Corporate Headquarters

Great Lakes Region, USA

AE Senior Thesis
April 13th, 2015

Mary Julia Haverty

Structural Option

Advisor H. Sustersic

Corporate Headquarters

Introduction
Problem Statement and Solution
Structural Depth
- Gravity System
- Lateral System

Green Roof Breadth
Enclosures Breadth
Conclusion

Introduction

Project Team

RTKL: Architect, Structural Engineer, Mechanical Engineer, Electrical Engineer, Plumbing, Telecommunications

Mark G. Anderson Consultants: Project Management

Neff and Associates: Civil Engineer

Keith Davis Group, LLC: Roof and Waterproofing Consultant

Building Height: 83.33’

Number of Stories: 5

Size: 659,554 GSF

Occupancy: Office and Retail

Location: Great Lakes Region

Cost: Withheld at owner’s request

Dates of Construction:
August 2014- Spring 2016

Project Delivery Type:
Design-Bid Build


Image Courtesy: RTKL and The Village Newspaper

Corporate Headquarters

Introduction
- Existing Structural System
  - Gravity System
  - Lateral System

Problem Statement and Solution

Structural Depth
- Gravity System
- Lateral System

Green Roof Breadth

Enclosures Breadth

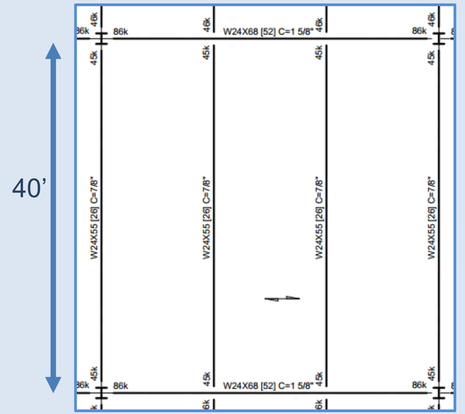
Conclusion

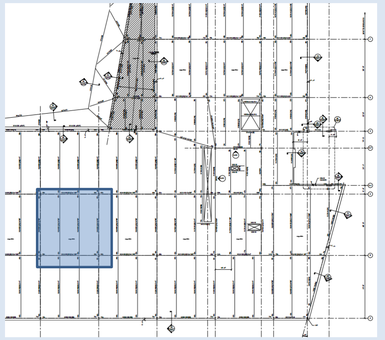
Gravity System

- Composite Steel Beams and Girders
  - beams spaced at 12.67’
  - average camber 1”
  - Average beam size W24x55
  - Average girder size W24x68
- Wide Flange Columns
  - spliced at level 3
  - Average column size W14x90

Design Loads	Dead Load (PSF)	Live Load (PSF)
Office Areas	61	65
Public Areas	61	100
Libraries	61	150
Main Server Room	76	250
Courtyard Grass Area	201	100
Courtyard Tree Area	441	100
Typical Roof	18	25
RTU Roof	117	25
Kitchen	144	150
A/V Suite	100	221

Existing Structural System





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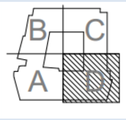


