Signal Hill Professional Center:

Implementing a Concrete Structural System

Joseph Henry,Structural Option
Dr. Linda Hanagan, Advisor
Penn State Architectural Engineering
Senior Thesis, Spring 2006

Building Introduction
Design Background

- 68,000 square feet of open office space
- Four Aboveground Floors
- Pre-framed for a bank, first floor
- Commercial/Light Industrial District of Manassas, VA
- Standard Suburban Office Building

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Building Introduction

Design Background

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Building Introduction

Notable Features, M Group Architects

21,000 square feet of parking area achieved through excavating into sloping site

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Notable Features, M Group Architects

Structure over parking area slopes with natural terrain

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Notable Features, M Group Architects

"SlenderCast" precast concrete wall system by Smith-Midland strives to:

•Reduce thermal transmission by up to 25%

•Protect façade from superstructure movement

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Building Introduction

Existing Structural System, Morabito Consultants

Goals

- To reduce floor section thickness and structure weight
- To lengthen spans for more open office space
- To utilize as few laborers as possible

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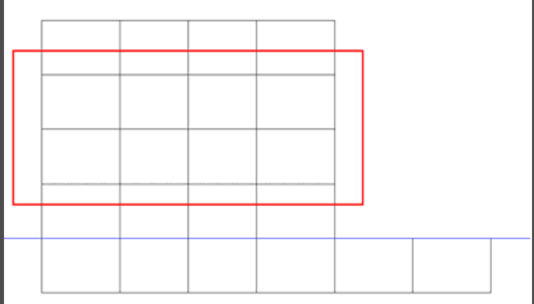
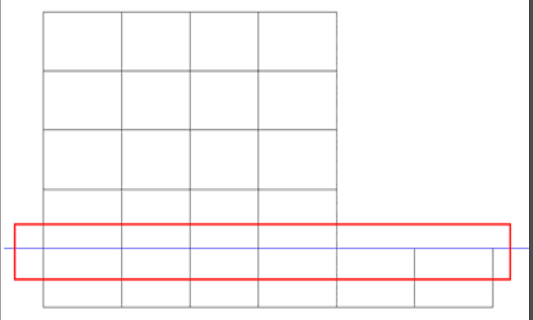
Concrete Structural Design

Existing Structural System, Morabito Consultants

Roof Structure: 3” deck on W12x16 Beams, W18x40 Girders



Office Floors 2-4: 3.5” Slab on 3” composite deck, W10x15 Beams, W21x44 Girders



Parking Deck/First Floor: 4” Slab on 2” composite deck, W10x15 Beams, W24x76 Girders

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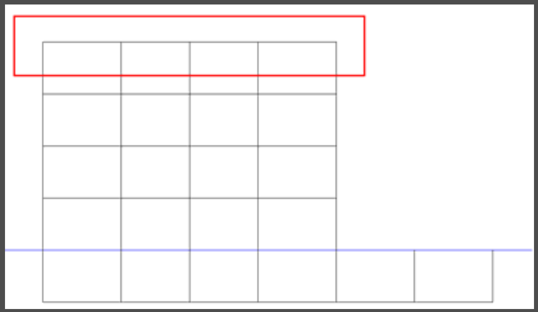
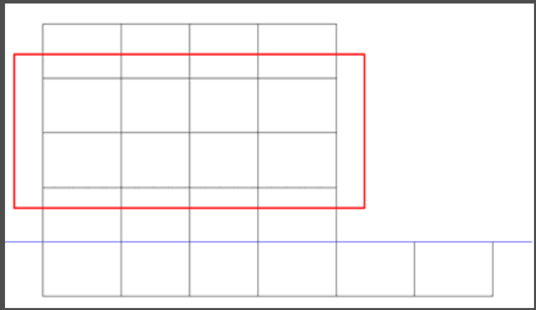
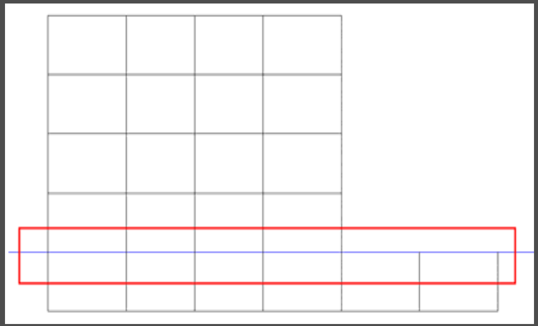
Existing Structural System, Morabito Consultants



Roof Structure: 3” deck on W12x16 Beams, W18x40 Girders



Office Floors 2-4: 3.5” Slab on 3” composite deck, W10x15 Beams, W21x44 Girders



Parking Deck/First Floor: 4” Slab on 2” composite deck, W10x15 Beams, W24x76 Girders

250 psf Fire Engine Load

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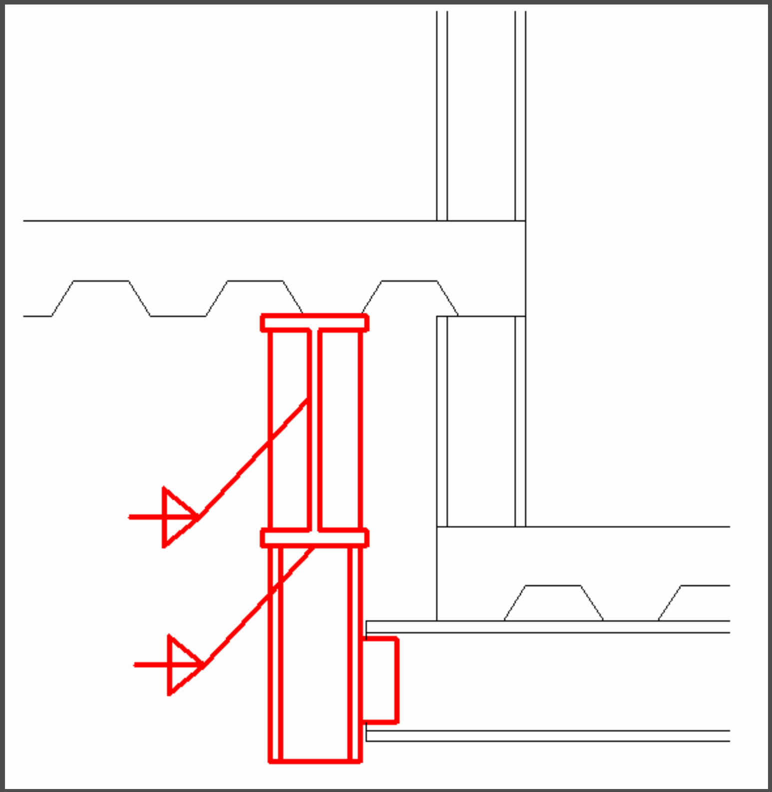
Building Introduction

Existing Structural System, Morabito Consultants

Undulating Parking Structure

- Attached to first floor diaphragm via coped beams and W6x25 hangers



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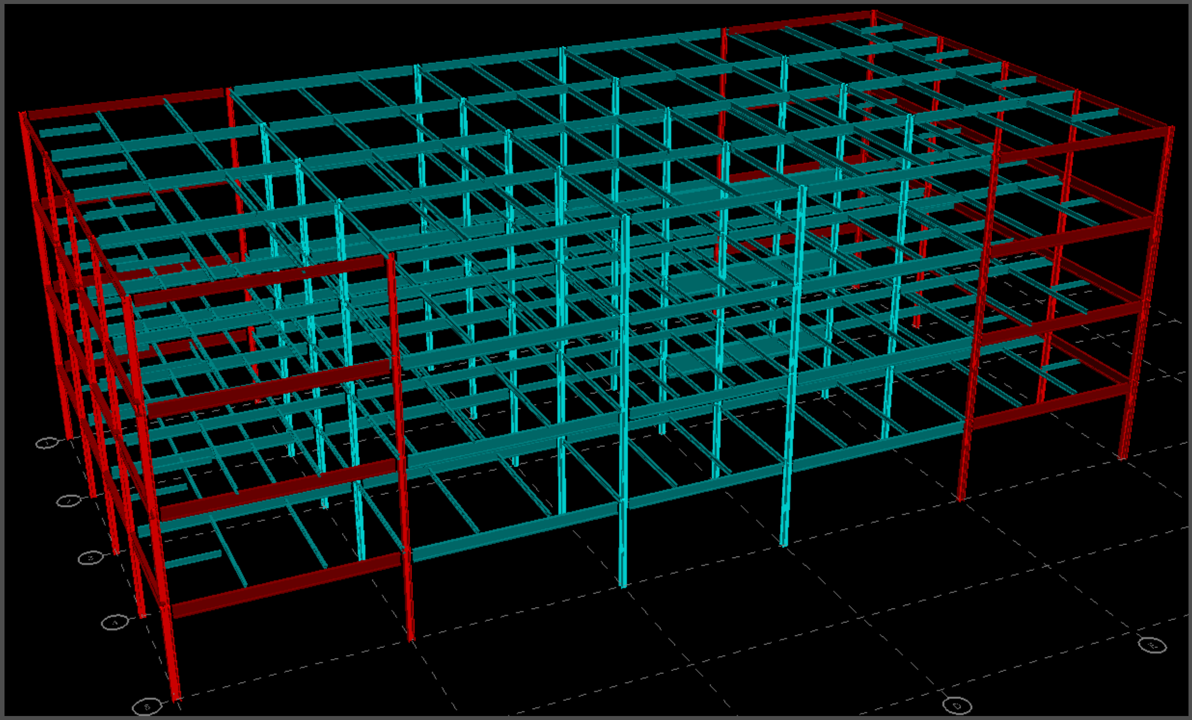
Building Introduction

Existing Structural System, Morabito Consultants

Lateral System

- Seismic Load Controls with 170k base shear
- Moment Frames on building perimeter anchored to shear walls in basement



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Thesis Intent

University of Leeds

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Design Problem

Manassas, Virginia

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Design Problem
Manassas, Virginia

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Design Problem

Manassas, Virginia

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Design Problem

Manassas, Virginia

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Thesis Outline

Concrete Structural Design

Design Includes:

- Floor Slab
- Lateral System
- Columns
- Footings
- Connection to Parking Structure

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Thesis Outline

Concrete Structural Design

Design Includes:

- •Floor Slab
- •Lateral System
- •Columns
- •Footings
- •Connection to Parking Structure

Evaluated Through:

- •Structural Efficiency
- •Architectural Impact
- •Cost/Schedule Impact
- •Possibility of Green Design

