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C O N S T R U C T I O N M A N A G E M E N T
D R . M I C H A E L H O R M A N

FINAL REPORT

OFFICE/RETAIL BUILDING
WASHINGTON, D.C.

S U B M I T T E D : A P R I L 0 9 , 2 0 0 8

Office/Retail Building - Washington, D.C.

PROJECT TEAM

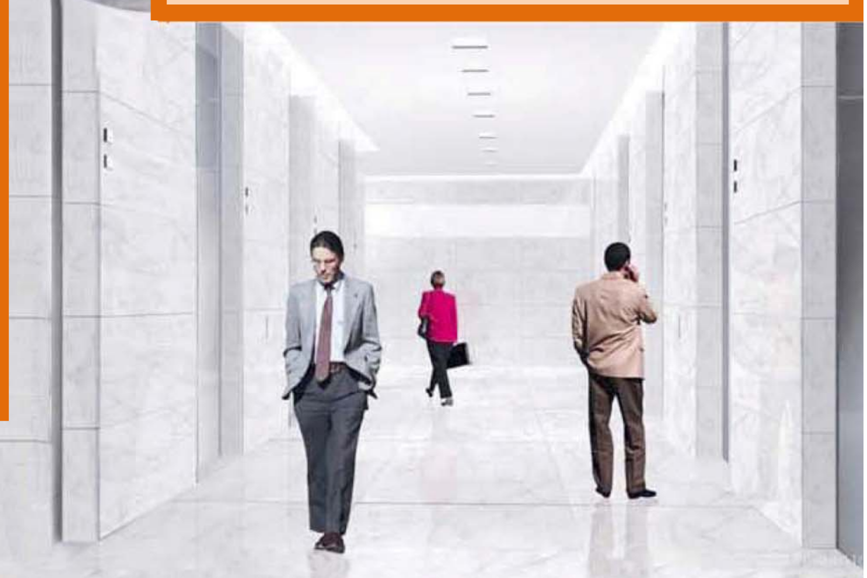
Owner: (undisclosed per owner's request)
General Contractor: Balfour Beatty Construction
Architect: WDG Architecture, PLLC
Structural Engineer: SK&A Structural Engineers, PLLC
Civil Engineer: A. Morton Thomas & Associates, Inc.
MEP Consultant: GHT Limited
Landscape Architect: Peter Liu Associates, Inc.
Curtain Wall Consultant: WJE Associates, Inc.

PROJECT OVERVIEW

- Major renovation of an existing office/retail building
- **Construction Dates:** July 2006 – September 2007
- **Size:** 503,000 SF (gross); 362,000 SF (occupied)
- **Height:** 10 stories above grade, three underground parking levels, and a mechanical penthouse level
- **Cost:** $33,597,800 (base building – core and shell)
- **Project Delivery Method:** Design-Bid-Build

ARCHITECTURAL FEATURES

- Glass and metal panel curtain wall system on two sides facing street and partially on west end
- Monumental roof cornice along East side
- New entrance canopy at East side
- Enhanced retail storefront at street level
- "L" shaped footprint allows for private courtyard
- Partial rooftop terrace overlooking the monuments
- Elegant new lobby featuring marble wall and floor panels
- Roof terrace consists of 2' x 2' concrete pavers over insulation and waterproof membrane, along with a fluid-applied protected membrane roofing system elsewhere



STRUCTURAL SYSTEM

- Primary structural and foundation system to remain
- Steel columns added along new mechanical shafts
- Steel beams added beneath penthouse floor slab to support new MEP equipment and roof loads
- Exterior façade consists of the glass and metal panel curtain wall system along with existing brick veneer over metal stud framing surrounding strip windows

MECHANICAL, ELECTRICAL, LIGHTING

- **Mechanical:** Two 2100 GPM cooling towers; six water-cooled air conditioning units ranging from 800 – 14,000 CFM; variable air volume boxes supply air to office and retail spaces; wet sprinkler system installed throughout occupied space.
- **Electrical:** Main switchgear is 265/460V, 3 phase, 4 wire; transformer system voltage is 460V primary to 208Y/120V secondary; 400kW/500kVA emergency generator located in penthouse.
- **Lighting:** Fluorescent fixtures in parking garage levels; incandescent fixtures throughout core in floors 2-10 and penthouse; wall sconces and luminous wall panels located in lobby.

TABLE OF CONTENTS

Abstract 1

Acknowledgements 4

Executive Summary 5

Project Overview 7
- Project Background 7
- Client Information 7
- Project Delivery Method 8
- Project Team 9
- Existing Conditions 10

Building Systems Summary 11
- Construction 11
- Demolition 11
- Structural 11
- Building Envelope 11
- Conveyance 12
- Mechanical 12
- Electrical 12

Project Logistics 13
- Site Layout Planning 13
- Detailed Project Schedule 14
- Project Estimate Summary 15
- General Conditions Estimate 17

Analysis 1 - Urban Development 19
- Problem Identification 19
- Proposal 20
- Goal 20
- Methodology 20
- Survey 20
- Depth Study - Urban Development 21
- Cost Impact 24
- Schedule Impact 24
- Constructability Impact 25
- Conclusion 25

Analysis 2 - Green Roof Implementation 27
Problem Identification 27
Proposal 27
Goal 27
Methodology 28
Benefits of Green Roofs 28
Green Roof Implementation 30
Structural Breadth Study - Green Roof Structural Steel Retrofit 31
Cost Impact 33
Schedule Impact 34
Constructability Impact 35
Conclusion 35

Analysis 3 - Building Envelope Performance 36
Problem Identification 36
Proposal 36
Goal 36
Methodology 36
Building Envelope Improvements 37
Mechanical Breadth Study - Thermal Analysis 39
Cost Impact 45
Schedule Impact 45
Constructability Impact 46
Conclusion 46

Final Conclusions 48

References 49

Appendices 50
A - Site Layout Planning 50
B - Curtain Wall Sequencing 52
C - Detailed Project Schedule 57
D - General Conditions Estimate 61
E - Cost Impact for Demo/New Construction 64
F - Schedule Impact for Demo/New Construction 66
G - Green Roof Layout 68
H - pcaSlab Input and Design Results 71
I - Structural Steel Retrofit to Support Green Roof 80
J - Hand Calculations for Structural Steel Retrofit 84
K - pcaColumn Input and Design Results 87
L - Energy 10 Results 91
M - Moisture Analysis 93

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EXECUTIVE SUMMARY

This existing downtown 10-story office/retail building was fully-renovated with a new façade and state-of-the-art building systems. Located at a street corner of the D.C. business district, this newly developed design prominently sets itself apart from its surrounding buildings. The new "skin" of the building features a glass curtain wall system with white metal panels on the two sides of the building facing the street, which replaces the existing strip windows and brick façade. The floor-to-ceiling glass provides office tenants plenty of natural light along with landmark views of our nation's capital. This vertically configured design also consists of a new monumental roof cornice to add to its architectural stature. Other new features include an entrance canopy, rooftop terrace, and an enhanced retail storefront at street level. The building footprint is shaped like an "L", which allows space for a private courtyard in the northwest corner of the site. The new glass vestibule on the east side of the building leads into an elegant lobby area highlighted by Carrara Italian Marble panels with luminous wall panels running along the perimeter.

New Entrance Lobby

A renovation of this magnitude presents some unique challenges to the general contractor. Any desired structural modification or MEP core drills in the existing concrete slab must be scanned for existing reinforcing bar and approved by the structural engineer, which can be a headache at times depending on how critical it may be and the time it takes to get approval. The demolition process was also hindered due to the limitations on the equipment used to not disturb the existing structure. The design team created drawings based off of 40-year-old plans while the building was occupied, thus preventing it from being analyzed and exposed. This makes the new design very subject to changes resulting from unforeseen conditions. The general contractor was responsible for constructing the base building, or the "core and shell", while a separate tenant contractor was hired to install the finishes in the general office spaces. This joint occupancy of the general contractor and the tenant contractor presented some coordination difficulties to the job as well.

The proposal topics below identify the areas used to research and analyze the office/retail building renovation project in Washington, D.C. For each area of analysis, the problem will be defined, along with the proposal, goal, and methodology intended for addressing the issue. Then, the analysis itself will be conducted, taking into consideration the impacts of cost, schedule, and constructability to the project, followed by a conclusion for the analysis. The following is a preview of each analysis conducted in this report:

Urban Development

This will involve studying a major decision that an owner faces during the beginning stages of development, especially in an urban location: Is it better to renovate the existing building, or demolish and re-build it? There are many issues involved with making this decision from the owner's standpoint, and the various factors relating to the project under study will be analyzed in detail.

Green Roof Implementation

There was no initial consideration for pursuing LEED points for a more sustainable design and construction project for the office/retail building. One potential design feature that promotes several of the LEED objectives is implementing a green roof system into the existing building. The cost analysis will include a structural breadth for retrofitting steel beams and girders to support the added load from the green roof.

Building Envelope Performance

Thermal comfort was a major concern in the existing building design, as the exterior walls did not contain insulation. The renovated building envelope system included a large scale glass and metal panel curtain wall system, which served as an upgrade to the envelope aesthetically and allowed for more natural day lighting. However, the thermal performance of the envelope system was not addressed as much as it should have been. This analysis includes a mechanical breadth study on proposing improvements to the thermal performance and energy efficiency of the building envelope system in a cost-effective manner.

PROJECT OVERVIEW

Project Background

This existing downtown 10-story office/retail building was fully-renovated with a new façade and state-of-the-art building systems. Located at a street corner of the D.C. business district, this newly developed design prominently sets itself apart from its surrounding buildings. The new "skin" of the building features a glass curtain wall system with white metal panels on the two sides of the building facing the street, which replaces the existing strip windows and brick façade. The floor-to-ceiling glass provides office tenants plenty of natural light along with landmark views of our nation's capital. This vertically configured design also consists of a new monumental roof cornice to add to its architectural stature. Other new features include an entrance canopy, rooftop terrace, and an enhanced retail storefront at street level. The building footprint is shaped like an "L", which allows space for a private courtyard in the northwest corner of the site. The new glass vestibule on the east side of the building leads into an elegant lobby area highlighted by Carrara Italian Marble panels with luminous wall panels running along the perimeter.

A renovation of this magnitude presents some unique challenges to the general contractor. Any desired structural modification or MEP core drills in the existing concrete slab must be scanned for existing reinforcing bar and approved by the structural engineer, which can be a headache at times depending on how critical it may be and the time it takes to get approval. The demolition process was also hindered due to the limitations on the equipment used to not disturb the existing structure. The design team created drawings based off of 40-year-old plans while the building was occupied, thus preventing it from being analyzed and exposed. This makes the new design very subject to changes resulting from unforeseen conditions. The general contractor was responsible for constructing the base building, or the "core and shell", while a separate tenant contractor was hired to install the finishes in the general office spaces. This joint occupancy of the general contractor and the tenant contractor presented some coordination difficulties to the job as well.

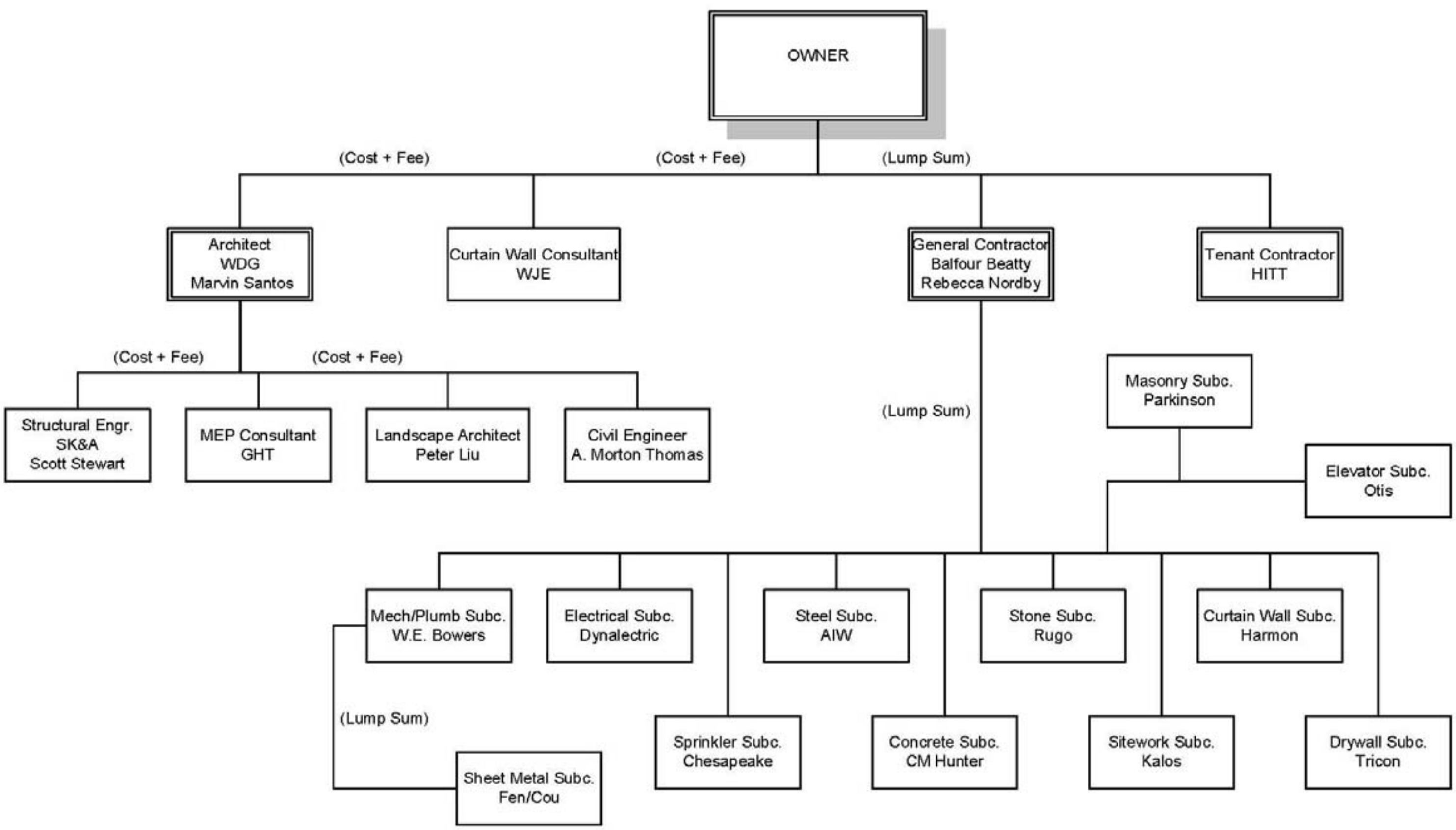
Client Information

The owner of this project is a major commercial real estate developer in the Washington, D.C. metropolitan region. With this office/retail building, they wanted to continue establishing their presence in the business district of Washington, D.C. with a repeat contractor, Balfour Beatty Construction. Their main focus throughout the course of the project was getting their tenants moved in as soon as possible, which seemed to influence every decision made during the construction process. The faster the project was completed, the sooner their tenants would start paying rent. This mindset caused them to be "hands off" at times in terms of day to day happenings and details with the contractor of the base building project. The owner seemed to worry much more about when the tenant contractor can begin work and anything that would affect their progress. Since this job was a "hard bid" project, the owner wanted as few added costs as possible.

Project Delivery Method

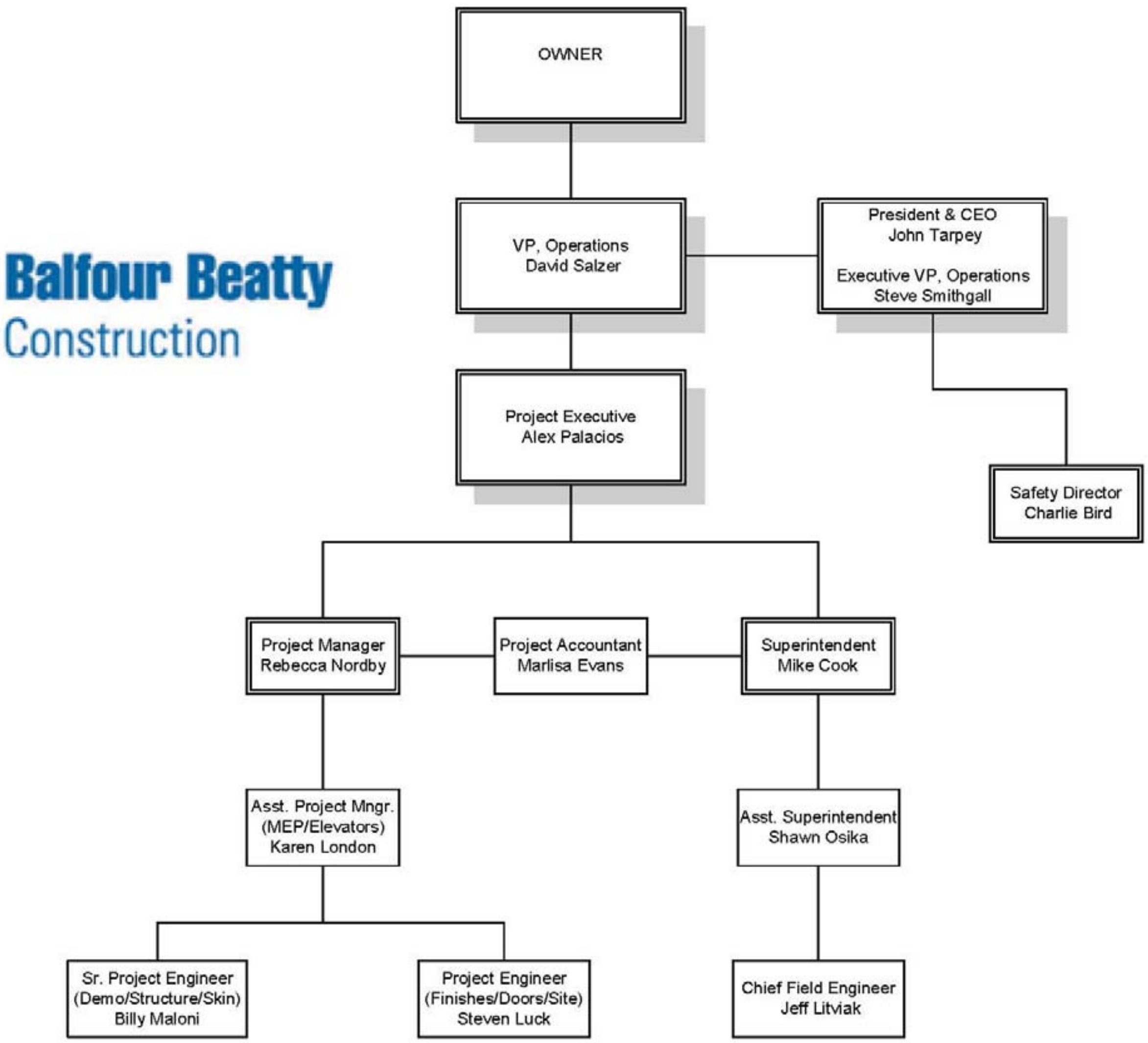
The project delivery system used in this office/retail building project was design-bid-build. This approach was taken to use competition to get the best price and value possible for the owner. The owner held "cost plus fee" contracts with the architect, WDG, and the curtain wall consultant, WJE. The contract between the owner and the general contractor was a "lump sum" agreement. The general contractor, Balfour Beatty, held "lump sum" contracts with each of their subcontractors and suppliers. The major subcontractors are indicated in the diagram below.

The general contractor was selected mostly through the bid, with some minor negotiations. Besides a typical start-up meeting used to establish procedures, there was little communication between the major parties (owner, architect, general contractor) before the project began. No teaming was done to open lines of communication. The owner waived the bond based on their confidence in the general contractor's resources.



Project Team

As outlined in the organizational chart below, the general contractor staffing plan of the office/retail building involves several hierarchical relationships, with the Vice President of Operations acting as the "middle man" between the company executives and the Owner. The Project Manager and Superintendent each have important management roles and report directly to the Project Executive, who in turn reports to the Vice President of Operations over him. The Assistant Project Manager reports to the project manager while also overseeing the Senior Project Engineer and the Project Engineer positions. The responsibilities of the major trades of the project are divided amongst the three sub-positions of the Project Manager. The Superintendent is also assigned an Assistant Superintendent who oversees the Chief Field Engineer of the project.



Existing Conditions

This urban project is pretty standard as far as typical city restrictions on construction. The allowable work hours were 7:00 AM – 7:00 PM, Monday through Saturday. The office/retail building sits at the corner of two busy one-way streets in a developed city block, making it hard to access and providing minimal lay down and delivery space. Aside from the new elevator pit, the soil/subsurface water condition was not really a factor in this case since the building was existing. The methods of construction were typical for a core and shell office building renovation of its type, as employed by many commercial developers throughout Washington, D.C.

Existing Building

New Construction

BUILDING SYSTEMS SUMMARY

Construction

The general contractor held lump sum contract for the base building core and shell with the owner of the office/retail renovation project. There were a few other tenant contractors on site, which included a contractor for all the general office space fit-outs as well as one for each retail space. The relatively small downtown D.C. jobsite presented some challenges for the general contractor, especially in coordination with the other tenant contractors on site. This was evident through issues with deliveries and construction sequencing.

Demolition

Since this project is a major renovation, there was a significant amount of demolition to be performed. Basically, only the cast in place concrete slabs, the rear façade, and eight elevators remained from the former building. There was also asbestos that was removed prior to demolition, which by contract included textured ceiling plaster in the main lobby and stairwells, floor tile and mastic in all stairwells and penthouse, and silver paint on metal flashing on the roof. Additional asbestos was found in the guts of fan coil units, floor tile throughout the building, valve gaskets in the penthouse, roofing material in penthouse troughs, and existing flashing at exterior CMU walls.

Structural

The building's primary structural system remained after demolition. The existing system included cast in place concrete slabs, ranging from 8" to 12" thick. There was no significant amount of new concrete work on this project. Several structural steel members were added along new mechanical shafts and beneath the penthouse floor slab to support the new MEP equipment and roof loads. Steel was also erected to support the building's new roof cornice and entrance canopy. The majority of the new masonry work consisted of two new elevator CMU shaft walls and other various CMU walls throughout the first floor and penthouse.

Building Envelope

The new "skin" of the building features a glass curtain wall system with white metal panels on the two sides of the building facing the street, as well as a portion of the west side. This replaces the existing strip windows and brick façade, vastly improving the supply of natural light to the office tenants and providing landmark views of the city. The two-story high glass panels were put into place by a crane, starting at one end of the building and making its way across to the other side. The curtain wall consultant, WJE, was selected to take the design responsibility. Harmon, the curtain wall contractor, made the necessary in-field modifications to properly erect the panels. The remainder of the building envelope consists of existing brick veneer over metal stud framing surrounding strip windows.

Conveyance

The conveying system of the office/retail building includes eight existing geared traction passenger elevators and two new hydraulic passenger elevators. The existing passenger elevators retained their capacities of 3500 pounds and speeds of 350 feet per minute, but had new cab finishes installed. They serve two basement levels, the lobby level, floors 2-10, and the penthouse level. The two new hydraulic passenger elevators of 3500 pound capacities and 150 feet per minute speeds serve the three basement levels and lobby level. Their purpose is to transport visitors from the underground parking area to sign in at the main lobby desk, which is a common security measure taken in many downtown D.C. buildings.

Mechanical

The majority of the mechanical equipment is located in the penthouse and basement levels. Throughout the building are six water cooled air conditioning units ranging from 800 CFM to 14,000 CFM supply, as well as two split system heat pump air conditioning units which produce 800 CFM each. Variable air volume boxes supply air to the office and retail spaces at a range of 0 – 800 CFM. This building also features two 2100 GPM cooling towers on the roof as well as a 550 gallon fuel oil tank in the Basement B-3 Level. The building's fire suppression system consists of a wet sprinkler system throughout the occupied section of the building, and a dry sprinkler system in the parking garage and penthouse levels.

Electrical

The building electricity runs through three switchboards, each of 4000 A, 265/460 V, 3 phase, 4 wire. Power is fed from the PEPCO transformer vault located in the penthouse. Seven transformers ranging from 15 – 225 kVA with a system voltage of 460 V primary to 208Y/120 secondary are stationed throughout the building. Two copper busways of 1600A and 2500A, 460V, 3 phase, 4 wire feed floors 2-10. A 400kW/500kVA emergency generator located in the penthouse backs up the electrical system. A unique feature of this building involves a slab heating system where copper heating cables are installed on the underside of the floor slab between the parking garage entrance and the first floor of office space (floor 2). The slab heating cables provide a minimum of 4 Watts of heat per square foot. The lighting of the building includes fluorescent fixtures throughout the parking garage levels, incandescent fixtures throughout the core of floors 2-10 and penthouse, and an elegant lobby area highlighted by luminous wall panels and sconces. Also, telecommunications/data rooms are located on each floor, which supply each future office and retail space.

PROJECT LOGISTICS

Site Layout Planning

The site plan of existing conditions clearly indicates a congested site in the business district of downtown Washington, D.C. There is a temporary jobsite trailer/office located on the third floor of the existing building. Parking is available on-site in the three levels of underground garage space. A temporary chain-link fence partially blocks off a portion of the street on the south and east sides of the building to allow for crane placement, deliveries, and staging areas. The rear courtyard is used for smaller amounts of stored materials. See Appendix B for a drawing of the site layout planning.

Site layout plans were also developed for various phases of construction in order to coordinate site accessibility, delivery schedules, and material storage, among other things. A major phase of the renovation of the office/retail building was the erection of the new glass and metal panel curtain wall system to the south and east façades. The congested site presented some challenges during this phase of construction, including the little amount of space to work with and the coordination concerns with the tenant contractors and subcontractors. For the new construction of the curtain wall, the glass panel placement was divided up into three phases.

Phase one included the curtain wall construction on the south façade of the building, facing the street level. A trailer with the glass panels delivery pulled just inside the chain link fence from the southwest construction access, which served as a staging area. A mobile crane with a 150 foot boom length was placed in approximate alignment with the center of the building. Appendices B-1 and B-4 help to better visualize phase one of the curtain wall glass panel erection.

Phase two of the curtain wall construction consisted of erecting the panels for the east façade facing the street level. The mobile crane was positioned at the center of the building. The glass panel staging area was located on a truck just north of the crane for easily accessible pick points. See Appendices B-2 and B-4 for phase two of the sequencing.

Phase three was a relatively short phase that involved only part of the west façade getting glass curtain wall panels. This section is all that is visible from the street because of the neighboring buildings. The crane was placed right at the parking garage entry, which caused the parking garage to be temporarily closed to the workers on site. This was inconvenient for all the workers who had to find parking elsewhere in the city or ride the metro to work, but seemed like the best option at the time to get the panels in place. The general contractor made sure to time this phase simultaneously with the finishes in the three underground parking garage levels. Refer to Appendices B-3 and B-4 for the final phase in erecting the curtain wall glass panels.

The general contractor and the curtain wall contractor worked well together to come up with a game plan to construct the curtain wall panels and storefront. The general contractor did run into some trouble in coordination with other tenant contractors and subcontractors at times. For instance, the concrete subcontractor was performing slab chipping on the existing concrete floor slabs to make the curtain wall panels fit, and became behind schedule. This delayed the curtain wall glass panel placement of phase one, which in turn affected the delivery schedule for certain trades. The delivery area was very small and congested, and part of the fence was bumped out to encompass a lane of the road during the hours of 9:30 AM – 3:00 PM. The location of the trailer with the panels was very important as the pick point for the crane. This location was affected at times due to the delay caused by slab chipping, and the curtain wall contractor would sometimes have difficulty swinging panels. These coordination issues often come up when working with many different contractors on a congested site, and the general contractor on the office/retail building handled the site layout for the curtain wall erection relatively well.

Detailed Project Schedule

The schedule for the office/retail building renovation project is a fast-paced 13 months, which includes extensive demolition and abatement. The foundation and structural systems of the building were slightly modified from the existing building with the new elevator pit for elevators #9-10 and steel bracing beneath the penthouse floor and throughout the major mechanical shafts. The finish sequencing for the core included a "top-down" approach for the interior and an "end-to-end" method for the curtain wall glass panel installation. Per the owner's interest, the bathrooms and electrical rooms were finished starting at Level 10 and working down to Level 2. It is important to point out that the owner had a special agreement with the curtain wall subcontractor which allowed them to complete their work after the general contractor's substantial completion date. Also, the tenant contractor was still performing work after substantial completion, which is why the occupancy milestone is placed towards the end of November. Appendix C includes the detailed project schedule followed in the office/retail building renovation project.