Corporate Headquarters

Introduction
- Existing Structural System
  - Gravity System
  - Lateral System

Problem Statement and Solution

Structural Depth
- Gravity System
- Lateral System

Green Roof Breadth

Enclosures Breadth

Conclusion

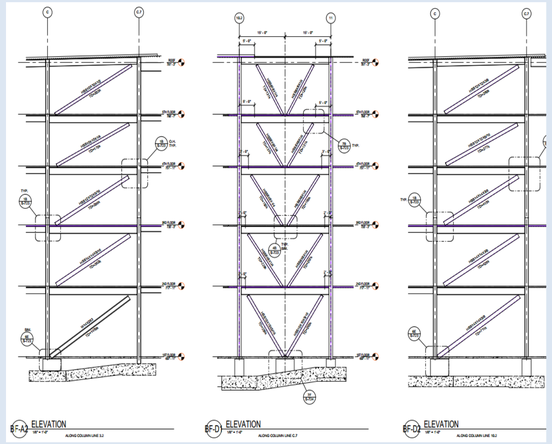
Existing Structural System

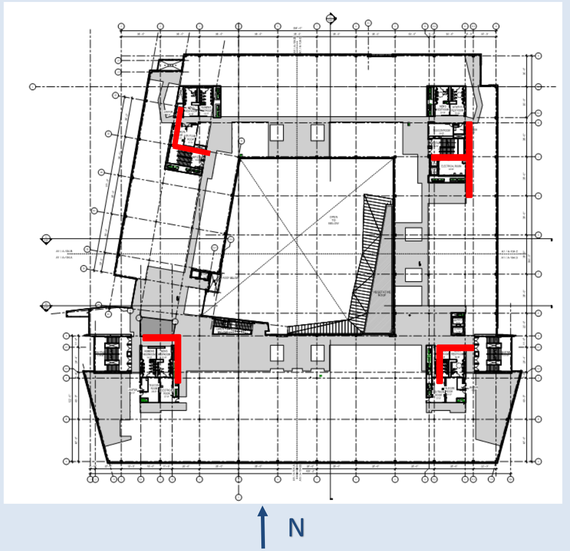
Lateral System

- Steel braced frames
- Two in each corner of the building, eight total

Wind Loading
- V=90 mph
- Base shear East-West= 423.16 kips
- Base shear North-South= 353.62 kips

Seismic Loading
- Site Class C
- Seismic Design Category A
- Base shear 572.35 kips





Corporate Headquarters

Introduction
Problem Statement and Solution
Structural Depth
    Gravity System
    Lateral System
Green Roof Breadth
Enclosures Breadth
Conclusion

Problem Statement

Scenario:
Owner has requested more office space

Goals:
1. Reshape courtyard green roof
    - Aid in design process, more regular bays
    - Remove tree area to reduce dead load
    - Gain office space on upper three floors

Corporate Headquarters

Introduction
Problem Statement and Solution
Structural Depth
    Gravity System
    Lateral System
Green Roof Breadth
Enclosures Breadth
Conclusion

Problem Statement

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    - Utilize open web steel joists and joist girders

Corporate Headquarters

Introduction
Problem Statement and Solution
Structural Depth
    Gravity System
    Lateral System
Green Roof Breadth
Enclosures Breadth
Conclusion

Problem Statement

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2. Redesign structural system to support new dead load
    - Utilize open web steel joists and joist girders
3. Explore new planting options and watertight systems
    - Redesign garden to focus on local plants
    - Select new waterproofing membrane

Corporate Headquarters

Introduction
Problem Statement and Solution
Structural Depth
- Gravity System
- Lateral System

Green Roof Breadth
Enclosures Breadth
Conclusion

Gravity System

Corporate Headquarters

Introduction
Problem Statement and Solution
Structural Depth
- Gravity System
  - Gravity Loads
  - Typical Roof Bay
  - Typical Floor Bay
  - Columns
  - Vibration Considerations
- Lateral System

Green Roof Breadth
Enclosures Breadth
Conclusion

Gravity Loads

Live Loading		
	Office	Roof
Live Load (PSF)	50	20
Partitions (PSF)	15	-
Snow (PSF)	-	17
Total Load (PSF)	65	20
Reduced LL	**41**	**20 (unreducable)**

Dead Loads		
	Office	Roof
Concrete Slab (PSF)	31	50
Metal Deck (PSF)	3	3
MEP (PSF)	5	10
Ceiling (PSF)	2	2
Flooring (PSF)	3	-
Sprinklers (PSF)	3	3
Framing Allowance (PSF)	5	10
Adhered Membrane (PSF)	-	1
Roof Board (PSF)	-	1
Insulation (PSF)	-	3
Vapor Retarder (PSF)	-	1
Total Load (PSF)	**52**	**84**

Corporate Headquarters

Introduction
Problem Statement and Solution
Structural Depth
- Gravity System
  - Gravity Loads
  - Typical Roof Bay
  - Typical Floor Bay
  - Columns
  - Vibration Considerations
- Lateral System