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Concrete Structural Design

Floor System

Two Way Slab Types

- Flat Plate
- Flat Slab with Edge Beams
- Flat Slab with Drops
- Flat Slab with Drops and Edge Beams
- Flat Slab with Beams between all columns

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Floor System

Two Way Slab Types

- Flat Plate
- Flat Slab with Edge Beams
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Evaluated Using

- Direct Design Method
- ADOSS

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Floor System

Two Way Slab Types

- Flat Plate
- Flat Slab with Edge Beams
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- Flat Slab with Beams between all columns

Evaluated Using

- Direct Design Method
- ADOSS

Using Four Column Layouts

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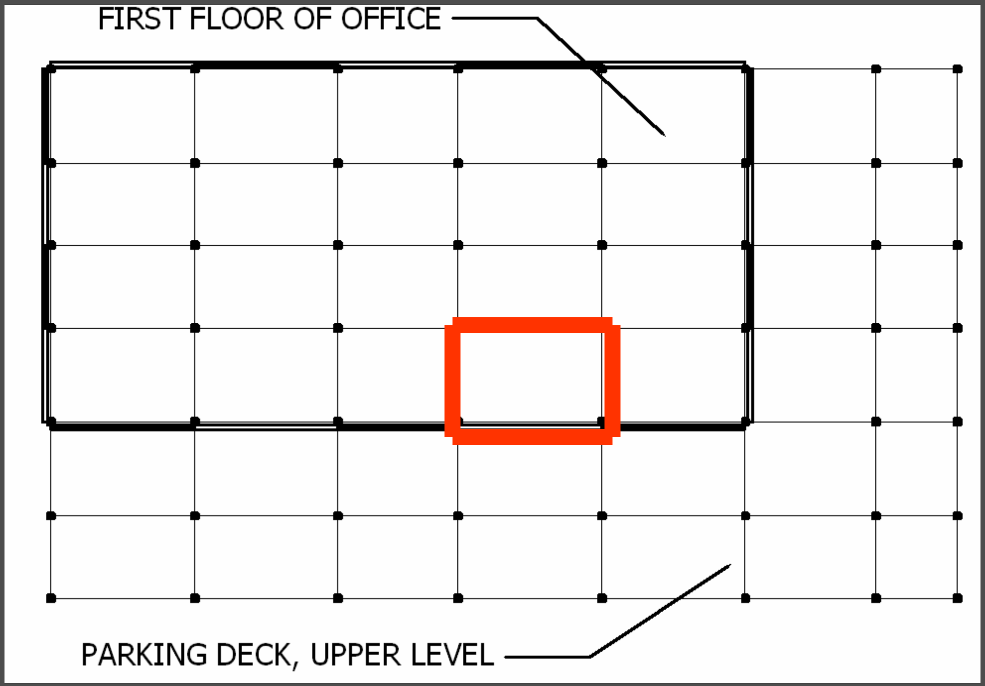
Floor System

Column Grid, Existing Layout

Maximum Bay Size = 20'-0"x30'-0"



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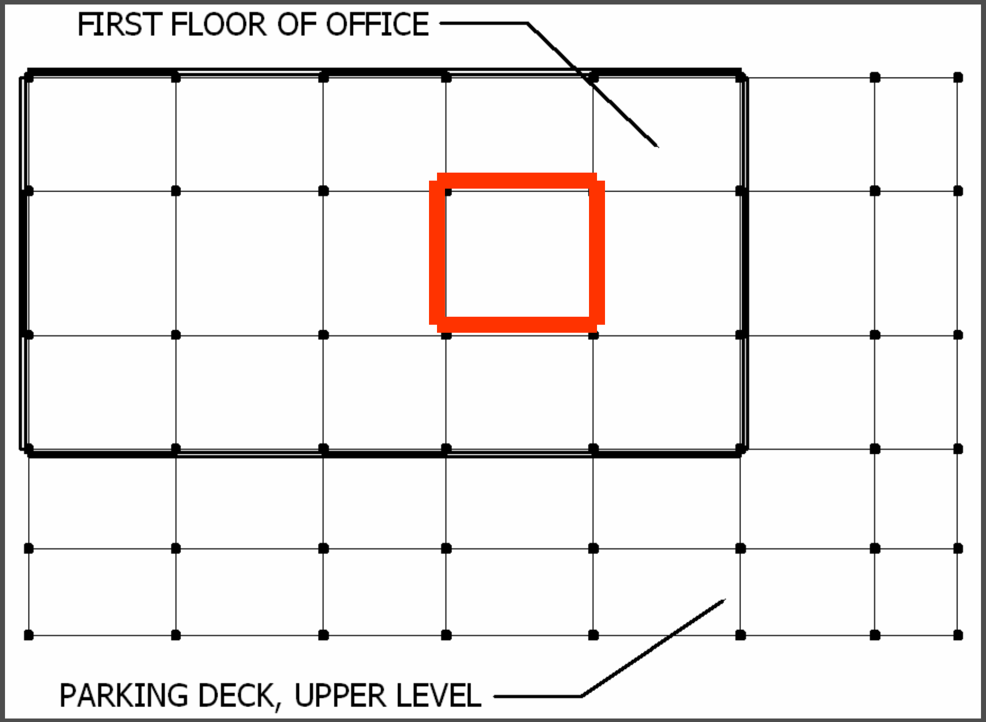
Floor System

Column Grid, Alternative #1

Maximum Bay Size = 30’-0”x30’-0”



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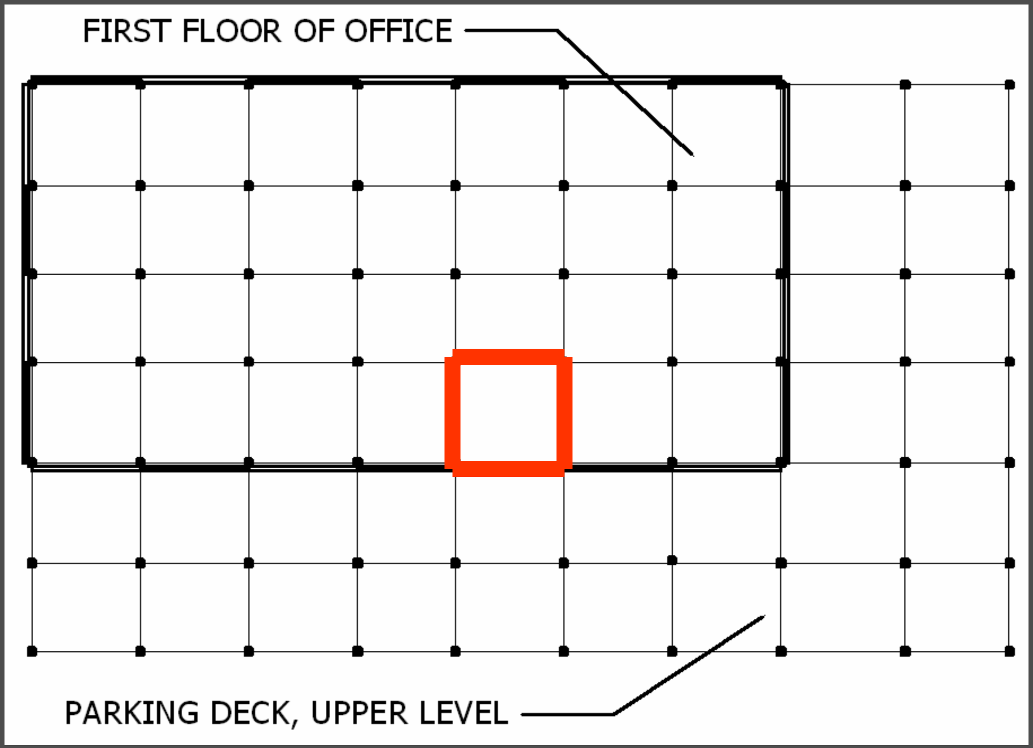
Floor System

Column Grid, Alternative #2

Maximum Bay Size = 20’-0”x21’-0”



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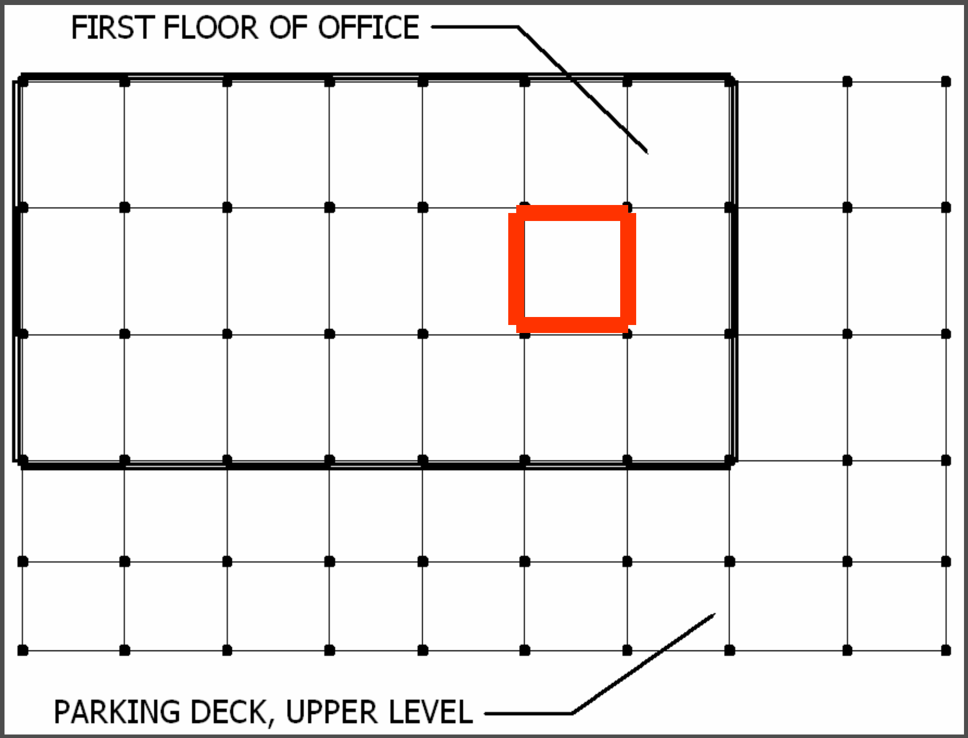
Floor System

Column Grid, Alternative #3

Maximum Bay Size = 25’-0”x21’-0”



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Floor System

Problems:	Solutions:

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Floor System

Problems:	Solutions:
•Flexure	•Thicker Slab, Beams between all columns

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Floor System

Problems:	Solutions:
•Flexure	•Thicker Slab, Beams between all columns
•Deflection	•Edge Beam

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Floor System

Problems:	Solutions:
•Flexure	•Thicker Slab, Beams between all columns
•Deflection	•Edge Beam
•Architecture	•Larger Spans

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Floor System

Problems:	Solutions:
•Flexure	•Thicker Slab, Beams between all columns
•Deflection	•Edge Beam
•Architecture	•Larger Spans
•Shear	•Drops, Larger Columns

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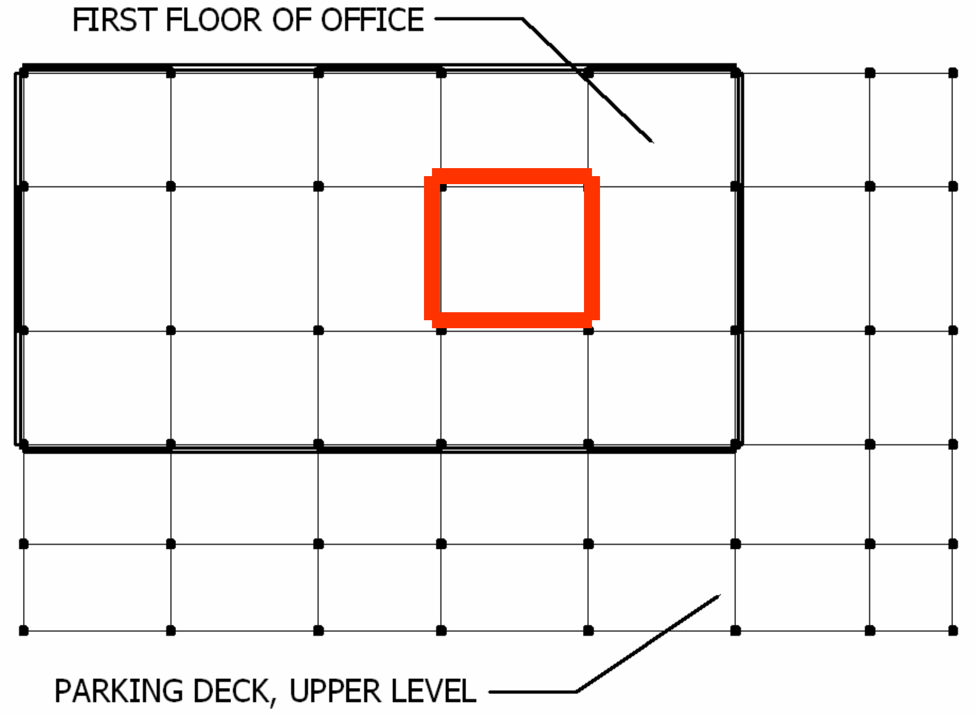
Floor System

Column Grid, Alternative #1

Maximum Bay Size = 30'-0"x30'-0"



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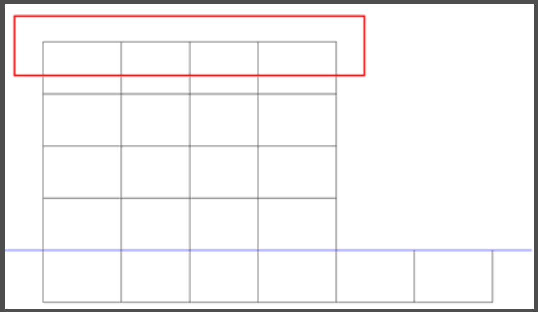
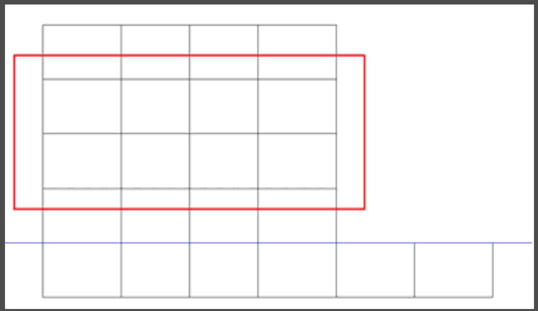
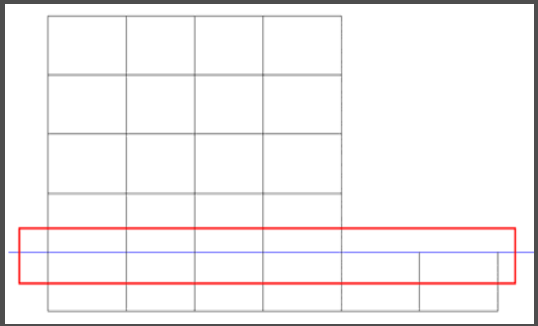
Floor System



Roof Structure: 8” Slab with 3.5” drops



Office Floors 2-4: 10” Slab with 3.5” drops, 4.5” drops at exterior columns



Parking Deck/First Floor: 11” Slab with 3.5” drops, 7” drops under parking live load

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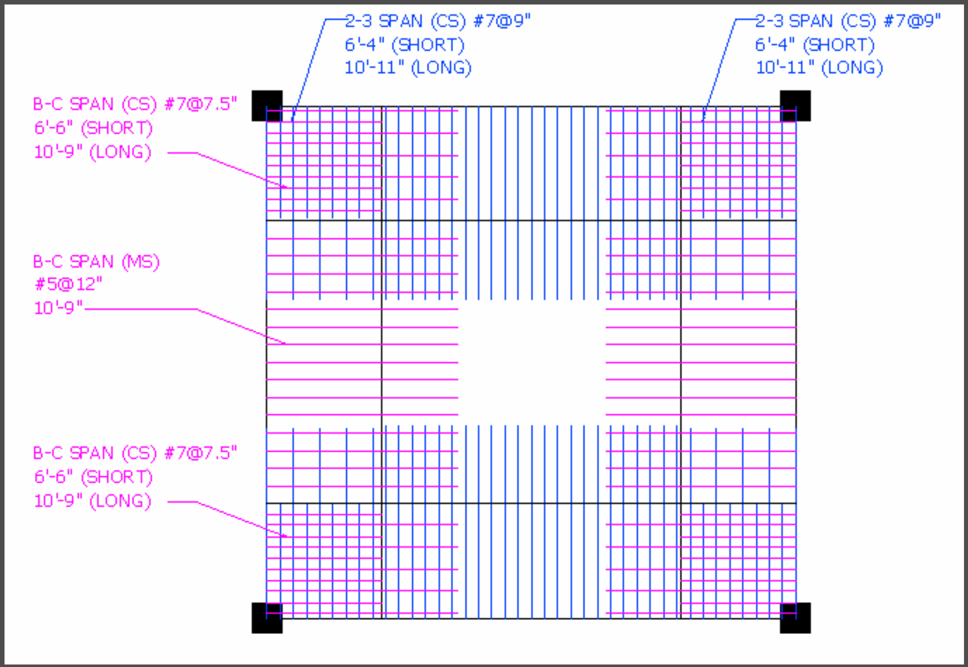
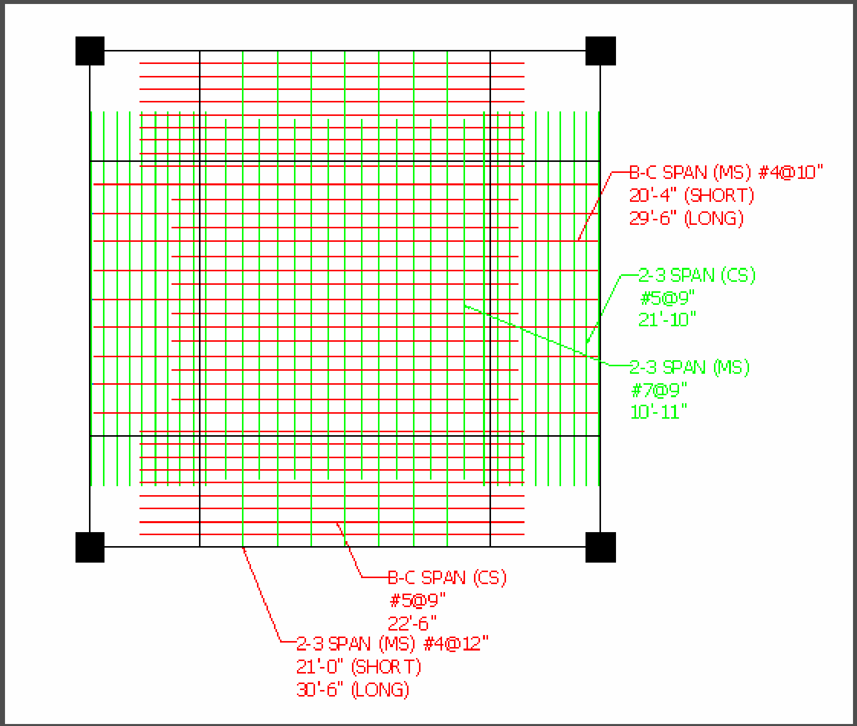
Floor System





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Lateral System

Location

- Limited wind pressures, seismic will control
- 170k seismic base shear increases to 354k under concrete system

Considerations

- Drift
- Structural Strength

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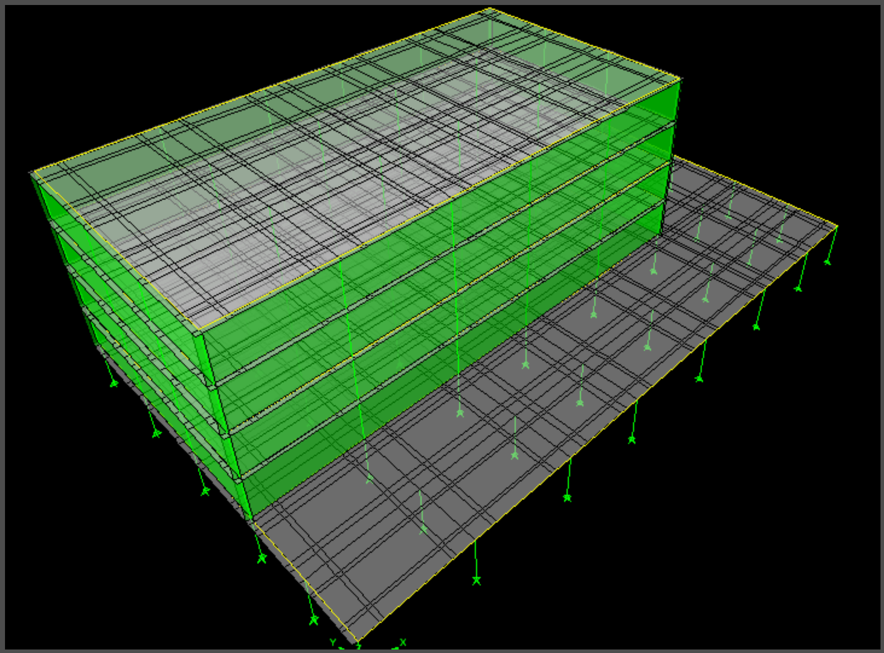
Lateral System