The following is a list of the key project dates associated with the construction of the office/retail building, followed by several paragraphs explaining the schedule of the important building systems:

Project Awarded	5/31/06
Notice to Proceed Issued	8/15/06
Interior Demolition Complete	12/1/06
Exterior Demolition Complete	12/7/06
HVAC Operational	5/1/07
Begin Curtain Wall Installation	5/15/07
Ribbon/Punch Windows Watertight	6/1/07
Storefront Watertight	7/2/07
Electrical Services Complete	6/27/07
Lobby Complete	7/31/07

Curtain Wall Watertight	8/15/07
Base Building Substantial Completion	9/17/07
Core Finishes Complete	9/17/07
Curtain Wall Substantial Completion	9/25/07
Finishes at Curtain Wall/Site Complete	10/9/07

Demolition served as a very extensive process on the office/retail building, as only the concrete slabs remained after the process was complete. Demolition permits were obtained right around the notice to proceed date of August 15, 2006, and abatement followed soon after. The interior demolition was a lengthy and selective process as all the existing office/retail spaces, as well as the MEP systems, were completely "gutted". The exterior brick facades facing the two intersecting streets were torn down starting in the middle of September and lasting into December. Also, the ribbon/punch windows in the rear of the building were taken out to be replaced later. This fast-paced demolition process was completed on December 7, 2006.

The new building envelope system consisted of the replacement of ribbon/punch windows in the rear of the building, a new glass storefront, and a glass and metal panel curtain wall. The ribbon/punch windows began to be replaced on January 10, 2007, and became watertight on June 1. The storefront installation lasted four and a half months, starting February 22, 2007 and watertight on July 2. Finally, the glass and metal panel curtain wall system began May 15, 2007 and became watertight three months later. The curtain wall went up fairly quickly due to prefabricated panels hoisted by a crane and put into place.

Since the owner is able to lease the upper floors before the lower ones, the MEP system rough-ins as well as the finishes were constructed from the top down. Also, there was a lot more work to be done in the service core of floors 2-10, making the MEP rough-ins and finishes scheduled to be performed before the perimeter. The parking garage, penthouse, and lobby MEP rough-ins and room finishes were performed in order. The lobby was one of the last areas to be worked on since it included marble wall and floor tiles in its finishes. Since the lobby was used as a storage area for various materials and was a common traffic area, it worked best to complete these stone finishes towards the end of the project.

Project Estimate Summary

The owner acquired this existing office/retail building a couple years ago for an undisclosed amount. The base building construction cost for the renovation project, which included very little site work, was estimated at $33,597,800. The total area of the building, not including the parking garage, is 362,000 square feet, making the construction cost $93/SF. The mechanical/plumbing package was worth about $9,510,000 ($26/SF, 28.3%). The electrical system cost was approximately $3,152,000 ($9/SF, 9.4%). Besides the existing structure, the structural system made up about $1,270,000 ($4/SF, 3.8%) of the total building cost.

100807-Office/Retail Building

Divisions | Information | Sources | Comments | User Defined

Target Date and Location: Aug 2006 District of Columbia

Building Size: 362,000

Currently Selected: **Bidding Requirements**

Div.#	Division/Subdivision	Base Cost	%	Sq. Cost	Projected
00	Bidding Requirem...	1,103,273	3.16	3.05	1,103,273
01	General Requirem...	3,472,927	9.93	9.59	3,472,927
03	Concrete	365,742	1.05	1.01	365,742
04	Masonry	917,020	2.62	2.53	917,020
05	Metals	1,097,225	3.14	3.03	1,097,225
06	Wood & Plastics	103,012	0.29	0.28	103,012
07	Thermal & Moistur...	530,880	1.52	1.47	530,880
08	Doors & Windows	11,038,954	31.57	30.49	11,038,954
09	Finishes	731,768	2.09	2.02	731,768
10	Specialties	1,708,512	4.89	4.72	1,708,512
12	Furnishings	650,590	1.86	1.80	650,590
14	Conveying Systems	2,248,044	6.43	6.21	2,248,044
15	Mechanical	6,988,352	19.99	19.30	6,988,352
16	Electrical	4,007,883	11.46	11.07	4,007,883
	Total Building Cost	34,964,181	100.00	96.59	34,964,181
	Total Project Cost	37,480,681			37,480,681

The table above represents a parametric estimate breakdown from the computer program "D4 Cost", which came out fairly similar to that of the office/retail building. Since the most similar D4 Cost project selected (medium rise office building with a curtain wall) was all new construction, the majority of the structural costs (Divisions 3 and 5) were removed to make the comparison more equal. The mechanical and plumbing (Division 15) systems in the office/retail building were significantly greater than the D4 Cost estimate, likely due to the state-of-the-art building systems in place. The electrical system of the D4 Cost was pricier than that of the office/retail building by $1,000,000. This is probably because the office/retail building contract is only based on the core and shell, which eliminates some cost of providing electric to the office and retail spaces.

R.S. Means 2008 Building Construction Cost Data							
Office Med Rise (5 to 10 Story)							
		SF Costs			% of Total		
	Location Factor	1/4	Median	3/4	1/4	Median	3/4
Total Project Costs	99.1	$90.68	$110.00	$145.68			
Plumbing	97.4	$2.70	$4.18	$5.99	2.8%	3.7%	4.5%
HVAC	97.4	$6.77	$9.69	$15.44	7.7%	9.4%	11.0%
Electrical	99.4	$6.76	$8.65	$11.98	6.4%	7.8%	10.0%

The table above indicates the square foot cost comparison of the office/retail building, utilizing R.S. Means Square Foot Cost Data, 2007 as a reference. The variances in cost data from this chart to the actual cost of the building most likely dealt with estimating using new construction costs (R.S. Means pricing data) versus renovation project costs. The cost per square foot of the office/retail building renovation fell between the lower quartile and median of the R.S. Means data. The mechanical and plumbing systems were more costly than the upper quartile of R.S. Means. The electrical systems came out to be almost exactly the median value in R.S. Means.

Office/Retail Building Estimate			
	Cost	$/SF	% of Total
Total Project Costs	$33,597,800	$92.81	
Plumbing/HVAC	$9,510,000	$26.27	28.3
Electrical	$3,152,000	$8.71	9.4
Structural	$1,270,000	$3.51	3.8

General Conditions Estimate

The general conditions estimate summary is used to show how the contractor broke up its costs for general conditions items. The office/retail building project lasted 13 months with an additional month for commissioning. A full-time project manager, assistant project manager, superintendent, and assistant superintendent were among eight salaried employees figured into the salaried staffing costs in the summary. After the substantial completion date, the senior project engineer, project engineer, chief field engineer, and project accountant left for another job, while the remainder of the staff stayed to complete the close-out items. The project executive on the job split his time among three jobs and was figured in for about five months of the project duration. A contractor's fee of 4% was included in the general conditions. The cost summary for salaried staffing totaled about $1.17 million.

The office support summary item included all the supplies and set-up equipment used to operate from the temporary third floor office, totaling around $128,000. Safety was also factored into the general conditions summary, and included safety equipment, perimeter protection, and covered walkways, which came out to be $47,500 in cost. Temporary utilities on the office/retailed building included temporary power, fire protection, and port-a-johns, totaling nearly $147,000. The miscellaneous items cost about $1.98 million, bringing the total cost of general conditions to $3,475,614. The general conditions summary table shown below lists each summary item, while the tables in Appendix D include a detailed breakdown of the general conditions costs estimated for the office/retail building project.

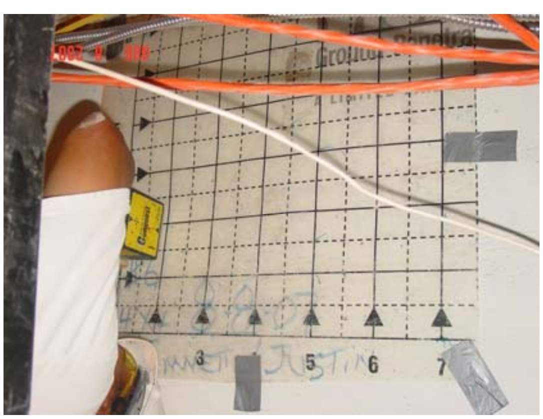
GENERAL CONDITIONS SUMMARY	
Description	**Amount**
Salaried Staffing	$1,170,400
Office Support	$128,254
Safety	$47,500
Temporary Utilities	$146,945
Other	$1,982,515
TOTAL:	**$3,475,614**

ANALYSIS 1 – URBAN DEVELOPMENT

Problem Identification

A construction industry issue critical to the office/retail building project pertains to the decision made by owners and developers to either renovate an existing building or demolish and re-build it, particularly in an urban setting. Space in a highly populated downtown area, such as Washington, D.C., is at a premium. Many times, construction in a downtown setting either involves a renovation of an existing building or a complete demolition of the existing building to be rebuilt with new construction. There are advantages and disadvantages for each method of development, and careful analysis should be considered for each project before any action is taken. A major challenge facing the industry in an urban market lies within what is the most profitable development method to ensure a high quality building is constructed at a reasonable cost.

For this renovation project in particular, a few issues arose that are unique to its type of development. During the interior demolition process, problems came up that significantly delayed the construction schedule. Since demolition was on the critical path, and no work could start before the interior walls were correctly gutted, a careful plan and assessment had to be done. In this case, there was confusion with the demolition contractor's scope of work, which in turn caused the project to not meet important milestone dates. Other schedule delays were caused by the quality of the existing building and the extent of required testing and repairing that turned out to be more than anticipated. This was particularly evident when hydro-testing the new strip windows turned up numerous leaks in the existing flashing system resulting in costly repairs. In addition to the selective demolition and flashing issues, the excessive number of core drilling submittals also produced some delay in schedule. The process for this particular submittal package included scanning for existing top and bottom reinforcing steel for each proposed penetration in the existing slab (see pictures below) and submitting a picture to the structural engineer for his approval. This process caused several time delays, as issues would inevitably come up requiring either new or relocated slab penetrations to be made right away. This could not be done until the contractor properly documented the area in question as a submittal to the structural engineer, who routinely took a couple weeks to review and return for approval.



Scanning for existing reinforcing bar – slab penetration submittal process

Proposal

Interaction with industry members, primarily developers, is the key to understanding the real-life factors involved with decisions related to urban development. A survey will be created and distributed to experienced owners and urban developers to help determine whether it is best to renovate an existing building or demolish and rebuild it. This will mostly benefit the owner/developer, but does affect all parties involved who work together to deliver the project.

Goal

The goal of the research is to come up with a systematic approach in determining the better development option for a project in an urban setting between renovation and new construction. I will aim to get at least ten industry professionals to complete the survey before summarizing the findings. Then, the research will be used to reflect specifically upon the office/retail building renovation project. A comparison will be made considering if the building would have been totally demolished and reconstructed as new, highlighting the impacts of cost, schedule, and constructability.

Methodology

1. Perform independent research on published articles to get background knowledge in urban development.
2. Create survey questions based on research conducted.
3. Interview industry professionals, including developers, architects, and contractors to get additional information on urban development.
4. Summarize results obtained from interview surveys.
5. Create the analysis of comparing new construction to renovation to identify selection criteria on a project to project basis based on the industry's input.
6. Use the analysis to reflect specifically on the office/retail building project, comparing cost, schedule, and constructability, among other factors.

Survey

The one-page industry survey contains questions geared towards understanding the important decisions owners/developers are faced with and what factors go into their decision of development method. The following questions were distributed out to industry members, primarily in the Washington, D.C. area:

- Where is your company located?
- In what location do you generally focus on development?
- In an urban setting, do you primarily choose to renovate an existing building over demolishing and rebuilding it as new, or vice versa?

- How important is the consideration of life cycle cost when compared to first cost when making the decision?
- Does the constructability of the project influence your decision?
- What are the other major factors involved with the decision?
- What are the advantages of demolishing and rebuilding as new?
- What are the advantages of renovating?
- What are the biggest challenges of demolishing and rebuilding as new?
- What are the biggest challenges of renovating?
- Do you use any post-construction evaluation tools to determine the success of the project? If so, please explain.
- Is there anything else you would like to comment on relating to urban development?

Depth Study – Urban Development

A total of seven industry members provided feedback on the survey, which came out to be a little shy of the goal of ten. However, the information gathered still proved to be very helpful in the urban development study. The responses I obtained were primarily from developers from larger firms in the D.C. area, but also included others in the central Pennsylvania and mid-Atlantic regions and former developers now working for general contractors. The highlighted responses to the survey questions are summarized below.

When determining whether to renovate an existing building or demolishing it and rebuilding it as new, one must keep in mind that real estate is opportunity based and economically driven. The ultimate goal is to make money as efficiently as possible, and the profit is based on the time invested into the project. Every building and site is different, and one must evaluate it on an individual basis. If the building is underdeveloped with no opportunity to increase the floor area ratio (FAR) without demolishing the building, then it probably is more effective to demo and rebuild. If the building could be expanded by adding floors or increasing floor size without demolition, then renovation may be the most cost effective option. Code compliance is always taken into consideration. Location is typically a factor because rents are affected by the market. If the local market cannot afford Class A office space, it does not make sense to potentially spend a lot of money to upgrade from a Class B office. Location also affects consideration for the floor layout, as Washington, D.C. is a concrete town and column bay depths are critical. Along with all of those considerations, each project is highly based on the tenant need and what they are willing to pay.

Life cycle cost compared to first cost is an important factor to consider when determining the development method. The extent of the impact depends on the type of owner and his investment into the building after construction. If the owner is a long-term holder, then life cycle cost is a huge factor to consider. A lot of this is due to the fact that tenant retention is based on providing a comfortable environment that is aesthetically pleasing. Other owners that turn around and sell buildings after construction are far more concerned with first cost. Life cycle cost consideration also depends on who is paying the utility bills in the lease arrangement and whether the building is owner-occupied or leased by a third party. If leased, sometimes first cost outweighs life cycle cost since the owner is not paying the monthly utility bills. The life cycle cost analysis can impact the marketability of the possible future sale of the building. One thing to keep in mind is that developers are not just building monuments, they are building profit centers.

Constructability always influences the development method decision to some extent, especially in urban areas. This is because it directly influences cost and schedule of the project. The more constructible and less restrictive the project is, the faster it can be built and the sooner it can be leased. Anything and everything can be constructed for a price.

The other major factors involved in the decision of development method include the project budget, leasing risk, site accessibility, zoning, jurisdictional incentives, environmental issues, hazardous materials, and the economy. Zoning constraints are very prominent within Washington, D.C., especially with building height. The "Height of Buildings Act" was passed by Congress in 1899 and amended in 1910, which limited the height of buildings in the downtown area to no more than the width of the adjacent street plus 20 feet. In other words, a building facing a 90-foot wide street can only be 110 feet tall. Aside from height restrictions, zoning constraints may include set back distance, floor area ratio (FAR), and historic preservation districts. FAR is the total square footage of the building divided by the square footage of the site.

The advantages of demolishing an existing building and rebuilding it as new include the major increase in flexibility of design and construction. There exists the potential of maximizing the floor-to-floor height and increasing the leasable floor area to earn more income from tenants. The owner can get exactly what he wants, which is typically a much better product as far as efficiency and providing amenities for the tenant than a renovation. Also compared to a renovation, there are far less risks of hidden site or construction costs, and the project can sometimes even be built faster and cheaper than trying to salvage some areas. Other than financing the project, the only major constraints for a building that is being demolished and re-built deal with zoning.

The advantages of renovating an existing building usually include a lower first cost and shorter construction schedule time, but there are exceptions. A shorter schedule time to construct the building equals a faster turnaround time of getting the tenant moved into the building to start collecting rent. Renovations also include some salvage value from the existing building that the owner otherwise would not have if he knocked it down.

The biggest challenges of complete demolition and rebuilding as new construction involve the economic factors of taking the building out of service for a long time by tearing it down as well as coordination of the demolition process. In urban areas, especially downtown Washington, D.C., the buildings are densely located in close proximity with each other. Keeping the adjacent existing structures intact, as well as working with the neighboring buildings throughout the duration of construction, are always a concern. Examples of issues arising when working together with the neighbors include anything from morning starting time with all the noise from construction equipment to potentially blocking accessibility to the neighboring building during deliveries to the site. Obtaining approvals and permits for demolition can sometimes be a problem, as the efforts of lobbyists for historic preservation can have a loud voice in Washington, D.C.. Also, proper disposal of hazardous materials is a concern with any substantial demolition.

Unknown and unforeseen conditions play a major part in the challenges of renovating an existing building. The risk of uncovering something that is more involved and costly than initially expected is always a concern. This includes the presence of hazardous materials, such as asbestos, where general contractors and other consultants aid in the efforts of analyzing the building before construction can begin. It can be difficult for the general contractor or construction manager to accurately forecast the price of the renovation project, particularly if they were not the original builders of the facility. There are many constraints from the existing building that must be dealt with in renovations, and code compliance can be an issue in that respect. Designers and contractors must try to make the old building and new building work together. Also, if the building is still occupied during the renovation, phasing of the project becomes very important to not disturb the ongoing building operation.

After the project is complete, several post-construction evaluation tools are used to revisit the development decision factors and ultimately determine project success. From an economic standpoint, it is measured whether or not the project met the budget, taking into account the design costs, construction costs, legal fees, etc. Cash flow analysis of measuring the cash flow out, or financing the project, versus the cash flow in, or the tenant leasing costs, is a common way to determine economic success. This includes how fast the building was leased, an evaluation of the change orders, and what the return on investment was. The most successful project is one that meets budget and schedule, and is fully occupied, stabilized, and has positive cash flow at the end of construction. Consideration of the lessons learned is valuable for most any type of development project.

Urban development is much more difficult to do than suburban development, mainly because there are many more factors and restrictions taken into consideration. With suburban development, there are typically four sides of the building to work on, as compared to sometimes just one side in urban settings. Every project is unique and it is difficult to assess which method is better until all the project scope is fully understood. One must clearly understand the processes associated with each phase, including the financials, market, building, legal, zoning, and environmental. Things typically do not get done if the numbers fail to add up, meaning buildings do not get built without financing. Ultimately, the marketplace determines what is important and what it will pay for; not the developer, the architect, or the construction manager. The commercial real estate and construction market in Washington, D.C. is usually pretty steady, and is uniquely driven a lot by the federal government. Maximizing the available leasing space, while minimizing the construction time, is the key to project success for developers. Urban development is not for the light of heart. Its rewards can be significant, but its risks are very high.

These survey responses from industry members were taken into consideration when evaluating the development method of renovation for the office/retail building and comparing it to if it would have been demolished and rebuilt as new. The impacts of cost, schedule, and constructability will certainly change with a different method of development.

Cost Impact

Using the information obtained from industry members through the urban development survey, a more educated comparison can be made for the office/retail building case as far as the impact of completely demolishing and rebuilding it as new. The cost impact of performing a demolition of a large magnitude and removing all of the salvage value of the existing structure equates to a higher first cost. A rough estimate was created to compare the first cost of the office/retail building if it was fully demolished and rebuilt to the existing estimate. The estimate was calculated by using R.S. Means cost data, using unit costs for the mass demolition of the structure, square foot costs for the new office space and underground parking garage, and approximating the cost of the penthouse structure above the tenth floor. Refer to Appendix E for the detailed cost breakdown of each major component of the project estimate. From the building estimate, the new first cost of the project demolition and construction is roughly $56,456,437, compared to the original construction cost of $33,597,800. The mass demolition estimate will be greater than $2,000,000 when considering the dumping and disposal fees at $95 per ton. The cost of demolishing the building and rebuilding it as new is nearly double the original project cost of the renovation.

Office/Retail Building Cost of Demolition and New Construction	
Mass Demolition	$1,949,467
Office/Retail Building	$38,285,921
Underground Parking Garage	$7,387,855
Penthouse Structure	$250,000
Subtotal	$47,873,243
Location Factor	99.1
Contractor Fees (10% GC's, 5% Overhead, 4% Profit)	19%
TOTAL COST	**$56,456,437**

Although there is a higher first cost associated with full demolition and rebuilding, the new construction opens up the doors for a much higher quality structure with increased sustainability and efficiency, an increased leasable area and floor-to-floor height, the potential for considerable life cycle cost savings, and a greater ability for innovative technologies to be implemented into the building design. This should not be overlooked by developers, especially ones that are long-term holders and have a lot invested into the building.

Schedule Impact

For the office/retail building, there were specific schedule delays caused by unknown and unforeseen conditions in the existing building. The aforementioned issues of selective interior demolition coordination, poor existing quality of the flashing system, and increased submittals dealing with core drilling and penetrating the existing slab all caused schedule delays for the renovation project. In hindsight, these delays could have been avoided with rebuilding the office/retail building as new construction. However, the erection of a ten-story building that stands over a 37,000 square foot building footprint includes three underground parking levels and a mechanical penthouse takes a considerable amount of time.

Once the building is totally demolished and the site cleared out, the added excavation, substructure, superstructure, and new brick facade erection will add on additional months that were not originally there to the project schedule. See Appendix F for the modified project schedule. The durations were approximated by comparing them to a similar type of building in downtown Washington, D.C. that was completely demolished and rebuilt. From the modified schedule, the new total project duration is nearly two years from "Notice to Proceed" to "Base Building Substantial Completion", compared to the original 13 months for the renovation.

Constructability Impact

In the case of demolishing and rebuilding the office/retail building, the project becomes easier to construct with less headaches for the parties involved, including the architect, general contractor, and owner. The demolition phase and clearing the site would likely be the most challenging part on a congested site with neighboring buildings in a dense urban location. Once that is taken care of, however, the new building would probably go up fairly easily without many issues in a region well-known and experienced in erecting concrete structures. Because the risk of uncovering something unexpected in the existing building is eliminated, the general contractor would be able to give a more accurate construction estimate and the amount of change orders would likely be reduced.

Conclusion

Through the surveys distributed to industry members and the information gathered from them, a lot of valuable insight was gained that focuses on the decision factors developers are faced with in the early planning stages of a project in an urban setting. The survey findings were then applied specifically to the office/retail building to take a closer look if it would have been wise to completely demolish and rebuilt the structure instead of performing a large-scale renovation.

Life cycle cost investment seemed valuable to consider since the owner was a long-term holder of the office/retail building, making demolition and new construction worthy of consideration. The building had existing conditions that maximized the zoning of height allowances, so there could be no additional floors added on. If the owner wished to gain more leasable floor area, he would have to expand the building out towards the northwest. The existing building was structurally stable, thus gaining some salvage value in the case of renovation. Also, the project site was in a densely populated urban setting with neighboring buildings, which could make the mass demolition of the structure a challenge. The contract documents from 1969 were mostly correct, although a detailed evaluation was still performed to update the existing conditions for the new contract documents. Finally, the local economy of office real estate market was fairly steady at the time of construction, so there was a low risk of leasing the space.

The owner of the office/retail building could not be reached for comment on whether he considered knocking the building down and rebuilding it as new. Even though it may prove to be a more valuable decision in terms of life cycle of the building and opportunity to increase the leasable floor area, it is speculated that he would not have invested the extra upfront money and time to construct a brand new building. This is evident based on his value engineering efforts and strong push for completion to get the tenants in the building as soon as possible to start the positive cash flow. A lot of the building structure was salvaged and transformed into a Class A office building with a reasonable budget and schedule for a renovation of that scale. If more information was available on the building's purchase price and tenant leasing rates, a detailed cash flow analysis could be performed to better understand the decision he would be faced with.

The remainder analyses of this office/retail building thesis report, "Analysis 2 – Green Roof Implementation" and "Analysis 3 – Building Envelope Performance", will further investigate the building from life cycle cost considerations and the ability for implementation based on the type of development strategy. Since the owner would likely stick to his renovation plan for the office/retail building, these analyses will comment on the potential for the owner to increase the performance and value of the building without having to tremendously increase the cost and schedule by demolishing and rebuilding it.

ANALYSIS 2 – GREEN ROOF IMPLEMENTATION

Problem Identification

The Leadership in Energy and Environmental Design (LEED) Green Building Rating System was developed in 1998 by the U.S. Green Building Council. It was created to encourage and accelerate a worldwide effort of sustainable green building and development practices through implementation of tools and performance criteria. LEED promotes the integrated approach to sustainability for buildings as a whole, and gives owners and operators the opportunity to have an immediate and measureable impact on the performance of their building. LEED certification is becoming more popular in today's design and construction industry as owners and developers are looking to become more environmentally friendly and sustainable.

One particular design feature of a building that promotes several of the LEED objectives is a green roof. By implementing a green roof system, there is a potential to score as many as 15 LEED credits under the US Green Building Council LEED Certification System, depending on design and level of integration with other building systems. Green roofs can potentially earn LEED credits under the following point categories:

- Reduced Site Disturbance, Protect or Restore Open Space
- Landscape Design That Reduces Urban Heat Islands, Roof
- Storm Water Management
- Water Efficient Landscaping
- Innovative Wastewater Technologies
- Innovation in Design

For the office/retail building, however, there was not much consideration given for implementing a green roof system or pursuing LEED points in design and construction for a more sustainable building.

Proposal

Consideration for green building through further investigation is a responsible step to take in today's increasingly sustainable world. Not only are there many benefits for the environment by building sustainably, but there can also be life cycle cost savings to the owner. I plan on analyzing the cost, schedule, and constructability impacts of retrofitting a green roof system into the office/retail building project.

Goal

Ideally, the pursuit of a more sustainable building and green roof implementation will produce low first costs and valuable life cycle cost savings to be attractive for the building owner. A low first cost, however, is typically not the case as green roofs require additional structural support, especially for retrofits that are not originally designed to support the load. The goal is to find sufficient benefits and life cycle cost savings to make it worth the owner's time and money.

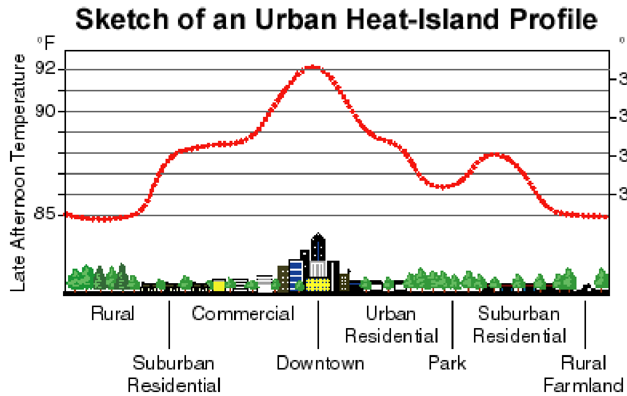
Methodology

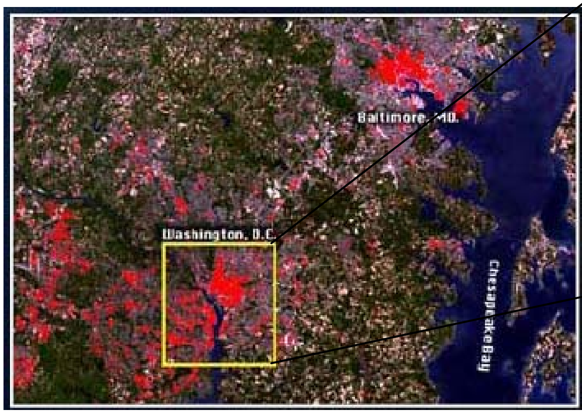
1. Investigate the benefits of green roofs as well as the various types of systems available for the office/retail building.
2. Select a green roof manufacturer and system to accomplish the sustainability goals of the office/retail building.
3. Calculate the cost, schedule, and constructability impacts of implementing the green roof, including the required structural addition to support the retrofit.
4. Discuss the research and findings with the owner of the office/retail building and gather his feedback on if a green roof system should have been pursued. This may give him something to consider for future projects.

Benefits of Green Roofs

Green roofs provide building owners with a return on investment, as well as social, economic, and environmental benefits. Economic benefits for the building owner include protection of the roofing membrane in a longer material lifespan, and energy savings for heating and cooling costs. Green roofs typically last twice as long as conventional roofs, thus decreasing maintenance and replacement costs. Energy savings vary depending on climate, size of building, and type of green roof. Warmer climates offer the greatest saving opportunities, since green roofs are more efficient at reducing air conditioning costs compared to lowering heating costs. Certain green roof systems can potentially reduce HVAC equipment size, roof drains, and the amount of standard insulation used throughout the building. They can also provide an amenity space for public recreation, and add an aesthetic appeal for tenants, thus increasing the property value and marketability of the building. Certain cities or regions have the benefits of a faster approval process, tax breaks, reimbursement grants, reduced storm water waste charges, and greenhouse gas emissions trading credits. Through research and contact with green roof vendors, Washington, D.C. does not have any particular federal incentives for implementing green roofs into building design.

