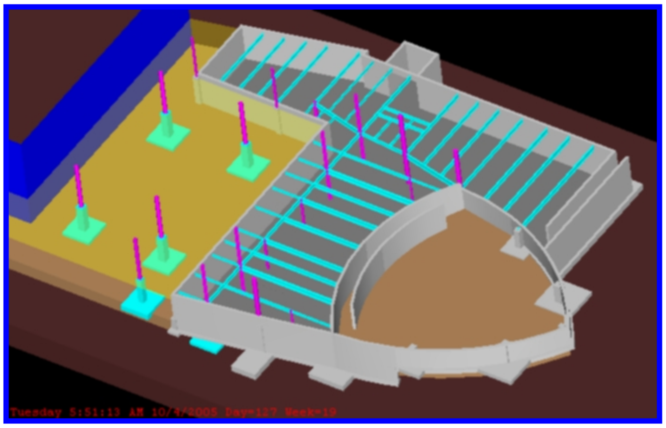


Further progress on the Lecture Hall foundation is noticed with the final wall and basement floor pours. The first phase of construction within the auditorium nose finally began the 13th. Over the next few days the nose foundation was excavated and poured. Work inside the Garden Atrium continued with running of conduit along grade and footing excavations.

By the 19th of September, as exemplified in the revised image, final backfilling of the auditorium was pretty much complete. Nose forms would have been removed and final installation of nose and atrium steel complete. Although further activities could have been shown over the next two deadlines, our purpose was target foundation erection and the implementation of rakers to accelerate scheduling in this scenario. Obviously with these results it is easy to observe the time saved due to stringent sequencing and a shoring system.

4 October 2005

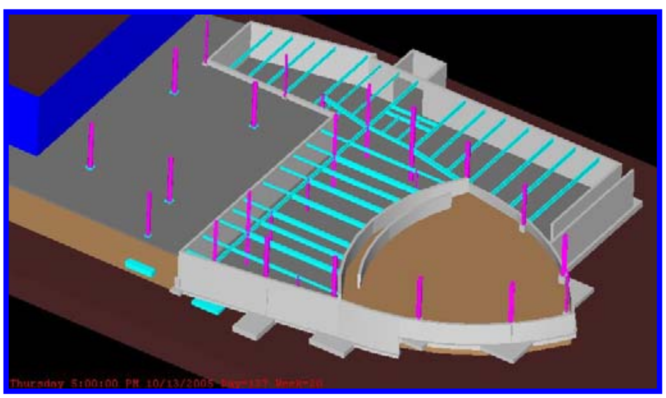
Actual



Two weeks after the revised foundation concluded, the auditorium nose wall was finally poured and forms stripped. With atrium steel going in, nose steel expected shortly, and final backfilling taking place, only a few last atrium activities were required for completion.

12 October 2005

Actual



A week later, the nose steel had been set and final pouring of the atrium slab took place. Over three weeks later than the carefully planned schedule, what could have been time savings, turned out to be time loss.

Conclusion

Within this analysis, the creation of alternative foundation schedules could have been endless. The revised timeline provided is an intuitive representation of a more efficient sequence of activities and addresses the problem spots noted in the original.

After a thorough investigation of the 4-dimensional models produced in *NavisWorks JetStream*, a savings of 23 work days was produced. With the purpose of targeting foundation erection, set start and end times needed to be developed. As stated earlier, four weeks of additional progress could have been shown for the revised schedule. Such a task was not achieved because of the need to emphasize a concrete date for foundation completion.

This large schedule reduction came with additional help from an Ulma raker shoring system costing an estimated $11,258. Initial project costs may suffer, but when comparing the general contractor's liquidated damage amount of $1,000 per day for late building turnover, shoring seems like a valuable option. Although a group of foundation activities may not all directly correlate to the Lecture Hall's critical path, it would have a significant impact on the progress to follow.

If the 23 day reduction can be applied to one month savings in project duration, a significant amount of General Conditions costs may be cut. Looking at the tables located in **Appendix H**, an estimated total difference of $45,437 is noted. Being approximately $34,179 more than shoring costs, this option is quite valuable.

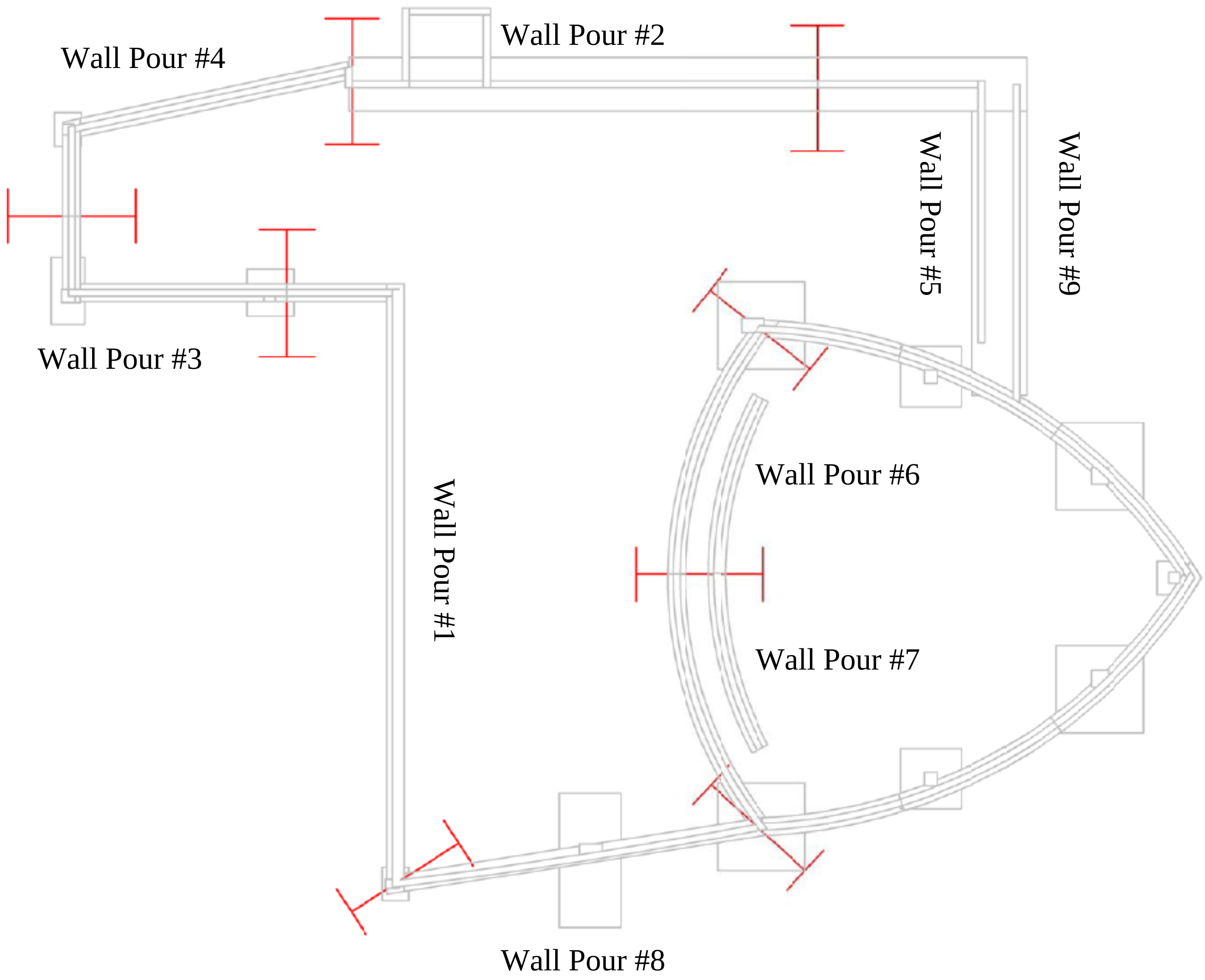


Figure 14. Foundation Wall Pour Sequencing

Overall Analysis Conclusions

In the case that project teams had adequate planning time before VE began, they may have been able to produce a larger pool of valuable items from which to choose. With additional time and increased communication between participants, foundation work and other interior building system costs could have been revised.

Considering the altered fiberglass reinforced polymer catwalk system provided by E.T. Techtonics, around $14,800 could have been saved. In addition to money, a decrease of 2 weeks in lead time and close to 3 weeks of construction time is expected.

Looking at alternative mechanical systems to replace two boilers, implementing electric resistance heat coils to the already existing air handling units is a viable option. An estimated $48,000 decrease and a reduction of 8-10 weeks for separate boiler installation time can be expected.