Drift Analysis from ETABS Model

- Rigid Diaphragm with Columns rigidly attached
- Lateral Loads applied to only top 4 diaphragms
- Drift measured from Basement Floor



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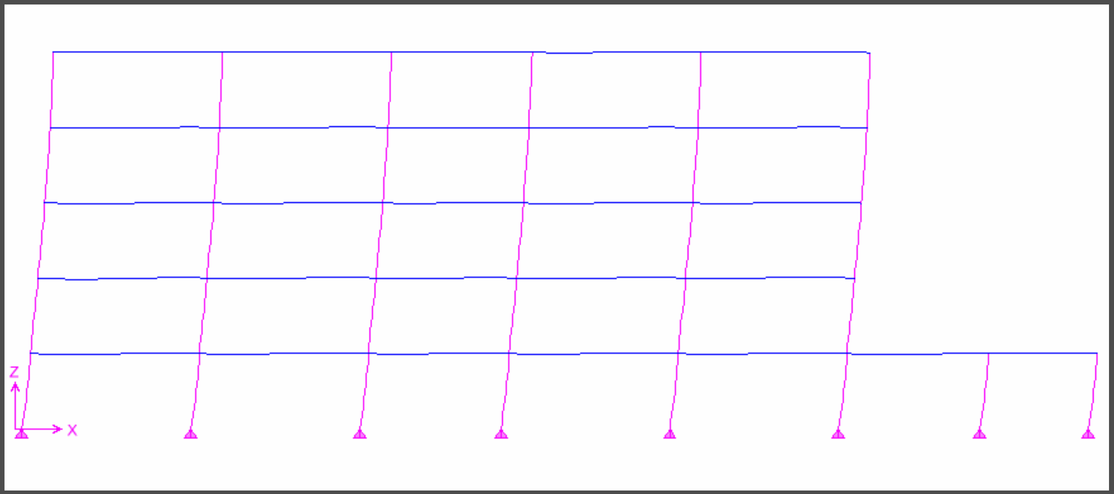
Lateral System

Drift Analysis from ETABS Model

Roof: 0.876”
Floor 4: 0.773”
Floor 3: 0.607”
Floor 2: 0.394”
Floor 1: 0.186”



Acceptable Drift:
H/400 = 1.57”

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Lateral System

Structural Analysis from ADOSS Model

- Horizontal Loads applied to Frame
- Flexure satisfactory
- Larger unbalanced moments at interior columns at Floors 2 and 3 a problem
- Larger columns necessary

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Columns and Footings

Using Moments and Loads from Structural Models

- Column sizes dictated by shear in floor system
- Per CRSI, minimum reinforcement in columns generally satisfactory
- Footing sizes drastically increase by 3-4x in area, by almost 2x in thickness

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Connection to Parking Structure

Beam Connection to Undulating Parking Structure

- Torsion
- Elevation

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Connection to Parking Structure

Beam	Size	Max Shear	Max Torsion	Max Moment	Steel Design Summary
A4-B4	20x44	80.7	107.9	888.6	(shear) #4 stirrups @ 14″ 11#5 long. Distributed on three sides (flexure) 4#10, 1#9
B4-C4	20x36	80.7	107.9	863.0	(shear) #4 stirrups @ 12″ 9 # 5 long. Distributed on three sides (flexure) 4#11, 1#10
C4-D4	20X30	80.7	107.9	516.9	(shear) #4 stirrups @ 10″ 7 #5 long. Distributed on three sides (flexure) 4#10, 1#9
D4-E4	20x26	80.7	107.9	7367	(shear) #4 stirrups @ 9.5″ 5 #5 long. Distributed on three sides (flexure) bottom row: 4#10, 1#1 top row: 5#9
E4-F4	20x28 +2″ elev.	80.7	107.9	7367	(shear) #4 stirrups @ 9.5″ 5 #5 long. Distributed on three sides (flexure) bottom row: 4#10, 1#1 top row: 5#9
F1-F2	24x34 +2″ elev.	96.0	151.0	606.4	(shear) #4 stirrups @ 10″ 7 # 5 long. Distributed on three sides (flexure) 4#11, 4#10
F2-F3 F3-F4	24x32	96.0	151.0	606.4	(shear) #4 stirrups @ 10″ 7 # 5 long. Distributed on three sides (flexure) 4#11, 4#10

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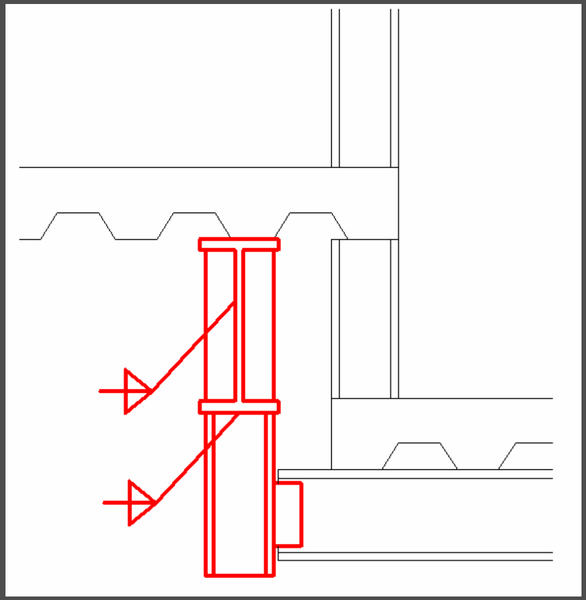
Additional Considerations

Beam Connection to Undulating Parking Structure

Steel Design



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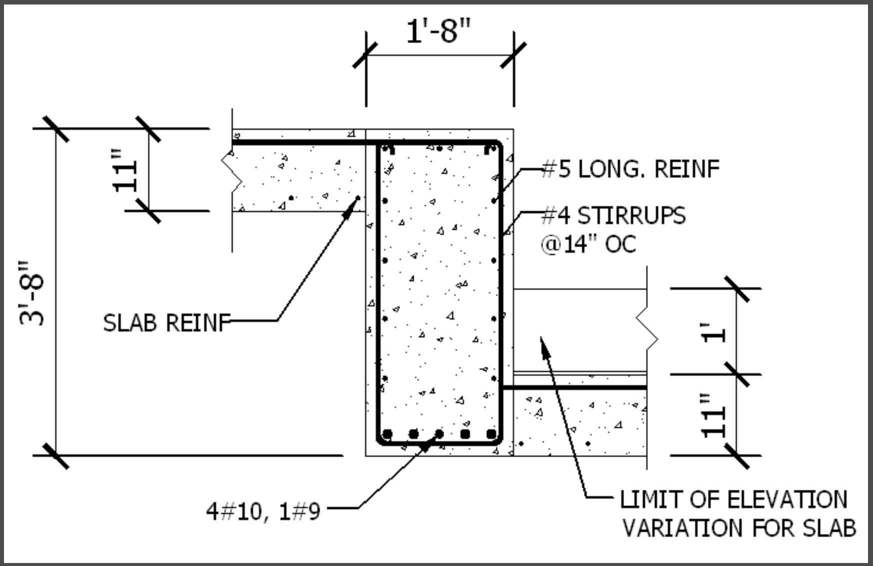

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Summary

- Drop panel system used throughout to combat shear
- Concrete Moment Frames sufficient for drift and lateral load resistance
- Column sizes dictated by shear and not axial loads
- Footing sizes drastically increase
- Connection to undulating parking structure achieved through beam

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Methods of Evaluation (Breadth Analyses)

- <u>Architectural Impact</u>: Number of Parking Spaces, Size of Obstructing Columns, Façade

- <u>Cost/Schedule Impact</u>: Overall Cost, Erection Time, and Local Adjustments

- <u>Possibility of Green Design</u>: Structural, Cost, and Aesthetic Implications of a Green Roof

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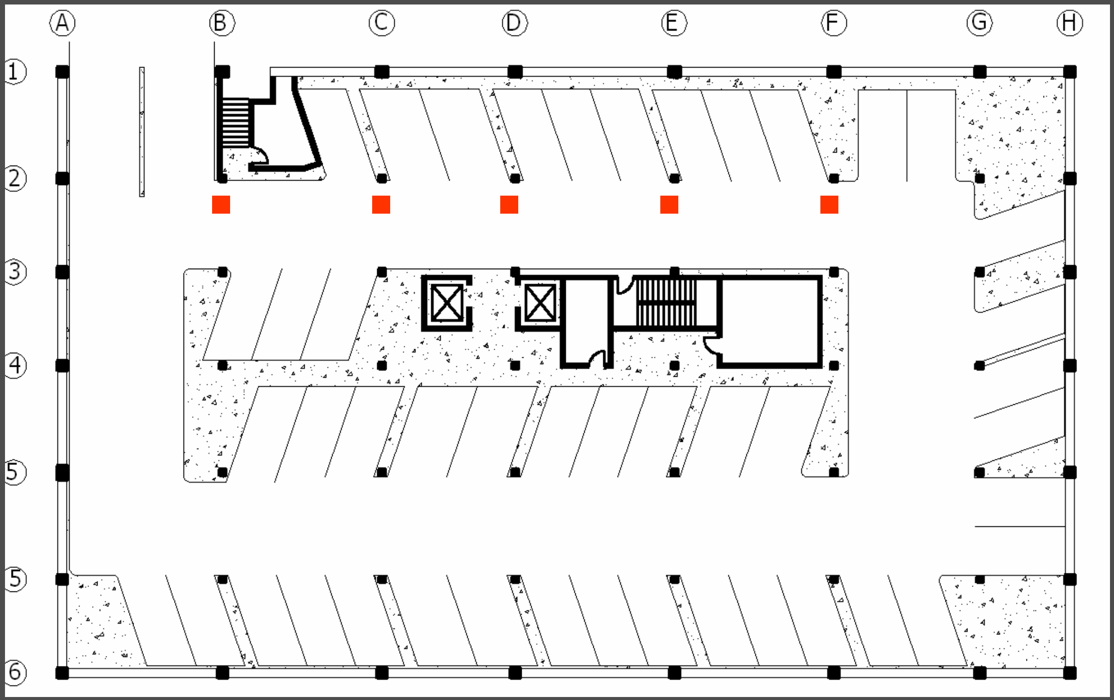
Architectural Design (Breadth 1)