Green Roof Breadth
Enclosures Breadth
Conclusion

Gravity System- Typical Roof Bay

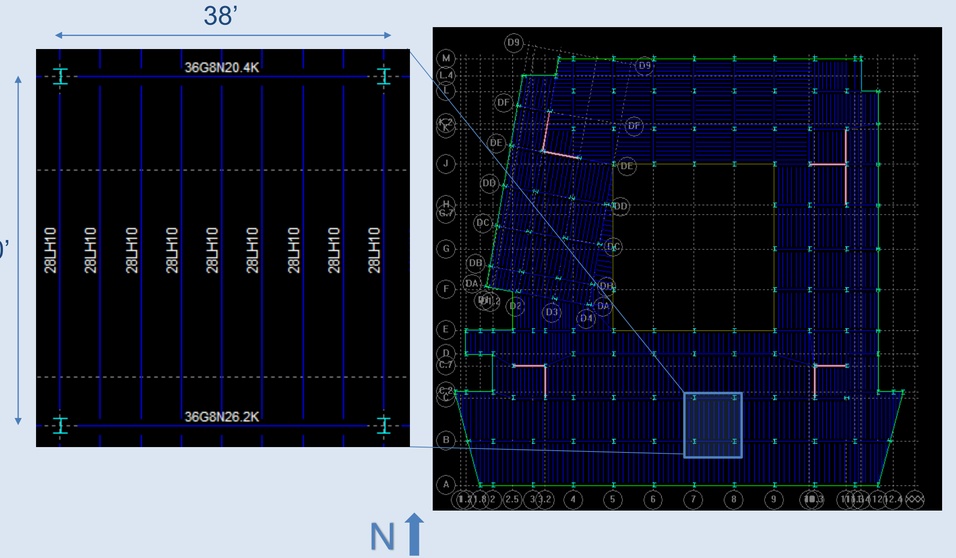
Typical Bay
1.5 VLR 18 gauge composite deck
- 4” normal weight topping
  - Achieves two hour fire rating
- Unshored, 2 span construction

Joists
- 28LH10
- 4.75’ spacing

Joist Girders
- 36G8N26.2K

- Joists and girders to be fire proofed for a two hour fire rating
- Deflection controlled depths
- Designed using RAM Structural System

Steel Joist System Roof Redesign



Corporate Headquarters

Introduction
Problem Statement and Solution
Structural Depth
- Gravity System
  - Gravity Loads
  - Typical Roof Bay
  - Typical Floor Bay
  - Columns
  - Vibration Considerations
- Lateral System

Green Roof Breadth
Enclosures Breadth
Conclusion

Gravity System- Typical Floor Bay

Typical Bay

1.5 VLR 18 gauge composite deck
- 3 ¼” lightweight topping
  - Achieves two hour fire rating
- Unshored, 2 span construction

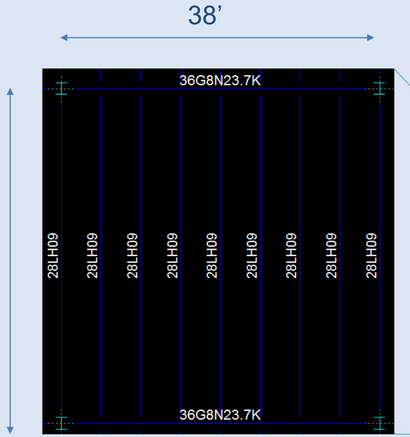
Joists
- 28LH09
- 4.75’ spacing

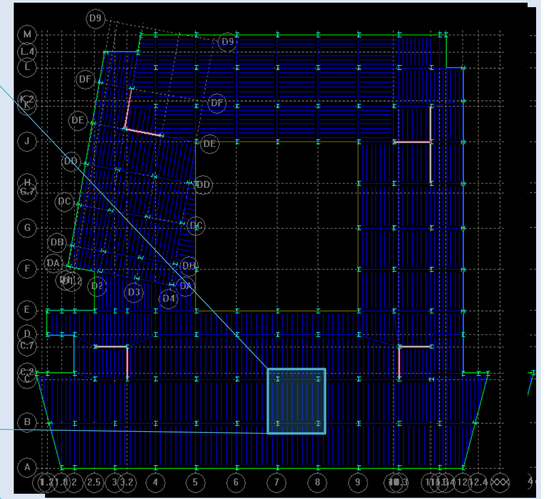
Joist Girders
- 36G8N23.7K

Joists and girders to be fire proofed for a two hour fire rating

Deflection controlled depths

Steel Joist System Floor Redesign





Corporate Headquarters

Introduction
Problem Statement and Solution
Structural Depth
- Gravity System
  - Gravity Loads
  - Typical Roof Bay
  - Typical Floor Bay
  - Columns
  - Vibration Considerations
- Lateral System