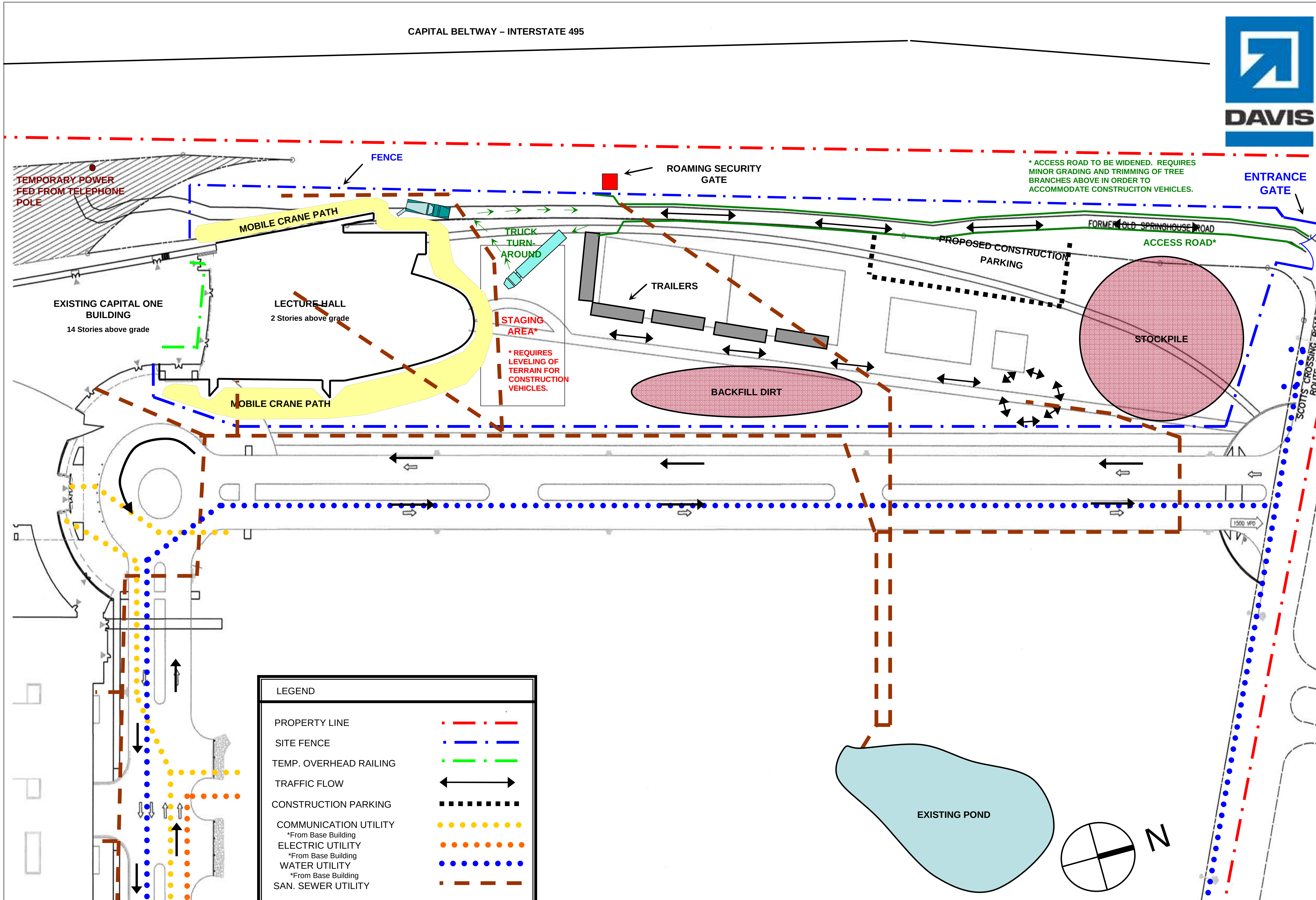
The final shoring and foundation re-sequencing analysis also provides valuable results. With an understanding of general conditions costs and $1,000 in liquidated damages for late building turnover, implementing additional raker installation and disassembly is still beneficial. Overall, a reduction of $34,100 in general conditions from a 23 work day cutback is projected.

After this investigation, DAVIS and Capital One could have saved an approximate $96,000 with the utilization of the value engineering options analyzed above. Not only would they have been able to save money, but cumulatively 4-6 weeks in schedule reduction was possible.

Appendices

Works Cited

Acknowledgements



Capital One

LECTURE HALL ADDITION

1680 CAPITAL ONE DRIVE, McLEAN, VA 22102

APPENDIX A

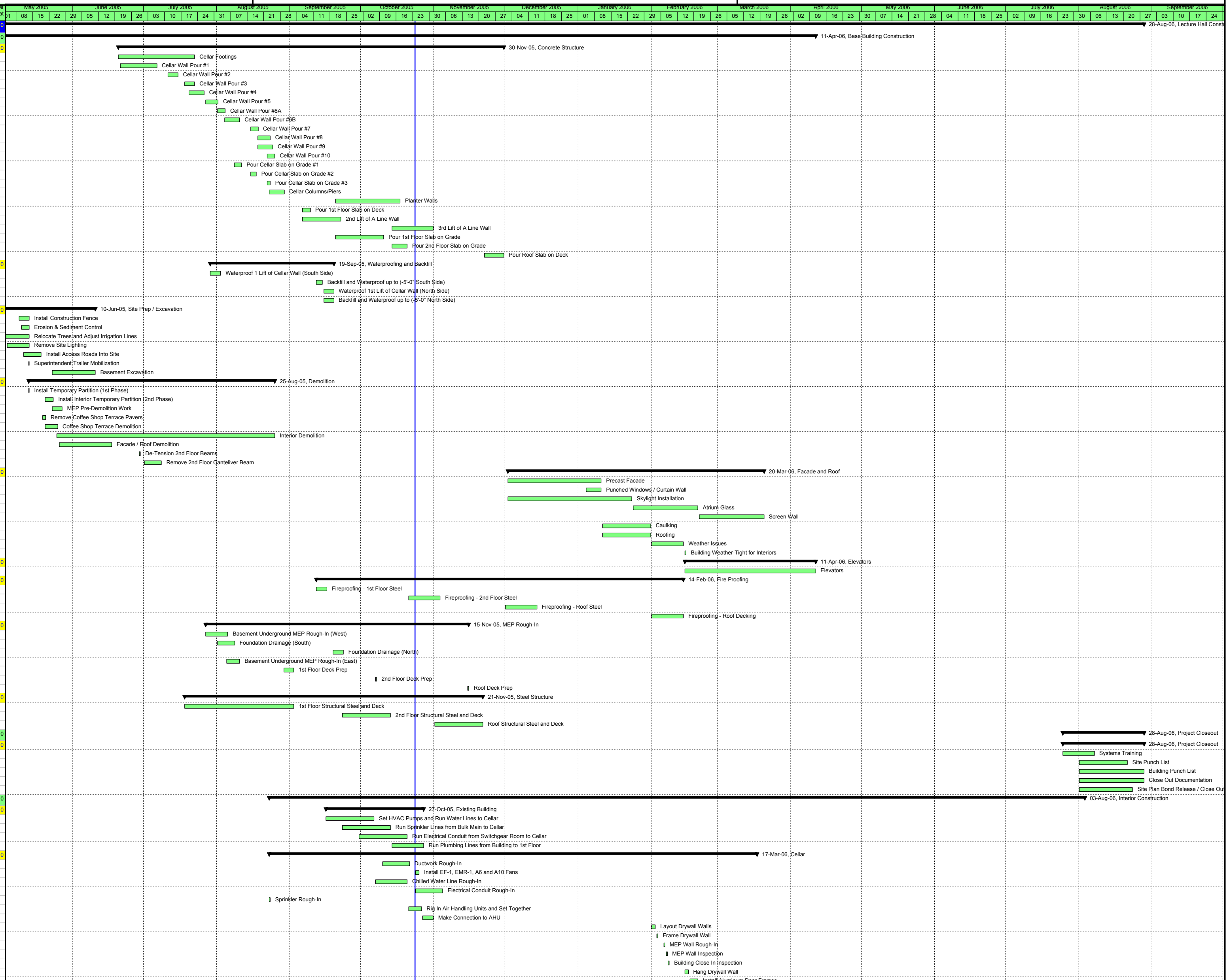
EXISTING SITE & UTILITY PLAN

Scale: NTS

Prepared by	Date	Sheet
Sean C. Ehlers Construction Management	April 3, 2006	1 of 1