The public benefits of green roofs include a wide range of social and environmental factors. The 'Urban Heat Island Effect' is the difference in temperature between a city and its surrounding area (see figure on beginning on next page). The temperature difference in urban areas can be as much as 10 degrees Fahrenheit, and is mainly caused by the expanse of hard and reflective surfaces (primarily roofs) which absorb solar radiation and re-radiate it as heat. By reducing the 'Urban Heat Island Effect', green roofs decrease in cost of meeting greenhouse gas reductions and adapting to climate change. The 'Urban Heat Island Effect' also contributes to the distribution of dust and production of smog throughout the city. Utilizing green roofs in urban settings reduces greenhouse gas emissions and ground level ozone. Green roofs also improve air quality by its plants filtering and re-oxygenating the air.





Urban Heat Island Effect, D.C. and surrounding area

Enlarged view of Washington, D.C.

Green roofs help reduce heat from moving through the roof, thus contributing as an insulator. The insulation properties are best when the growing medium has the properties of low soil density and high moisture content, with plants that contain a high leaf area index. Not only do green roofs have an impact on the heat gain and heat loss of a building itself, but they also affect the humidity, air quality, and reflected heat in the surrounding neighborhood.

The impacts on storm water retention of green roofs are very beneficial. Water is stored by the substrate layer, then taken up by the plants and evaporated into the atmosphere. Depending on the plants and depth of substrate layer, green roofs can retain 70-90% of the precipitation that falls on them during the summer and 25-40% during the winter. Green roofs not only reduce the amount of storm water runoff, but also delay the time at which runoff occurs, thus resulting in decreased stress on sewer systems at periods of high water flow.

Another benefit of implementing a green roof system is sound insulation from the soil and plants. Sound waves produced from rooftop machinery or airplanes can be absorbed, reflected, or deflected. The substrate layer typically blocks lower sound frequencies, while the plants block higher sound frequencies. In terms of how beneficial a green roof can be in terms of sound insulation, an eight-inch thick substrate layer can reduce sound by 50 decibels.

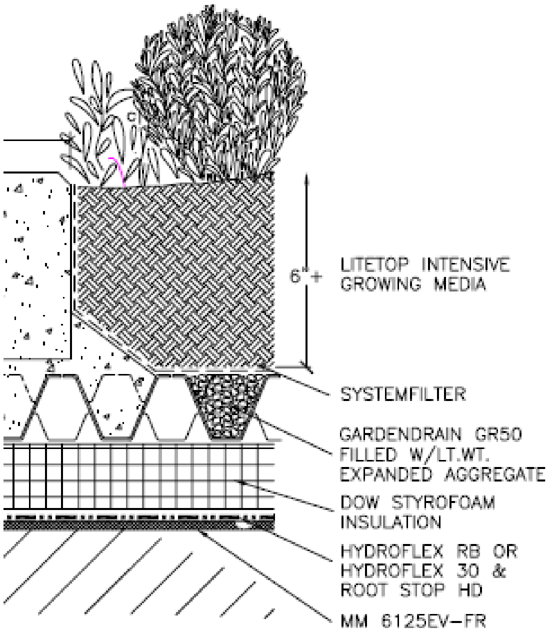
There are also some psychological studies that have been performed on the therapeutic effects of green roofs to the public. They have shown that the natural view of the green roof holds the viewers' attention, diverting their awareness away from worrisome thoughts, and therefore improving their health. Implementing a green roof on top of an office building may effectively promote a relaxing environment for the worker to take a lunch break and get away from the potentially stressful day at work.

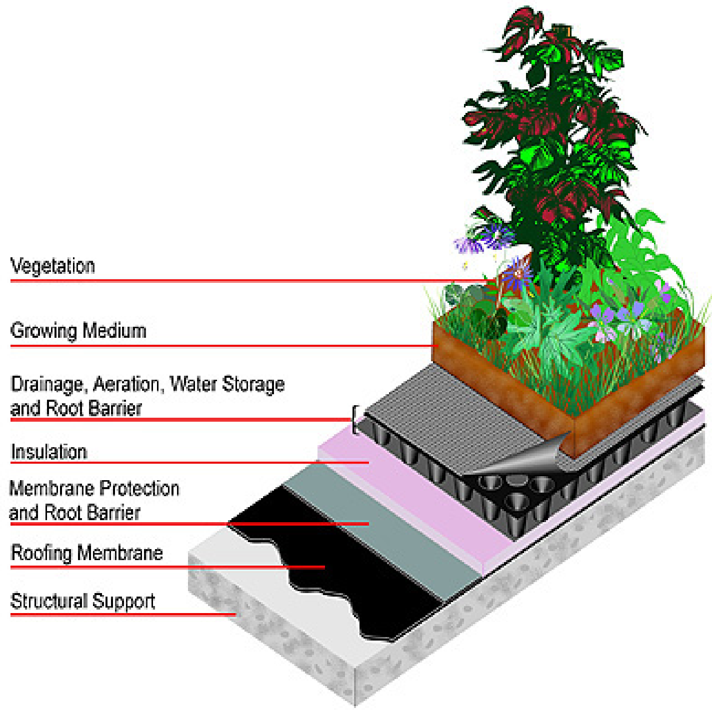
Green Roof Implementation

Green roofs are categorized as either intensive or extensive, mainly depending on the depth of the growing medium. Intensive green roof assemblies allow for many variations of landscapes intended for human interaction, including recreational, sporting, and leisure purposes. Compared to an extensive green roof assembly, the drainage/retention layer is typically deeper and filled with expanded aggregate to allow for greater water storage and support a greater depth of growing medium. The depth of the growing medium varies with type and size of plants proposed to be grown in the soil, but typically ranges from six inches to several feet. Intensive green roof designs typically include a mixture of both hard and soft landscaping, which requires the drainage/retention layer to support any type of landscape to permit excess water to drain unobstructed. They also require regular maintenance, such as watering, fertilizing, and mowing. Extensive green roof assemblies, in contrast, are designed to be virtually self-sustaining and require a minimal amount of maintenance. The growing medium can be very shallow, as little as three inches thick, and the system as a whole in generally very light.

Since the office/retail building renovation was designed for a more interactive rooftop, the proposed green roof assembly was chosen to be an intensive system. To incorporate an intensive system, the depth of the growing medium should be minimal to reduce the cost of further structural support, yet deep enough to maintain flowers and small shrubs. The manufacturer Hydrotech seemed to have a quality intensive green roof system with an overall light saturated system weight (45 psf) compared to the others researched. The system layers and components are listed below, in order, starting from the top layer:

- "Intensive" Vegetation (perennials and shrubs)
- Litetop Growing Media (8" depth)
- Systemfilter
- Gardendrain GR50
- Aggregate (lightweight)
- Styrofoam Insulation
- Rootstop HD and Hydroflex 30
- Monolithic Membrane 6125 EV-FR
- Surface Conditioner
- Substrate / Structural Support





Appendix G shows the roof layout plan for the proposed area of the new intensive green roof system. The areas were designed around the new rooftop terrace for public access, as well as on the south and west side of the building for maximum exposure to sunlight for vegetation growth. Also, it is important to point out the requirement for vegetation-free zones around the perimeter of the building and at all roof penetrations. These penetrations include a 4" wet stack vent and several davit bases for window washing. To address this issue, there will be 2' x 2' walkway pads placed around the roof penetrations, similar to those designed for the rooftop terrace. The existing roof drains are located around the center of each of the three major areas of vegetation, which could effectively serve as the drainage point for the rainwater that was not absorbed from each vegetation area.

For further analysis of thermal performance and energy savings of the proposed green roof system, please see "Analysis 3 – Building Envelope Performance".

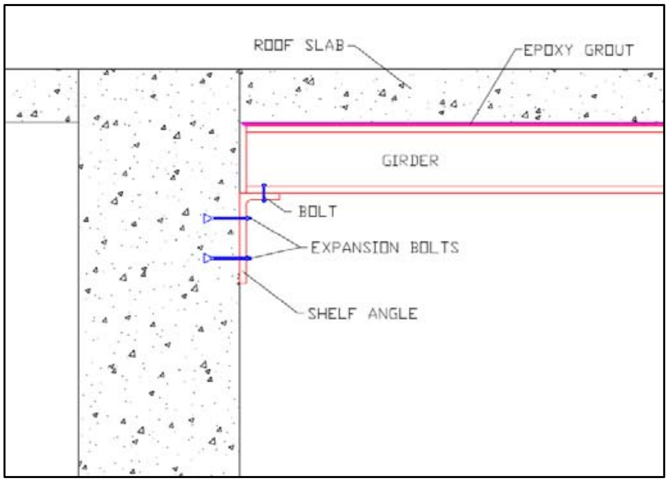
Structural Breadth Study – Green Roof Structural Steel Retrofit

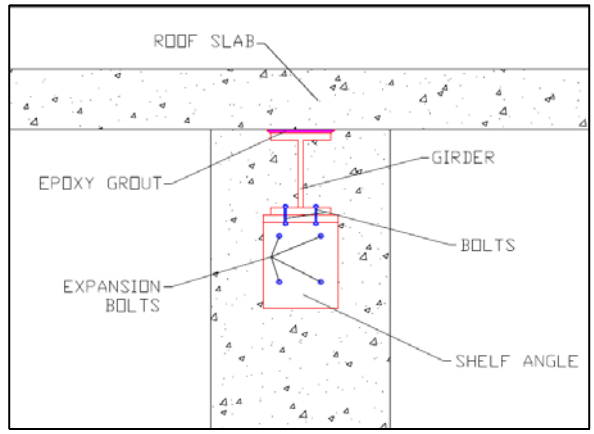
The existing two-way concrete slab of the original structure was designed to withstand the dead load of the roofing system and a live load of 30 psf. The other conditions of the concrete slab included a compressive strength of 3000 psi and an eight inch depth with #4 reinforcement bars spaced at 14 inches on center. The proposed Hydrotech Garden Roof system design adds an additional dead load of 45 psf and a new live load of 100 psf factored in for public roof access. To test the structural integrity of the existing structure to see if any extra steel was needed after adding the additional green roof loads, the computer program "pcaSlab" was used. A typical bay was entered into the program, and as expected, the existing slab could not support the additional loads of the green roof. The bar spacing of the existing slab is below the minimum allowable value by code. The input and design results of "pcaSlab" can be found in Appendix H.

In order to "beef up" the structural integrity of the existing roof to withstand the loads of the proposed green roof, steel beams were retrofitted beneath the roof slab. After calculating the distributed loads with the tributary areas and factoring using the Load and Resistance Factor Design (LRFD) load combination of 1.2(dead load) x 1.6(live load), the Thirteenth Edition of the American Institute of Steel Construction Manual was used to size the support beams and girders. Appendix I shows the proposed structural steel retrofit underneath the existing roof slab to support the green roof, with the new beams highlighted in red. Appendix I-3 shows exactly how the retrofit fits under the proposed green roof design, which is highlighted in yellow. The Structural Retrofit Schedule below corresponds to the labeled members in the appendix drawings. The typical interior beams (B_1) were sized to be W8x31, while the perimeter beams (B_2) were W8x24 and W8x28, depending on if it was affected by the load from the exterior façade. For example, beam type B_3 is sized based on an assumed additional line load of 400 pounds per lineal foot since it also partially supports the north façade. The typical interior girders (G_1) supporting the load of a beam on both sides were sized to be W10x49, while the perimeter girders (G_2) supporting the load of only one beam were sized at W10x33.

Structural Retrofit Schedule			
Beam Type	**Size**	**Length**	**Count**
B_1	W 8 x 31	20'	23
B_2	W 8 x 24	20'	3
B_3	W 8 x 28	20'	2
B_4	W 8 x 24	14'	1
B_5	W 8 x 31	14'	3
Girder Type	**Size**	**Length**	**Count**
G_1	W 10 x 49	20'	10
G_2	W 10 x 33	20'	8
Angle Type	**Size**	**Length**	**Count**
x	L 4 x 3 x 3/8	5-1/2"	36

The girders are tied into the existing concrete columns with support provided by shelf angles, which are connected to the columns using expansion bolts. It is important that the existing reinforcing bar is not struck while bolting the shelf angles into the existing columns, as that may result in negatively affecting the structural integrity of the building. This type of connection, as compared to using double angle connections from the girders into the columns, allows for much more flexibility with the position of the expansion bolts to not impact the existing rebar. Also, epoxy grout is placed in the space between the girders and existing slab to tie the support system together. The top of the next page details two different section views of the shelf angle connection that ties the girders into the existing concrete columns.





Section views of shelf angle connection

Steel beams are run perpendicular to the girders, and spaced at each girder end as well as at the midpoint. Similar column and slab connections as the girders are used for the beams. Please reference Appendix J for the hand calculations of sizing the beams and girders involved in the retrofit. The W18x steel beams around the perimeter of the area of the retrofit in the new structural drawings tie into the green roof support system and do not need resized to support the adjoining beams and girders. The beams are connected to the girders with bolted single angle connections. Using Table 10-11 "Bolted/Welded Single-Angle Connections" of the AISC Manual, these angle connections are sized to be L4x3x3/8, with two bolts spaced vertically and a 5-1/2" angle length.

To verify that the existing concrete columns could withstand the transferred load of the new green roof from the beams and girders, the computer program "pcaColumn" was used. The existing concrete column reinforcing conditions are 12 #7 bars spaced evenly in the 24" x 24" column. According to the results of the program, the maximum allowable axial load of the existing columns is around 1000 kips. Considering the total transferred load of the existing roof slab plus the proposed green roof system equals only 134 kips, the existing columns can easily support the added load. These results are included in Appendix K.

Cost Impact

In general, the cost of implementing a green roof varies considerably depending on the type of system and factors such as depth of growing medium, selected plants, insulation thickness, and use of irrigation. The Hydrotech Intensive Garden Roof system selected for the office/retail building is estimated to cost $25 per square foot for the material and labor to install it. R.S. Means Cost Data 2007 was also used to price the added cost for labor and materials for the structural retro-fit support for the green roof system. The breakdown is detailed on the top of the next page:

COST IMPACT - Green Roof Implementation						
RS Means #	**Item**	**Description**	**Quantity**	**Unit**	**Cost / Unit**	**Cost**
-	Hydrotech Intesive Garden Roof	Green Roof	7,016	SF	$25.00	$175,400
05 12 23.75	Structural Steel Members	W 8 x 24	74	LF	$36.11	$2,672
	Structural Steel Members	W 8 x 28	40	LF	$41.11	$1,644
	Structural Steel Members	W 8 x 31	502	LF	$44.61	$22,394
	Structural Steel Members	W 10 x 33	160	LF	$47.11	$7,538
	Structural Steel Members	W 10 x 49	200	LF	$66.61	$13,322
05 12 23.40	Lightweight Framing	L 4 x 3 x 3/8	140	LB	$3.32	$466
-	Lightweight Framing	L 8 x 6 x 1 Shelf Angle	2,829	LB	$3.32	$9,392
05 05 23.10	Bolts and Hex Nuts	Expansion Anchors	36	EA	$20.69	$745
03 61 20.10	Construction Grout	Epoxy Grout	976	SF	$13.60	$13,274
				Subtotal:	$246,846	
				Location Factor:	99.1	
				TOTAL COST OF GREEN ROOF:	**$244,624**	

As shown in the table above, the added project cost of the intensive green roof system is $244,624, which is about a 20 percent increase of the overall structural system cost. Also, green roofs require regular maintenance for the vegetation and growing medium, so the additional labor costs associated with that should not be overlooked.

While this expense requires a much greater initial investment, it is important to keep in mind the benefits of implementing a green roof system. The major advantages of the intensive system include extending the life of the roofing membrane in the coverage area, as well as reducing storm water runoff and helping to reduce the heating and cooling costs of the office/retail building. For a more detailed breakdown of energy cost savings, please refer to "Analysis 3 – Building Envelope Performance".

Schedule Impact

The structural steel retrofit that supports the added load of the roof slab should take place during the rest of the structural steel installation, which occurs on November 9, 2006 for a 20-day duration. Since the penthouse MEP equipment and new roofing material are installed shortly after the structural steel installation is complete in the original schedule, there is very little room to add days to the activity to accommodate the installation of the additional structural steel members. However, the structural steel installation can start before the November 9 date since there is nothing that would interfere on the tenth floor after abatement is complete, which is scheduled to be finished September 15, 2006. The only potential coordination issue is for roughing-in the MEP equipment, but the subcontractor could always start on the ninth floor and work down to come back to the tenth after the retrofitted steel beams are in place. According to R.S. Means Cost Data 2007, the productivity of installing steel beams and girders of the specified size is 550 lineal feet per day, which equates to about two days for the total retrofit. To factor in extra time for hoisting the members and fastening the connections, this duration should be rounded up to one week. Instead of starting the structural steel installation on November 9, the workers could begin on November 2, 2006. Overall, there is no affect of the structural steel retrofit for the green roof on the overall project schedule.

For additional explanation of the schedule impact of implementing the green roof system itself, refer to the "Schedule Impact" section of "Analysis 3 – Building Envelope Performance".

Constructability Impact

Implementing a green roof system to an existing structure is somewhat inhibited by the existing conditions in place, especially if the roof slab is not design to support the added dead loads from the green roof and live loads of occupancy. If the building was knocked down and rebuilt with the green roof as part of the new design, the roof slab could be increased in size and strength to support the added loads. The major concern with retrofitting the structural steel support beams and girders is the coordination issue of the MEP systems in the tenth floor ceiling's plenum space. To overcome this problem, coordination meetings are suggested between the steel and MEP subcontractors to work out exactly where the ductwork, piping, and conduit are running and how to construct the systems around the steel already put into place ahead of time. Also, each column must be scanned for the location of existing rebar before the expansion bolts can be fastened. The option to utilize shelf angles rather than double angles from the structural members straight into the existing column allow for increased flexibility on the location of the expansion bolts to avoid striking any existing rebar. The placement of the expansion bolts on the face of the shelf angle can vary without really affecting the fastening strength too much.

For additional explanation of the constructability impact of implementing the green roof system itself, refer to the "Constructability Impact" section of "Analysis 3 – Building Envelope Performance".

Conclusion

Although implementing the proposed intensive green roof system would bring about a lot of added benefits to the office/retail building, it may be tough to convince the owner that it is worth the added cost of the retrofit. The system cost of $244,624 probably would not pay for itself over a reasonable amount of time in this case, but would likely add value to the property for the leasing tenants. The green roof would definitely add an aesthetic appeal to the new rooftop patio, and would be a nice environment for the office workers to take a break for some fresh air and enjoy the views of the downtown Washington, D.C. area. The building owner could not be reached for comment on this green roof study, but based on the fact that LEED accreditation was not originally pursued and that several other proposed building features were value engineered out, it is speculated that he would advise against green roof implementation.

ANALYSIS 3 – BUILDING ENVELOPE PERFORMANCE

Problem Identification

Originally built in the early 1970's, the office/retail building did not contain insulated exterior walls in its envelope. The renovated design consisted of replacing the entire east and south façades, and partially the west façade, with a new glass and metal panel curtain wall system. Also, every strip window on the west and north façades was replaced as well. While this is certainly an upgrade to the building envelope system aesthetically and allowed for much more natural day lighting, the thermal performance of the building should have been further addressed. The exterior walls on the west and north façades remained un-insulated, and the new curtain wall system contained metal panels without insulation. This will likely bring about comfort issues with the office tenants and cause the HVAC systems to work harder in the summer and winter months.

Proposal

In order to address the thermal comfort concerns of the new design, I am proposing to improve the thermal performance of the building envelope system without adding a significant upfront cost for the owner. I plan on measuring the thermal performance of the building when adding insulation to the north and west facades, and well as behind the curtain wall metal panels. After selecting specific materials and quantities to improve the system, I also plan on considering the cost and schedule impacts to the project. I will also consider the thermal performance of the proposed green roof system mentioned in "Analysis 2 – Green Roof Implementation". While the proposed system improvements present some added cost to the project, it will likely benefit the owner in the end in terms of energy savings.

Goal

The goal of the proposed building envelope system is to create a positive life-cycle cost savings in terms of lowering the operating costs of heating and cooling. Also, it is important that the proposed system is not too extensive and does not impact the overall project schedule. A better performing building envelope system in terms of thermal conductivity will lead to a higher quality building with more satisfied and productive tenants.

Methodology

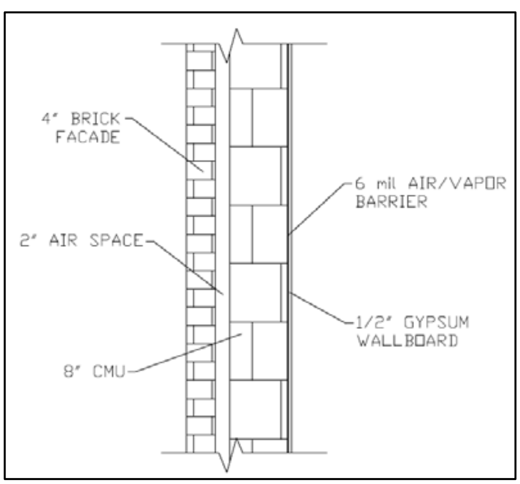
1. Perform independent research on building envelope systems and how to economically improve thermal performance.
2. Consider how to promote a better performing building envelope system for the office/retail building based on cost and schedule implications.
3. Select specific materials for the proposed building envelope system and obtain thermal properties (R-values) of existing system as well as proposed system.

4. Compare the thermal performances of the proposed building envelope system to measure how well the building conducts heat when compared to the existing system by using a U-Value analysis in Microsoft Excel.
5. Enter the building envelope data for the existing and proposed systems into the software tool "Energy 10" to identify the energy and cost savings associated with implementing a new building envelope design.
6. Analyze the cost, schedule, and constructability impacts of the proposed building envelope system.
7. Contact the owner and general contractor to gather feedback on my analysis to see if it would have been worth upgrading the building envelope system.

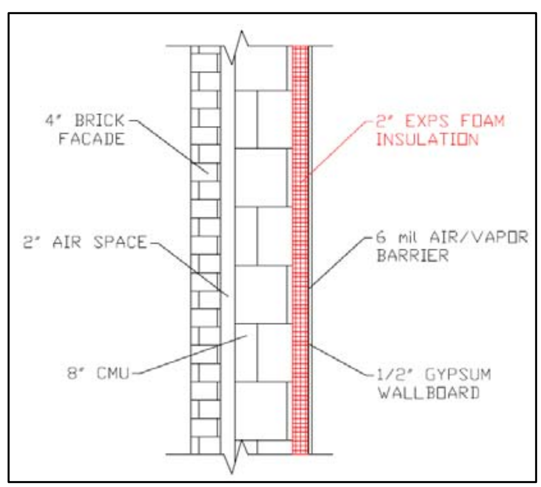
Building Envelope Improvements

Since much of the new façade area of the office/retail building is composed of glass, the makeup of the glass panels were initially considered as an area to improve upon the thermal performance of the building envelope. However, given the low emissivity coatings on the insulated glazing units, there could not have been much improvement made at a reasonable cost. A low emissivity coating is an extremely thin metallic layer deposited directly on the surface of the glass panes. The coating is designed to reduce the heat loss due to infrared radiation from the warmer pane of glass to a cooler pane, which in turn reduces the overall U-value of the window. Instead, the focus for improving the building envelope thermal performance moved to the un-insulated CMU walls and metal panels.

For the newly proposed building envelope system, a two-inch layer of extruded polystyrene (EXPS) foam insulation was added on the inside of the CMU block wall for the north and west façades. The diagram below shows this proposed addition to the wall as a typical section cut out of this area, with the EXPS foam insulation layer labeled in red.

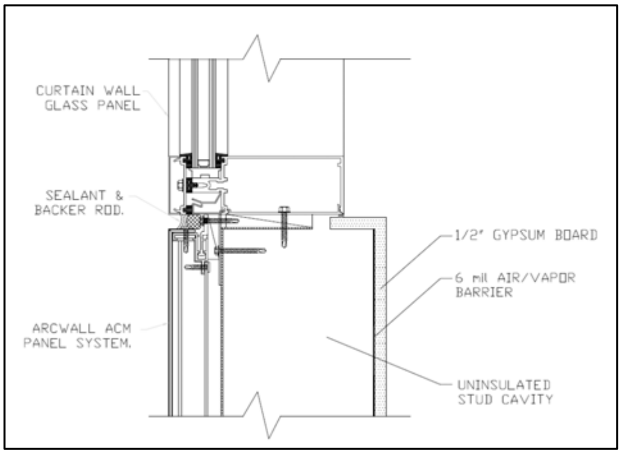


Existing Wall System

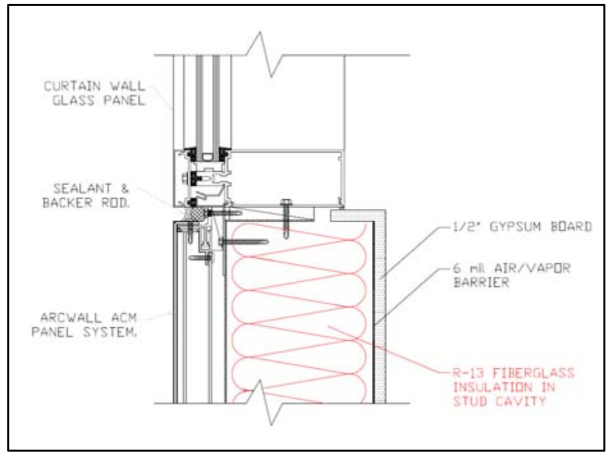


Proposed Wall System

Along with that, R-13 insulation was installed on the interior side of the curtain wall metal panels throughout the remainder of the building. The diagram below shows the proposed addition to the wall as a section cut through the curtain wall sill, with the R-13 fiberglass insulation layer labeled in red.

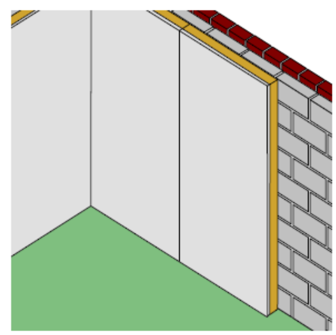


Existing wall system



Proposed Wall System

EXPS foam insulation (yellow layer on the right diagram) provides a thermal resistance value (R-value) of 5.0 per inch, as well as several other major benefits to a wall system. Aside from its added thermal efficiency, EXPS insulation also resists the intrusion of moisture, thus increasing its long-term energy performance. Moisture may come in contact with the insulation both during construction and throughout the life of the building, and if absorbed, will drastically reduce the R-value. Other benefits of EXPS insulation include a high compressive strength and resistance to air infiltration.



For the proposed building envelope system for the office/retail building, the two-inch layer of EXPS insulation will be adhered to the inside of the existing CMU block and taped at each edge to help resist air infiltration for improved energy efficiency. A thin layer of air and vapor barrier will then be installed between the EXPS insulation and the gypsum wallboard to help resist moisture build-up. Since moisture generally moves from higher temperatures to lower temperatures, the vapor barrier is placed on the warm side (inside) of the wall in a relatively cool climate like Washington, D.C. to prevent condensation and mold from building up inside the wall. During the summer months, however, the regional climate can get very hot and humid, which may pose an issue with condensation build-up between the insulation and air/vapor barrier layers. EXPS insulation is typically installed for new buildings in the air space between the brick façade and CMU block wall, but considering the cost and schedule impacts of tearing down the brick façade to install this layer of insulation, this proposed design seemed to be a much more desirable alternative to the owner.

Mechanical Breadth Study – Thermal Analysis

When comparing the thermal performance of the proposed building envelope system to its existing system, the overall heat transfer coefficients (U-values) were calculated for each wall design. Each layer of the wall from outside to inside was considered and factored into the equation, which took the inverse of the total sum of the R-values. As shown in the table below, the U-value of the wall system decreased significantly from 0.275 to 0.073 ($Btu/ft^2 \cdot °F \cdot hr$) by adding the layer of EXPS foam to the system. The yellow highlighted materials and properties are part of the proposed wall system and not in the original.

North & West Façade - Wall					
(Area = 30,655 SF)					
Existing System			Proposed System		
Material	Thickness	R-Value	Material	Thickness	R-Value
Exterior Air Film	-	0.33	Exterior Air Film	-	0.33
Brick Façade	4"	0.44	Brick Façade	4"	0.44
Air Space	2"	1.02	Air Space	2"	1.02
CMU	8"	0.71	CMU	8"	0.71
Air/Vapor Barrier	6 mil	-	EXPS Rigid Foam Board	2"	10.0
Gypsum Wallboard	1/2"	0.45	Air/Vapor Barrier	6 mil	-
Interior Air Film	-	0.68	Gypsum Wallboard	1/2"	0.45
			Interior Air Film	-	0.68
	SUM of R-Values	3.63		SUM of R-Values	13.63
U-Value of System = 0.275			**U-Value of System = 0.073**		

Aside from the added layer of EXPS insulation to the north and west exterior walls, R-13 fiberglass insulation was added to the stud cavity inside the metal panels of the curtain wall system. Using the same U-value calculation method as mentioned above, the table below shows the thermal performance of the existing wall system compared to the proposed system. The U-value decreased from 0.360 to 0.068 ($Btu/ft^2 \cdot °F \cdot hr$) by insulating the stud cavity on the inside of the metal panels.