Overview and Problem Statement

- Parking Area: New Column Layout overlaps with interior driveway by 2'-6"
- Office Layouts: Interior Corridor area needs to be moved to accommodate parking area and new column layouts
- Façade Layouts: 24" wide columns block windows

Architectural Design (Breadth 1)

Overview and Problem Statement



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Overview and Problem Statement

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Floorplan evaluated by the Building Owner and Managers Association Industry Standard

Façade evaluated by simplifying Precast Panel use

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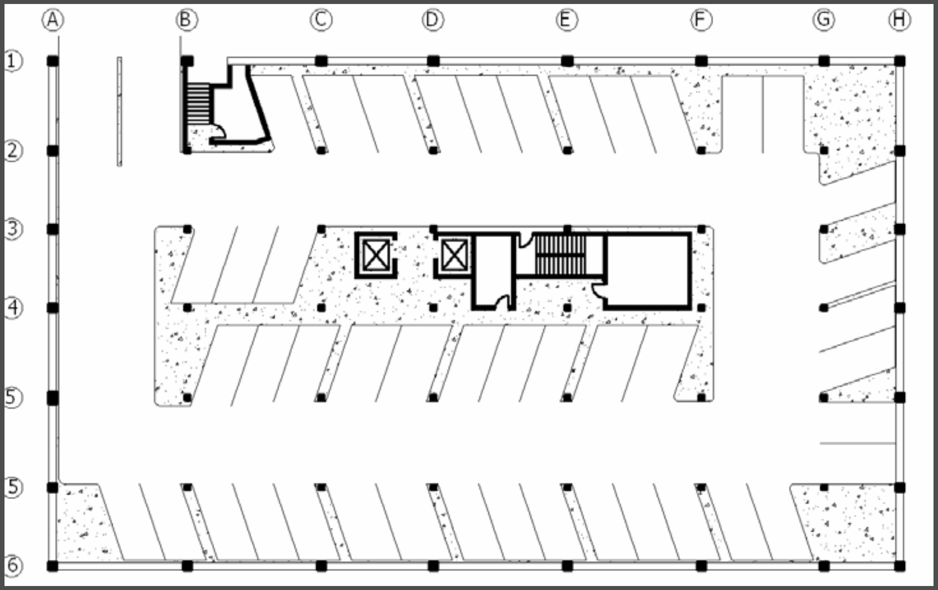
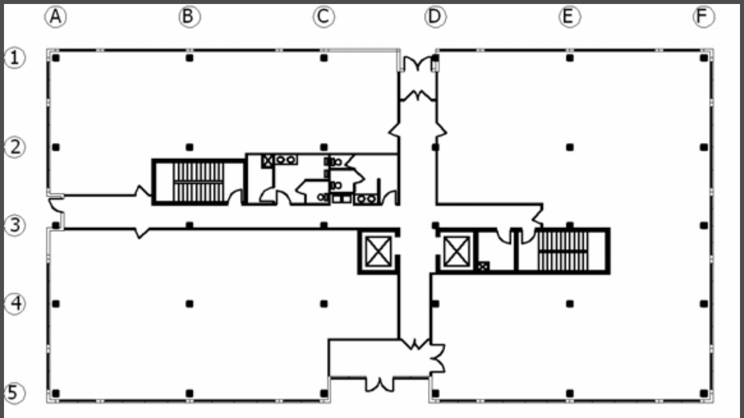
Architectural Design (Breadth 1)

Existing Design





- Total Rentable Area: 36,730 square feet
- R/U Ratio: 16.74%
- Underground Parking Spaces: 44

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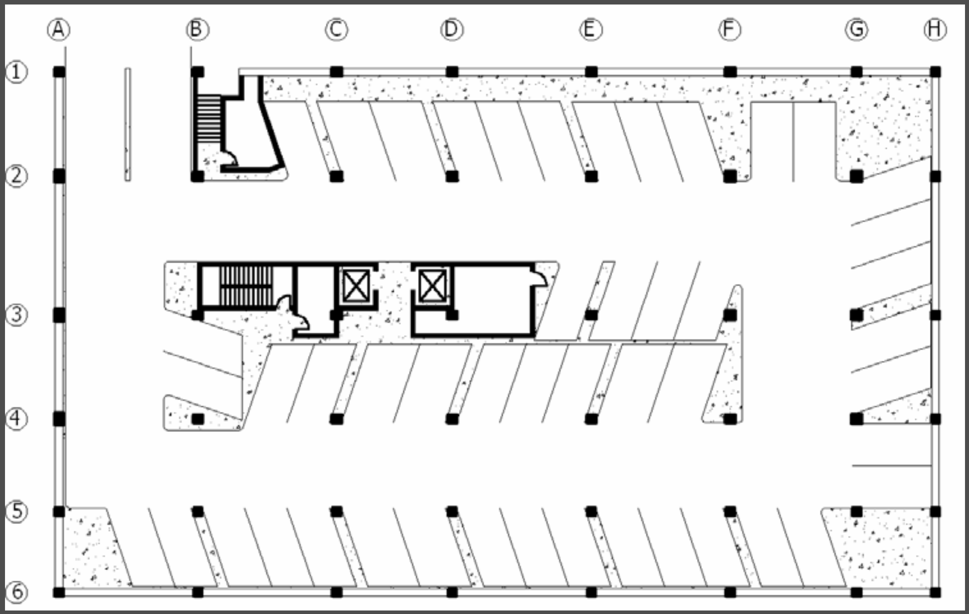
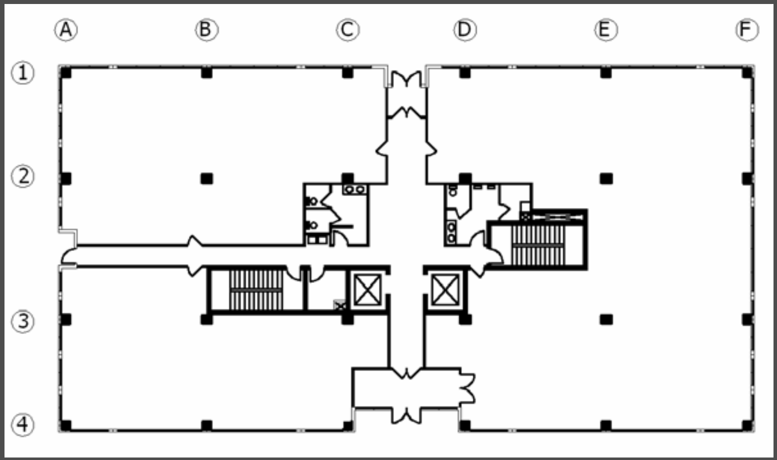
Architectural Design (Breadth 1)
Alternative #1





- Total Rentable Area: 37,740 square feet
- R/U Ratio: 14.77%
- Underground Parking Spaces: 48

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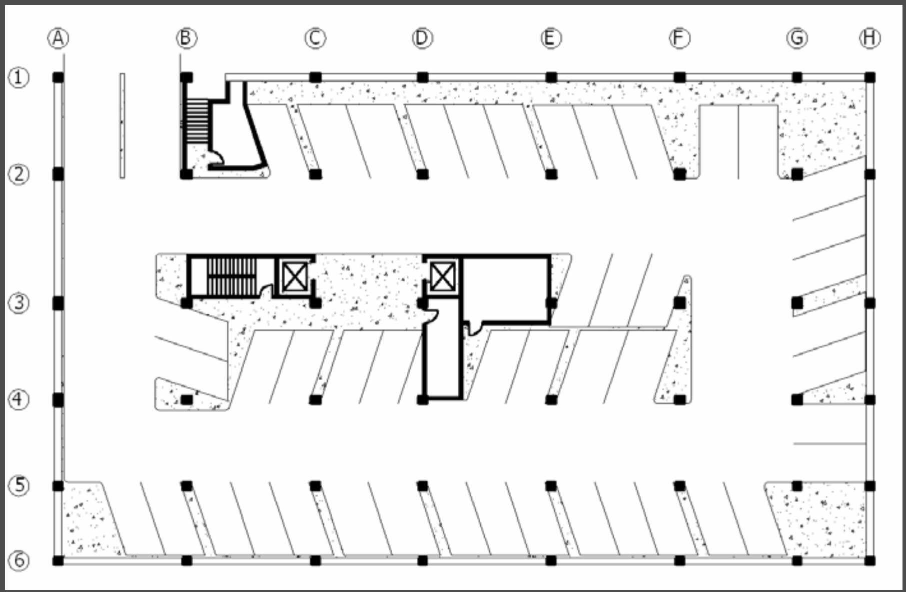
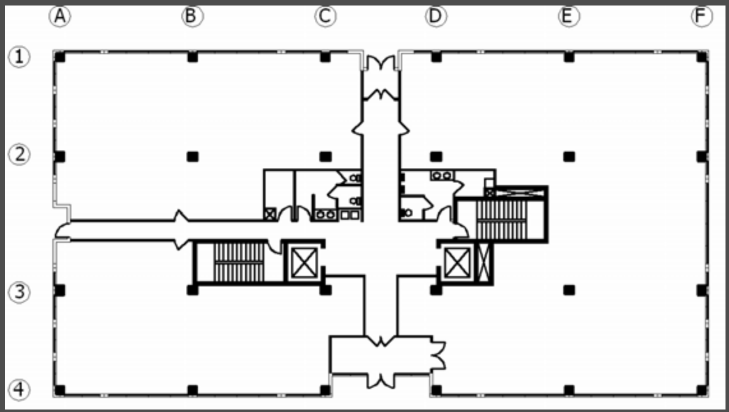
Architectural Design (Breadth 1)

Alternative #2





- Total Rentable Area: 37,027 square feet
- R/U Ratio: 16.09%
- Underground Parking Spaces: 46