Lecture Hall Construction - DAVIS | Classic WBS Layout | April 3, 2006

Activity ID	Activity Name	Original Duration	Start	Finish	Total Float
	Lecture Hall Constructi...	336	03-May-05	28-Aug-06	0
	Base Building Construc...	239	03-May-05	11-Apr-06	0
	Concrete Structure	114	20-Jun-05	30-Nov-05	0
A0	Cellar Footings	24	20-Jun-05	22-Jul-05	
A0	Cellar Wall Pour #1	11	21-Jun-05	06-Jul-05	
A0	Cellar Wall Pour #2	5	11-Jul-05	15-Jul-05	
A0	Cellar Wall Pour #3	5	18-Jul-05	22-Jul-05	
A0	Cellar Wall Pour #4	5	20-Jul-05	26-Jul-05	
A0	Cellar Wall Pour #5	4	27-Jul-05	01-Aug-05	
A0	Cellar Wall Pour #6A	4	01-Aug-05	04-Aug-05	
A0	Cellar Wall Pour #6B	5	04-Aug-05	10-Aug-05	
A0	Cellar Wall Pour #7	4	15-Aug-05	18-Aug-05	
A0	Cellar Wall Pour #8	4	18-Aug-05	23-Aug-05	
A0	Cellar Wall Pour #9	5	18-Aug-05	24-Aug-05	
A0	Cellar Wall Pour #10	4	22-Aug-05	25-Aug-05	
A0	Pour Cellar Slab on Grad...	4	08-Aug-05	11-Aug-05	
A0	Pour Cellar Slab on Grad...	3	15-Aug-05	17-Aug-05	
A0	Pour Cellar Slab on Grad...	2	22-Aug-05	23-Aug-05	
A0	Cellar Columns/Piers	5	23-Aug-05	29-Aug-05	
A0	Planter Walls	20	20-Sep-05	17-Oct-05	
A0	Pour 1st Floor Slab on D...	4	06-Sep-05	09-Sep-05	
A0	2nd Lift of A Line Wall	13	06-Sep-05	22-Sep-05	
A0	3rd Lift of A Line Wall	12	14-Oct-05	31-Oct-05	
A0	Pour 1st Floor Slab on G...	15	20-Sep-05	10-Oct-05	
A0	Pour 2nd Floor Slab on ...	5	14-Oct-05	20-Oct-05	
A0	Pour Roof Slab on Deck	5	22-Nov-05	30-Nov-05	
	Waterproofing and Backfill	36	29-Jul-05	19-Sep-05	0
A0	Waterproof 1 Lift of Cell...	3	29-Jul-05	02-Aug-05	
A0	Backfill and Waterproof ...	3	12-Sep-05	14-Sep-05	
A0	Waterproof 1st Lift of C...	3	15-Sep-05	19-Sep-05	
A0	Backfill and Waterproof ...	3	15-Sep-05	19-Sep-05	
	Site Prep / Excavation	28	03-May-05	10-Jun-05	0
A0	Install Construction Fence	5	09-May-05	13-May-05	
A0	Erosion & Sediment Con...	4	10-May-05	13-May-05	
A0	Relocate Trees and Adju...	9	03-May-05	13-May-05	
A0	Remove Site Lighting	8	04-May-05	13-May-05	
A0	Install Access Roads Int...	6	11-May-05	18-May-05	
A0	Superintendent Trailer M...	1	13-May-05	13-May-05	
A0	Basement Excavation	14	23-May-05	10-Jun-05	
	Demolition	73	13-May-05	25-Aug-05	0
A0	Install Temporary Partiti...	1	13-May-05	13-May-05	
A0	Install Interior Temporary...	2	20-May-05	23-May-05	
A0	MEP Pre-Demolition Work	5	23-May-05	27-May-05	
A0	Remove Coffee Shop T...	2	19-May-05	20-May-05	
A0	Coffee Shop Terrace De...	4	20-May-05	25-May-05	
A0	Interior Demolition	65	25-May-05	25-Aug-05	
A0	Facade / Roof Demolition	16	26-May-05	17-Jun-05	
A0	De-Tension 2nd Floor B...	1	29-Jun-05	29-Jun-05	
A0	Remove 2nd Floor Cant...	5	01-Jul-05	08-Jul-05	
	Facade and Roof	75	02-Dec-05	20-Mar-06	0
A1	Precast Facade	26	02-Dec-05	10-Jan-06	
A1	Punched Windows / Curt...	5	04-Jan-06	10-Jan-06	
A1	Skylight Installation	35	02-Dec-05	23-Jan-06	
A1	Atrium Glass	20	24-Jan-06	20-Feb-06	
A1	Screen Wall	20	21-Feb-06	20-Mar-06	
A1	Caulking	15	11-Jan-06	31-Jan-06	
A1	Roofing	15	11-Jan-06	31-Jan-06	
A1	Weather Issues	10	01-Feb-06	14-Feb-06	
A1	Building Weather-Tight f...	1	15-Feb-06	15-Feb-06	
	Elevators	40	15-Feb-06	11-Apr-06	0
A2	Elevators	40	15-Feb-06	11-Apr-06	
	Fire Proofing	108	12-Sep-05	14-Feb-06	0
A0	Fireproofing - 1st Floor ...	5	12-Sep-05	16-Sep-05	
A0	Fireproofing - 2nd Floor ...	10	21-Oct-05	03-Nov-05	
A0	Fireproofing - Roof Steel	10	01-Dec-05	14-Dec-05	
A1	Fireproofing - Roof Deck...	10	01-Feb-06	14-Feb-06	
	MEP Rough-In	79	27-Jul-05	15-Nov-05	0
A0	Basement Underground ...	8	27-Jul-05	05-Aug-05	
A1	Foundation Drainage (S...	6	01-Aug-05	08-Aug-05	
A1	Foundation Drainage (N...	5	19-Sep-05	23-Sep-05	
A1	Basement Underground ...	4	05-Aug-05	10-Aug-05	
A1	1st Floor Deck Prep	5	29-Aug-05	02-Sep-05	
A1	2nd Floor Deck Prep	1	07-Oct-05	07-Oct-05	
A1	Roof Deck Prep	1	15-Nov-05	15-Nov-05	
	Steel Structure	90	18-Jul-05	21-Nov-05	0
A0	1st Floor Structural Steel...	35	18-Jul-05	02-Sep-05	
A0	2nd Floor Structural Stee...	15	23-Sep-05	13-Oct-05	
A0	Roof Structural Steel an...	15	01-Nov-05	21-Nov-05	
	Project Closeout	25	25-Jul-06	28-Aug-06	0
	Project Closeout	25	25-Jul-06	28-Aug-06	0
990	Systems Training	10	25-Jul-06	07-Aug-06	
991	Site Punch List	15	01-Aug-06	21-Aug-06	
992	Building Punch List	20	01-Aug-06	28-Aug-06	
993	Close Out Documentation	20	01-Aug-06	28-Aug-06	
994	Site Plan Bond Release /...	17	01-Aug-06	23-Aug-06	
	Interior Construction	241	23-Aug-05	03-Aug-06	0
	Existing Building	30	16-Sep-05	27-Oct-05	0
A2	Set HVAC Pumps and R...	15	16-Sep-05	06-Oct-05	
A2	Run Sprinkler Lines from...	15	23-Sep-05	13-Oct-05	
A2	Run Electrical Conduit fr...	15	30-Sep-05	20-Oct-05	
A2	Run Plumbing Lines from...	10	14-Oct-05	27-Oct-05	
	Cellar	144	23-Aug-05	17-Mar-06	0
A4	Ductwork Rough-In	10	10-Oct-05	21-Oct-05	
A4	Install EF-1, EMR-1, A6 ...	2	24-Oct-05	25-Oct-05	
A4	Chilled Water Line Roug...	10	07-Oct-05	20-Oct-05	
A4	Electrical Conduit Rough-In	10	24-Oct-05	04-Nov-05	
A4	Sprinkler Rough-In	1	23-Aug-05	23-Aug-05	
A4	Rig In Air Handling Units ...	4	21-Oct-05	26-Oct-05	
A4	Make Connection to AHU	3	27-Oct-05	31-Oct-05	
A4	Layout Drywall Walls	2	01-Feb-06	02-Feb-06	
A4	Frame Drywall Wall	1	03-Feb-06	03-Feb-06	
A4	MEP Wall Rough-In	1	06-Feb-06	06-Feb-06	
A4	MEP Wall Inspection	1	07-Feb-06	07-Feb-06	
A4	Building Close In Inspecti...	1	08-Feb-06	08-Feb-06	
A4	Hang Drywall Wall	2	15-Feb-06	16-Feb-06	
A4	Install Aluminum Door Fr...	2	17-Feb-06	20-Feb-06	