Curtain Wall - Metal Panels					
(Area = 9,100 SF)					
Existing System			Proposed System		
Material	Thickness	R-Value	Material	Thickness	R-Value
Exterior Air Film	-	0.33	Exterior Air Film	-	0.33
Aluminum Panel	1/32"		Aluminum Panel	1/32"	
Thermo-Plastic Core	1/8"	0.63	Thermo-Plastic Core	1/8"	0.63
Aluminum Panel	1/32"		Aluminum Panel	1/32"	
Stud Cavity (Air)	3-1/2"	1.02	Insulated Stud Cavity (R-13)	3-1/2"	13.0
Air/Vapor Barrier	6 mil	-	Air/Vapor Barrier	6 mil	-
Gypsum Wallboard	1/2"	0.45	Gypsum Wallboard	1/2"	0.45
Interior Air Film	-	0.68	Interior Air Film	-	0.68
	SUM of R-Values	2.78		SUM of R-Values	14.76
U-Value of System = 0.360			**U-Value of System = 0.068**		

The green roof proposed in "Analysis 2 – Green Roof Implementation" also has some potential for improvements in the thermal performance of the office/retail building. The vegetation blocks heat transfer from the roof in the form of solar radiation. Other thermal performance factors vary widely based on the moisture content and porosity of the growing medium, or soil. In the best case scenario, the soil is perfectly dry, and the air voids in the soil have a high thermal performance value. According to the manufacturer of the Hydrotech Intensive Garden Roof system, the "Litetop Intensive Growing Media" layer provides an R-value in the order of 2.0 per inch when dry. The two-inch drainage layer is treated as an air layer since no water is draining. The filter fabric, moisture retention mat, and root barrier have negligible thermal resistance. The best-case scenario thermal performance of the green roof system is compared to the existing system below. Under completely dry soil conditions, the U-value of the portion of the roof that is proposed as green would fall from 0.075 to 0.033 (Btu/ft^2·°F·hr).

Roof - Green Roof Portion BEST CASE SCENARIO - Dry Soil					
(Area = 7,016 SF)					
Existing System			Proposed System		
Material	Thickness	R-Value	Material	Thickness	R-Value
Exterior Air Film	-	0.33	Exterior Air Film	-	0.33
Stone Ballast	1/2"	0.05	Vegetation	2" - 12"	-
Membrane	2"	1.70	Growing Medium	8"	16.0
EXPS Rigid Foam Board	2"	10.0	Filter Fabric	1/8"	-
Concrete Slab	8"	0.58	Drainage Layer	2"	1.07
Interior Air Film	-	0.74	Moisture Retention Mat	3/16"	-
			EXPS Rigid Foam Board	2"	10.0
			Root Barrier	1/32"	-
			Membrane	2"	1.70
			Concrete Slab	8"	0.58
			Interior Air Film	-	0.74
	SUM of R-Values	13.40		SUM of R-Values	30.42
U-Value of System = 0.075			**U-Value of System = 0.033**		

In the worst case scenario, the soil is completely saturated, and the thermal performance of the green roof system is not much better than that of the existing roof. Since the rainwater is a similar temperature to that of the outdoor air, each layer that is designed to hold and drain the water is considered to have negligible insulation value. The only green roof system materials acting as insulators beyond the drainage layer and moisture protection mat remain to be the insulation board, membrane, and concrete slab, which is the same as the existing roofing system. The worst-case scenario thermal performance of the green roof system is compared to the existing system on top of the next page. In this case, the U-value remains unchanged at 0.075 (Btu/ft^2·°F·hr).

Roof - Green Roof Portion WORST CASE SCENARIO - Saturated Soil					
(Area = 7,016 SF)					
Existing System			Proposed System		
Material	Thickness	R-Value	Material	Thickness	R-Value
Exterior Air Film	-	0.33	Exterior Air Film	-	0.33
Stone Ballast	1/2"	0.05	Vegetation	2" - 12"	-
Membrane	2"	1.70	Growing Medium	8"	-
EXPS Rigid Foam Board	2"	10.0	Filter Fabric	1/8"	-
Concrete Slab	8"	0.58	Drainage Layer	2"	-
Interior Air Film	-	0.74	Moisture Retention Mat	3/16"	-
			EXPS Rigid Foam Board	2"	10.0
			Root Barrier		-
			Membrane		1.70
			Concrete Slab	8"	0.58
			Interior Air Film	-	0.74
	SUM of R-Values	13.40		SUM of R-Values	13.35
U-Value of System = 0.075			**U-Value of System = 0.075**		

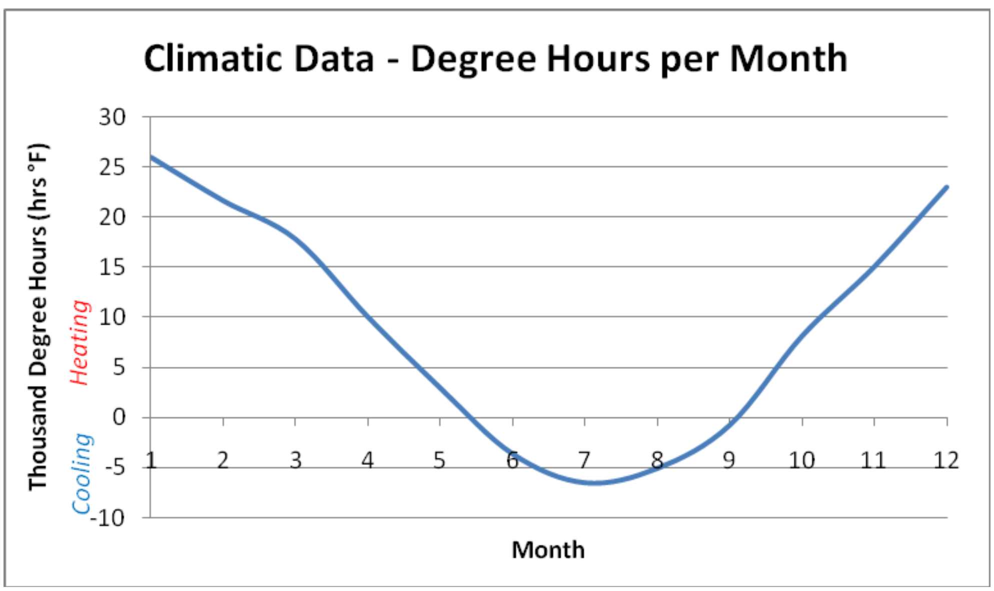
For comparison purposes, an average U-value was calculated by researching the annual average days of precipitation of 0.01 inches of more. According to <www.met.utah.edu>, it rains an average of 112 days per year in the Washington, D.C. region. This number was taken as a fraction over the total number of days per year and factored into the average U-value calculation. Based on this calculation, the U-value of the green roof system in the Washington, D.C. region is figured to be around 0.046 (Btu/ft^2·°F·hr), compared to 0.075 (Btu/ft^2·°F·hr) for the existing roof.

Average U-Value Calculation - Proposed Green Roof System
Avg. U = ((112/365)*0.075)+((1-(112/365))*0.033)
Avg. U = 0.046 (Btu/ft^2•°F•h)

To see how the thermal performance improvements of the proposed building envelope system affect the energy savings of the building as a whole, further calculations were performed. Climatic data of monthly average temperatures for the Washington D.C. region were obtained from and measured against an indoor air temperature of 70°F to calculate heating degree days and cooling degree days. The "degree days" calculation is a good way to generally keep track of how much demand there is for energy heating or cooling the building. The cooler the weather is in the region equates to a larger number of heating degree days, and vice versa. A larger number of heating and cooling degree days leads to an increased demand for energy used to heat the building. The chart at the beginning on the next page depicts the degree hours of heating and cooling calculations per month (converted from degree days for unit calculation purposes) for the Washington, D.C. region, assuming an indoor air temperature of 70 °F.

Monthly Climatic Data - Washington, D.C.							
Month	Int Air Temp	Ext Air Temp	Difference	Deg Days	Deg Hours	Heating	Cooling
JAN	70	35	35	1085	26,040	26,040	
FEB	70	38	32	904	21,696	21,696	
MAR	70	46	24	744	17,856	17,856	
APR	70	56	14	420	10,080	10,080	
MAY	70	66	4	124	2,976	2,976	
JUN	70	75	-5	150	-3,600		3,600
JUL	70	79	-9	270	-6,480		6,480
AUG	70	77	-7	210	-5,040		5,040
SEP	70	71	-1	30	-720		720
OCT	70	59	11	341	8,184	8,184	
NOV	70	49	21	630	15,120	15,120	
DEC	70	39	31	961	23,064	23,064	
					SUM (hrs °F)	**125,016**	**15,840**

The graph below also represents the degree hours per month (1 – 12 on x-axis) for the Washington, D.C. region. The line dips below the zero degree hours line halfway through the month of May through the beginning of September, which represents cooling degree hours. Data graphed above the zero line, on the other hand, represents heating degree hours.



The equation "Q = A * U * ΔT" is used to calculate the annual amount of heat loss or heat gain of the building (Btu), with "A" representing the area of the envelope system (ft²), "U" for the total U value of the envelope system (Btu/ft²·°F·hr), and "ΔT" for the total annual heating or cooling degree hours (hrs·°F), converted from degree days. These were calculated for both the existing building envelope system as well as the proposed system. The total annual heat loss and heat gain are converted from Btu to kWh and added together. The value of the proposed system is compared against the existing system, and then divided by the

HVAC system efficiency to equal the energy savings of the building's heating and cooling systems. The HVAC system efficiency of the office/retail building is assumed to be 0.8. According to the Energy Information Administration, the average energy cost for Washington, D.C. in December of 2007 was 12.3 cents per kWh. Finally, the energy cost per kWh is multiplied by the annual energy savings of the improved wall system to show the total cost savings per year of the new building envelope system. The spreadsheet calculations for the north and west façades, curtain wall metal panels, and proposed green roof system are shown below. The U value of the proposed green roof system was figured to be a combination of the best case and worst case scenario of Washington, D.C. for comparison purposes.

North & West Façade - Wall	Existing	Proposed	Difference
U Value (Btu / ft²·°F·h)	0.275	0.073	
Area (ft²)	30,655	30,655	
Annual Heat Loss (Btu)	1,053,900,507	279,762,680	
Annual Heat Loss (kWh)	**308,868**	**81,990**	**226,877**
Annual Heat Gain (Btu)	133,533,180	35,446,990	
Annual Heat Gain (kWh)	**39,135**	**10,388**	**28,746**
		Annual Heat Loss and Gain (kWh)	255,624
		Energy Savings (kWh)	319,530
		Energy Cost ($/kWh)	0.123
		Total Annual Energy Cost Savings	$39,302

Curtain Wall - Metal Panels	Existing	Proposed	Difference
U Value (Btu / ft²·°F·h)	0.360	0.068	
Area (ft²)	9,100	9,100	
Annual Heat Loss (Btu)	409,552,416	77,359,901	
Annual Heat Loss (kWh)	**120,028**	**22,672**	**97,356**
Annual Heat Gain (Btu)	51,891,840	9,801,792	
Annual Heat Gain (kWh)	**15,208**	**2,873**	**12,335**
		Annual Heat Loss and Gain (kWh)	109,691
		Energy Savings (kWh)	137,114
		Energy Cost ($/kWh)	0.123
		Total Annual Energy Cost Savings	$16,865

Green Roof	Existing	Proposed	Difference
U Value (Btu / ft²·°F·h)	0.075	0.046	
Area (ft²)	7,016	7,016	
Annual Heat Loss (Btu)	65,783,419	40,241,910	
Annual Heat Loss (kWh)	**19,279**	**11,794**	**7,485**
Annual Heat Gain (Btu)	8,335,008	5,098,802	
Annual Heat Gain (kWh)	**2,443**	**1,494**	**948**
		Annual Heat Loss and Gain (kWh)	8,434
		Energy Savings (kWh)	10,542
		Energy Cost ($/kWh)	0.123
		Total Annual Energy Cost Savings	$1,297

The addition of EXPS insulation along the inside of the CMU for the north and west façades had a significant annual energy cost savings of $39,302. The added fiberglass insulation inside the metal panels and the proposed green roof section saved annual energy costs of $16,865 and $1,297, respectively. The total energy savings of the proposed building envelope thermal improvements equals $57,464 annually.

Along with the hand calculations of thermal performance of the proposed system improvements, computer software was used to identify and model the HVAC system output and energy savings associated with the new building envelope system as a whole. Energy 10 is a program that is used by architects, engineers, and builders to quickly identify cost-effective and energy-saving measures in designing a low-energy building. Since the program is geared towards smaller commercial buildings, only the top floor of the commercial office space was analyzed. The space was split up into two zones, a perimeter zone (10' inside exterior wall) and a core zone, in order to more effectively measure the thermal properties of the exterior walls. For comparison purposes, the green roof was also inputted into the proposed building envelope design. Energy 10 is designed to compare two building types in terms of energy efficiency, and "Building 1" was given the parameters of the current conditions of the office/retail building project while "Building 2" was given the proposed building envelope improvements. Please refer to Appendix L for the summary page of "Building 1" and "Building 2", comparing the total conduction, the average U-value, and the rated HVAC system output and air flow for the envelope of the zone. Through the Energy 10 analysis, the average U-value decreased from 0.077 (Btu/ft²·°F·hr) in the existing design to 0.066 (Btu/ft²·°F·hr) in the new design. Also, the HVAC system produced a better rated output and air flow in the proposed design, making it possible to downsize the system and save money from its decreased energy demand.

Cost Impact

R.S. Means Cost Data 2007 was used to price the added cost for labor and materials for the proposed building envelope wall systems. The breakdown is as follows:

COST IMPACT - Building Envelope Improvements						
RS Means #	**Item**	**Description**	**Quantity**	**Unit**	**Cost / Unit**	**Cost**
07 21 13.10	Rigid Insulation	Extruded polystyrene, 2" thick, R10	30,655	SF	$1.46	$44,756
07 21 16.20	Blanket Insulation for Walls	Foil faced fiberglass, 3.5" thick, R13	9,100	SF	$0.82	$7,462
				Subtotal:	$52,218	
				Location Factor:	99.1	
				TOTAL COST OF BUILDING ENVELOPE IMPROVEMENTS:	**$51,748**	

As shown in the table above, the added cost to the building for the proposed building envelope wall system improvements is $51,748, which is about a 0.02% increase of the overall project cost. As previously calculated, the added cost for the proposed intensive green roof system, including the structural steel retrofit, is $244,624. For additional explanation of the cost impact of adding the green roof as part of the proposed building envelope system, refer to the "Cost Impact" section of "Analysis 2 – Green Roof Implementation".

Schedule Impact

The construction schedule impact of the proposed building envelope system was minimal. The installation of EXPS insulation and air/vapor barrier needs to occur before the drywall installation. Per the existing construction schedule, finish work on the perimeter walls begins on February 13, 2007 for a 122-day duration. Since this is a core and shell project and there is no tenant fit-out work that occurs until after the general contractor's substantial completion date, this activity is very flexible and can be pushed back a few weeks while the EXPS insulation and air/vapor barrier is installed ahead of the drywall and painting. According to R.S. Means Cost Data 2007, the productivity of installing foam insulation is 730 square feet per day with one carpenter, which equates to a total duration of about 14 days with three carpenters. This will only slightly delay the perimeter wall finishes, as drywall can be installed over the insulation and air vapor barrier progressively as it is installed around the north and west façades.

The installation of the R-13 fiberglass insulation in the stud cavity behind the curtain wall metal panels must occur before the installation of the curtain wall metal panel system on May 15, 2007. For 9,100 square feet of insulation to be installed in the cavity walls at a given rate of 1,150 square feet per day for one carpenter, it would take a total of four days with two carpenters. The only schedule activity that could possibly interfere with this is the perimeter wall finishes, which include the hat channels and drywall on the perimeter columns in the same area as the metal panels are to be installed. However, this would not be difficult to work around, as the perimeter column finishes are minimal.

The installation of the proposed green roof on the southwest corner of the building can take place anytime after the new fluid applied roofing membrane is installed, which is scheduled to be completed by March 20, 2007. Since this marks the beginning of spring, anytime shortly after the completion of the roofing would be beneficial for the vegetation being planted. According to a roofing contractor, intensive green roofs typically take an extra week to install than a regular built-up roof, so a target completion date of March 27 is a reasonable assumption for the 7000 + square foot area of the green roof on the southwest corner. This one week delay will not delay the overall project schedule.

The proposed improvements on the building envelope system, including the EXPS foam and air/vapor barrier inside the north and west CMU block walls, the R-13 fiberglass insulation is the stud cavity behind the metal panels, and the proposed green roof will not affect the overall project schedule. This can be made possible with minimal planning and coordination with other trades.

Constructability

The only constructability issues involved with the proposed building envelope system involve minor coordination with other trades and having less space on the roof to store materials. During the actual project construction, particularly in the spring and summer months when the green roof would be in place, the southwest section of the roof was used as a storage space for various materials such as metal panels, roof canopy steel, and some MEP equipment to be installed in the penthouse. These materials could simply be stored on the north side of the roof instead, as there was plenty of unused space. For quality assurance, it is important that the EXPS foam and R-13 fiberglass insulation is installed properly, especially in the joints, to maximize its affect on reducing thermal conductivity of the wall system.

Conclusion

The improvements made to the building envelope by adding insulation to the wall systems greatly benefited the office/retail building. I would expect the owner to buy into the added upfront cost of greatly improving the thermal performance of the wall systems for $51,748 with the energy savings of $56,167 per year. This is basically suggesting that the wall improvements would pay for themselves in terms of energy savings in less than a year. Along with a decreased energy demand for the HVAC system, there is also an opportunity to decrease the size of the heating and air conditioning units, which will save the owner money as well.

As for the proposed 7,000+ square feet of the roof being converted into an intensive green roof system, the cost investment would not be worth the heat transfer improvement and energy savings. If the building under study was located in a drier climate with a very low annual rainfall rate, the energy savings with the green roof would be much more worth the investment.

To further investigate the condensation concern in the north and west wall proposed design, a moisture analysis was conducted with the temperature and relative humidity extremes of 38°C and 90% RH for summer and -20°C and 90% RH for winter. Reference Appendix M for the spreadsheet comparing the permeance (M) and vapor resistance (R_v) of each layer of the wall. This information is used to calculate the vapor pressure (P) and vapor saturation pressure (P_{sat}) at each material's surface, which is then used to indicate where condensation takes place, or when P is greater than P_{sat}. During the extreme winter conditions, condensation occurs on the inside surface of the brick, but is not an issue since the moisture can drain through the airspace and out weep holes. The concern is during the extreme summer conditions, where condensation occurs between the insulation and air/vapor barrier and has nowhere to drain. Too much moisture build-up can cause mold problems in the building which can be harmful to one's health. The performance of the proposed wall system is very beneficial to the owner based on thermal analysis and energy savings, but further research could be conducted to address the condensation concern. This issue can potentially be resolved by simply modifying the type of air and vapor barrier or by using Tyvek, which acts as an air barrier with a high vapor permeance.

FINAL CONCLUSIONS

In this thesis project, several modifications were proposed and analyzed for the design and construction of the office/retail building in Washington, D.C.. These proposed changes had a number of benefits tied to them, as well as other findings that would likely be rejected by the owner. The urban development research highlighted the decision factors developers are faced with in the preliminary planning stages of a project, which also then impact the construction. The goal of the development process is to make money as efficiently as possible, keeping in mind the first cost versus the life cycle cost considerations. This input from the industry members was used to analyze the renovation project under study and compare it to if it had been completely demolished and rebuilt as new. The study resulted in almost double the upfront cost and another year added to the construction schedule, which was speculated not to be the development strategy of choice by the owner of this project. The remaining two analyses considered the potential for the owner to increase the performance and value of the building given the development method of the original plan for renovation.

The green roof study measured how attractive all the benefits of implementing such a system would be to the office/retail building in terms of its cost, schedule, and constructability impacts. Aside from the green roof's positive influence on the environment and life-cycle of the building, it would also add an aesthetic appeal to the new rooftop patio and create a nice outdoor environment for the office workers. However, the upfront cost of nearly $250,000 for the intensive system including the structural support beneath the roof slab would likely be too much to convince the owner that it is worth implementing. There are likely other economically friendly sustainable design and construction features worth looking into for in an increasingly environmentally conscious world.

The proposed building envelope performance improvements were relatively inexpensive for the new wall systems, considering the thermal enhancements in terms of energy efficiency and savings. The added two-inch layer of EXPS foam insulation in the north and west façades and the R-13 insulation layer behind the curtain wall metal panels paid for themselves in less than one year with the amount of energy saved that powers the heating and air conditioning systems. The owner would likely buy into the thermal performance of the proposed improvements of the wall systems, keeping in mind the need for further investigation of the type and placement of the air and vapor barrier to control condensation. The intensive green roof system, on the other hand, did not have very impressive energy savings compared to the upfront cost of the system, and would not be recommended for the reasons of gaining thermal performance.

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ASHRAE Handbook of Fundamentals

R.S. Means Construction Cost Data 2008

Industry Members

Sean Cahill, Louis Dreyfus Property Group

Burgin Dossett, Crosland

Bill Forrey, Wohlsen Construction (formerly employed at Horst Development)

Meera Friemel, Greenebaum-Rose

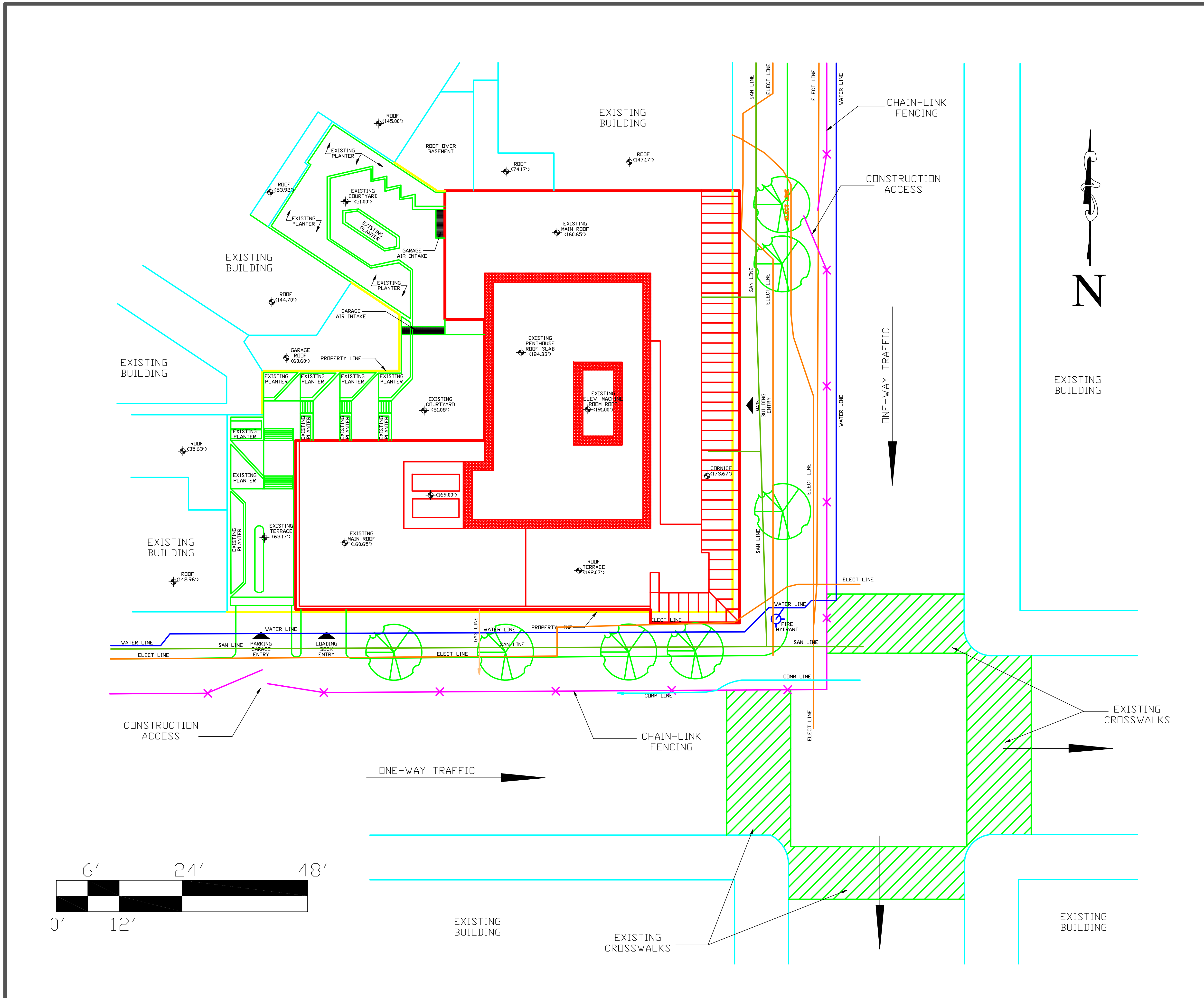
Mark Konchar, Balfour Beatty Construction (formerly employed with a private developer)