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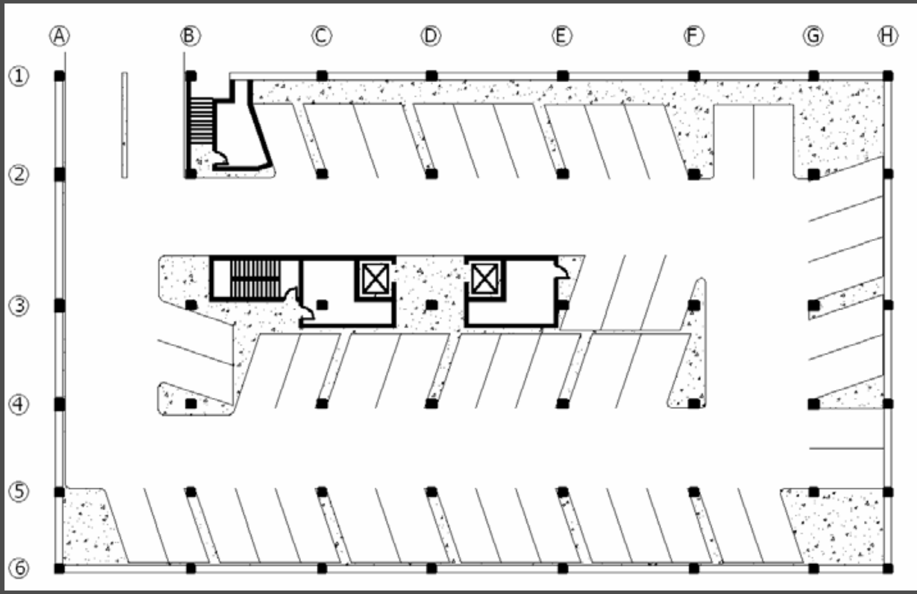
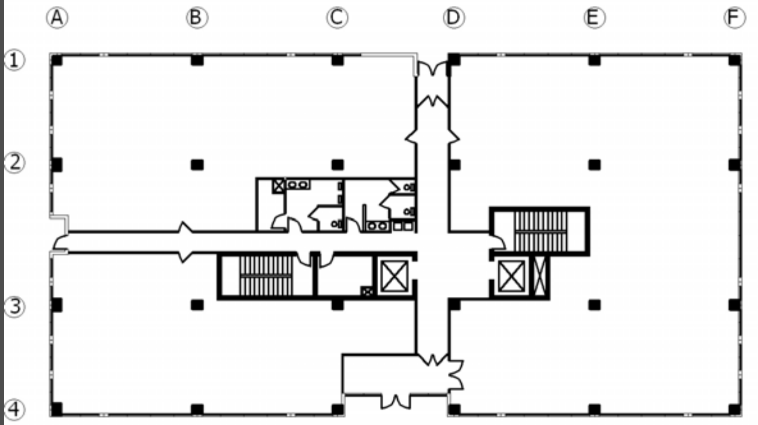
Architectural Design (Breadth 1)

Alternative #3





- Total Rentable Area: 37,116 square feet
- R/U Ratio: 15.90%
- Underground Parking Spaces: 47

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Architectural Design (Breadth 1)

Floorplan Study Summary

•Average Annual Rental Value per usable square feet in Prince William County is $25

•Parking Spaces, if rented, could cost $50/month

Increased Annual Revenue to the Owner:

$7,425 to $21,150

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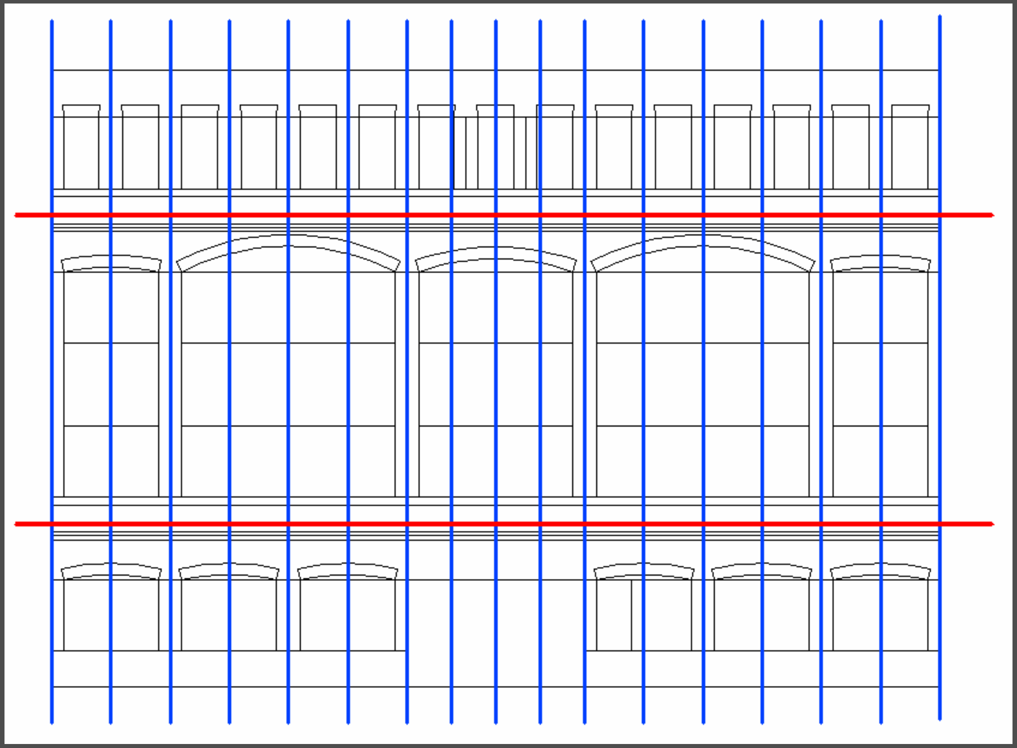
Architectural Design (Breadth 1)

Façade Study

- Precast Panels can be shifted and moved to suit the structural layout
- Horizontally, panels adhere to 3'-9" and 5'-0" modules
- Vertically, the design details draw from base-shaft-capital office building icon



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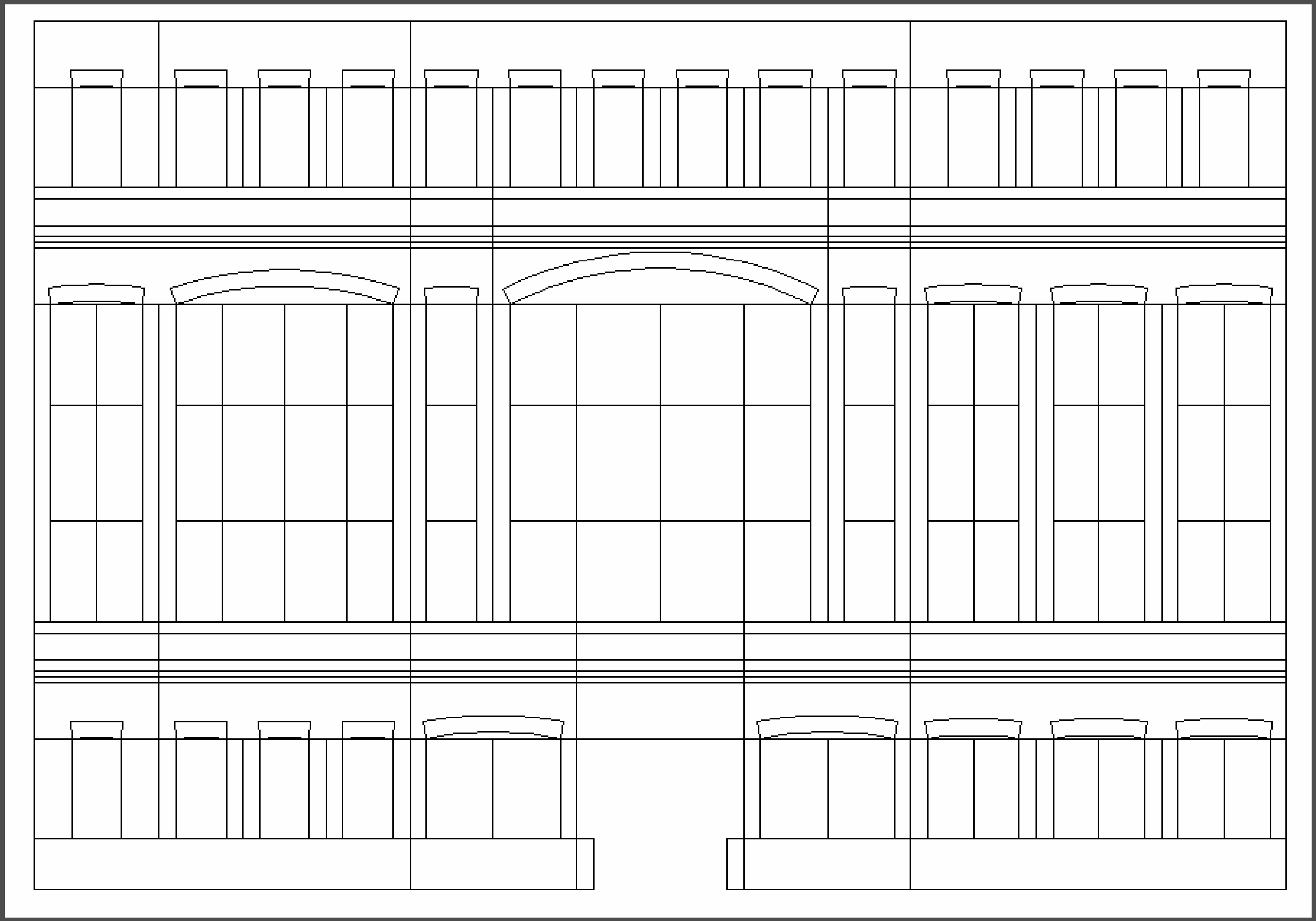
Architectural Design (Breadth 1)