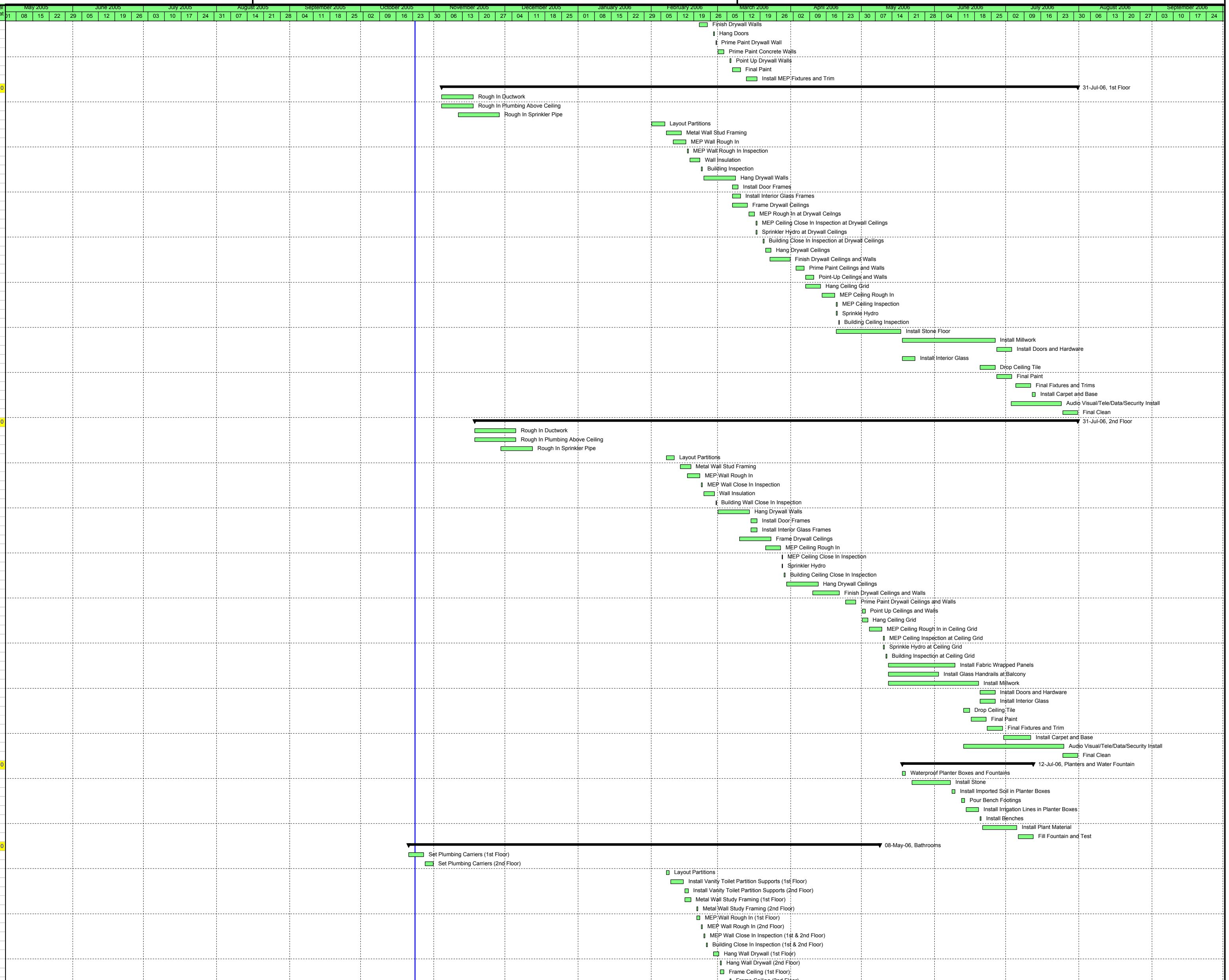


Actual Work | Critical Remaining Work | Summary
Remaining Work | Milestone

Page 1 of 3

TASK filter: All Activities

Activity ID	Activity Name	Original Duration	Start	Finish	Total Float
A4	Finish Drywall Walls	4	21-Feb-06	24-Feb-06	
A4	Hang Doors	1	27-Feb-06	27-Feb-06	
A4	Prime Paint Drywall Wall	1	28-Feb-06	28-Feb-06	
A4	Prime Paint Concrete W...	3	01-Mar-06	03-Mar-06	
A4	Point Up Drywall Walls	1	06-Mar-06	06-Mar-06	
A4	Final Paint	4	07-Mar-06	10-Mar-06	
A4	Install MEP Fixtures and ...	5	13-Mar-06	17-Mar-06	
1st Floor		186	04-Nov-05	31-Jul-06	0
A6	Rough In Ductwork	10	04-Nov-05	17-Nov-05	
A6	Rough In Plumbing Abov...	10	04-Nov-05	17-Nov-05	
A6	Rough In Sprinkler Pipe	10	11-Nov-05	28-Nov-05	
A6	Layout Partitions	4	01-Feb-06	06-Feb-06	
A6	Metal Wall Stud Framing	5	07-Feb-06	13-Feb-06	
A6	MEP Wall Rough In	4	10-Feb-06	15-Feb-06	
A6	MEP Wall Rough In Insp...	1	16-Feb-06	16-Feb-06	
A6	Wall Insulation	3	17-Feb-06	21-Feb-06	
A6	Building Inspection	1	22-Feb-06	22-Feb-06	
A6	Hang Drywall Walls	10	23-Feb-06	08-Mar-06	
A6	Install Door Frames	3	07-Mar-06	09-Mar-06	
A6	Install Interior Glass Fra...	4	07-Mar-06	10-Mar-06	
A6	Frame Drywall Ceilings	5	07-Mar-06	13-Mar-06	
A6	MEP Rough In at Drywall...	3	14-Mar-06	16-Mar-06	
A6	MEP Ceiling Close In Ins...	1	17-Mar-06	17-Mar-06	
A6	Sprinkler Hydro at Drywa...	1	17-Mar-06	17-Mar-06	
A6	Building Close In Inspecti...	1	20-Mar-06	20-Mar-06	
A6	Hang Drywall Ceilings	3	21-Mar-06	23-Mar-06	
A6	Finish Drywall Ceilings a...	7	23-Mar-06	31-Mar-06	
A6	Prime Paint Ceilings and...	4	03-Apr-06	06-Apr-06	
A6	Point-Up Ceilings and W...	2	07-Apr-06	10-Apr-06	
A6	Hang Ceiling Grid	5	07-Apr-06	13-Apr-06	
A6	MEP Ceiling Rough In	4	14-Apr-06	19-Apr-06	
A6	MEP Ceiling Inspection	1	20-Apr-06	20-Apr-06	
A6	Sprinkle Hydro	1	20-Apr-06	20-Apr-06	
A6	Building Ceiling Inspection	1	21-Apr-06	21-Apr-06	
A6	Install Stone Floor	20	20-Apr-06	17-May-06	
A6	Install Millwork	27	18-May-06	26-Jun-06	
A6	Install Doors and Hardware	5	27-Jun-06	03-Jul-06	
A6	Install Interior Glass	4	18-May-06	23-May-06	
A6	Drop Ceiling Tile	5	20-Jun-06	26-Jun-06	
A6	Final Paint	5	27-Jun-06	03-Jul-06	
A6	Final Fixtures and Trims	5	05-Jul-06	11-Jul-06	
A6	Install Carpet and Base	2	12-Jul-06	13-Jul-06	
A6	Audio Visual/Tele/Data/...	15	03-Jul-06	24-Jul-06	
A6	Final Clean	5	25-Jul-06	31-Jul-06	
2nd Floor		176	18-Nov-05	31-Jul-06	0
A7	Rough In Ductwork	10	18-Nov-05	05-Dec-05	
A7	Rough In Plumbing Abov...	10	18-Nov-05	05-Dec-05	
A7	Rough In Sprinkler Pipe	10	29-Nov-05	12-Dec-05	
A7	Layout Partitions	4	07-Feb-06	10-Feb-06	
A7	Metal Wall Stud Framing	5	13-Feb-06	17-Feb-06	
A7	MEP Wall Rough In	4	16-Feb-06	21-Feb-06	
A7	MEP Wall Close In Inspe...	1	22-Feb-06	22-Feb-06	
A7	Wall Insulation	3	23-Feb-06	27-Feb-06	
A7	Building Wall Close In In...	1	28-Feb-06	28-Feb-06	
A7	Hang Drywall Walls	10	01-Mar-06	14-Mar-06	
A7	Install Door Frames	3	15-Mar-06	17-Mar-06	
A7	Install Interior Glass Fra...	3	15-Mar-06	17-Mar-06	
A7	Frame Drywall Ceilings	10	10-Mar-06	23-Mar-06	
A7	MEP Ceiling Rough In	5	21-Mar-06	27-Mar-06	
A7	MEP Ceiling Close In Ins...	1	28-Mar-06	28-Mar-06	
A7	Sprinkler Hydro	1	28-Mar-06	28-Mar-06	
A7	Building Ceiling Close In ...	1	29-Mar-06	29-Mar-06	
A7	Hang Drywall Ceilings	10	30-Mar-06	12-Apr-06	
A7	Finish Drywall Ceilings a...	10	10-Apr-06	21-Apr-06	
A7	Prime Paint Drywall Ceili...	5	24-Apr-06	28-Apr-06	
A7	Point Up Ceilings and W...	2	01-May-06	02-May-06	
A7	Hang Ceiling Grid	3	01-May-06	03-May-06	
A7	MEP Ceiling Rough In in ...	4	04-May-06	09-May-06	
A7	MEP Ceiling Inspection ...	1	10-May-06	10-May-06	
A7	Sprinkle Hydro at Ceiling...	1	10-May-06	10-May-06	
A7	Building Inspection at Ce...	1	11-May-06	11-May-06	
A7	Install Fabric Wrapped P...	20	12-May-06	09-Jun-06	
A7	Install Glass Handrails at...	15	12-May-06	02-Jun-06	
A7	Install Millwork	26	12-May-06	19-Jun-06	
A7	Install Doors and Hardware	5	20-Jun-06	26-Jun-06	
A7	Install Interior Glass	5	20-Jun-06	26-Jun-06	
A7	Drop Ceiling Tile	3	13-Jun-06	15-Jun-06	
A7	Final Paint	5	16-Jun-06	22-Jun-06	
A7	Final Fixtures and Trim	5	23-Jun-06	29-Jun-06	
A7	Install Carpet and Base	7	30-Jun-06	11-Jul-06	
A7	Audio Visual/Tele/Data/...	30	13-Jun-06	25-Jul-06	
A7	Final Clean	5	25-Jul-06	31-Jul-06	
Planters and Water Fountain		38	18-May-06	12-Jul-06	0
A8	Waterproof Planter Boxe...	2	18-May-06	19-May-06	
A8	Install Stone	12	22-May-06	07-Jun-06	
A8	Install Imported Soil in Pl...	2	08-Jun-06	09-Jun-06	
A8	Pour Bench Footings	2	12-Jun-06	13-Jun-06	
A8	Install Irrigation Lines in ...	4	14-Jun-06	19-Jun-06	
A8	Install Benches	1	20-Jun-06	20-Jun-06	
A8	Install Plant Material	10	21-Jun-06	05-Jul-06	
A8	Fill Fountain and Test	5	06-Jul-06	12-Jul-06	
Bathrooms		138	21-Oct-05	08-May-06	0
A5	Set Plumbing Carriers (1...	5	21-Oct-05	27-Oct-05	
A5	Set Plumbing Carriers (2...	2	28-Oct-05	31-Oct-05	
A5	Layout Partitions	2	07-Feb-06	08-Feb-06	
A5	Install Vanity Toilet Partit...	4	09-Feb-06	14-Feb-06	
A5	Install Vanity Toilet Partit...	2	15-Feb-06	16-Feb-06	
A5	Metal Wall Study Framin...	3	15-Feb-06	17-Feb-06	
A5	Metal Wall Study Framin...	1	20-Feb-06	20-Feb-06	
A5	MEP Wall Rough In (1st ...	2	20-Feb-06	21-Feb-06	
A5	MEP Wall Rough In (2nd...	1	22-Feb-06	22-Feb-06	
A5	MEP Wall Close In Inspe...	1	23-Feb-06	23-Feb-06	
A5	Building Close In Inspecti...	1	24-Feb-06	24-Feb-06	
A5	Hang Wall Drywall (1st Fl...	3	27-Feb-06	01-Mar-06	
A5	Hang Wall Drywall (2nd F...	1	02-Mar-06	02-Mar-06	
A5	Frame Ceiling (1st Floor)	2	02-Mar-06	03-Mar-06	
A5	Frame Ceiling (2nd Floor)	1	06-Mar-06	06-Mar-06	