Roberta Liss, CB Richard Ellis

David Miller, Boston Properties

APPENDIX A

SITE LAYOUT PLANNING



DEREK BAUER

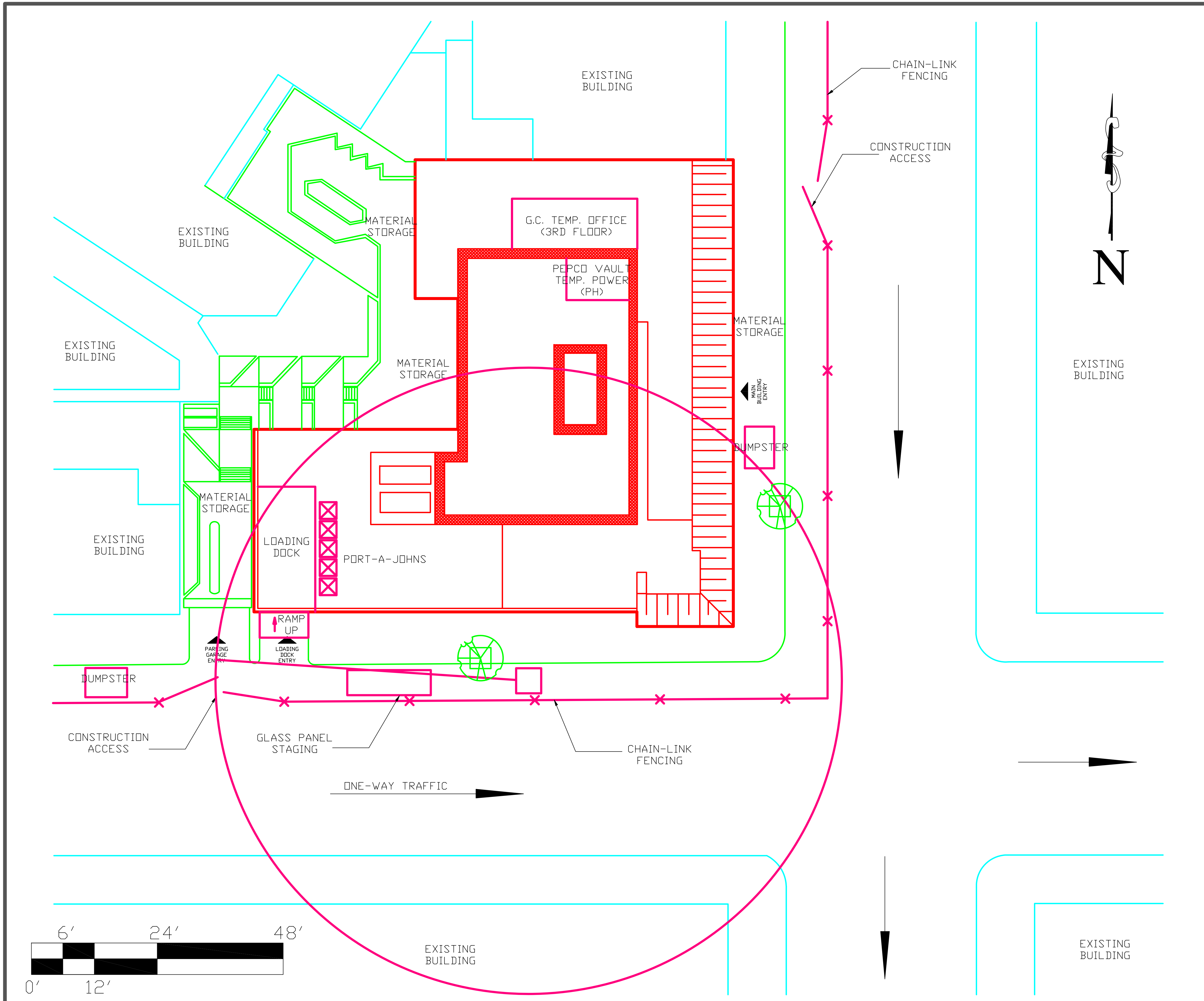
APPENDIX A

SITE LAYOUT PLANNING

OFFICE/RETAIL BUILDING

APPENDIX B

CURTAIN WALL SEQUENCING



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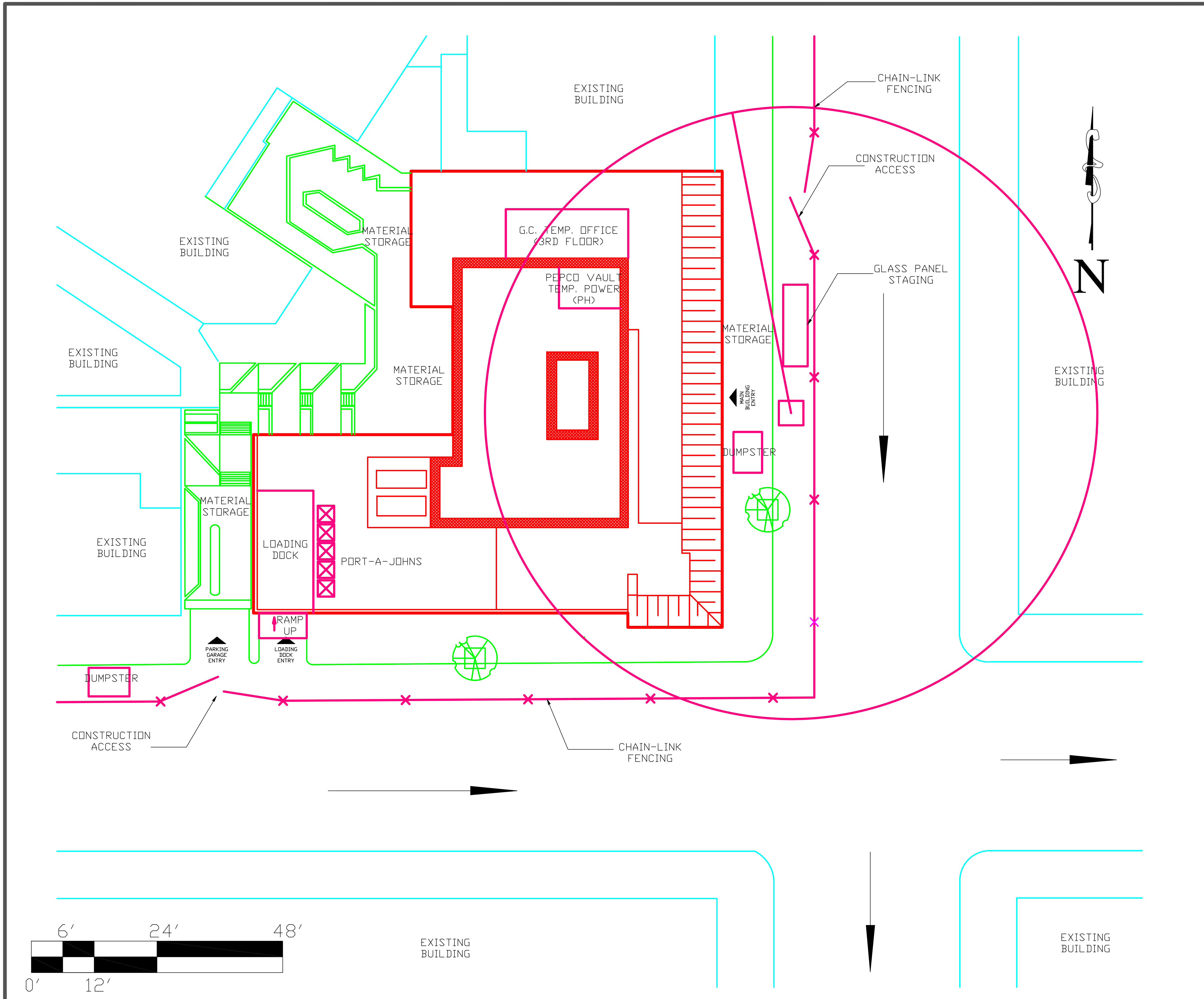
APPENDIX B-1

CURTAIN WALL PHASE 1

OFFICE/RETAIL BUILDING



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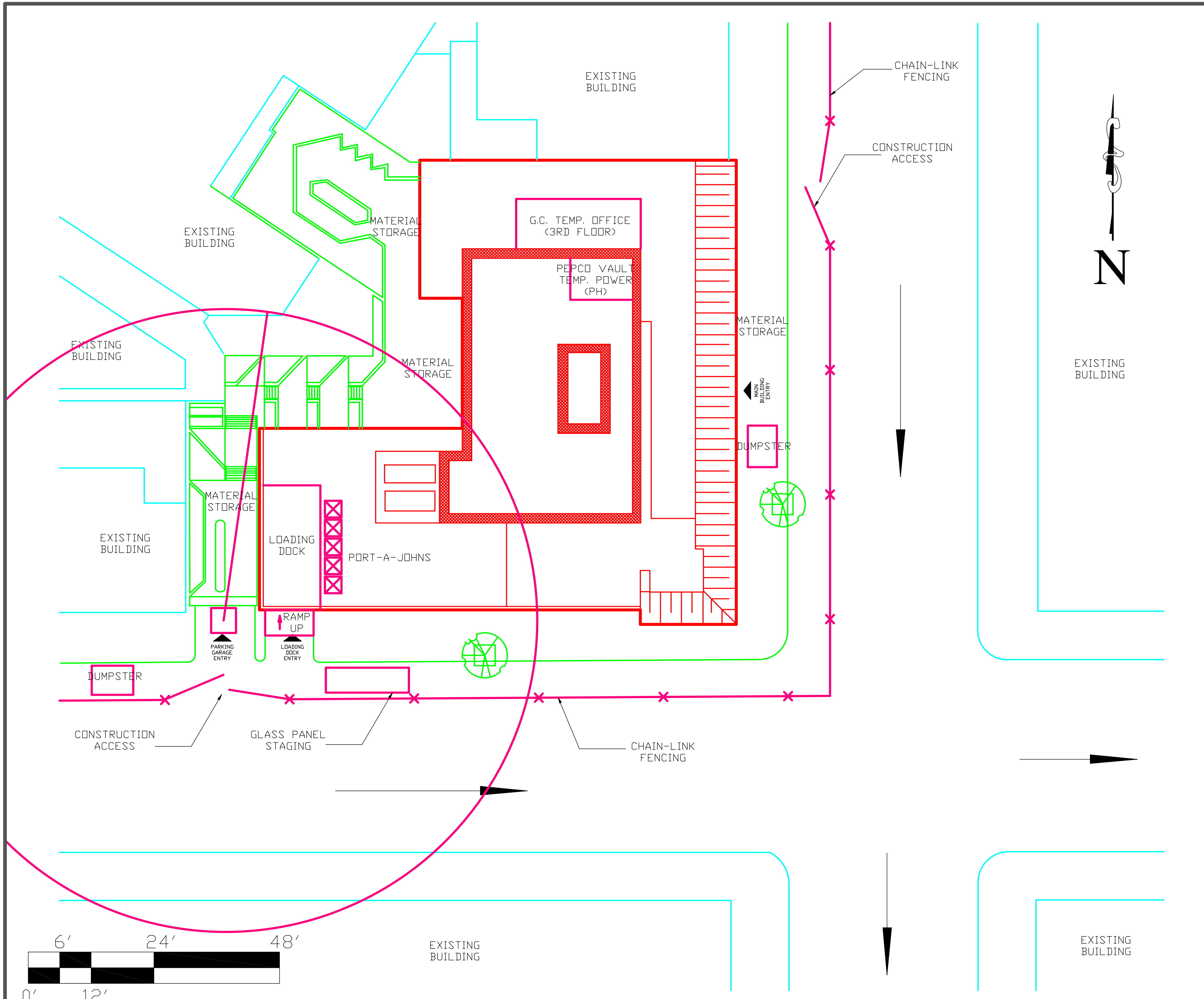
APPENDIX B-2

CURTAIN WALL PHASE 2

OFFICE/RETAIL BUILDING



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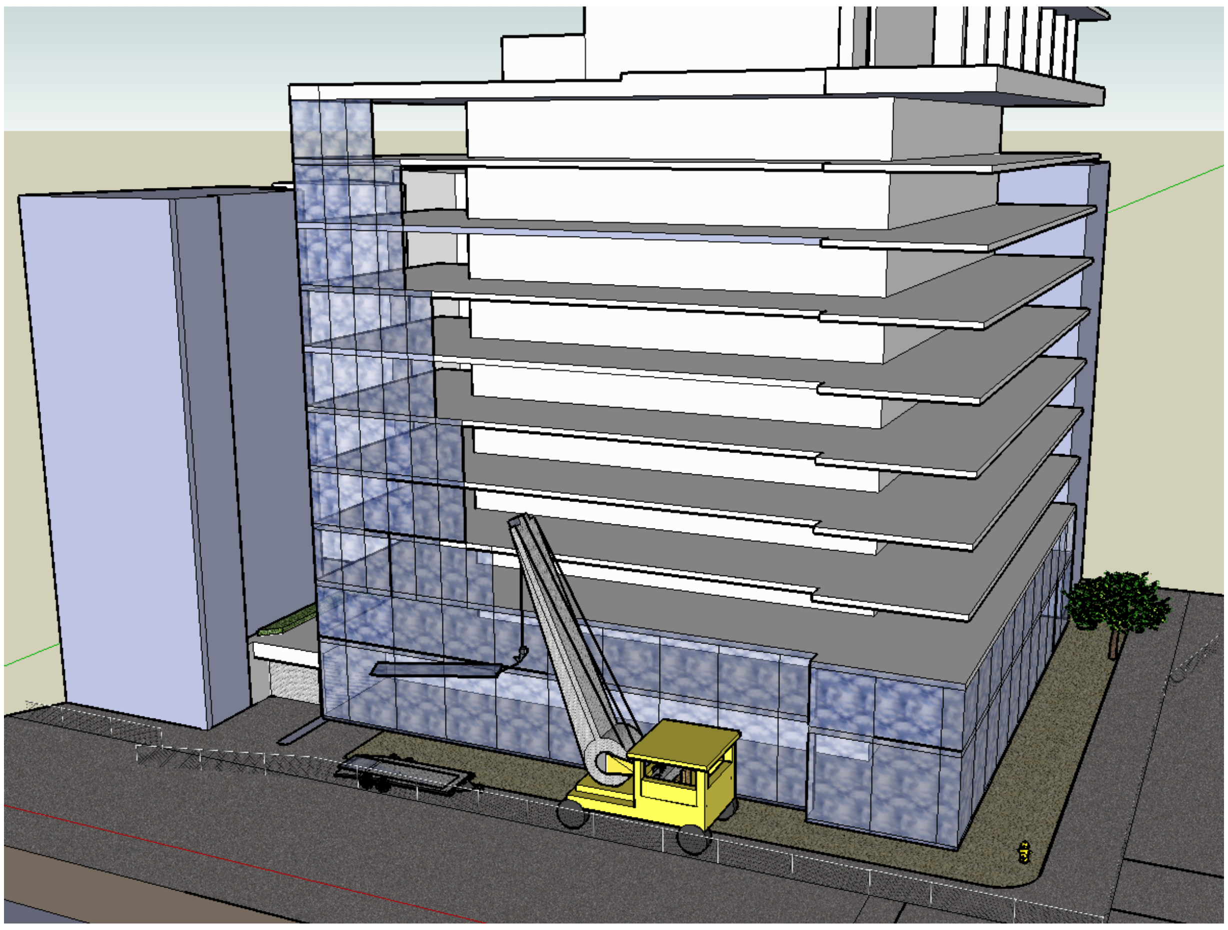
APPENDIX B-3

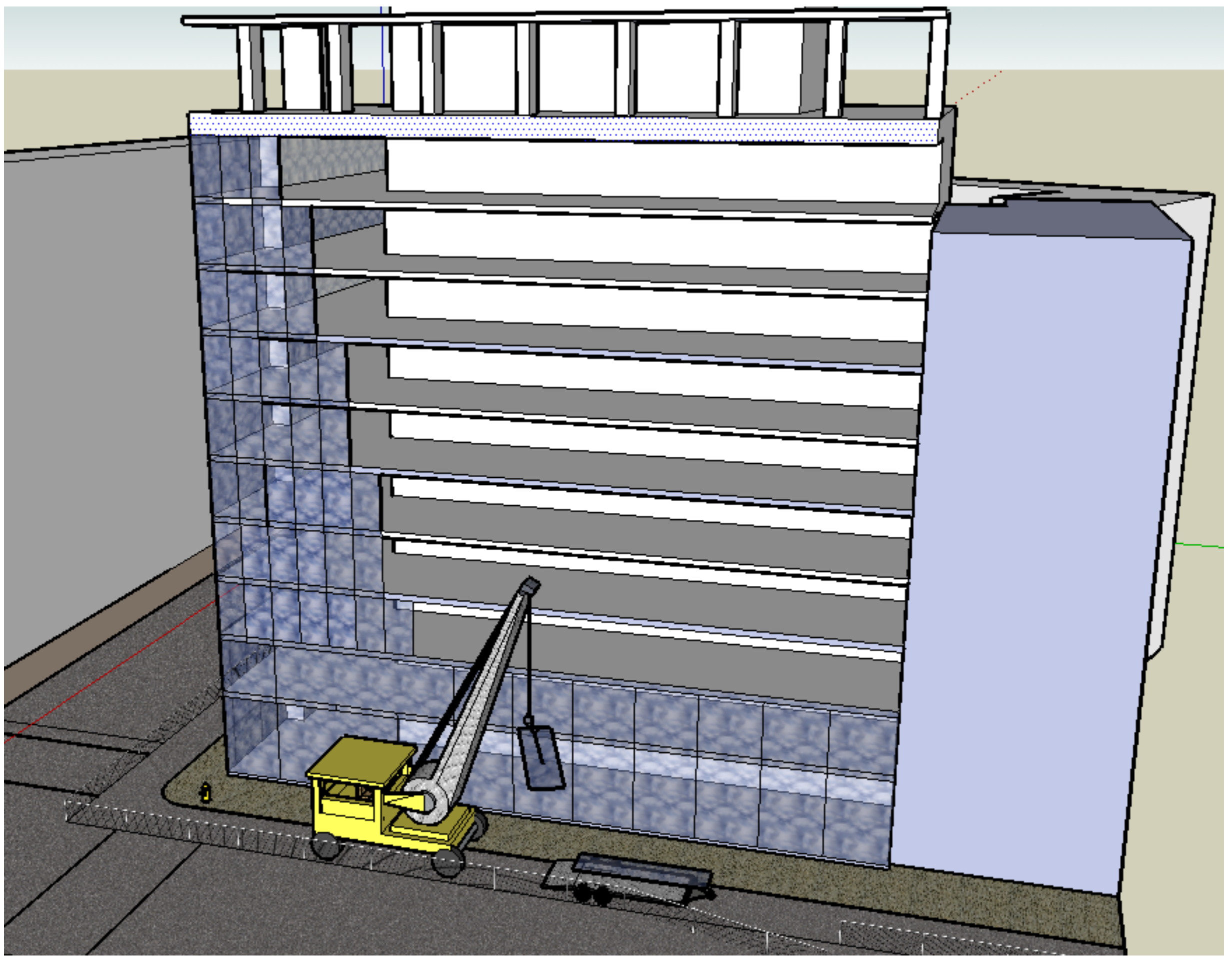
CURTAIN WALL PHASE 3

OFFICE/RETAIL BUILDING

APPENDIX B-4 – 3-D SEQUENCING OF CURTAIN WALL

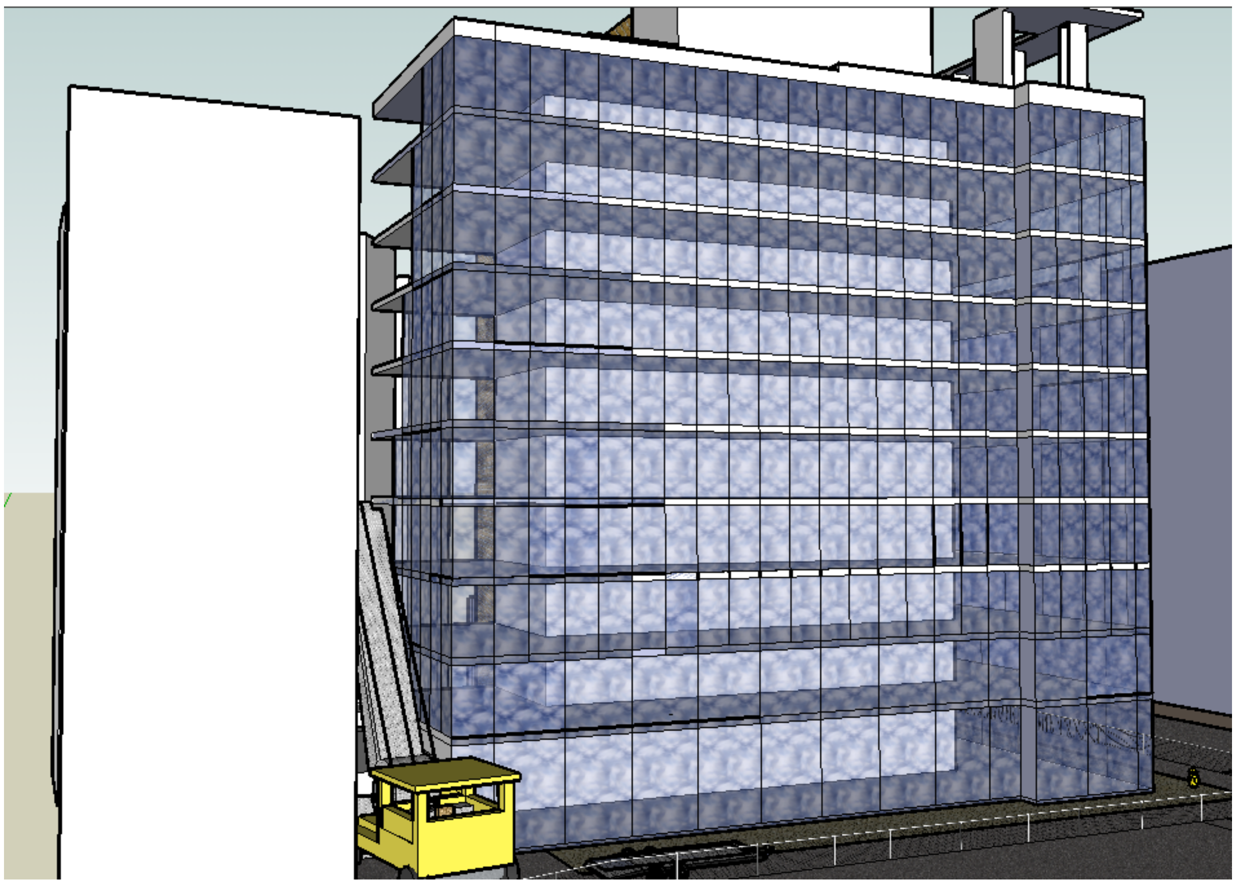
PHASE 1





PHASE 2

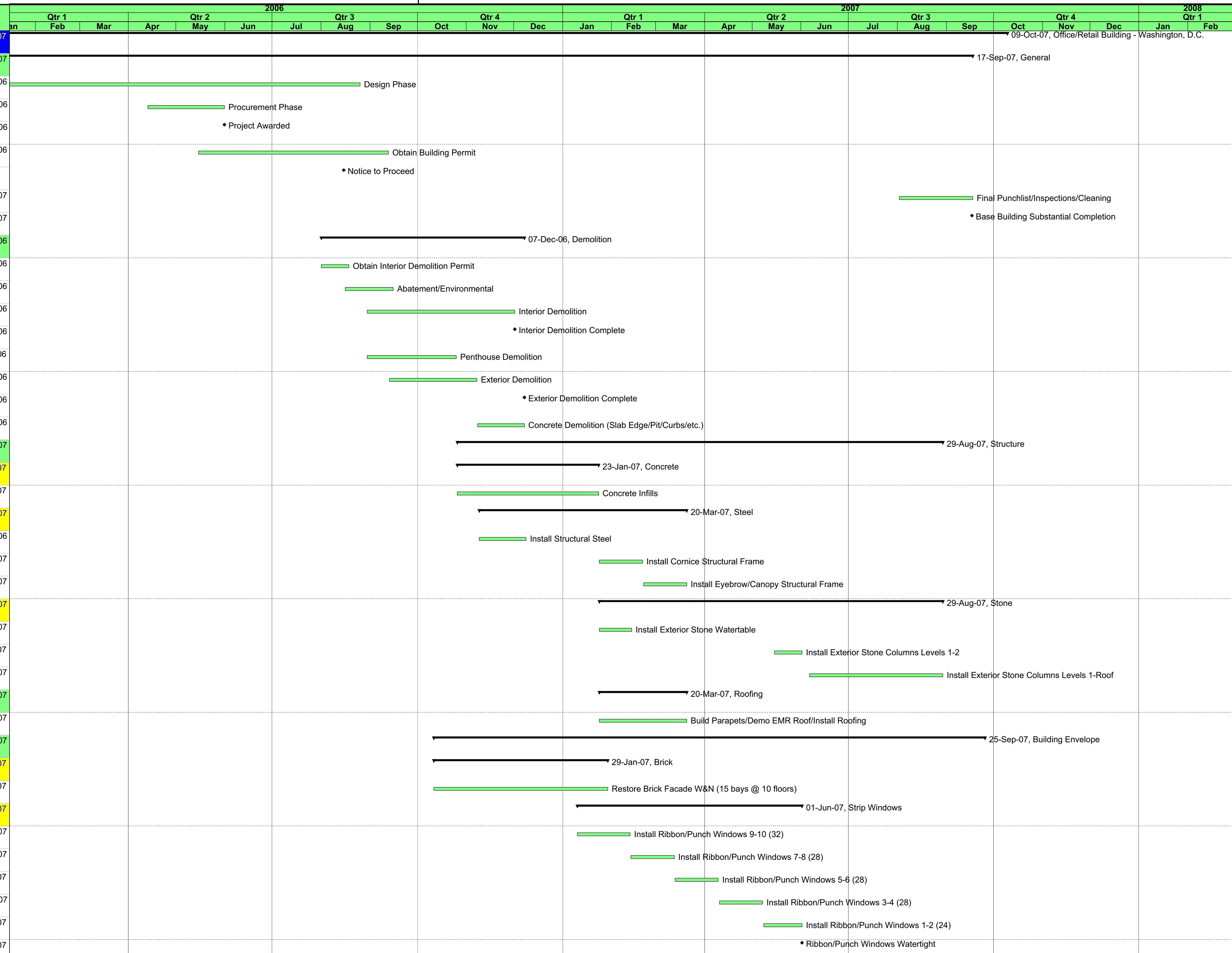
PHASE 3



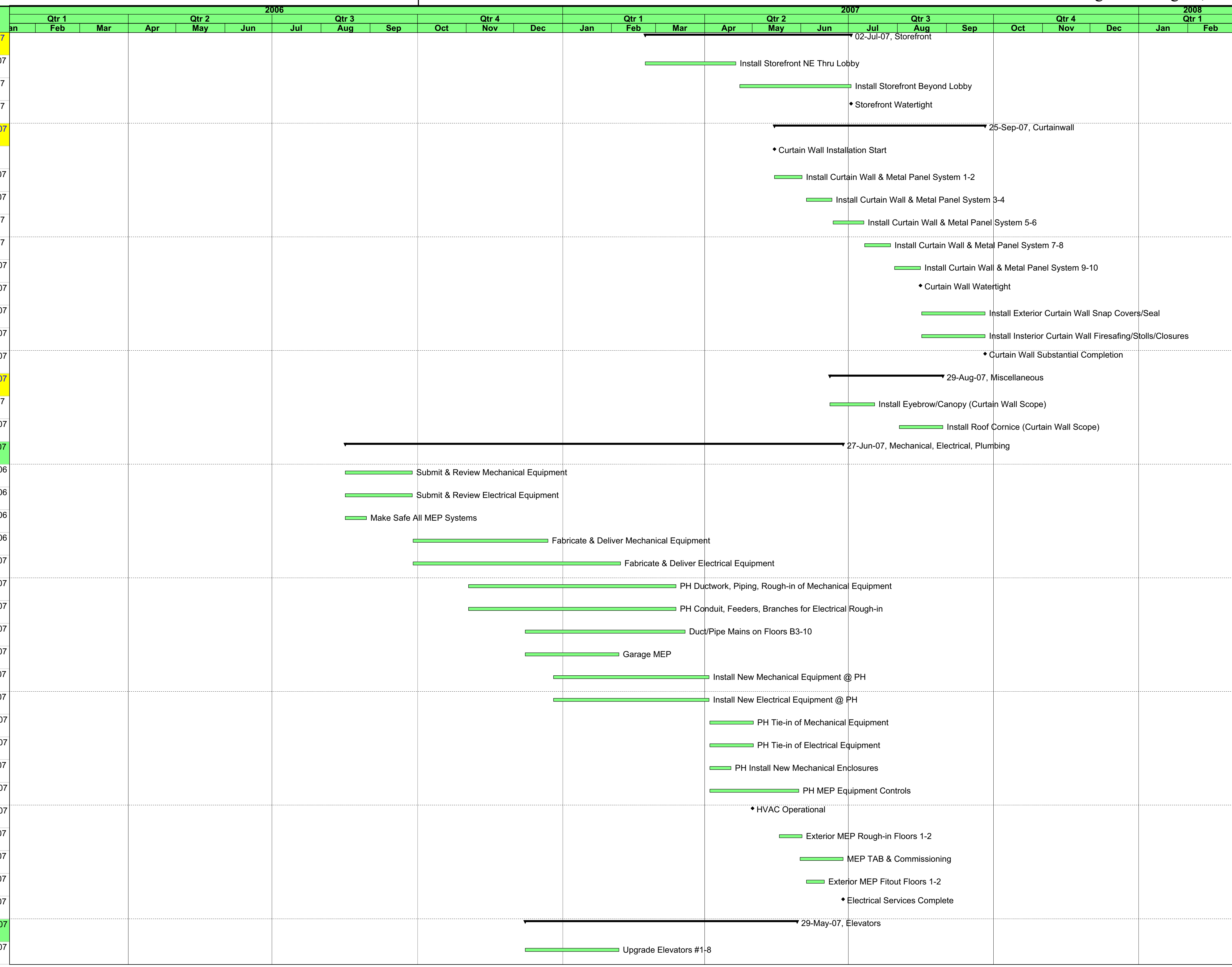
APPENDIX C

DETAILED PROJECT SCHEDULE

Activity ID	Activity Name	Original Durat...	Start	Finish
Office/Retail Building - Washington, D.C.		451	03-Jan-06	09-Oct-07
General		435	03-Jan-06	17-Sep-07
GENRL01	Design Phase	167	03-Jan-06	25-Aug-06
GENRL02	Procurement Phase	34	13-Apr-06	31-May-06
GENRL03	Project Awarded	0		31-May-06
GENRL04	Obtain Building Permit	84	15-May-06	12-Sep-06
GENRL05	Notice to Proceed	0	15-Aug-06	
GENRL06	Final Punchlist/Inspections/Cleaning	32	02-Aug-07	17-Sep-07
GENRL07	Base Building Substantial Completion	0		17-Sep-07
Demolition		90	01-Aug-06	07-Dec-06
DEMO01	Obtain Interior Demolition Permit	14	01-Aug-06	18-Aug-06
DEMO02	Abatement/Environmental	22	16-Aug-06	15-Sep-06
DEMO03	Interior Demolition	65	30-Aug-06	01-Dec-06
DEMO04	Interior Demolition Complete	0		01-Dec-06
DEMO05	Penthouse Demolition	40	30-Aug-06	25-Oct-06
DEMO06	Exterior Demolition	40	13-Sep-06	07-Nov-06
DEMO07	Exterior Demolition Complete	0		07-Dec-06
DEMO08	Concrete Demolition (Slab Edge/Pit/Curbs/etc.)	20	08-Nov-06	07-Dec-06
Structure		214	26-Oct-06	29-Aug-07
Concrete		60	26-Oct-06	23-Jan-07
CONC01	Concrete Infills	60	26-Oct-06	23-Jan-07
Steel		90	09-Nov-06	20-Mar-07
STEEL01	Install Structural Steel	20	09-Nov-06	08-Dec-06
STEEL02	Install Cornice Structural Frame	20	24-Jan-07	20-Feb-07
STEEL03	Install Eyebrow/Canopy Structural Frame	20	21-Feb-07	20-Mar-07
Stone		154	24-Jan-07	29-Aug-07
STONE01	Install Exterior Stone Watertable	15	24-Jan-07	13-Feb-07
STONE02	Install Exterior Stone Columns Levels 1-2	13	15-May-07	01-Jun-07
STONE03	Install Exterior Stone Columns Levels 1-Roof	60	06-Jun-07	29-Aug-07
Roofing		40	24-Jan-07	20-Mar-07
ROOF01	Build Parapets/Demo EMR Roof/Install Roofing	40	24-Jan-07	20-Mar-07
Building Envelope		243	11-Oct-06	25-Sep-07
Brick		75	11-Oct-06	29-Jan-07
ENVL01	Restore Brick Facade W&N (15 bays @ 10 floors)	75	11-Oct-06	29-Jan-07
Strip Windows		102	10-Jan-07	01-Jun-07
ENVL02	Install Ribbon/Punch Windows 9-10 (32)	24	10-Jan-07	12-Feb-07
ENVL03	Install Ribbon/Punch Windows 7-8 (28)	20	13-Feb-07	12-Mar-07
ENVL04	Install Ribbon/Punch Windows 5-6 (28)	20	13-Mar-07	09-Apr-07
ENVL05	Install Ribbon/Punch Windows 3-4 (28)	20	10-Apr-07	07-May-07
ENVL06	Install Ribbon/Punch Windows 1-2 (24)	18	08-May-07	01-Jun-07
ENVL07	Ribbon/Punch Windows Watertight	0		01-Jun-07