Façade Study, Horizontal Play



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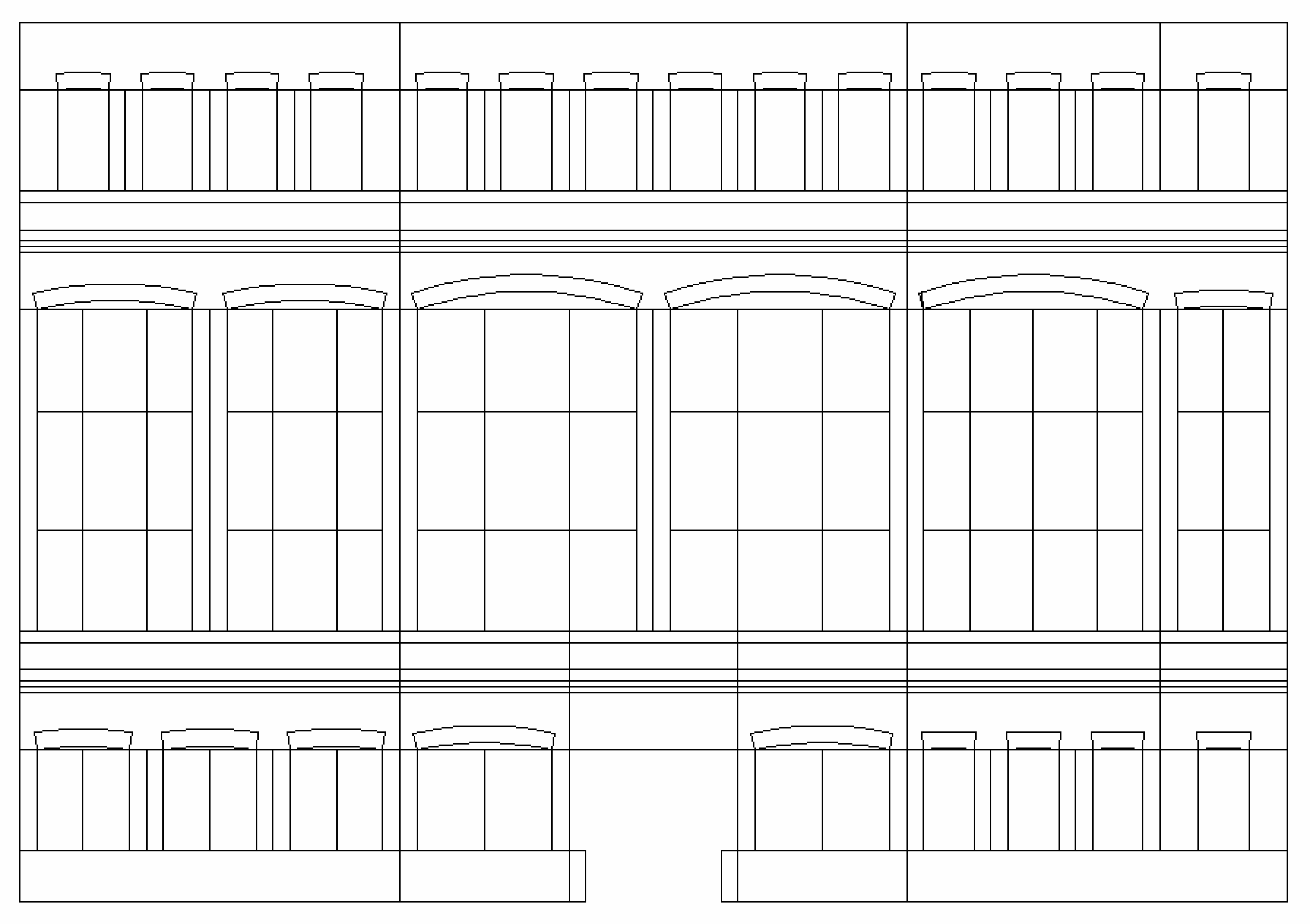
Architectural Design (Breadth 1)

Façade Study, Horizontal Play



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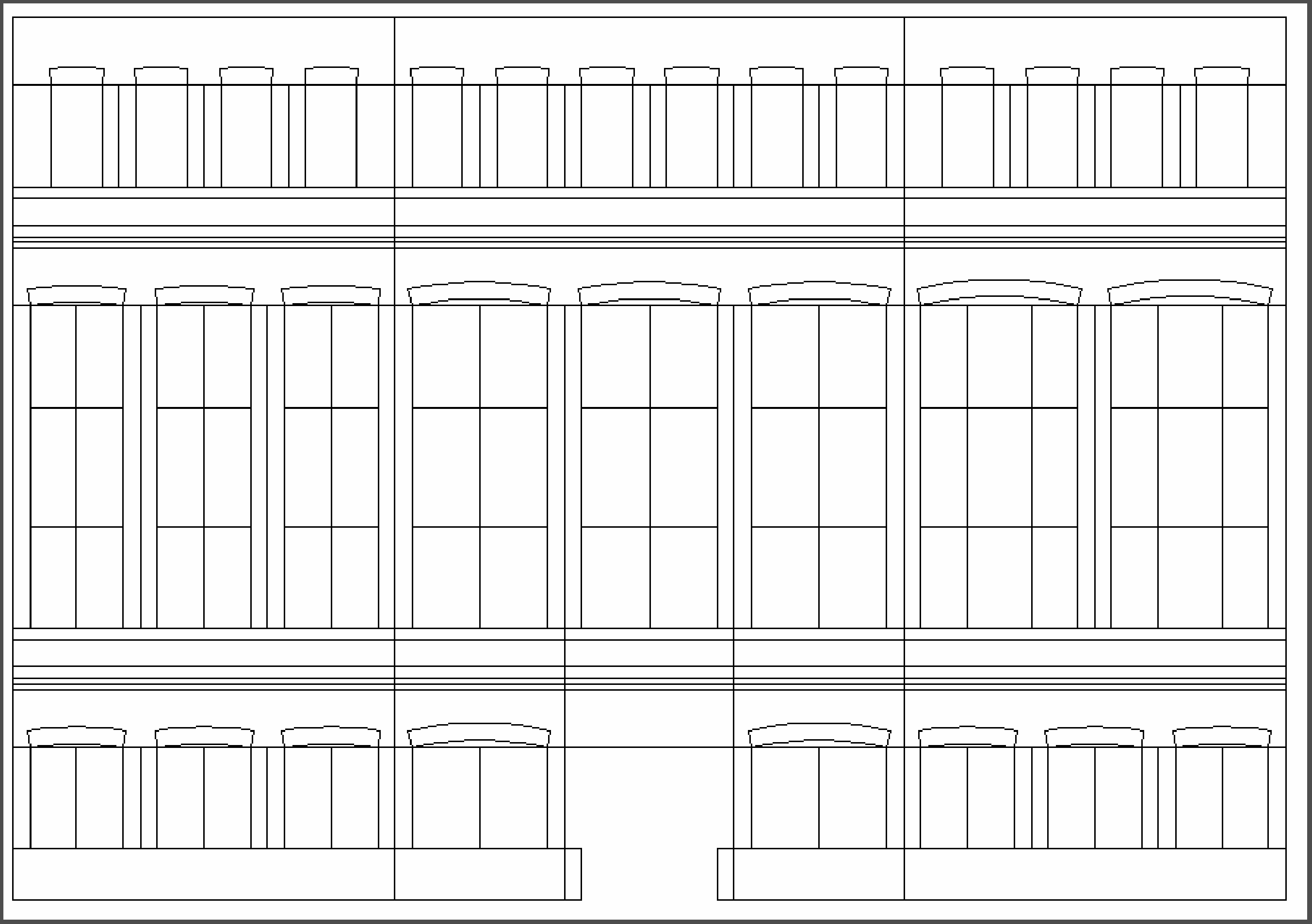
Architectural Design (Breadth 1)

Façade Study, Horizontal Play



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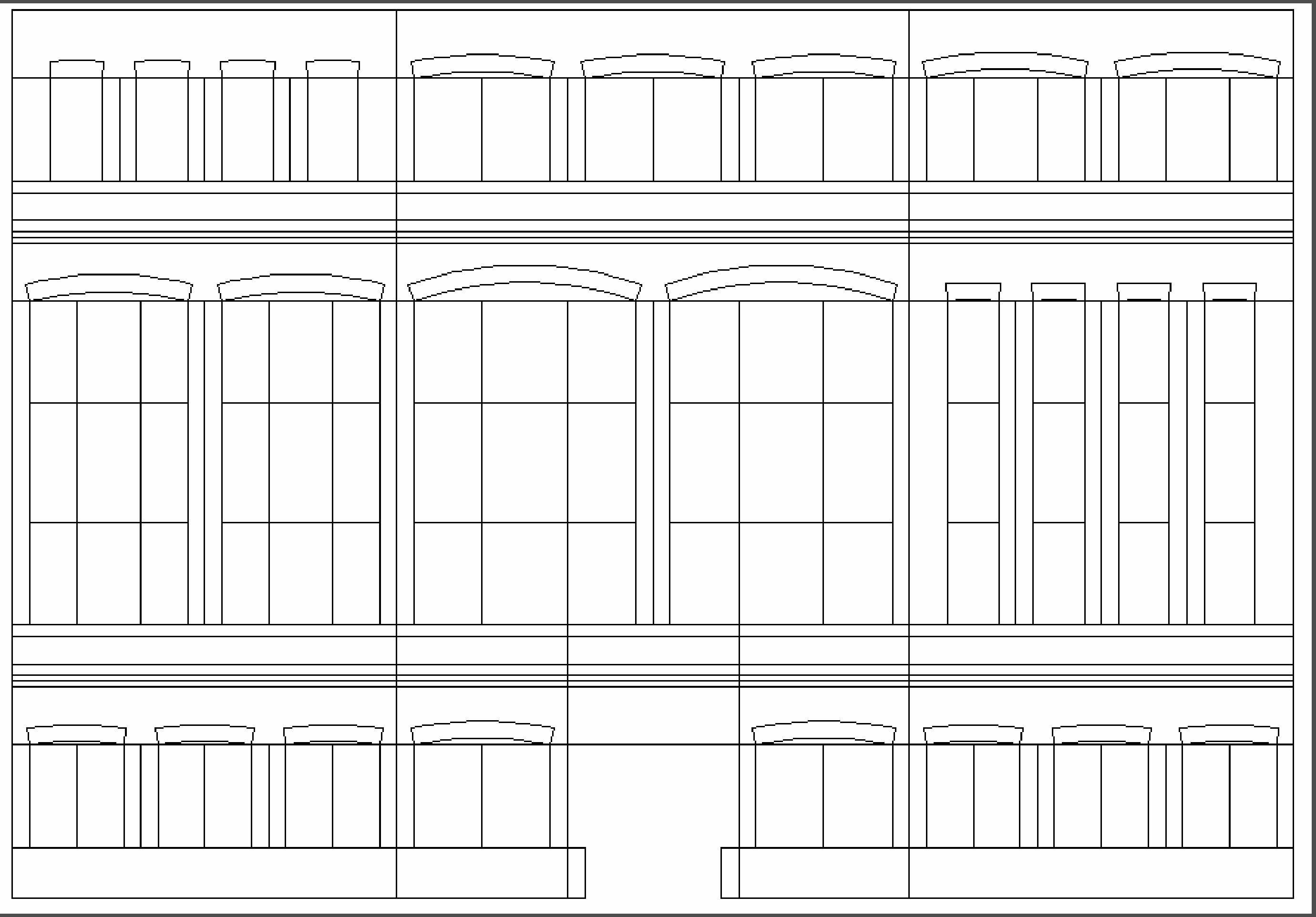
Architectural Design (Breadth 1)