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

Page 2 of 3

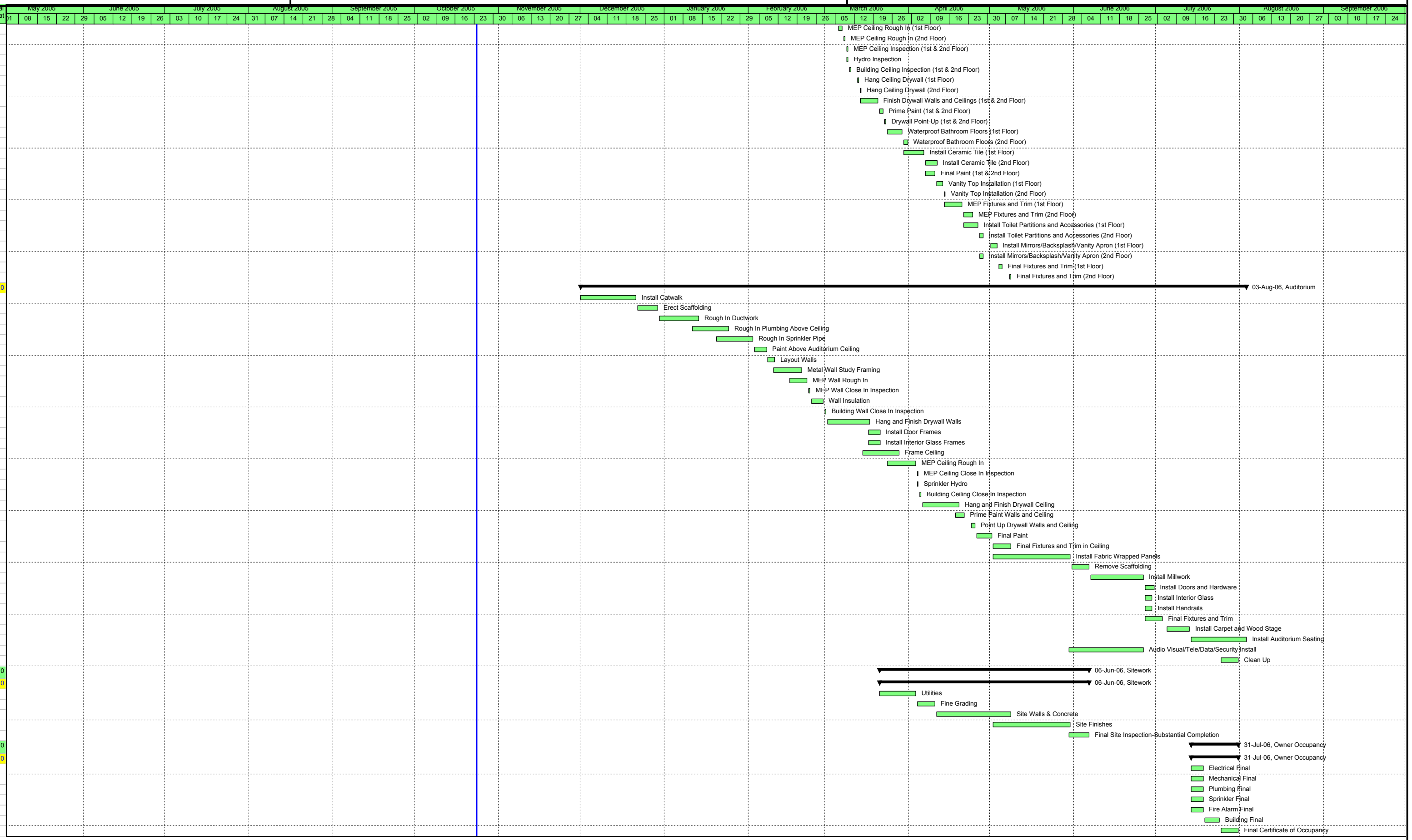
TASK filter: All Activities

Lecture Hall Construction - DAVIS

Classic WBS Layout

April 3, 2006

Activity ID	Activity Name	Original Duration	Start	Finish	Total Float
A51	MEP Ceiling Rough In (1...	2	06-Mar-06	07-Mar-06	
A51	MEP Ceiling Rough In (2...	1	08-Mar-06	08-Mar-06	
A51	MEP Ceiling Inspection (...	1	09-Mar-06	09-Mar-06	
A51	Hydro Inspection	1	09-Mar-06	09-Mar-06	
A51	Building Ceiling Inspectio...	1	10-Mar-06	10-Mar-06	
A51	Hang Ceiling Drywall (1st...	1	13-Mar-06	13-Mar-06	
A51	Hang Ceiling Drywall (2n...	1	14-Mar-06	14-Mar-06	
A51	Finish Drywall Walls and ...	5	14-Mar-06	20-Mar-06	
A52	Prime Paint (1st & 2nd Fl...	2	21-Mar-06	22-Mar-06	
A52	Drywall Point-Up (1st & ...	1	23-Mar-06	23-Mar-06	
A52	Waterproof Bathroom Fl...	4	24-Mar-06	29-Mar-06	
A52	Waterproof Bathroom Fl...	2	30-Mar-06	31-Mar-06	
A52	Install Ceramic Tile (1st ...	6	30-Mar-06	06-Apr-06	
A52	Install Ceramic Tile (2nd ...	3	07-Apr-06	11-Apr-06	
A52	Final Paint (1st & 2nd Flo...	2	07-Apr-06	10-Apr-06	
A52	Vanity Top Installation (1...	3	11-Apr-06	13-Apr-06	
A52	Vanity Top Installation (2...	1	14-Apr-06	14-Apr-06	
A52	MEP Fixtures and Trim (...	5	14-Apr-06	20-Apr-06	
A53	MEP Fixtures and Trim (...	2	21-Apr-06	24-Apr-06	
A53	Install Toilet Partitions an...	4	21-Apr-06	26-Apr-06	
A53	Install Toilet Partitions an...	2	27-Apr-06	28-Apr-06	
A53	Install Mirrors/Backsplas...	3	01-May-06	03-May-06	
A53	Install Mirrors/Backsplas...	2	27-Apr-06	28-Apr-06	
A53	Final Fixtures and Trim (...	2	04-May-06	05-May-06	
A53	Final Fixtures and Trim (...	1	08-May-06	08-May-06	
	Auditorium	172	01-Dec-05	03-Aug-06	0
A80	Install Catwalk	15	01-Dec-05	21-Dec-05	
A80	Erect Scaffolding	5	22-Dec-05	29-Dec-05	
A80	Rough In Ductwork	10	30-Dec-05	13-Jan-06	
A80	Rough In Plumbing Abov...	10	11-Jan-06	24-Jan-06	
A80	Rough In Sprinkler Pipe	10	20-Jan-06	02-Feb-06	
A80	Paint Above Auditorium ...	3	03-Feb-06	07-Feb-06	
A80	Layout Walls	3	08-Feb-06	10-Feb-06	
A80	Metal Wall Study Framing	7	10-Feb-06	20-Feb-06	
A80	MEP Wall Rough In	5	16-Feb-06	22-Feb-06	
A80	MEP Wall Close In Inspe...	1	23-Feb-06	23-Feb-06	
A80	Wall Insulation	3	24-Feb-06	28-Feb-06	
A81	Building Wall Close In In...	1	01-Mar-06	01-Mar-06	
A81	Hang and Finish Drywall ...	12	02-Mar-06	17-Mar-06	
A81	Install Door Frames	3	17-Mar-06	21-Mar-06	
A81	Install Interior Glass Fra...	3	17-Mar-06	21-Mar-06	
A81	Frame Ceiling	10	15-Mar-06	28-Mar-06	
A81	MEP Ceiling Rough In	7	24-Mar-06	03-Apr-06	
A81	MEP Ceiling Close In Ins...	1	04-Apr-06	04-Apr-06	
A81	Sprinkler Hydro	1	04-Apr-06	04-Apr-06	
A81	Building Ceiling Close In ...	1	05-Apr-06	05-Apr-06	
A81	Hang and Finish Drywall ...	10	06-Apr-06	19-Apr-06	
A82	Prime Paint Walls and C...	4	18-Apr-06	21-Apr-06	
A82	Point Up Drywall Walls a...	2	24-Apr-06	25-Apr-06	
A82	Final Paint	4	26-Apr-06	01-May-06	
A82	Final Fixtures and Trim in...	5	02-May-06	08-May-06	
A82	Install Fabric Wrapped P...	20	02-May-06	30-May-06	
A82	Remove Scaffolding	5	31-May-06	06-Jun-06	
A82	Install Millwork	14	07-Jun-06	26-Jun-06	
A82	Install Doors and Hardware	4	27-Jun-06	30-Jun-06	
A82	Install Interior Glass	3	27-Jun-06	29-Jun-06	
A82	Install Handrails	3	27-Jun-06	29-Jun-06	
A83	Final Fixtures and Trim	5	27-Jun-06	03-Jul-06	
A83	Install Carpet and Wood ...	7	05-Jul-06	13-Jul-06	
A83	Install Auditorium Seating	15	14-Jul-06	03-Aug-06	
A83	Audio Visual/Tele/Data/...	20	30-May-06	26-Jun-06	
A83	Clean Up	5	25-Jul-06	31-Jul-06	
	Sitework	55	21-Mar-06	06-Jun-06	0
	Sitework	55	21-Mar-06	06-Jun-06	0
A26	Utilities	10	21-Mar-06	03-Apr-06	
A27	Fine Grading	5	04-Apr-06	10-Apr-06	
A28	Site Walls & Concrete	20	11-Apr-06	08-May-06	
A29	Site Finishes	20	02-May-06	30-May-06	
A30	Final Site Inspection-Sub...	6	30-May-06	06-Jun-06	
	Owner Occupancy	12	14-Jul-06	31-Jul-06	0
	Owner Occupancy	12	14-Jul-06	31-Jul-06	0
1000	Electrical Final	3	14-Jul-06	18-Jul-06	
1010	Mechanical Final	3	14-Jul-06	18-Jul-06	
1020	Plumbing Final	3	14-Jul-06	18-Jul-06	
1030	Sprinkler Final	3	14-Jul-06	18-Jul-06	
1040	Fire Alarm Final	3	14-Jul-06	18-Jul-06	
1050	Building Final	4	19-Jul-06	24-Jul-06	
980	Final Certificate of Occu...	5	25-Jul-06	31-Jul-06	



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

TASK filter: All Activities

Appendix C – Research Survey

Partnering for Value Engineering

Company: ______________________________ ***Years in Industry:*** ______________________
Name (optional): ________________________ ***Current Project Type:*** ___________________
Position: _______________________________ ***Delivery Method:*** _______________________

The first section of the questionnaire consists of 6 questions related to Value Engineering and similar activities. Please respond to each question regarding your current project. Additional comments to increase understanding of the answers may be added at the conclusion of this survey.

1. Please verify the approximate release dates of Design Documents listed on the timeline below.

   50% (__________) 75% (__________) 100% (__________)

2. On the timeline above, please indicate when value engineering was first performed.
3. Do you feel that the timing of the VE process was appropriate for your given project? If not, why and how could it be improved?
4. In the table below, please indicate the percentage of value engineering time which was directed to *reducing costs versus adding value*. (ie: 90% Reduce cost/10% Add Value)

Reduce cost to meet budget	**Add value** to better meet goals

5. In the table below, indicate which entities were the sources of VE suggestions.

______%	Owner
______%	Architect
______%	Engineer
______%	GC/CM

100% Total

6. What steps were taken to identify the Owner's needs and priorities *prior to the Value Engineering process*?

The second section of the questionnaire consists of 9 positive statements to which you are requested to indicate how much you strongly agree (5) or strongly disagree (1). Please rate the accompanying statements to indicate how you feel in relation to the other project teams on your current job.