Activity ID	Activity Name	Original Durat...	Start	Finish
Storefront		92	22-Feb-07	02-Jul-07
ENVL08	Install Storefront NE Thru Lobby	42	22-Feb-07	20-Apr-07
ENVL09	Install Storefront Beyond Lobby	50	23-Apr-07	02-Jul-07
ENVL10	Storefront Watertight	0		02-Jul-07
Curtainwall		93	15-May-07	25-Sep-07
ENVL11	Curtain Wall Installation Start	0	15-May-07	
ENVL12	Install Curtain Wall & Metal Panel System 1-2	13	15-May-07	01-Jun-07
ENVL13	Install Curtain Wall & Metal Panel System 3-4	13	04-Jun-07	20-Jun-07
ENVL14	Install Curtain Wall & Metal Panel System 5-6	13	21-Jun-07	10-Jul-07
ENVL15	Install Curtain Wall & Metal Panel System 7-8	13	11-Jul-07	27-Jul-07
ENVL16	Install Curtain Wall & Metal Panel System 9-10	13	30-Jul-07	15-Aug-07
ENVL17	Curtain Wall Watertight	0		15-Aug-07
ENVL18	Install Exterior Curtain Wall Snap Covers/Seal	28	16-Aug-07	25-Sep-07
ENVL19	Install Insterior Curtain Wall Firesafing/Stolls/Closures	28	16-Aug-07	25-Sep-07
ENVL20	Curtain Wall Substantial Completion	0		25-Sep-07
Miscellaneous		51	19-Jun-07	29-Aug-07
ENVL22	Install Eyebrow/Canopy (Curtain Wall Scope)	20	19-Jun-07	17-Jul-07
ENVL23	Install Roof Cornice (Curtain Wall Scope)	20	02-Aug-07	29-Aug-07
Mechanical, Electrical, Plumbing		220	16-Aug-06	27-Jun-07
MEP01	Submit & Review Mechanical Equipment	30	16-Aug-06	27-Sep-06
MEP02	Submit & Review Electrical Equipment	30	16-Aug-06	27-Sep-06
MEP03	Make Safe All MEP Systems	10	16-Aug-06	29-Aug-06
MEP04	Fabricate & Deliver Mechanical Equipment	60	28-Sep-06	22-Dec-06
MEP05	Fabricate & Deliver Electrical Equipment	90	28-Sep-06	06-Feb-07
MEP06	PH Ductwork, Piping, Rough-in of Mechanical Equipment	90	02-Nov-06	13-Mar-07
MEP07	PH Conduit, Feeders, Branches for Electrical Rough-in	90	02-Nov-06	13-Mar-07
MEP08	Duct/Pipe Mains on Floors B3-10	70	08-Dec-06	19-Mar-07
MEP09	Garage MEP	40	08-Dec-06	05-Feb-07
MEP10	Install New Mechanical Equipment @ PH	70	26-Dec-06	03-Apr-07
MEP11	Install New Electrical Equipment @ PH	70	26-Dec-06	03-Apr-07
MEP12	PH Tie-in of Mechanical Equipment	20	04-Apr-07	01-May-07
MEP13	PH Tie-in of Electrical Equipment	20	04-Apr-07	01-May-07
MEP14	PH Install New Mechanical Enclosures	10	04-Apr-07	17-Apr-07
MEP15	PH MEP Equipment Controls	40	04-Apr-07	30-May-07
MEP16	HVAC Operational	0		01-May-07
MEP17	Exterior MEP Rough-in Floors 1-2	10	18-May-07	01-Jun-07
MEP18	MEP TAB & Commissioning	20	31-May-07	27-Jun-07
MEP19	Exterior MEP Fitout Floors 1-2	10	04-Jun-07	15-Jun-07
MEP20	Electrical Services Complete	0		27-Jun-07
Elevators		120	08-Dec-06	29-May-07
ELEV01	Upgrade Elevators #1-8	40	08-Dec-06	05-Feb-07



Activity ID	Activity Name	Original Durat...	Start	Finish
ELEV02	Elevators #1-8 Cab Demo/Finishes	80	06-Feb-07	29-May-07
ELEV03	Install Elevators #9-10	40	20-Feb-07	16-Apr-07
ELEV04	Elevators #9-10 Cab Finishes	20	17-Apr-07	14-May-07
Finishes		238	01-Nov-06	09-Oct-07
Core		222	01-Nov-06	17-Sep-07
FINSH01	Core Walls/MEP Rough-in/Finishes 9-10	60	01-Nov-06	29-Jan-07
FINSH02	Core Walls/MEP Rough-in/Finishes 7-8	60	08-Dec-06	05-Mar-07
FINSH03	Core Walls/MEP Rough-in/Finishes 5-6	60	16-Jan-07	09-Apr-07
FINSH04	Core Walls/MEP Rough-in/Finishes 3-4	60	20-Feb-07	14-May-07
FINSH05	Core Walls/MEP Rough-in/Finishes 1-2	60	27-Mar-07	19-Jun-07
FINSH06	Core Finishes Complete	0		17-Sep-07
Perimeter		168	13-Feb-07	09-Oct-07
FINSH07	Perimeter Walls/MEP Rough-in/Finishes 9-10	30	13-Feb-07	26-Mar-07
FINSH08	Perimeter Walls/MEP Rough-in/Finishes 7-8	30	13-Mar-07	23-Apr-07
FINSH09	Perimeter Walls/MEP Rough-in/Finishes 5-6	30	10-Apr-07	21-May-07
FINSH10	Perimeter Walls/MEP Rough-in/Finishes 3-4	30	15-May-07	26-Jun-07
FINSH11	Perimeter Walls/MEP Rough-in/Finishes 1-2	30	20-Jun-07	01-Aug-07
FINSH12	Perimeter Finishes at Curtain Wall	20	12-Sep-07	09-Oct-07
Parking Garage		105	30-Jan-07	26-Jun-07
FINSH13	Parking Garage Core/Fitness Walls/MEP Rough-ins/Finishes	60	30-Jan-07	23-Apr-07
FINSH14	Parking Garage Paint/Parking Spaces	25	22-May-07	26-Jun-07
Penthouse		20	18-Apr-07	15-May-07
FINSH15	Penthouse Finishes	20	18-Apr-07	15-May-07
Lobby		60	07-May-07	31-Jul-07
FINSH16	Lobby MEP/Finishes	60	07-May-07	31-Jul-07
FINSH17	Lobby Complete	0		31-Jul-07
Sitework		100	18-May-07	09-Oct-07
SITE01	Site Utilities/Concrete/Paving/Finishes	100	18-May-07	09-Oct-07
SITE02	Finishes at Site Complete	0		09-Oct-07

APPENDIX D

GENERAL CONDITIONS ESTIMATE

Appendix D – General Conditions Estimate

GENERAL CONDITIONS ESTIMATE						
Cost Code	Description	Lab/Mat	Quantity	Units	Unit Price	Amount
010030-A	Bonds/Insurance/Permits	Mat	1	LS	$167,989	$167,989
010040-A	Contractor's Fee	Mat	1	LS	$1,343,912	$1,343,912
010050-A	Company Owned Equipment	Mat	1	LS	$16,250	$16,250
010080-A	Vehicle Fuel	Mat	2	EA	$2,500	$5,000
010100-A	Preventive Maintenance	Lab	13	MO	$385	$5,000
010120-A	Parking Fees	Mat	1	LS	$1,350	$1,350
011280-A	Office & Sheds	Mat	1	LS	$5,000	$5,000
011300-A	Trailer Set-up/Takedown	Lab	1	LS	$250	$250
011320-A	Furniture	Mat	1	LS	$727	$727
011380-A	Office Security System	Mat	1	LS	$5,100	$5,100
011420-A	Office Clean-up Labor	Lab	13	MO	$348	$4,525
011450-A	Office Maintenance and Repairs	Lab	13	MO	$108	$1,400
012500-A	Telephone Monthly Charges	Mat	13	MO	$1,162	$15,100
012520-A	Telephone Co Installation Charges	Lab	1	LS	$1,500	$1,500
012550-A	Phone System Equipment & Installation	Lab/Mat	1	LS	$3,500	$3,500
012600-A	Jobsite Radios	Mat	8	EA	$450	$3,600
012620-A	Mobile Phone	Mat	13	MO	$569	$7,400
012650-A	Computer Equipment	Mat	10	EA	$1,370	$13,695
012670-A	Software	Mat	10	EA	$70	$702
012680-A	Phone/Data Cabling	Mat	10	EA	$100	$1,000
012720-A	Drinking Water in Office	Mat	57	WK	$43	$2,450
012730-A	Office Supplies	Mat	13	MO	$808	$10,500
012750-A	Office Equipment	Mat	13	MO	$77	$1,000
012760-A	Office Equipment Maintenance	Lab	13	MO	$346	$4,500
012780-A	Postage and Shipping	Mat	57	WK	$246	$14,000
012800-A	Drawing Reproduction	Mat	1	LS	$7,000	$7,000
012820-A	Record and As-Built Documents	Mat	1	LS	$2,500	$2,500
012850-A	Travel	Mat	13	MO	$492	$6,400
012880-A	Ceremonies/Meetings/Entertainment	Mat	13	MO	$423	$5,500
012900-A	Jobsite Progress Photos	Mat	13	MO	$171	$2,225
012950-A	Professional Photography	Mat	1	LS	$10,400	$10,400
013030-L	Rodman	Lab	57	WK	$505	$28,800
013050-A	Surveying Equipment	Mat	1	LS	$8,520	$8,520
013100-A	Survey Materials	Mat	1	LS	$5,000	$5,000
013150-A	Professional Engineering/Survey	Mat	1	LS	$7,000	$7,000
014010-L	Project Carpenter	Lab	57	WK	$1,035	$59,000
014020-L	Project Laborer	Lab	114	WK	$704	$80,240
014050-A	Warehouse Facilities - on site	Mat	1	LS	$1,200	$1,200
014200-A	Equipment Rental	Mat	1	LS	$10,500	$10,500
014450-L	Temp Elevator Operator	Lab	57	WK	$613	$34,944
014550-A	Rough Hardware	Mat	1	LS	$1,500	$1,500
014600-A	Small Tools	Mat	1	LS	$7,000	$7,000
014700-A	Protection Materials	Mat	1	LS	$12,350	$12,350
014750-S	Trash Haul-Off	Mat	57	WK	$1,196	$68,200

GENERAL CONDITIONS ESTIMATE (CONT.)						
014800-A	Office Clean-up	Mat	57	WK	$27	$1,538
014800-L	Office Clean-up	Lab	57	WK	$260	$14,792
014850-A	Trash Chute	Mat	1	LS	$4,000	$4,000
014900-A	Final Clean	Mat	1	LS	$102,440	$102,440
014900-L	Final Clean	Lab	1	LS	$3,120	$3,120
014950-A	Ice, Water and Cups	Mat	57	WK	$29	$1,680
015100-A	Temp Chainlink Fence	Mat	1	LS	$7,500	$7,500
015400-A	Temporary Toilets	Mat	5	EA	$1,728	$8,640
015450-A	Signs	Mat	1	LS	$6,500	$6,500
015550-A	Pest/Rodent Control	Mat	1	LS	$2,000	$2,000
016050-A	Safety Equipment and Supplies	Mat	1	LS	$2,500	$2,500
016150-A	Drug Testing	Mat	1	LS	$320	$320
016200-A	Perimeter Protection	Mat	1	LS	$19,750	$19,750
016200-L	Perimeter Protection	Lab	1	LS	$20,750	$20,750
016250-A	Covered Entrance and Walk	Mat	1	LS	$2,500	$2,500
017100-A	Temporary Power Consumption	Mat	13	MO	$2,692	$35,000
017200-A	Power Consumption w/HVAC	Mat	13	MO	$6,154	$80,000
017650-A	Building Weather Protection	Mat	1	LS	$7,200	$7,200
017700-A	Temporary Fire Protection	Mat	1	LS	$2,105	$2,105
018200-A	Curtain Wall Consultant	Mat	1	LS	$3,000	$3,000
019990-A	Miscellaneous General Conditions	Mat	1	LS	$3,500	$3,500
019999-L	Project Executive	Lab	5	MO	$0	$0
019999-L	Project Manager	Lab	14	MO	$0	$0
019999-L	Assistant Project Manager	Lab	14	MO	$0	$0
019999-L	Senior Project Engineer	Lab	13	MO	$0	$0
019999-L	Project Engineer	Lab	12	MO	$0	$0
019999-L	Superintendent	Lab	14	MO	$0	$0
019999-L	Assistant Superintendent	Lab	14	MO	$0	$0
019999-L	Chief Field Engineer	Lab	13	MO	$0	$0
019999-L	Project Accountant	Lab	13	MO	$0	$0
019999-L	Total Salaried Employees on Site	Lab	1	LS	$1,170,400	$1,170,400
				TOTAL G.C. COSTS:	**$3,492,964**	

APPENDIX E

COST IMPACT FOR DEMO/NEW CONSTRUCTION

Appendix E – Cost Impact of Demo/New Construction

R.S. Means 2007 Square Foot Cost Data Office/Retail Occupied Space					
10 floors - 361,660 SF Area - 894 LF Perimeter		R.S. Means	R.S. Means	Actual	NOTES
Exterior Wall	S.F. Area	250,000	300,000	361,660	Data is extrapolated
	L.F. Perimeter	640	700	774	
Face Brick with Concrete Block Back-up	R/Conc. Frame	$123.65	$122.40	$120.85	
Adjustments	Perimeter Adj.	$2.15	$1.75	$1.13	Adjusted per 100 LF
	Story Hgt. Adj.	$1.10	$1.00	$0.88	Adjusted per 1 ft

Square Foot Estimate	$120.85
Perimeter Adjustment	$1.36
Story Height Adjustment	-$0.88
Adjusted Square Foot Cost	$121.33
Subtotal	$43,921,460

	Description	Unit	$ Cost	Project Cost	
Additives	Elevators, Electric passenger, 5 stops	EA	$134,300	$805,800	6 additional elevators than specified
	Additional stop	EA	$7,875	$315,000	5 additional stops for 8 of the elevators
			Total Additives	$1,120,800	
Deductions	(Assume 15% of office space cost)				Approximated deduction since building
			Interiors Deduct	-$6,756,339	is core and shell and core is not very large

TOTAL COST	**$38,285,921**

R.S. Means 2007 Square Foot Cost Data Underground Parking Garage					
3 floors - 120,500 SF Area - 876 LF Perimeter		R.S. Means	Actual	R.S. Means	NOTES
Exterior Wall	S.F. Area	100,000	120,500	125,000	Data is interpolated
	L.F. Perimeter	900	982	1,000	
Reinforced Concrete	R/Conc. Frame	$63.35	$62.24	$62.00	
Adjustments	Perimeter Adj.	$1.00	$0.88	$0.85	Adjusted per 100 LF
	Story Hgt. Adj.	$0.85	$0.81	$0.80	Adjusted per 1 ft

Square Foot Estimate	$62.24
Perimeter Adjustment	-$0.93
Story Height Adjustment	$0.00
Adjusted Square Foot Cost	$61.31
TOTAL COST	**$7,387,855**

RS Means 2007 Building Construction Cost Data
Mass Demolition of Building

RS Means #	Item	Description	Quantity	Unit	Cost / Unit	Cost
02 41 16.13	Building Demolition	Concrete, including haul	4,070,000	CF	$0.32	$1,302,400
02 41 16.17	Building Foundation Demo	Floors, 6" Reinforced Concrete	120,503	SF	$4.17	$502,498
	Building Foundation Demo	Walls, 8" Reinforced Block	36,000	SF	$1.93	$69,552
	Building Foundation Demo	6" Plan Concrete - Reinforced	1,440	SF	$4.17	$6,005
	Building Foundation Demo	Footings 2' x 3'	480	LF	$16.85	$8,088
	Building Foundation Demo	Hauling Foundation Demo	53,333	CF	$12.02	$641,063
					TOTAL COST*	**$1,949,467**

*Does not include additional cost of dumping and disposal fees ($95/ton)

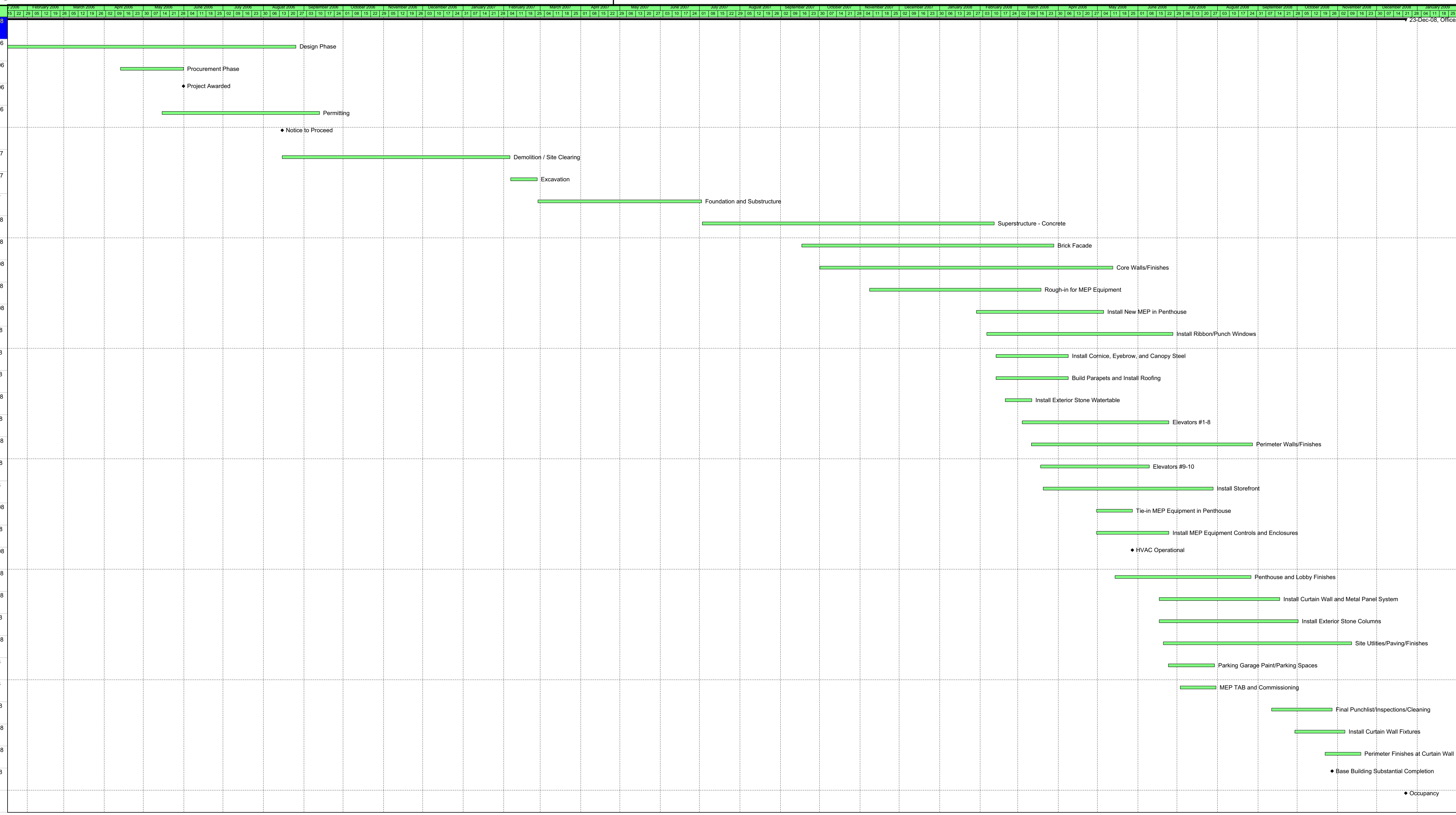
APPENDIX F

SCHEDULE IMPACT FOR DEMO/NEW CONSTRUCTION

Office/Retail Building - Washington, D.C.

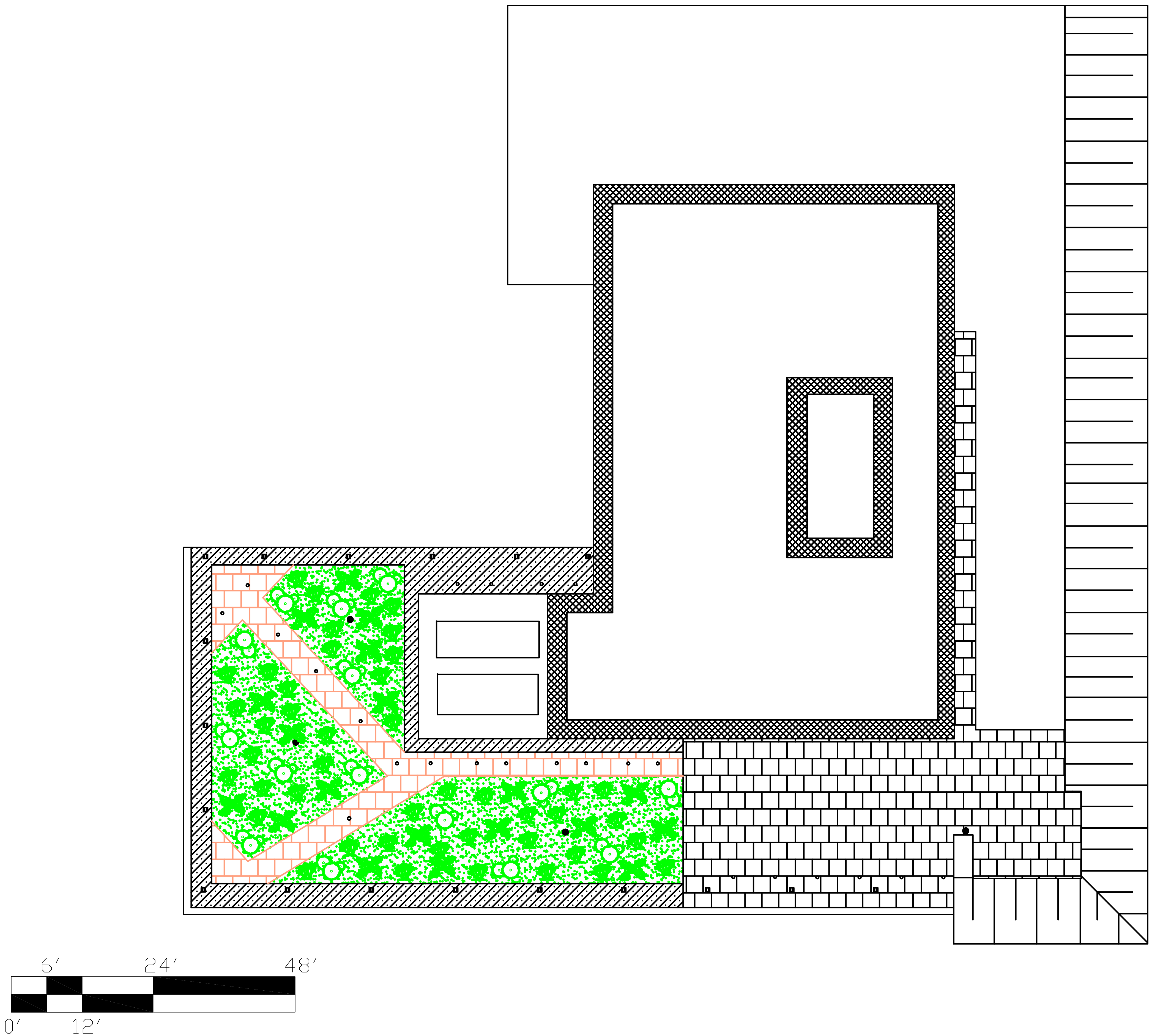
Schedule for Demolition and New Construction

Activity ID	Activity Name	Original Duration	Start	Finish
	Office/Retail Building - Washington, D.C.	768	03-Jan-06	23-Dec-08
001	Design Phase	167	03-Jan-06	25-Aug-06
002	Procurement Phase	34	13-Apr-06	31-May-06
003	Project Awarded	0		31-May-06
004	Permitting	84	15-May-06	12-Sep-06
005	Notice to Proceed	0	15-Aug-06	
006	Demolition / Site Clearing	120	15-Aug-06	05-Feb-07
007	Excavation	15	06-Feb-07*	26-Feb-07
008	Foundation and Substructure	90	27-Feb-07	02-Jul-07
009	Superstructure - Concrete	160	03-Jul-07	11-Feb-08
010	Brick Facade	140	17-Sep-07	28-Mar-08
011	Core Walls/Finishes	161	01-Oct-07	12-May-08
012	Rough-in for MEP Equipment	94	08-Nov-07*	18-Mar-08
013	Install New MEP in Penthouse	70	29-Jan-08*	05-May-08
014	Install Ribbon/Punch Windows	103	06-Feb-08*	27-Jun-08
015	Install Cornice, Eyebrow, and Canopy Steel	40	13-Feb-08*	08-Apr-08
016	Build Parapets and Install Roofing	40	13-Feb-08*	08-Apr-08
017	Install Exterior Stone Watertable	15	20-Feb-08*	11-Mar-08
018	Elevators #1-8	81	04-Mar-08*	24-Jun-08
019	Perimeter Walls/Finishes	122	11-Mar-08*	27-Aug-08
020	Elevators #9-10	60	18-Mar-08*	09-Jun-08
021	Install Storefront	93	20-Mar-08*	28-Jul-08
022	Tie-in MEP Equipment in Penthouse	20	30-Apr-08*	27-May-08
023	Install MEP Equipment Controls and Enclosures	40	30-Apr-08*	24-Jun-08
024	HVAC Operational	0		27-May-08
025	Penthouse and Lobby Finishes	75	14-May-08*	26-Aug-08
026	Install Curtain Wall and Metal Panel System	67	17-Jun-08*	17-Sep-08
027	Install Exterior Stone Columns	77	17-Jun-08*	01-Oct-08
028	Site Utlities/Paving/Finishes	103	20-Jun-08*	11-Nov-08
029	Parking Garage Paint/Parking Spaces	26	24-Jun-08*	29-Jul-08
030	MEP TAB and Commissioning	20	03-Jul-08*	30-Jul-08
031	Final Punchlist/Inspections/Cleaning	33	11-Sep-08*	27-Oct-08
032	Install Curtain Wall Fixtures	29	29-Sep-08*	06-Nov-08
033	Perimeter Finishes at Curtain Wall	20	22-Oct-08*	18-Nov-08
034	Base Building Substantial Completion	0		27-Oct-08
035	Occupancy	0	23-Dec-08*	



APPENDIX G

GREEN ROOF LAYOUT

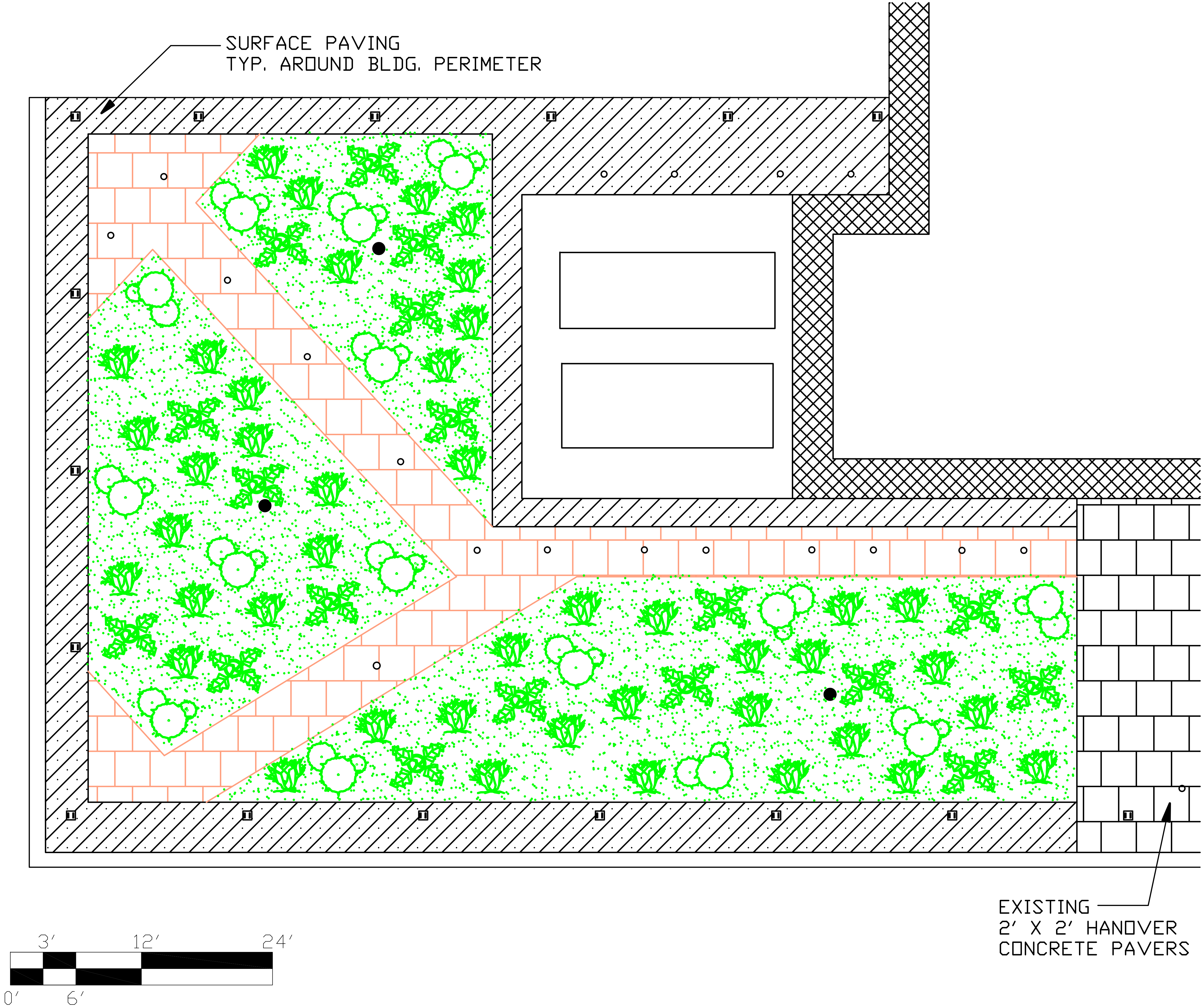


DEREK BAUER

APPENDIX G-1

GREEN ROOF LAYOUT

OFFICE/RETAIL BUILDING



DEREK BAUER

APPENDIX G-2

GREEN ROOF DESIGN

OFFICE/RETAIL BUILDING

APPENDIX H

PCA SLAB INPUT AND DESIGN RESULTS

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pcaSlab v1.51 (TM)

A Computer Program Analysis, Design, and Investigation of
Reinforced Concrete Slab and Continuous Beam Systems

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```
============================================================================================
[1] INPUT ECHO
============================================================================================

General Information:
====================
   File name: \\aep.coeaccess.psu.edu\profiles$\dcb217\Desktop\pcaSlab2.slb
   Project: Office/Retail Building
   Frame:                                     Engineer: Derek Bauer
   Code: ACI 318-02       Mode: Design        Reinforcement Database: ASTM A615
   Number of supports = 6 + Left cantilever + Right cantilever
   Floor System: Two-Way

   Live load pattern ratio = 75%
   Minimum free edge for punching shear = 10 times slab thickness
   Deflections are based on cracked section properties.
   In negative moment regions, Ig and Mcr DO NOT include flange/slab contribution (if available)
   Compression reinforcement calculations NOT selected.