Façade Study, Horizontal and Vertical Play



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Architectural Design (Breadth 1)

Façade Study, Horizontal and Vertical Play

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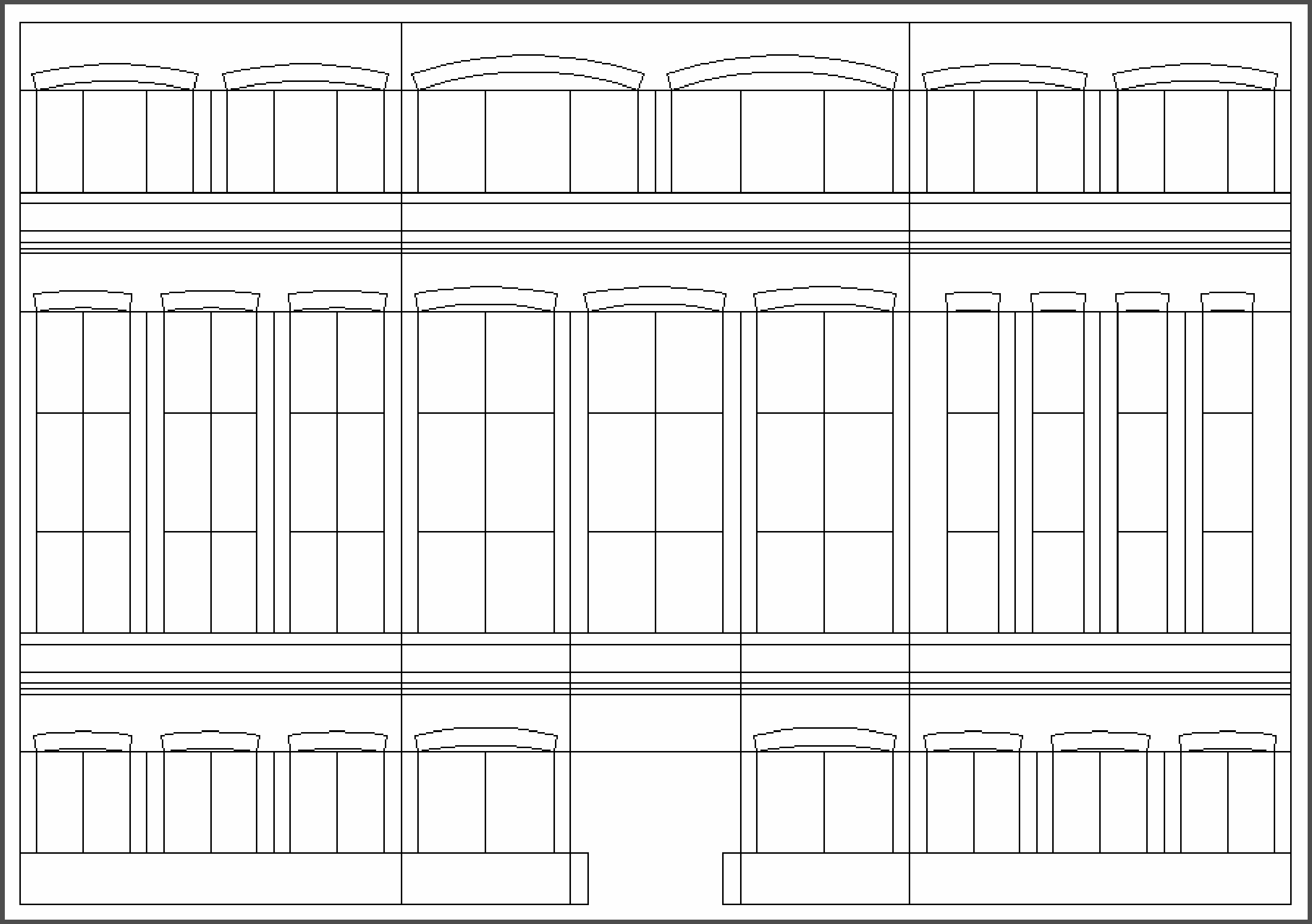
Architectural Design (Breadth 1)

Façade Study, Horizontal and Vertical Play



JOSEPH HENRY
Structural
Hanagan, Advisor

Architectural Design (Breadth 1)

Façade Study, Most Economical Redesign

- Windows completely free of column obstructions
- Maximum number of panels re-used
- Panels kept under 30’-0” wide

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Structural
Hanagan, Advisor

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Structural
Hanagan, Advisor

Cost / Schedule Analysis (Breadth 2)

Cost Estimates from R.S. Means 2006

Material	Cost	Construction Duration
Concrete System		
Columns, Slabs, Beams	$1,120,566	14 weeks
Footings	$230,887	2 weeks
Steel System		
Columns and Beams	$668,928	8 weeks
Deck and Shear Studs	$170,345	
Poured Conc. On Deck	$162,010	
Fireproofing	$73,044	
Total	$1,074,327	12 weeks, 4 days
Footings	$73,044	3 days

- Composite Steel Costs $1,147,371 over 13.5 weeks
- Concrete Costs $1,351,453 over 16 weeks
- $200,000+ cost difference in favor of Steel

JOSEPH HENRY
Structural
Hanagan, Advisor

Cost / Schedule Analysis (Breadth 2)

Concrete vs. Steel, Local Influences

- Local Cost Adjustments

Location	Concrete Costs	Steel Costs
Washington, DC	0.992	1.062
Fairfax, VA	0.921	0.921
Arlington, VA	0.902	0.898
Alexandria, VA	0.915	0.952
Winchester, VA	0.795	0.891

Cost / Schedule Analysis (Breadth 2)

Concrete vs. Steel, Local Influences

- Lead Times: After Design Completion, Procurement, Submittals, and Approvals, it takes 12 weeks to produce structural steel and only 3 weeks to produce rebar

- Supply and Demand: Washington DC area on Portland Cement Association's "tight cement supply" list for 2005 and 2006

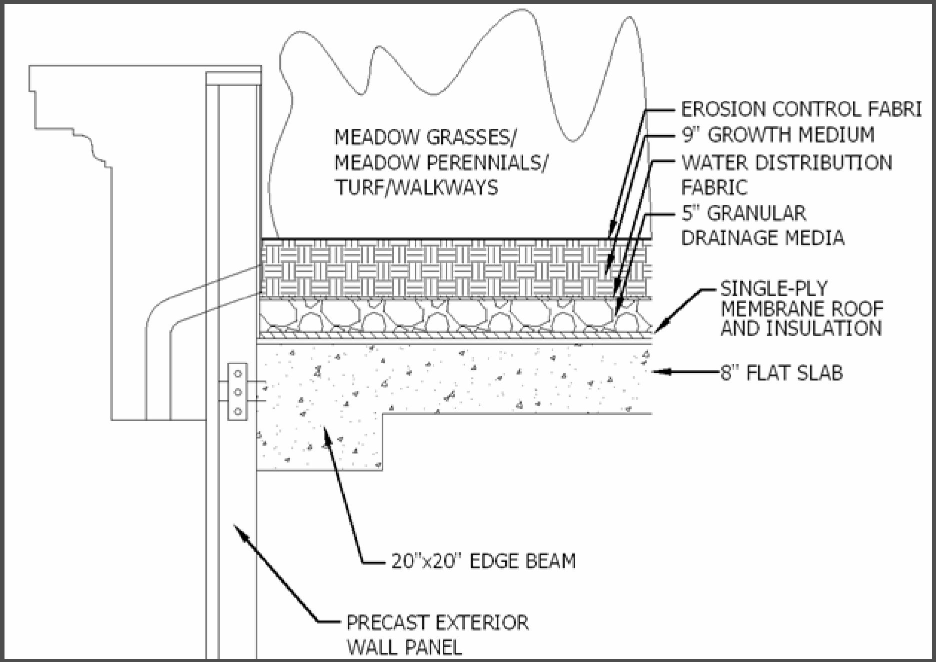
- Weather: Per ACI 318-05 concrete must be kept above freezing, which may add cost and duration

Green Roof Addition (Breadth 3)

Overview of Green Roof Types

Information from Roofscapes, Inc.

System	Thickness/ Sat.Weight
Flower Carpet	2-3"/ 12-18 psf
Aromatic Garden	3-4"/ 18-24 psf
Savannah	4-6"/ 24-36 psf
Meadows	6-9"/ 36-54 psf



JOSEPH HENRY
Structural
Hanagan, Advisor

Green Roof Addition (Breadth 3)

Why a Green Roof?

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Structural
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Structural
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Green Roof Addition (Breadth 3)

Implications of Green Roof

Increased Costs

- For enlarged roof system: $17,500 for steel, $30,000 for concrete
- $10-13 to install and 4-6 man hours per 1000 square feet per year to maintain
- $90,000 to $117,000 to install (10% of structural system price)
- $720 to $1,080 to maintain

Green Roof Addition (Breadth 3)

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Benefits

- Per LEED Green Building Rating System, eligible for 1 point (Heat Island Effect: Roof, Credit 7.2)
- Reduced noise transmission through roof structure
- Increased R-values in roof system

Final Conclusions

Original Composite Steel Design Review

Pro

- Light
- Small Columns
- Cheaper
- Faster

Con

- Average 12” deeper section depth than concrete
- Complicated connections at parking structure
- Less drift resistance
- Time consuming fire protection needed

JOSEPH HENRY
Structural
Hanagan, Advisor

Final Conclusions

Reinforced Concrete Design Review

Pro

- Smaller floor section depth
- Simpler connections to parking structure
- More drift resistant
- No fireproofing required
- More effectively resists water damage from green roof

Con

- Heavy system with larger footings
- Large obstructing columns
- More expensive by $200,000
- Longer erection time by 2.5 weeks

JOSEPH HENRY
Structural
Hanagan, Advisor

Final Conclusions

Recommendations

Hybrid Structure: Concrete up to First Floor
Composite Steel Above

- Fireproofing simplified between office area and underground parking
- Better appearance, smaller section depth in parking area
- Simplified connections to parking structure
- Good cost and schedule compromise
- Concrete first floor helps resist lateral loads

JOSEPH HENRY
Structural
Hanagan, Advisor

Thank You

Questions and Comments?

JOSEPH HENRY
Structural
Hanagan, Advisor