1. I feel I am working in a trusting environment: ____
2. I feel I am working in a positive atmosphere and being respected: ____
3. I feel that good communication is being maintained: ____
4. I feel that working relationships are honest and upheld with integrity: ____
5. I feel that I am working in a team, with no exclusions: ____
6. When disputes arise, I feel that they are being resolved in a timely manner: ____
7. I feel that disputes are being resolved considering the needs of everyone: ____
8. I feel that every party is contributing to the overall goal of the Contract: ____
9. I feel that every party is working to minimize waste from design and construction: ____

The final section of the questionnaire consists of 2 short answer questions related to Value Engineering. Please respond to each question that may apply to your current project.

1. What are the attributes of successful VE processes?

2. How would you define success for your current project?

Thank you for participating in this survey. For your convenience, please email this attachment to sce120@psu.edu or print the survey out and fax your response to (814) 863-4789 Attention: Sean Ehlers.

Appendix D – Catwalk Calculations

Steel Catwalk Load Calculations:

Assumptions:

- Considering HSS 5x5x5/16 hangers and W8x28 girders are the critical members
- The catwalk is 1' wide, with largest spans of 25'
- Load requirements are 40 PSF LL and 20 PSF DL

HSS 5x5x5/16 hanger –

Tributary Area = 25' x 1' = 25 ft^2

1.2(20 PSF) + 1.6(40 PSF) = 88 PSF

25 ft^2 x 88 PSF = 2,000 lb

Stress = P/A = 2.2 kips / 8.42 in^2 = 0.27 ksi < 50 ksi

W8x28 girder –

W = 88 PSF x 1' = 88 PLF

V_u = (wl)/2 = (88 PLF x 25 ft)/2 = 1,100 lbs

M_u = $(wl^2)/8$ = [8 PLF x $(25ft)^2$]/8 = 6,875 ft-lbs

*DL & LL: $\Delta = (5wl^4)/384EI$

= [5 x 88 PLF x $(25ft)^4$ x 1728 in^3] / (384 x 29e3 ksi x 98 in^4 x 1,000 lbs) = 0.272 in

0.272 in < 0.625 = (25 ft x 12 in/ft) / 480

*LL: $\Delta = (5wl^4)/384EI$

= 5 x 64 PLF x $(25ft)^4$ x 1728 in^3] / (384 x 29e3 ksi x 98 in^4 x 1,000 lbs) = 0.198 in

0.198 in < 0.833 = (25 ft x 12 in/ft) / 360

$Z_{required} = M_u / \Phi_b F_y$ = (6,875 ft-lbs x 12 in) / (0.9 x 50 ksi x 1,000lbs) = 1.83 in^3

Aluminum Catwalk Load Calculations:

Assumptions:

- Considering HSS 4x4x3/16 hangers and W10x210 girders are the critical members
- The catwalk is 1' wide, with largest spans of 25'
- Load requirements are 40 PSF LL and 20 PSF DL
- F_y = 35 ksi and E = 10e3 ksi for alloy 6061-T6
- Additional material characteristics are to be that of steel, allowing for the same equations

HSS 4x4x3/16 hanger –

Stress = P/A = 2.2 kips / 2.87 in2 = 0.77 ksi < 35 ksi

W8x28 girder –

W = 88 PSF x 1' = 88 PLF

V_u = (wl)/2 = (88 PLF x 25 ft)/2 = 1,100 lbs

M_u = $(wl^2)/8$ = [8 PLF x $(25ft)^2$]/8 = 6,875 ft-lbs

*DL & LL: $\Delta = (5wl^4)/384EI$

= [5 x 88 PLF x $(25\ ft)^4$ x 1728 in^3] / (384 x 10e3 ksi x 155.8 in^4 x 1,000 lbs) = 0.496 in

0.496 in < 0.625 = (25 ft x 12 in/ft) / 480

*LL: $\Delta = (5wl^4)/384EI$

= [5 x 64 PLF x $(25\ ft)^4$ x 1728 in^3] / (384 x 10e3 ksi x 155.8in^4 x 1,000 lbs) = 0.198 in

0.37 in < 0.833 = (25 ft x 12 in/ft) / 360

FRP Catwalk Load Calculations:

No calculations were evaluated for this section. E.T. Techtonics estimator considered the 40 PSF live load and 20 PSF deal load.

Wood Catwalk Load Calculations:

No calculations were evaluated for this section. The steel hangers remained in this design and have already been checked. Manufactured I-beams were recommended by a Georgia-Pacific Product Guide.

Appendix E – Detailed Catwalk Estimations

Table 12. Detailed Steel Catwalk Estimate

Main Strip (2)

Quantity	Type	Lb/ft	Length (ft)	Weight (lbs)	Total Weight	Labor ($/LF)	Labor ($)	Total Labor
4	W8x28	28	12	336	1344.0	3.96	47.52	190.08
4	W8x28	28	25	700	2800.0	3.96	99.00	396.00
4	W8x28	28	25	700	2800.0	3.96	99.00	396.00
4	W8x28	28	9	252	1008.0	3.96	35.64	142.56
8	L 5x31/2x5/16	8.72	12	104.64	837.1	7.10	85.20	681.60
8	L 5x31/2x5/16	8.72	25	218	1744.0	7.10	177.50	1420.00
8	L 5x31/2x5/16	8.72	25	218	1744.0	7.10	177.50	1420.00
8	L 5x31/2x5/16	8.72	9	78.48	627.8	7.10	63.90	511.20
26	W6x12	12	2	24	624.0	3.63	7.26	188.76
24	L 4x4x3/8	9.72	6	58.32	1399.7	7.00	42.00	1008.00
32	HSS 4x4x5/16	14.8	3.5	51.8	1657.6	9.00	31.50	1008.00
20	HSS 5x5x5/16	19	10	190	3800.0	30.00	300.00	6000.00
80	L 3x3x1/4	4.89	4	19.56	1564.8	6.85	27.40	2192.00
				Cum Weight	21951.0		Labor Cost	$ 15,554.20
				Cum Tonnage	10.98		Material Cost	$ 21,951.04
							Total Cost	$ 37,505.24

Middle Wing (2)

Quantity	Type	Lb/ft	Length (ft)	Weight (lbs)	Total Weight	Labor ($/LF)	Labor ($)	Total Labor
4	W8x28	28	14	392	1568.0	3.96	55.44	221.76
6	W6x12	12	2	24	144.0	3.63	7.26	43.56
6	L 4x4x3/8	9.72	6	58.32	349.9	7.00	42.00	252.00
8	HSS 4x4x5/16	14.8	3.5	51.8	414.4	9.00	31.50	252.00
4	HSS 5x5x5/16	19	10	190	760.0	30.00	300.00	1200.00
24	L 3x3x1/4	4.89	4	19.56	469.4	6.85	27.40	657.60
				Cum Weight	3705.8		Labor Cost	$2,626.92
				Cum Tonnage	1.85		Material Cost	$3,705.76
							Total Cost	$6,332.68

Middle Strip

Quantity	Type	Lb/ft	Length (ft)	Weight (lbs)	Total Weight	Labor ($/LF)	Labor ($)	Total Labor
4	W8x28	28	20	560	2240.0	3.96	79.20	316.80
2	W8x28	28	18	504	1008.0	3.96	71.28	142.56
8	L 5x31/2x5/16	8.72	20	174.4	1395.2	7.10	142.00	1136.00
4	L 5x31/2x5/16	8.72	18	156.96	627.8	7.10	127.80	511.20
8	W6x12	12	2	24	192.0	3.63	7.26	58.08
9	L 4x4x3/8	9.72	6	58.32	524.9	7.00	42.00	378.00
12	HSS 4x4x5/16	14.8	3.5	51.8	621.6	9.00	31.50	378.00
9	HSS 5x5x5/16	19	10	190	1710.0	30.00	300.00	2700.00
40	L 3x3x1/4	4.89	4	19.56	782.4	6.85	27.40	1096.00
5	W8x28	28	4	112	560.0	3.96	15.84	79.20
3	W8x28	28	9	252	756.0	3.96	35.64	106.92
				Cum Weight	10417.9		Labor Cost	$6,902.76
				Cum Tonnage	5.21		Material Cost	$10,417.92
							Total Cost	$17,320.68

Top Tail

Quantity	Type	Lb/ft	Length (ft)	Weight (lbs)	Total Weight	Labor ($/LF)	Labor ($)	Total Labor
1	W8x28	28	5	140	140.0	3.96	19.80	19.80
1	W10x30	30	5	150	150.0	2.48	12.40	12.40
4	L 5x31/2x5/16	8.72	5	43.6	174.4	7.10	35.50	142.00
4	L 3x3x1/4	4.89	4	19.56	78.2	6.85	27.40	109.60
2	HSS 5x5x5/16	19	10	190	380.0	30.00	300.00	600.00
2	HSS 4x4x5/16	14.8	3.5	51.8	103.6	9.00	31.50	63.00
2	W6x12	12	2	24	48.0	3.63	7.26	14.52
				Cum Weight	1074.2		Labor Cost	$961.32
				Cum Tonnage	0.54		Material Cost	$1,074.24
							Total Cost	$2,035.56

Metal Grating

Width (ft)	Length (ft)	Ft^2	Material ($/ft^2)	Material ($)	Labor ($/ft^2)	Labor ($)	Total Cost
2	240	480	10.00	4800.00	2.00	960.00	5760.00
						Total Cost	$5,760.00