Material Properties:
====================
            Slabs|Beams       Columns
           ------------   ------------
   wc    =          150            150 lb/ft3
   f'c   =            3              3 ksi
   Ec    =       3320.6         3320.6 ksi
   fr    =      0.41079        0.41079 ksi

   fy    =           60 ksi, Bars are not epoxy-coated
   fyv   =           60 ksi
   Es    =        29000 ksi

Reinforcement Database:
===============
   Units: Db (in), Ab (in^2), Wb (lb/ft)
   Size       Db       Ab       Wb    Size       Db       Ab       Wb
   ---- -------- -------- --------    ---- -------- -------- --------
     #3     0.38     0.11     0.38      #4     0.50     0.20     0.67
     #5     0.63     0.31     1.04      #6     0.75     0.44     1.50
     #7     0.88     0.60     2.04      #8     1.00     0.79     2.67
     #9     1.13     1.00     3.40     #10     1.27     1.27     4.30
    #11     1.41     1.56     5.31     #14     1.69     2.25     7.65
```

```
    #18     2.26     4.00    13.60

Span Data:
==========
   Slabs: L1, wL, wR (ft); t, Hmin (in)
   Span Loc        L1        t       wL       wR     Hmin
   ---- ---- -------- -------- -------- -------- --------
      1 ExtL    1.000    10.00   11.000   11.000     4.00 LC
      2 Int    22.000    10.00   11.000   11.000     8.00
      3 Int    20.000    10.00   11.000   11.000     6.55
      4 Int    20.000    10.00   11.000   11.000     6.55
      5 Int    21.000    10.00   11.000   11.000     6.91
      6 Int    21.000    10.00   11.000   11.000     7.60
      7 ExtR    1.000    10.00   11.000   11.000     4.00 RC

Support Data:
=============
   Columns: c1a, c2a, c1b, c2b (in); Ha, Hb (ft)
   Supp      c1a      c2a       Ha        c1b      c2b       Hb  Red%
   ---- -------- -------- --------   -------- -------- --------  ----
      1    24.00    24.00    0.000      24.00    24.00   10.000   100
      2    24.00    24.00    0.000      24.00    24.00   10.000   100
      3    24.00    24.00    0.000      24.00    24.00   10.000   100
      4    24.00    24.00    0.000      24.00    24.00   10.000   100
      5    24.00    24.00    0.000      24.00    24.00   10.000   100
      6    24.00    24.00    0.000      24.00    24.00   10.000   100

   Boundary Conditions: Kz (kip/in); Kry (kip-in/rad)
   Supp    Spring Kz   Spring Kry Far End A Far End B
   ---- ------------ ------------ --------- ---------
      1            0            0     Fixed     Fixed
      2            0            0     Fixed     Fixed
      3            0            0     Fixed     Fixed
      4            0            0     Fixed     Fixed
      5            0            0     Fixed     Fixed
      6            0            0     Fixed     Fixed

Load Data:
==========
   Load Cases and Combinations:
   Case     SELF     Dead     Live     Wind       EQ
   Type     DEAD     DEAD     LIVE  LATERAL  LATERAL
   U1      1.400    1.400    0.000    0.000    0.000
   U2      1.200    1.200    1.600    0.000    0.000
   U3      1.200    1.200    1.600    0.800    0.000
   U4      1.200    1.200    1.600   -0.800    0.000
   U5      1.200    1.200    1.000    1.600    0.000
   U6      1.200    1.200    1.000   -1.600    0.000
   U7      0.900    0.900    0.000    1.600    0.000
   U8      0.900    0.900    0.000   -1.600    0.000
   U9      1.200    1.200    1.000    0.000    1.000
   U10     1.200    1.200    1.000    0.000   -1.000
   U11     0.900    0.900    0.000    0.000    1.000
   U12     0.900    0.900    0.000    0.000   -1.000

   Span Loads:
   Span Case               Wa
   ---- -------- ------------
   Area Loads - Wa (lb/ft2):
      1 Dead               45
      2 Dead               45
      3 Dead               45
      4 Dead               45
      5 Dead               45
      6 Dead               45
      7 Dead               45
      1 Live              100
      2 Live              100
      3 Live              100
      4 Live              100
      5 Live              100
      6 Live              100
      7 Live              100

   Support Loads:   --- NONE ---

   Support Displacements:   --- NONE ---

   Lateral Load Effects - M (k-ft):
   Span Case            Mleft       Mright
   ---- -------- ------------ ------------
      1 EQ                  0            0
      2 EQ                  0            0
      3 EQ                  0            0
      4 EQ                  0            0
      5 EQ                  0            0
      6 EQ                  0            0
```

7 EQ	0	0
1 Wind	0	0
2 Wind	0	0
3 Wind	0	0
4 Wind	0	0
5 Wind	0	0
6 Wind	0	0
7 Wind	0	0

Reinforcement Criteria:
=======================

	Top bars		Bottom bars		Stirrups		
	Min	Max	Min	Max	Min	Max	
Slabs and Ribs:							
Bar Size	#4	#4	#4	#4			
Bar spacing	14.00	14.00	14.00	14.00			in
Reinf ratio	0.14	5.00	0.14	5.00			%
Cover	0.75		0.75				in
Beams:							
Bar Size	#5	#8	#5	#8	#3	#5	
Bar spacing	1.00	18.00	1.00	18.00	6.00	18.00	in
Reinf ratio	0.14	5.00	0.14	5.00			%
Cover	1.50		1.50				in

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pcaSlab v1.51 (TM)

A Computer Program Analysis, Design, and Investigation of
Reinforced Concrete Slab and Continuous Beam Systems

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[2] DESIGN RESULTS

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Top Reinforcement:

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Units: Width (ft), Mmax (k-ft), Xmax (ft), As (in^2), Sp (in)

Span	Strip	Zone	Width	Mmax	Xmax	AsMin	AsMax	SpReq	AsReq	Bars	
1	Column	Left	11.00	0.00	0.000	2.376	16.094	11.000	0.000	12-#4	*4
		Middle	11.00	0.00	0.000	2.376	16.094	11.000	0.000	12-#4	*4
		Right	11.00	0.00	0.000	2.376	16.094	9.429	0.000	14-#4	*4
	Middle	Left	11.00	0.00	0.000	2.376	16.094	11.000	0.000	12-#4	*4
		Middle	11.00	0.00	0.000	2.376	16.094	11.000	0.000	12-#4	*4
		Right	11.00	0.00	0.000	2.376	16.094	11.000	0.000	12-#4	*4
2	Column	Left	11.00	106.68	1.000	2.376	16.094	9.429	2.707	14-#4	*4
		Middle	11.00	0.00	11.000	0.000	16.094	0.000	0.000	---	
		Right	10.00	206.02	21.000	2.160	14.631	4.286	5.405	28-#4	*4
	Middle	Left	11.00	-0.00	1.000	2.376	16.094	11.000	0.000	12-#4	*4
		Middle	11.00	0.00	11.000	0.000	16.094	0.000	0.000	---	
		Right	12.00	68.68	21.000	2.592	17.557	11.077	1.723	13-#4	*4
3	Column	Left	10.00	179.05	1.000	2.160	14.631	4.286	4.657	28-#4	*4
		Middle	10.00	0.00	10.000	0.000	14.631	0.000	0.000	---	
		Right	10.00	135.12	19.000	2.160	14.631	6.667	3.467	18-#4	*4
	Middle	Left	12.00	59.68	1.000	2.592	17.557	11.077	1.494	13-#4	*4
		Middle	12.00	0.00	10.000	0.000	17.557	0.000	0.000	---	
		Right	12.00	45.04	19.000	2.592	17.557	11.077	1.124	13-#4	*4
4	Column	Left	10.00	139.27	1.000	2.160	14.631	6.667	3.578	18-#4	*4
		Middle	10.00	0.00	10.000	0.000	14.631	0.000	0.000	---	
		Right	10.00	151.34	19.000	2.160	14.631	6.000	3.903	20-#4	*4
	Middle	Left	12.00	46.42	1.000	2.592	17.557	11.077	1.158	13-#4	*4
		Middle	12.00	0.00	10.000	0.000	17.557	0.000	0.000	---	
		Right	12.00	50.45	19.000	2.592	17.557	11.077	1.260	13-#4	*4
5	Column	Left	10.00	153.11	1.000	2.160	14.631	6.000	3.951	20-#4	*4

		Middle	10.50	0.00	10.500	0.000	15.362	0.000	0.000	---	
		Right	10.50	182.70	20.000	2.268	15.362	4.846	4.745	26-#4	*4
	Middle	Left	12.00	51.04	1.000	2.592	17.557	11.077	1.275	13-#4	*4
		Middle	11.50	0.00	10.500	0.000	16.825	0.000	0.000	---	
		Right	11.50	60.90	20.000	2.484	16.825	10.615	1.526	13-#4	*4
6	Column	Left	10.50	196.59	1.000	2.268	15.362	4.846	5.127	26-#4	*4
		Middle	10.50	0.00	10.500	0.000	15.362	0.000	0.000	---	
		Right	10.50	87.41	20.000	2.268	15.362	10.500	2.209	12-#4	*4
	Middle	Left	11.50	65.53	1.000	2.484	16.825	10.615	1.644	13-#4	*4
		Middle	11.50	0.00	10.500	0.000	16.825	0.000	0.000	---	
		Right	11.50	-0.00	20.000	2.484	16.825	10.615	0.000	13-#4	*4
7	Column	Left	10.50	0.00	1.000	2.268	15.362	10.500	0.000	12-#4	*4
		Middle	10.50	0.00	1.000	2.268	15.362	10.500	0.000	12-#4	*4
		Right	10.50	0.00	1.000	2.268	15.362	10.500	0.000	12-#4	*4
	Middle	Left	11.50	0.00	1.000	2.484	16.825	10.615	0.000	13-#4	*4
		Middle	11.50	0.00	1.000	2.484	16.825	10.615	0.000	13-#4	*4
		Right	11.50	0.00	1.000	2.484	16.825	10.615	0.000	13-#4	*4

NOTES:
*4 - Bar spacing below minimum allowable value.

Top Bar Details:

Units: Length (ft)

		Left				Continuous		Right			
Span	Strip	Bars	Length	Bars	Length	Bars	Length	Bars	Length	Bars	Length
1	Column	---		---		12-#4	1.00	2-#4	1.00	---	
	Middle	---		---		12-#4	1.00	---		---	
2	Column	12-#4	7.60	2-#4	5.00	---		14-#4	7.60	14-#4	5.00
	Middle	12-#4	5.40	---		---		13-#4	6.75	---	
3	Column	14-#4	7.68	14-#4	4.60	---		11-#4	6.94	7-#4	4.60
	Middle	13-#4	7.62	---		---		13-#4	6.62	---	
4	Column	11-#4	6.94	7-#4	4.60	---		11-#4	6.94	9-#4	4.60
	Middle	13-#4	6.37	---		---		13-#4	6.62	---	
5	Column	11-#4	7.27	9-#4	4.80	---		13-#4	7.27	13-#4	4.80
	Middle	13-#4	6.69	---		---		13-#4	7.19	---	
6	Column	13-#4	7.27	13-#4	4.80	---		12-#4	7.27	---	
	Middle	13-#4	6.94	---		---		13-#4	5.18	---	
7	Column	---		---		12-#4	1.00	---		---	
	Middle	---		---		13-#4	1.00	---		---	

Bottom Reinforcement:

Units: Width (ft), Mmax (k-ft), Xmax (ft), As (in^2), Sp (in)

Span	Strip	Width	Mmax	Xmax	AsMin	AsMax	SpReq	AsReq	Bars	
1	Column	11.00	0.00	0.000	0.000	16.094	0.000	0.000	---	
	Middle	11.00	0.00	0.000	0.000	16.094	0.000	0.000	---	
2	Column	11.00	128.46	10.000	2.376	16.094	7.765	3.278	17-#4	*4
	Middle	11.00	85.64	10.000	2.376	16.094	11.000	2.161	12-#4	*4
3	Column	10.00	77.18	10.250	2.160	14.631	10.909	1.947	11-#4	*4
	Middle	12.00	51.46	10.250	2.592	17.557	11.077	1.286	13-#4	*4
4	Column	10.00	83.71	10.000	2.160	14.631	10.909	2.116	11-#4	*4
	Middle	12.00	55.81	10.000	2.592	17.557	11.077	1.396	13-#4	*4
5	Column	10.50	87.74	10.250	2.268	15.362	10.500	2.217	12-#4	*4
	Middle	11.50	58.49	10.250	2.484	16.825	10.615	1.465	13-#4	*4
6	Column	10.50	115.10	11.750	2.268	15.362	8.400	2.931	15-#4	*4
	Middle	11.50	76.73	11.750	2.484	16.825	10.615	1.930	13-#4	*4
7	Column	10.50	0.00	0.000	0.000	15.362	0.000	0.000	---	
	Middle	11.50	0.00	0.000	0.000	16.825	0.000	0.000	---	

NOTES:
*4 - Bar spacing below minimum allowable value.

Bottom Bar Details:

Units: Start (ft), Length (ft)

		Long Bars			Short Bars		
Span	Strip	Bars	Start	Length	Bars	Start	Length
1	Column	---			---		

	Middle	---			---
2	Column	17-#4	0.00	22.00	---
	Middle	12-#4	0.00	22.00	---
3	Column	11-#4	0.00	20.00	---
	Middle	13-#4	0.00	20.00	---
4	Column	11-#4	0.00	20.00	---
	Middle	13-#4	0.00	20.00	---
5	Column	12-#4	0.00	21.00	---
	Middle	13-#4	0.00	21.00	---
6	Column	15-#4	0.00	21.00	---
	Middle	13-#4	0.00	21.00	---
7	Column	---			---
	Middle	---			---

Flexural Capacity:
==================

Units: From, To (ft), As (in^2), PhiMn (k-ft)

Span	Strip	From	To	AsTop	AsBot	PhiMn-	PhiMn+
1	Column	0.000	0.500	2.80	0.00	-110.26	0.00
		0.500	1.000	2.80	0.00	-110.26	0.00
	Middle	0.000	0.500	2.40	0.00	-94.89	0.00
		0.500	1.000	2.40	0.00	-94.89	0.00
2	Column	0.000	1.000	2.80	3.40	-110.26	133.06
		1.000	3.631	2.80	3.40	-110.26	133.06
		3.631	5.001	2.40	3.40	-94.89	133.06
		5.001	6.231	2.40	3.40	-94.89	133.06
		6.231	7.600	0.00	3.40	0.00	133.06
		7.600	8.000	0.00	3.40	0.00	133.06
		8.000	11.000	0.00	3.40	0.00	133.06
		11.000	14.000	0.00	3.40	0.00	133.06
		14.000	14.400	0.00	3.40	0.00	133.06
		14.400	15.769	0.00	3.40	0.00	133.06
		15.769	16.999	2.80	3.40	-109.94	133.06
		16.999	18.369	2.80	3.40	-109.94	133.06
		18.369	21.000	5.60	3.40	-212.96	133.06
		21.000	22.000	5.60	3.40	-212.96	133.06
	Middle	0.000	1.000	2.40	2.40	-94.89	94.89
		1.000	4.401	2.40	2.40	-94.89	94.89
		4.401	5.401	0.00	2.40	0.00	94.89
		5.401	8.000	0.00	2.40	0.00	94.89
		8.000	11.000	0.00	2.40	0.00	94.89
		11.000	14.000	0.00	2.40	0.00	94.89
		14.000	15.250	0.00	2.40	0.00	94.89
		15.250	16.250	0.00	2.40	0.00	94.89
		16.250	21.000	2.60	2.40	-102.81	94.89
		21.000	22.000	2.60	2.40	-102.81	94.89
3	Column	0.000	1.000	5.60	2.20	-212.96	86.96
		1.000	3.421	5.60	2.20	-212.96	86.96
		3.421	4.601	2.80	2.20	-109.94	86.96
		4.601	6.500	2.80	2.20	-109.94	86.96
		6.500	7.300	0.00	2.20	0.00	86.96
		7.300	7.680	0.00	2.20	0.00	86.96
		7.680	10.000	0.00	2.20	0.00	86.96
		10.000	12.700	0.00	2.20	0.00	86.96
		12.700	13.060	0.00	2.20	0.00	86.96
		13.060	14.386	0.00	2.20	0.00	86.96
		14.386	15.399	2.20	2.20	-86.96	86.96
		15.399	16.726	2.20	2.20	-86.96	86.96
		16.726	19.000	3.60	2.20	-140.08	86.96
		19.000	20.000	3.60	2.20	-140.08	86.96
	Middle	0.000	1.000	2.60	2.60	-102.81	102.81
		1.000	6.625	2.60	2.60	-102.81	102.81
		6.625	7.300	0.00	2.60	0.00	102.81
		7.300	7.625	0.00	2.60	0.00	102.81
		7.625	10.000	0.00	2.60	0.00	102.81
		10.000	12.700	0.00	2.60	0.00	102.81
		12.700	13.375	0.00	2.60	0.00	102.81
		13.375	14.375	0.00	2.60	0.00	102.81
		14.375	19.000	2.60	2.60	-102.81	102.81
		19.000	20.000	2.60	2.60	-102.81	102.81
4	Column	0.000	1.000	3.60	2.20	-140.08	86.96
		1.000	3.231	3.60	2.20	-140.08	86.96
		3.231	4.601	2.20	2.20	-86.96	86.96
		4.601	5.571	2.20	2.20	-86.96	86.96
		5.571	6.940	0.00	2.20	0.00	86.96
		6.940	7.300	0.00	2.20	0.00	86.96
		7.300	10.000	0.00	2.20	0.00	86.96

	10.000	12.700	0.00	2.20	0.00	86.96
	12.700	13.060	0.00	2.20	0.00	86.96
	13.060	14.412	0.00	2.20	0.00	86.96
	14.412	15.399	2.20	2.20	-86.96	86.96
	15.399	16.752	2.20	2.20	-86.96	86.96
	16.752	19.000	4.00	2.20	-154.94	86.96
	19.000	20.000	4.00	2.20	-154.94	86.96
Middle	0.000	1.000	2.60	2.60	-102.81	102.81
	1.000	5.375	2.60	2.60	-102.81	102.81
	5.375	6.375	0.00	2.60	0.00	102.81
	6.375	7.300	0.00	2.60	0.00	102.81
	7.300	10.000	0.00	2.60	0.00	102.81
	10.000	12.700	0.00	2.60	0.00	102.81
	12.700	13.375	0.00	2.60	0.00	102.81
	13.375	14.375	0.00	2.60	0.00	102.81
	14.375	19.000	2.60	2.60	-102.81	102.81
	19.000	20.000	2.60	2.60	-102.81	102.81
5 Column	0.000	1.000	4.00	2.40	-154.94	94.78
	1.000	3.431	4.00	2.40	-154.94	94.78
	3.431	4.801	2.20	2.40	-86.96	94.78
	4.801	5.901	2.20	2.40	-86.96	94.78
	5.901	7.270	0.00	2.40	0.00	94.78
	7.270	7.650	0.00	2.40	0.00	94.78
	7.650	10.500	0.00	2.40	0.00	94.78
	10.500	13.350	0.00	2.40	0.00	94.78
	13.350	13.730	0.00	2.40	0.00	94.78
	13.730	14.997	0.00	2.40	0.00	94.78
	14.997	16.199	2.60	2.40	-102.46	94.78
	16.199	17.467	2.60	2.40	-102.46	94.78
	17.467	20.000	5.20	2.40	-199.24	94.78
	20.000	21.000	5.20	2.40	-199.24	94.78
Middle	0.000	1.000	2.60	2.60	-102.81	102.71
	1.000	5.687	2.60	2.60	-102.81	102.71
	5.687	6.687	0.00	2.60	0.00	102.71
	6.687	7.650	0.00	2.60	0.00	102.71
	7.650	10.500	0.00	2.60	0.00	102.71
	10.500	13.350	0.00	2.60	0.00	102.71
	13.350	13.813	0.00	2.60	0.00	102.71
	13.813	14.813	0.00	2.60	0.00	102.71
	14.813	20.000	2.60	2.60	-102.71	102.71
	20.000	21.000	2.60	2.60	-102.71	102.71
6 Column	0.000	1.000	5.20	3.00	-199.24	117.72
	1.000	3.431	5.20	3.00	-199.24	117.72
	3.431	4.801	2.60	3.00	-102.46	117.72
	4.801	5.901	2.60	3.00	-102.46	117.72
	5.901	7.270	0.00	3.00	0.00	117.72
	7.270	7.650	0.00	3.00	0.00	117.72
	7.650	10.500	0.00	3.00	0.00	117.72
	10.500	13.350	0.00	3.00	0.00	117.72
	13.350	13.730	0.00	3.00	0.00	117.72
	13.730	15.063	0.00	3.00	0.00	117.72
	15.063	20.000	2.40	3.00	-94.78	117.72
	20.000	21.000	2.40	3.00	-94.78	117.72
Middle	0.000	1.000	2.60	2.60	-102.71	102.71
	1.000	5.937	2.60	2.60	-102.71	102.71
	5.937	6.937	0.00	2.60	0.00	102.71
	6.937	7.650	0.00	2.60	0.00	102.71
	7.650	10.500	0.00	2.60	0.00	102.71
	10.500	13.350	0.00	2.60	0.00	102.71
	13.350	15.819	0.00	2.60	0.00	102.71
	15.819	16.819	0.00	2.60	0.00	102.71
	16.819	20.000	2.60	2.60	-102.71	102.71
	20.000	21.000	2.60	2.60	-102.71	102.71
7 Column	0.000	0.500	2.40	0.00	-94.78	0.00
	0.500	1.000	2.40	0.00	-94.78	0.00
Middle	0.000	0.500	2.60	0.00	-102.71	0.00
	0.500	1.000	2.60	0.00	-102.71	0.00

Slab Shear Capacity:
====================

Units: b, d (in), Xu (ft), PhiVc, Vu(kip)

Span	b	d	Vratio	PhiVc	Vu	Xu
1	264.00	9.00	1.000	195.21	0.00	0.00
2	264.00	9.00	1.000	195.21	82.47	20.25
3	264.00	9.00	1.000	195.21	69.32	1.75
4	264.00	9.00	1.000	195.21	66.96	18.25
5	264.00	9.00	1.000	195.21	72.15	19.25
6	264.00	9.00	1.000	195.21	79.27	1.75
7	264.00	9.00	1.000	195.21	0.00	0.00

Flexural Transfer of Negative Unbalanced Moment at Supports:
==

Units: Width (in), Munb (k-ft), As (in^2)

Supp	Width	GammaF*Munb	Comb	Pat	AsReq	AsProv	Additional Bars
1	54.00	110.13	U2	All	2.927	1.107	10-#4
2	54.00	49.87	U2	Even	1.270	2.432	---
3	54.00	30.56	U2	Even	0.769	1.610	---
4	54.00	29.52	U2	Odd	0.742	1.778	---
5	54.00	39.47	U2	Even	0.999	2.197	---
6	54.00	95.27	U2	All	2.504	0.972	8-#4

Punching Shear Around Columns:

Units: Vu (kip), Munb (k-ft), vu (psi), Phi*vc (psi)

Supp	Vu	vu	Munb	Comb	Pat	GammaV	vu	Phi*vc	
1	85.32	105.3	125.21	U2	All	0.383	173.2	164.3	*EXCEEDED
2	177.07	149.0	-49.12	U2	All	0.400	166.8	164.3	*EXCEEDED
3	153.26	129.0	7.91	U2	All	0.400	131.9	164.3	
4	160.23	134.9	3.41	U2	All	0.400	136.1	164.3	
5	176.69	148.7	25.64	U2	All	0.400	158.0	164.3	
6	80.52	99.4	-104.13	U2	All	0.383	155.9	164.3	

Maximum Deflections:

Units: Dz (in)

	Frame			Column Strip			Middle Strip		
Span	Dz(DEAD)	Dz(LIVE)	Dz(TOTAL)	Dz(DEAD)	Dz(LIVE)	Dz(TOTAL)	Dz(DEAD)	Dz(LIVE)	Dz(TOTAL)
1	0.010	0.007	0.017	0.016	0.012	0.028	0.004	0.003	0.007
2	-0.091	-0.073	-0.164	-0.134	-0.108	-0.242	-0.048	-0.038	-0.086
3	-0.027	-0.028	-0.055	-0.040	-0.042	-0.081	-0.016	-0.017	-0.033
4	-0.035	-0.033	-0.068	-0.053	-0.049	-0.101	-0.021	-0.020	-0.041
5	-0.039	-0.043	-0.082	-0.056	-0.061	-0.116	-0.024	-0.027	-0.051
6	-0.072	-0.052	-0.124	-0.111	-0.081	-0.192	-0.036	-0.026	-0.062
7	0.009	0.006	0.015	0.015	0.010	0.025	0.003	0.002	0.006

Material Takeoff:

Reinforcement in the Direction of Analysis

Top Bars:	1472.5 lb	<=>	13.89 lb/ft	<=>	0.631 lb/ft^2
Bottom Bars:	1810.9 lb	<=>	17.08 lb/ft	<=>	0.777 lb/ft^2
Stirrups:	0.0 lb	<=>	0.00 lb/ft	<=>	0.000 lb/ft^2
Total Steel:	3283.5 lb	<=>	30.98 lb/ft	<=>	1.408 lb/ft^2
Concrete:	1943.3 ft^3	<=>	18.33 ft^3/ft	<=>	0.833 ft^3/ft^2

APPENDIX I

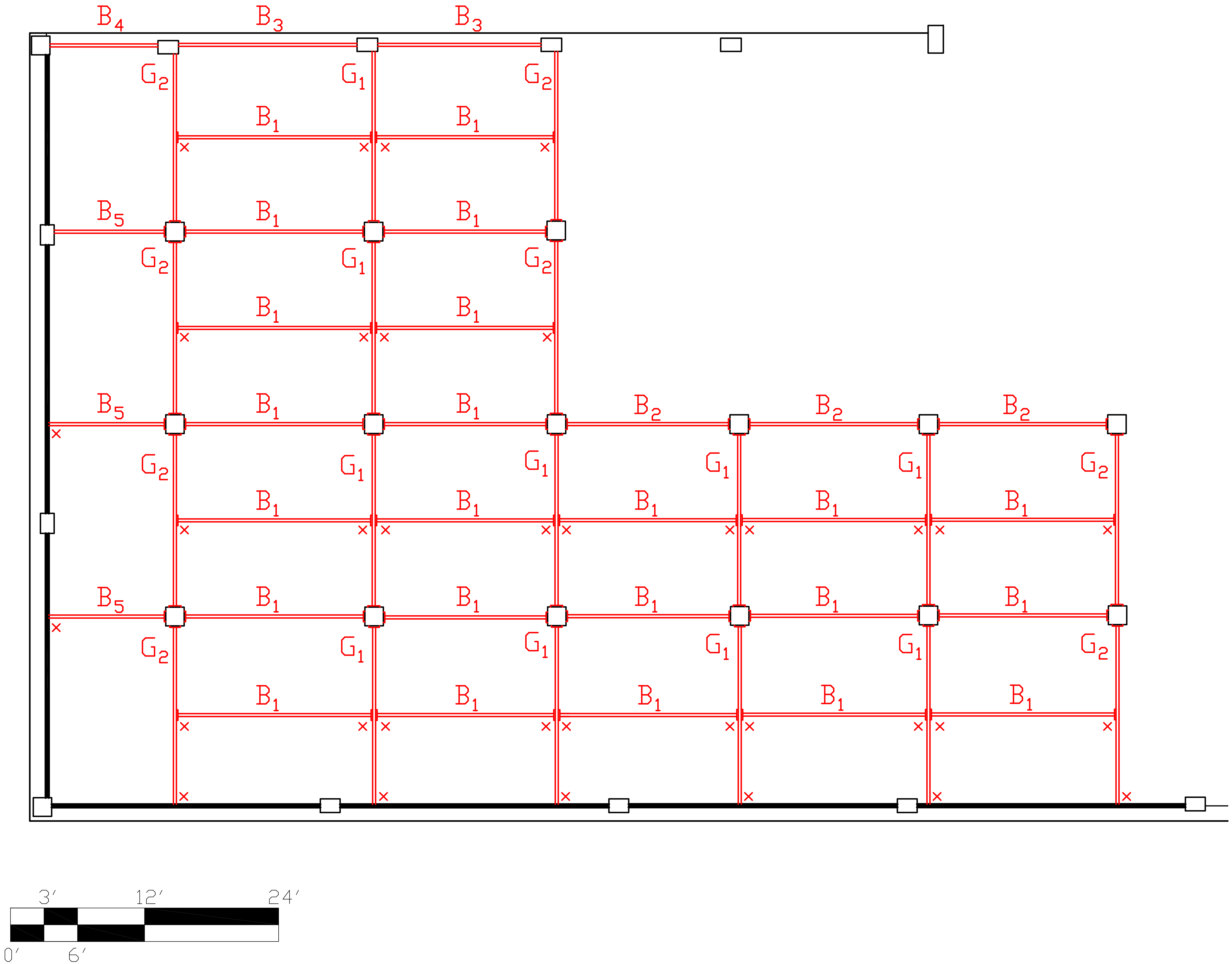
STRUCTURAL STEEL RETROFIT TO SUPPORT GREEN ROOF

DEREK BAUER

APPENDIX I-1

GREEN ROOF RETROFIT

OFFICE/RETAIL BUILDING

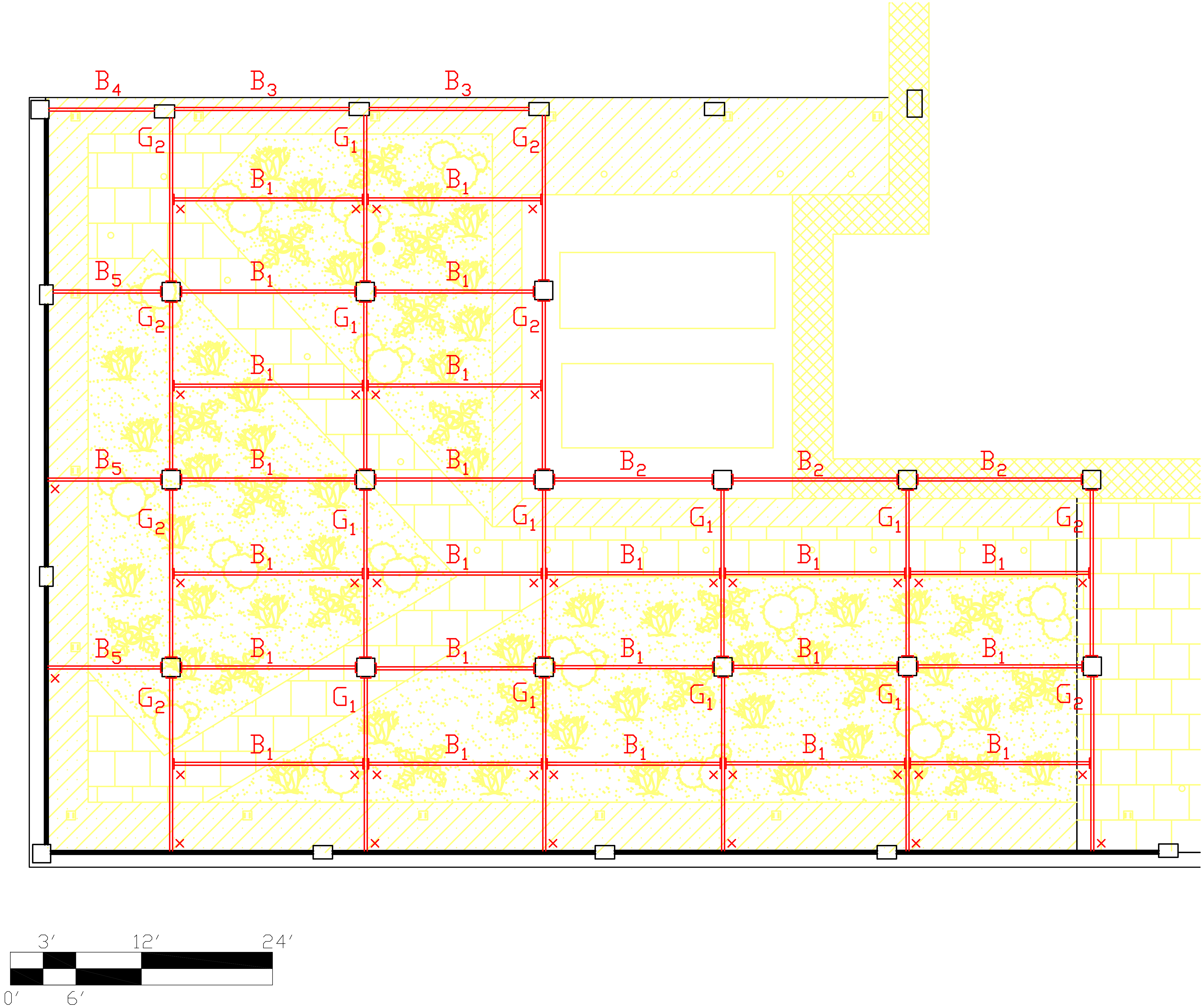


DEREK BAUER

APPENDIX I-2

GREEN ROOF RETROFIT

OFFICE/RETAIL BUILDING



DEREK BAUER

APPENDIX I-3

GREEN ROOF RETROFIT

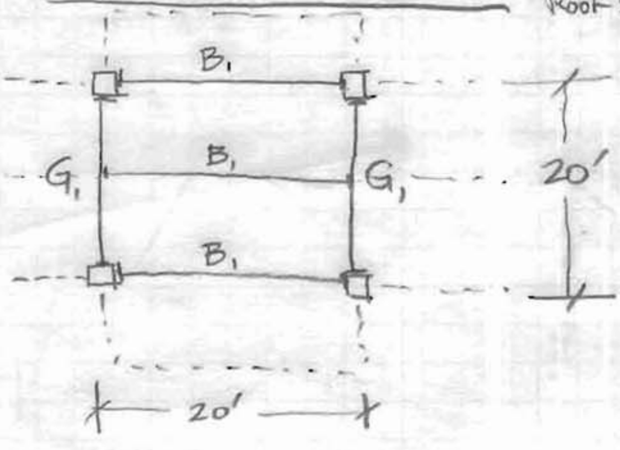
OFFICE/RETAIL BUILDING

APPENDIX J

HAND CALCULATIONS FOR STRUCTURAL STEEL RETROFIT

STRUCTURAL BREADTH STUDY – HAND CALCULATIONS
GREEN ROOF STRUCTURAL STEEL RETROFIT

TYPICAL INTERIOR SPAN (BENEATH ROOF SLAB)



EXISTING ROOF SLAB CONDITIONS

8" SLAB THICKNESS
3000 PSI COMPRESSIVE STRENGTH
#4 REBAR @ 14" O.C.

DESIGNED FOR: 30 PSF LIVE + SLAB SELF-WEIGHT

ADDED LOAD FOR GREEN ROOF

LIVE: +70 PSF – (100 PSF OCCUPANCY)

DEAD: +45 PSF – GREEN ROOF

INTERIOR BEAM DESIGN (B1)

$$\omega_D = (45\ \text{PSF})(10') = 450\ \text{PLF}$$

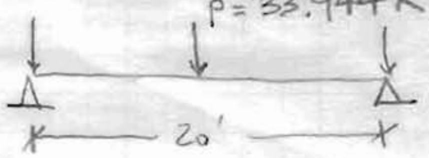
$$\omega_L = (70\ \text{PSF})(10') = 700\ \text{PLF}$$

$$\omega_u = 1.2(450\ \text{PLF}) + 1.6(700\ \text{PLF}) = 1660\ \text{PLF}$$

$$M_{\omega_u} = \frac{\omega L^2}{8} = \frac{(1660\ \text{PLF})(20')^2}{8} = 83{,}000\ \text{LB-FT} = 83\ \text{k-Ft}$$

AISC MANUAL – TABLE 3-10: $\boxed{\text{USE W8×31}}$

INTERIOR GIRDER DESIGN (G1)



$$P_{B_1} = \frac{\left[w_{u_{B_1}} + (SW_{B_1})(1.2)\right] L_{B_1}}{2}$$

$$P_{B_1} = \frac{\left[1660\ \text{PLF} + (31\ \text{PLF})(1.2)\right] 20'}{2} = 16.972\ \text{k}$$

× 2 BEAMS
33.944 k

$$M_{max} = \frac{PL}{4} = \frac{(33.944\text{k})(20\ \text{ft})}{4} = 169.72\ \text{k-Ft}$$

AISC MANUAL – TABLE 3-10: $\boxed{\text{USE W10×49}}$

STRUCTURAL BREADTH STUDY – HAND CALCULATIONS
GREEN ROOF STRUCTURAL STEEL RETROFIT (CONT.)

PERIMETER BEAM DESIGN (B2)

$\omega_D = (45\ \text{PSF})(5') = 225\ \text{PLF}$

$\omega_L = (70\ \text{PSF})(5') = 350\ \text{PLF}$

$\omega_u = 1.2(225\ \text{PLF}) + 1.6(350\ \text{PLF}) = 830\ \text{PLF}$

$M_{\omega_u} = \dfrac{\omega L^2}{8} = \dfrac{(830\ \text{PLF})(20')^2}{8} = 41.5\ \text{k-ft}$ $\boxed{\text{USE W8×24}}$

PERIMETER BEAM DESIGN (B3)

$\omega_D = (45\ \text{PSF})(5') + 400\ \text{PLF}$ (ASSUMED LINE LOAD FROM EXTERIOR FACADE) $= 625\ \text{PLF}$

$\omega_L = 350\ \text{PLF}$

$\omega_u = 1.2(625\ \text{PLF}) + 1.6(350\ \text{PLF}) = 1310\ \text{PLF}$

$M_{\omega_u} = \dfrac{\omega L^2}{8} = \dfrac{(1310)(20')^2}{8} = 65.5\ \text{k-ft}$ $\boxed{\text{USE W8×28}}$

PERIMETER BEAM DESIGN (B4)

$\omega_D = (45\ \text{PSF})(10') + 400\ \text{PLF} = 850\ \text{PLF}$

$\omega_L = (70\ \text{PSF})(10') = 700\ \text{PLF}$

$\omega_u = 1.2(850\ \text{PLF}) + 1.6(700\ \text{PLF}) = 2140\ \text{PLF}$

$M_{\omega_u} = \dfrac{(2140\ \text{PLF})(14')^2}{8} = 52.4\ \text{k-ft}$ $\boxed{\text{USE W8×24}}$

INTERIOR BEAM DESIGN (B5)

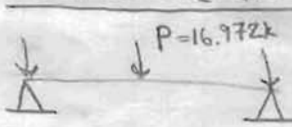
$\omega_D = (45\ \text{PSF})(20') = 900\ \text{PLF}$

$\omega_L = (70\ \text{PSF})(20') = 1400\ \text{PLF}$

$\omega_u = 1.2(900\ \text{PLF}) + 1.6(1400\ \text{PLF}) = 3320\ \text{PLF}$

$M_{\omega_u} = \dfrac{(3320\ \text{PLF})(14')^2}{8} = 81.3\ \text{k-ft}$ $\boxed{\text{USE W8×31}}$

PERIMETER GIRDER DESIGN (G2)



$P_{B_1} = 16.972\ \text{k}$ (LOAD OF ONE BEAM)

$M_{max} = \dfrac{PL}{4} = \dfrac{(16.972^k)(20')}{4} = 84.9\ \text{k-ft}$

$\boxed{\text{USE W10×33}}$

APPENDIX K

PCA COLUMN INPUT AND DESIGN RESULTS