Cum Total	$ 68,954.16
Sub Profit	+10%
Final Total	$ 75,849.58

Table 13. Detailed Aluminum Catwalk Estimate

	Quantity	Type	Lb/ft	Length (ft)	Weight (lbs)	Total Weight	Material ($/lb)	Material ($)	Labor ($/lb)	Labor ($)	Total Cost
Main Strip (2)	4	W10x10	10.286	12	123.432	493.7	2.19	1081.26	1.64	809.71	1890.98
	4	W10x10	10.286	25	257.15	1028.6	2.19	2252.63	1.64	1686.90	3939.54
	4	W10x10	10.286	25	257.15	1028.6	2.19	2252.63	1.64	1686.90	3939.54
	4	W10x10	10.286	9	92.574	370.3	2.19	810.95	1.64	607.29	1418.23
	8	L 5x5x3/8	4.28	12	51.36	410.9	2.19	899.83	1.64	673.84	1573.67
	8	L 5x5x3/8	4.28	25	107	856.0	2.19	1874.64	1.64	1403.84	3278.48
	8	L 5x5x3/8	4.28	25	107	856.0	2.19	1874.64	1.64	1403.84	3278.48
	8	L 5x5x3/8	4.28	9	38.52	308.2	2.19	674.87	1.64	505.38	1180.25
	26	W8x7	7.023	2	14.046	365.2	2.19	799.78	1.64	598.92	1398.70
	24	L 4x4x1/2	4.41	6	26.46	635.0	2.19	1390.74	1.64	1041.47	2432.20
	32	HSS 4x4x3/16	3.44	3.5	12.04	385.3	2.19	843.76	1.64	631.86	1475.62
	20	HSS 4x4x3/16	3.44	10	34.4	688.0	2.19	1506.72	1.64	1128.32	2635.04
	80	L 3x3x1/4	1.68	4	6.72	537.6	2.19	1177.34	1.64	881.66	2059.01
										Total Cost	$ 30,499.75
Middle Wing (2)	4	W10x10	10.286	14	144.004	576.0	2.19	1261.5	1.64	944.67	2206.14
	6	W8x7	7.023	2	14.046	84.3	2.19	184.6	1.64	138.21	322.78
	6	L 4x4x1/2	4.41	6	26.46	158.8	2.19	347.7	1.64	260.37	608.05
	8	HSS 4x4x3/16	3.44	3.5	12.04	96.3	2.19	210.9	1.64	157.96	368.91
	4	HSS 4x4x3/16	3.44	10	34.4	137.6	2.19	301.3	1.64	225.66	527.01
	24	L 3x3x1/4	1.68	4	6.72	161.3	2.19	353.2	1.64	264.50	617.70
										Total Cost	$4,650.59
Middle Strip	4	W10x10	10.286	20	205.72	822.9	2.19	1802.1	1.64	1349.52	3151.63
	2	W10x10	10.286	18	185.148	370.3	2.19	810.9	1.64	607.29	1418.23
	8	L 5x5x3/8	4.28	20	85.6	684.8	2.19	1499.7	1.64	1123.07	2622.78
	4	L 5x5x3/8	4.28	18	77.04	308.2	2.19	674.9	1.64	505.38	1180.25
	8	W8x7	7.023	2	14.046	112.4	2.19	246.1	1.64	184.28	430.37
	9	L 4x4x1/2	4.41	6	26.46	238.1	2.19	521.5	1.64	390.55	912.08
	12	HSS 4x4x3/16	3.44	3.5	12.04	144.5	2.19	316.4	1.64	236.95	553.36
	9	HSS 4x4x3/16	3.44	10	34.4	309.6	2.19	678.0	1.64	507.74	1185.77
	40	L 3x3x1/4	1.68	4	6.72	268.8	2.19	588.7	1.64	440.83	1029.50
	5	W10x10	10.286	4	41.144	205.7	2.19	450.5	1.64	337.38	787.91
	3	W10x10	10.286	9	92.574	277.7	2.19	608.2	1.64	455.46	1063.68
										Total Cost	$14,335.56
Top Tail	1	W10x10	10.286	5	51.43	51.4	2.19	112.6	1.64	84.35	196.98
	1	W10x8	8.76	5	43.8	43.8	2.19	95.9	1.64	71.83	167.75
	4	L 5x5x3/8	4.28	5	21.4	85.6	2.19	187.5	1.64	140.38	327.85
	4	L 3x3x1/4	1.68	4	6.72	26.9	2.19	58.9	1.64	44.08	102.95
	2	HSS 4x4x3/16	3.44	10	34.4	68.8	2.19	150.7	1.64	112.83	263.50
	2	HSS 4x4x3/16	3.44	3.5	12.04	24.1	2.19	52.7	1.64	39.49	92.23
	2	W8x7	7.023	2	14.046	28.1	2.19	61.5	1.64	46.07	107.59
										Total Cost	$1,258.85

	Width (ft)	Length (ft)	Ft^2	Material ($/ft^2)	Material ($)	Labor ($/ft^2)	Labor ($)	Total Cost
Metal Grating	2	240	480	10.00	4800.00	2.00	960.00	5760.00
							Total Cost	$5,760.00

Cum Total	$ 56,504.74
Sub Profit	+10%
Final Total	$ 62,155.22

Table 14. Detailed Wood Catwalk Estimate

Main Strip (2)

Quantity	Type	Length (ft)	Total Length	Material ($/LF)	Material ($)	Labor ($/LF)	Labor ($)	Total Cost
4	GPI 40	12	48.0	2.23	107.0	0.51	24.48	131.52
8	GPI 40	13	104.0	2.23	231.9	0.51	53.04	284.96
8	GPI 40	13	104.0	2.23	231.9	0.51	53.04	284.96
4	GPI 40	9	36.0	2.23	80.3	0.51	18.36	98.64
8	2x6	12	96.0	0.59	56.6	0.57	54.72	111.36
8	2x6	25	200.0	0.59	118.0	0.57	114.00	232.00
8	2x6	25	200.0	0.59	118.0	0.57	114.00	232.00
8	2x6	9	72.0	0.59	42.5	0.57	41.04	83.52
26	2x10	2	52.0	1.29	67.1	0.66	34.32	101.40
24	2x10	6	144.0	1.29	185.8	0.66	95.04	280.80
24	4x4 Columns	3.5	84.0	2.34	196.6	0.89	74.76	271.32
80	2x4	4	320.0	0.37	118.4	0.32	102.40	220.80
							Total Cost	$ 2,333.28

Middle Wing (2)

Quantity	Type	Length (ft)	Total Length	Material ($/LF)	Material ($)	Labor ($/LF)	Labor ($)	Total Cost
4	GPI 40	14	56.0	2.23	124.9	0.51	28.56	153.44
6	2x10	2	12.0	1.29	15.5	0.66	7.92	23.40
6	2x10	6	36.0	1.29	46.4	0.66	23.76	70.20
8	4x4 Columns	3.5	28.0	2.34	65.5	0.89	24.92	90.44
24	2x4	4	96.0	0.37	35.5	0.32	30.72	66.24
							Total Cost	$403.72

Middle Strip

Quantity	Type	Length (ft)	Total Length	Material ($/LF)	Material ($)	Labor ($/LF)	Labor ($)	Total Cost
4	GPI 65	20	80.0	2.23	178.4	0.51	40.80	219.20
2	GPI 65	18	36.0	2.23	80.3	0.51	18.36	98.64
8	2x6	20	160.0	0.59	94.4	0.57	91.20	185.60
4	2x6	18	72.0	0.59	42.5	0.57	41.04	83.52
8	2x10	2	16.0	1.29	20.6	0.66	10.56	31.20
9	2x10	6	54.0	1.29	69.7	0.66	35.64	105.30
12	4x4 Columns	3.5	42.0	2.34	98.3	0.89	37.38	135.66
40	2x4	4	160.0	0.37	59.2	0.32	51.20	110.40
5	GPI 25	4	20.0	2.23	44.6	0.51	10.20	54.80
3	GPI 25	9	27.0	2.23	60.2	0.51	13.77	73.98
							Total Cost	$1,098.30

Top Tail

Quantity	Type	Length (ft)	Total Length	Material ($/LF)	Material ($)	Labor ($/LF)	Labor ($)	Total Cost
2	GPI 40	5	10.0	2.23	22.3	0.51	5.10	27.40
4	2x6	5	20.0	0.59	11.8	0.57	11.40	23.20
4	2x4	4	16.0	0.37	5.9	0.32	5.12	11.04
2	4x4 Columns	3.5	7.0	2.34	16.4	0.89	6.23	22.61
2	2x10	2	4.0	1.29	5.2	0.66	2.64	7.80
							Total Cost	$92.05

Hangers

Quantity	Type	Lb/ft	Length (ft)	Weight (lbs)	Total Weight	Labor ($/LF)	Labor ($)	Total Labor
4	W10x30	30	9	270	1080	2.48	22.32	89.28
43	HSS 5x5x5/16	19	10	190	8170.0	30.00	300.00	12900.00
				Cum Weight	9250.0		Labor Cost	$12,989.28
				Cum Tonnage	4.63		Material Cost	$9,250.00
							Total Cost	$22,239.28

Metal Grating

Width (ft)	Length (ft)	Ft^2	Material ($/ft^2)	Material ($)	Labor ($/ft^2)	Labor ($)	Total Cost
2	240	480	10.00	4800.00	2.00	960.00	5760.00
						Total Cost	$5,760.00

Cum Total	$ 31,926.63
Sub Profit	+10%
Final Total	$ 35,119.29

Appendix F – Mechanical Calculations

Geothermal Heat Pump:

In order to estimate the size of units needed for this system, the boiler MBtu/hr (1,000 British thermal units per hour) must be calculated. As an aside, Btu's are a unit of energy used in the United States and is defined as the amount of heat required to raise the temperature of one of water by one degree Fahrenheit.

Provided in the mechanical schedule, the two boilers have an entering water temperature of 140°F and a leaving water temperature of 180°F. Moreover, they are designed to provide the Lecture hall space with 67 gallons of water per minute (gpm). The sensible cooling load equation to follow can be utilized to help convert the 40°F change and 67 gpm into MBtu/hr.

$Q = C_p \times \cdot m \times \Delta T$, where

Q = total heat

C_p = specific heat of water at 80°F and 1atm

$\cdot m$ = mass flow rate of water

ΔT = change in temperature

This equation will change to $Q = C_p \times \cdot V \times \rho \times \Delta T$ since we have a volumetric flow per minute, where:

$\cdot V$ = volume flow rate

ρ = density of water at 80°F and 1 atm

a = conversion from gpm to cfm

$\cdot V$ = a x gpm = (0.133681 ft2/min / gal/min) x 67 gpm = 8.957 cfm

C_p = 0.9991 Btu/lbm-R

ΔT = 40°F

$\rho = 62.22\ lb_m/ft^3$

Substituting these numbers gives us Q = 22271Btu/min. Multiplying this by 60 min/hr and dividing by 1,000 Btu/MBtu = 1,336 MBtu/hr. In order to satisfy the existing boiler system, heat pumps will have to supply the Lecture Hall with around 1,336 MBtu/hr.