```
OOOOOOO    OOOOO    OOOOO    OOOOO    OOOOO   OO
OO     OO  OO    OO  OO    OO  OO    OO  OO    OO  OO
OO     OO  OO    OO  OO    OO  OO    OO  OO    OO  OO
OO     OO  OO        OO    OO  OO        OO    OO  OO
OO     OO  OO        OOOOOOO  OO        OO    OO  OO
OOOOOOO    OO    OO  OO    OO  OO    OO  OO    OO  OO
OO         OO    OO  OO    OO  OO    OO  OO    OO  OO
OO          OOOOO    OO    OO   OOOOO    OOOOO   OOOOO  (TM)
```

==
Computer program for the Strength Design of Reinforced Concrete Sections
==

General Information:

File Name: untitled.col
Project:
Column: Engineer:
Code: ACI 318-02 Units: English

Run Option: Investigation Slenderness: Not considered
Run Axis: X-axis Column Type: Structural

Material Properties:

f'c = 3 ksi fy = 60 ksi
Ec = 3122.02 ksi Es = 29000 ksi
Ultimate strain = 0.003 in/in
Beta1 = 0.85

Section:

Rectangular: Width = 24 in Depth = 24 in

Gross section area, Ag = 576 in^2
Ix = 27648 in^4 Iy = 27648 in^4
Xo = 0 in Yo = 0 in

Reinforcement:

Rebar Database: ASTM A615

Size	Diam (in)	Area (in^2)	Size	Diam (in)	Area (in^2)	Size	Diam (in)	Area (in^2)
# 3	0.38	0.11	# 4	0.50	0.20	# 5	0.63	0.31
# 6	0.75	0.44	# 7	0.88	0.60	# 8	1.00	0.79
# 9	1.13	1.00	# 10	1.27	1.27	# 11	1.41	1.56
# 14	1.69	2.25	# 18	2.26	4.00			

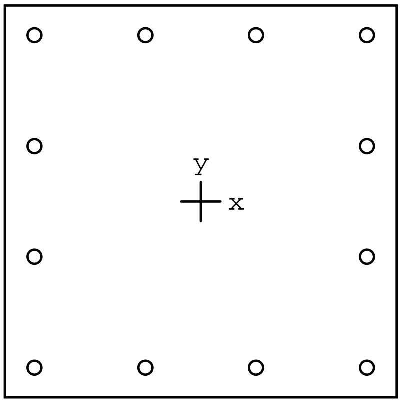
Confinement: Tied; #3 ties with #10 bars, #4 with larger bars.
phi(a) = 0.8, phi(b) = 0.9, phi(c) = 0.65

Layout: Rectangular
Pattern: All Sides Equal (Cover to transverse reinforcement)
Total steel area, As = 7.20 in^2 at 1.25%
12 #7 Cover = 1 in

Axial Load and Corresponding Moment Capacities: (see user's manual for notation)

Load No.	fPn kip	fMnx k-ft	N.A. depth in
1	133.6	424.6	5.54
		-424.6	5.54

*** Program completed as requested! ***



Code: ACI 318-02

Units: English

Run axis: About X-axis

Run option: Investigation

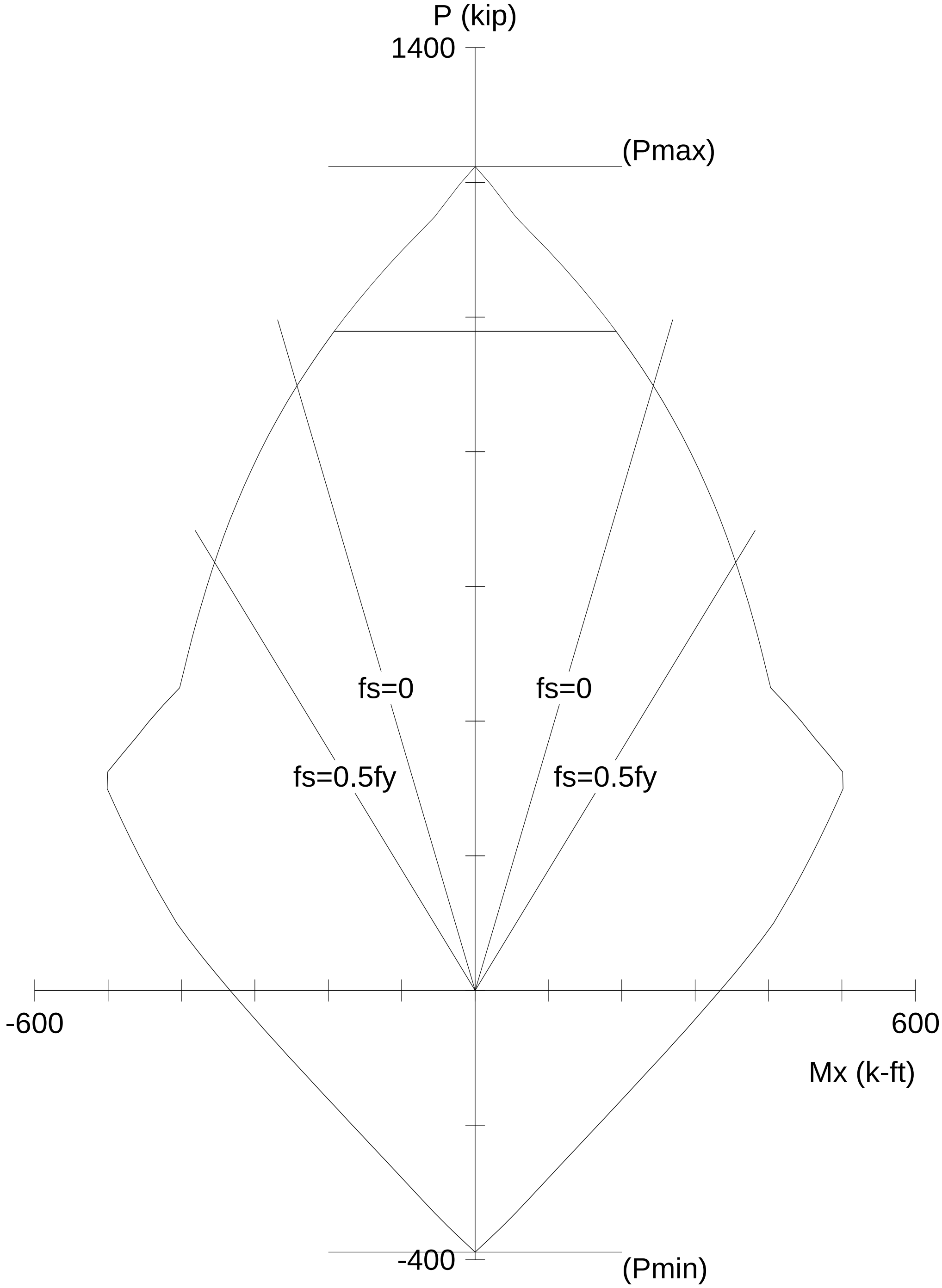
Slenderness: Not considered

Column type: Structural

Bars: ASTM A615

Date: 04/07/08

Time: 23:25:52



File: untitled.col

Project:

Column:		Engineer:	
f'c = 3 ksi	fy = 60 ksi	Ag = 576 in^2	12 #7 bars
Ec = 3122 ksi	Es = 29000 ksi	As = 7.20 in^2	Rho = 1.25%
fc = 2.55 ksi	fc = 2.55 ksi	Xo = 0.00 in	Ix = 27648 in^4
e_u = 0.003 in/in		Yo = 0.00 in	Iy = 27648 in^4
Beta1 = 0.85		Clear spacing = 5.92 in	Clear cover = 1.38 in
Confinement: Tied	phi(a) = 0.8, phi(b) = 0.9, phi(c) = 0.65		

APPENDIX L

ENERGY 10 RESULTS

Energy-10 Summary Page Apr 09, 2008
Project: PROJ5 **Project Directory:** y:\bauer\PROJ5

Description:	Existing Design	New Design
Scheme Number:	1 / Saved	2 / Not Saved
Library Name:	Local Only	Local Only
Simulation status, Thermal/DL	out of date/NA	out of date/NA
Weather file:	STERLING.ET1	STERLING.ET1
Floor Area, ft^2	37000.0	37000.0
Surface Area, ft^2	90880.0	90880.0
Volume, ft^3	444000.0	444000.0
Total Conduction UA, Btu/h-F	6995.0	5998.4
Average U-value, Btu/hr-ft^2-F	0.077	0.066
Wall Construction	curtain wall, R=2.8,etc	curtain wall 2, R=2.8,etc
Roof Construction	flat, r-19, R=13.4	flat, r-19, R=15.5
Floor type, insulation	Slab on Grade, Reff=43.8,etc	Slab on Grade, Reff=48.2,etc
Window Construction	east curtain wall, U=0.27,etc	east curtain wall glass, U=0.27,etc
Window Shading	None	None
Wall total gross area, ft^2	16880	16880
Roof total gross area, ft^2	37000	37000
Ground total gross area, ft^2	37000	37000
Window total gross area, ft^2	6619	6619
Windows (N/E/S/W:Roof)	12/1/1/6:0	12/1/1/6:0
Glazing name	double low-e, U=0.26	double low-e, U=0.26

Operating parameters for zone 1

HVAC system	DX Cooling with Gas Furnace	DX Cooling with Gas Furnace
Rated Output (Heat/SCool/TCool),kBtu/h	310/296/395	477/270/360
Rated Air Flow/MOOA,cfm	10544/1800	12000/1800
Heating thermostat	72.0 °F, no setback	72.0 °F, no setback
Cooling thermostat	75.0 °F, no setup	75.0 °F, no setup
Heat/cool performance	eff=80,EER=8.9	eff=80,EER=8.9
Economizer?/type	no/NA	no/NA
Duct leaks/conduction losses, total %	2/0	2/0
Peak Gains; IL,EL,HW,OT; W/ft^2	1.00/0.33/0.26/1.52	1.00/0.33/0.26/1.52
Added mass?	none	none
Daylighting?	no	no
Infiltration, in^2	ELA=497.2	ELA=497.2

Operating parameters for zone 2

HVAC system	DX Cooling with Gas Furnace	DX Cooling with Gas Furnace
Rated Output (Heat/SCool/TCool),kBtu/h	430/563/751	994/563/750
Rated Air Flow/MOOA,cfm	19373/3750	25000/3750
Heating thermostat	72.0 °F, no setback	72.0 °F, no setback
Cooling thermostat	75.0 °F, no setup	75.0 °F, no setup
Heat/cool performance	eff=80,EER=8.9	eff=80,EER=8.9
Economizer?/type	no/NA	no/NA
Duct leaks/conduction losses, total %	2/0	2/0
Peak Gains; IL,EL,HW,OT; W/ft^2	1.78/0.33/0.26/1.52	1.78/0.33/0.26/1.52
Added mass?	none	none
Daylighting?	no	no
Infiltration, in^2	ELA=738.4	ELA=738.4

No Simulation Results Available

Photovoltaics System Summary:

Description:	Existing Design	New Design
PV System Definition Status:	Undefined	Undefined
Total PV Array Area, ft^2 / m^2	--	--
Total PV Rated Output, kW	--	--
Total Inverter Rated Capacity, kW	--	--
Total PV System First Cost, $	--	--

(See Menu "Reports\Perf. Summary Reports\PV Summary" for additional details.)

Solar Hot Water System Summary:

Collector Array Area, ft^2 / m^2	--	--
Storage Capacity, gal. / liters	--	--

APPENDIX M

MOISTURE ANALYSIS

EXTREME WINTER CONDITIONS

		Thickness (mm)	C (W/(m²*K))	R ((m²*K)/W)	M (ng/(s*Pa*m²))	R_v ((s*Pa*m²)/ng)
Outdoor Air						
Layer 1	Brick	102	12.90	0.078	98.43	0.010
Layer 2	Airspace	51	5.57	0.180	inf.	0.000
Layer 3	CMU	203	8.00	0.125	98.43	0.010
Layer 4	EXPS Insulation	51	0.57	1.761	39.37	0.025
Layer 5	Air/Vapor Barrier	-	-	-	5	0.200
Layer 6	Gypsum Wallboard	13	12.62	0.079	944.9	0.001
Indoor Air						
				2.222		0.247

Temp. (°C)	Temp. (K)	RH (%)	P_{sat} (Pa)	P (Pa)
-20	253.15	90	126.33	113.69
-18.57	254.58	112.37	142.77	160.42
-15.26	257.89	85.12	188.46	160.42
-12.95	260.20	91.02	227.58	207.15
19.54	292.69	14.20	2281.82	323.97
19.54	292.69	54.51	2281.82	1243.81
21	294.15	50	2497.36	1248.68

KEY	
C	Thermal Conductance
R	Thermal Resistance
M	Permeance
Rv	Vapor Resistance
RH	Relative Humidity
Psat	Vapor Saturation Pressure
P	Vapor Pressure

EXTREME SUMMER CONDITIONS

		Thickness (mm)	C (W/(m²*K))	R ((m²*K)/W)	M (ng/(s*Pa*m²))	R_v ((s*Pa*m²)/ng)
Outdoor Air						
Layer 1	Brick	102	12.90	0.078	98.43	0.010
Layer 2	Airspace	51	5.57	0.180	inf.	0.000
Layer 3	CMU	203	8.00	0.125	98.43	0.010
Layer 4	EXPS Insulation	51	0.57	1.761	39.37	0.025
Layer 5	Air/Vapor Barrier	-	-	-	5	0.200
Layer 6	Gypsum Wallboard	13	12.62	0.079	944.9	0.001
Indoor Air						
				2.222		0.247

Temp. (°C)	Temp. (K)	RH (%)	P_{sat} (Pa)	P (Pa)
38	311.15	90	6646.02	5981.41
37.41	310.56	89.91	6436.25	5786.57
36.03	309.18	96.90	5971.98	5786.57
35.08	308.23	98.69	5666.20	5591.72
21.61	294.76	196.95	2591.83	5104.59
21.61	294.76	48.96	2591.83	1268.98
21	294.15	50	2497.36	1248.68