Electric Heating Coils:

As calculated above, the estimated heating load at the air handling units is 1,336 MBtu/hr. Looking at the three different air handling units and the spaces they serve, it is important to get an idea of mixed air temperatures within each system and calculate their sensible heating capacity. Depending on the amount of MBtu/hr, one can get an idea of the required heat coil demands for sizing. Speaking with Capital One's MEP engineer, supply and mixed air temperatures were obtained. The following numbers are at full load, design conditions in the worst case scenario.

- AHU-1 services the offices with 4,800 cfm, needing 77.5°F supply air from 48.9°F mixed air
- AHU-2 services the atrium with 19,200 cfm, needing 75.8°F supply air from 43.9°F mixed air
- AHU-3 services the auditorium with 10,725 cfm, needing 72.4°F supply air from 33°F mixed air

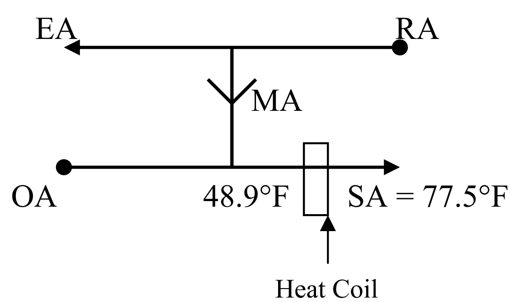
Using the same $Q = C_p \times \cdot m \times \Delta T$ equation as before, but adjusting it for air because the heating no longer deals with water, gives us Q = 1.08 x cfm x ΔT. The 1.08 includes the density of air, C_p and conversion factors for air only. The sum of all these quantities should be approximately the same value as the 1,336 MBtu/hr calculated before for the geothermal heat pump system.

For AHU-1: $Q_1 = 1.08 \times cfm \times \Delta T$

$Q_1 = 1.08 \times 4800cfm \times (77.5°F - 48.9°F)$

$Q_1 = 148.1$ MBtu/hr

Figure 14. Heat Coil Schematic for AHU-1



For AHU-2: $Q_2 = 1.08 \times cfm \times \Delta T$

$Q_2 = 1.08 \times 19{,}200cfm \times (75.8°F – 43.9°F)$

$Q_2 = 456.3$ MBtu/hr

For AHU-2: $Q_3 = 1.08 \times cfm \times \Delta T$

$Q_3 = 1.08 \times 19{,}200cfm \times (72.4°F - 33°F)$

$Q_3 = 659.7$ MBtu/hr

Lastly, in order to calculate the required amount of energy for the electric heat coils, divide each coil's MBtu/hr by 3.412 to obtain kilowatts (kW). This will give us 44 kW for coil #1, 194 kW for #2, and 134 kW for #3.

Appendix G – Shoring Calculations

*** Earth Pressure for Common Conditions of Loading:**

Assumptions:

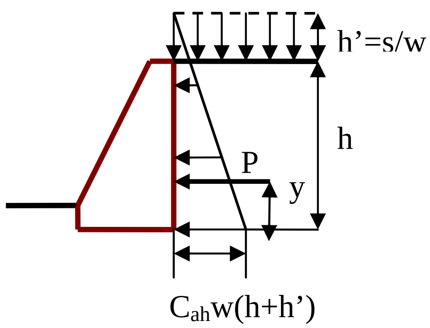
- Backfill material is considered "silty sands, poorly graded sand-silt mixes"
- As stated in the Subsurface Exploration and Geotechnical Engineering Analysis, the active soil pressure is 45 lbs/sf of depth and the at-rest soil pressure is 60 lbs/sf of depth
- Backfill height will be for the worst case scenario of 9'
- Soil surcharge (s) from the backhoe and roller drum will be 115 lb/ft^2
- Unit weight (w) of the soil is 110 pcf
- PAmax for Ulma posts = 8,500 lbs

$h' = s/w$

$y = \frac{h^2 + 3hh'}{3(h + 2h')}$

$P = 1/2 C_{ah} wh(h+2h')$

Figure 15. Earth Pressure
(horizontal surface with surcharge)



Finding the soil force per horizontal foot –

$C_{ah}wh$ = 60 x height

y = h/3 = 9 ft / 3 = 3 ft

P = ½ x 60 x (9ft)^2 = 2,430 lb/horizontal foot

h' = 1.05 ft

y = [(9ft)^2 + 3 x 9ft x 1.05ft] / [3 x (9ft x 2 x 1.05ft)] = 3.28 ft

P = ½ x 60 x 9ft (9 ft x 2 x 1.05 ft) = 2,997 lbs/horizontal foot

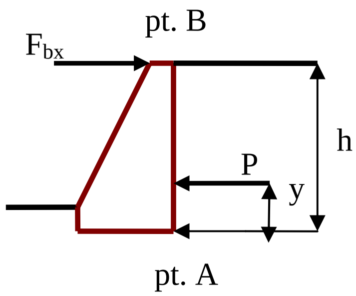
Finding the axial load in the shoring –

h = 9'

y = 3.28 '

P = 2,997 lbs

Figure 16. Free Body Diagram



Sum of Moments about pt. A =

2,997 lbs (3.28') – F_{bx} (9') = 0

F_{bx} = 1093 lbs

To find the axial load in the Ulma post –

($1093^2 + 1093^2$) ^ ½ = 1546 lbs

Assuming each post has a max PA of 8,500 lbs, shores have to be spaced between 5 and 6 feet on-center along the face of the walls.

***Nilson 2004**

Appendix H – General Conditions

For the two following tables, only the major management and labor costs have been included. The first table represents the DAVIS' exact estimates provided to Capital One within their GMP contract. Within the **Foundation Shoring and Sequencing** analysis, approximately 4 weeks of construction time could have been removed, had DAVIS implemented a revised schedule. In order to evaluate a cost difference between the two timetables, four weeks have been removed from appropriate employee's unit quantities in the second table.

Table 10. Actual General Conditions

			Material		Labor		Material	Labor
SUPERVISION & PROJECT MANAGEMENT	Quantity	Unit	Rate	Cost	Rate	Cost	Total Cost	Total Cost
Vice President	N/A		In Fee					
Project Executive	N/A		In Fee					
Project Manager	52	Wks	N/A		$1,395	$72,540	$0	$72,540
Assistant Project Manager	52	Wks	N/A		$1,005	$52,260	$0	$52,260
Senior Superintendent	52	Wks	N/A		$2,117	$110,084	$0	$110,084
Superintendent	44	Wks	N/A		$1,313	$57,772	$0	$57,772
MEP Coordinator	5	Wks	N/A		$1,000	$5,000	$0	$5,000
Senior Layout Engineer	26	Wks	N/A		$791	$20,566	$0	$20,566
Layout Engineer	26	Wks	N/A		$450	$11,700	$0	$11,700
Total Supervision & Management						**$329,922**	**$0**	**$329,922**

			Material		Labor		Material	Labor
MISCELLANEOUS LABOR	Quantity	Unit	Rate	Cost	Rate	Cost	Total Cost	Total Cost
Misc. Labor	52	Wks	N/A		$697.85	$36,288	$0	$36,288
Courier	52	Wks	N/A		$110.90	$5,767	$0	$5,767
Dump Truck - Driver	40	Hrs	N/A		$114.14	$4,566	$0	$4,566
Total Miscellaneous Labor						**$46,621**	**$0**	**$46,621**

			Material		Labor		Material	Labor
CATEGORY TOTALS	Quantity	Unit	Rate	Cost	Rate	Cost	Total Cost	Total Cost
Supervision & Project Management							$0	$329,922
Miscellaneous Labor							$0	$46,621
Subtotal							**$0**	**$376,543**
Insurance & Employee Benefits	46	%					$0	$173,210
Total General Conditions							**$0**	**$549,752**
GRAND TOTAL								**$549,752**

Table 11. Revised General Conditions

SUPERVISION & PROJECT MANAGEMENT	Quantity	Unit	Material Rate	Material Cost	Labor Rate	Labor Cost	Material Total Cost	Labor Total Cost
Vice President	N/A		In Fee					
Project Executive	N/A		In Fee					
Project Manager	48	Wks	N/A		$1,395	$66,960	$0	$66,960
Assistant Project Manager	48	Wks	N/A		$1,005	$48,240	$0	$48,240
Senior Superintendent	48	Wks	N/A		$2,117	$101,616	$0	$101,616
Superintendent	40	Wks	N/A		$1,313	$52,520	$0	$52,520
MEP Coordinator	5	Wks	N/A		$1,000	$5,000	$0	$5,000
Senior Layout Engineer	26	Wks	N/A		$791	$20,566	$0	$20,566
Layout Engineer	26	Wks	N/A		$450	$11,700	$0	$11,700
Total Supervision & Management						**$306,602**	**$0**	**$306,602**

MISCELLANEOUS LABOR	Quantity	Unit	Material Rate	Material Cost	Labor Rate	Labor Cost	Material Total Cost	Labor Total Cost
Misc. Labor	48	Wks	N/A		$697.85	$33,497	$0	$33,497
Courier	48	Wks	N/A		$110.90	$5,323	$0	$5,323
Total Miscellaneous Labor						**$38,820**	**$0**	**$38,820**

CATEGORY TOTALS	Quantity	Unit	Material Rate	Material Cost	Labor Rate	Labor Cost	Material Total Cost	Labor Total Cost
Supervision & Project Management							$0	$306,602
Miscellaneous Labor							$0	$38,820
Subtotal							**$0**	**$345,422**
Insurance & Employee Benefits	46	%					$0	$158,894
Total General Conditions							**$0**	**$504,316**
GRAND TOTAL								**$504,316**

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