Green Roof Breadth
Enclosures Breadth
Conclusion

Gravity System- Columns

- Wide flange steel columns
- Typical sizes
  - W14x132 (interior)
  - W12x79 (exterior)
- Spliced on level 3
- Designed using RAM Structural Systems- Columns

Live Load Reduction

$$L = L_o\left(0.25 + \frac{4.57}{\sqrt{K_{LL}A_T}}\right)$$

L=41 psf

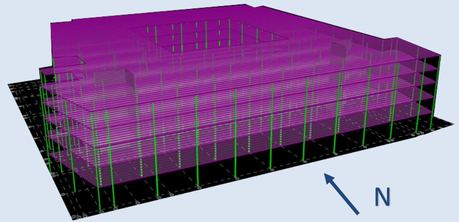
Lo=65 psf
KLL=1.0
At=38’x40’ = 1520 sq ft

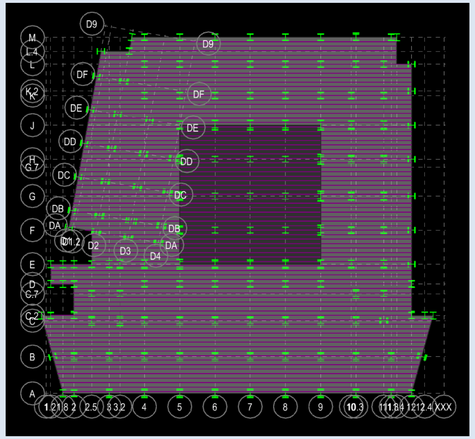
Main Roof	
5	W14x68
4	W14x68
3	W14x132
2	W14x132
1	W14x132

Interior Column

Main Roof	
5	W12x45
4	W12x45
3	W12x79
2	W12x79
1	W12x79

Exterior Column





Corporate Headquarters

Introduction
Problem Statement and Solution
Structural Depth
- Gravity System
  - Gravity Loads
  - Typical Roof Bay
  - Typical Floor Bay
  - Columns
  - Vibration Considerations
- Lateral System

Green Roof Breadth
Enclosures Breadth
Conclusion

Gravity System- Vibration Considerations

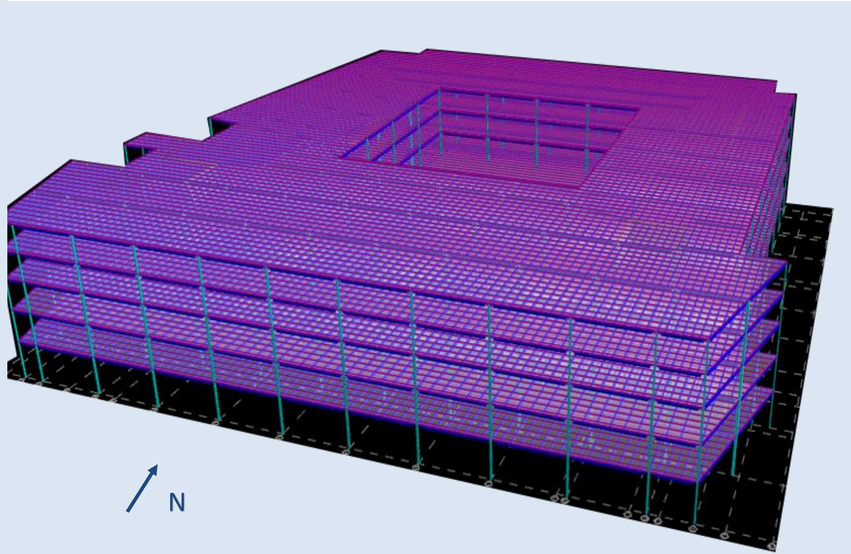
- Major area of concern in steel joist floor systems
- Helped limit joist spacing
- Upper floors of building primary concern

Ap/g < 0.005 for office areas

Fn= 2.6 Hz
Ap/g = 0.0015

$$\frac{a_p}{g} = \frac{P_o \exp(-0.35 f_n)}{\beta W}$$

Criteria found in AISC Design Guide 11, Ch 4, Design for Walking Excitation



Corporate Headquarters

Introduction
Problem Statement and Solution
Structural Depth
    Gravity System
    Lateral System
Green Roof Breadth
Enclosures Breadth
Conclusion

Lateral System

Corporate Headquarters

Introduction
Problem Statement and Solution
Structural Depth
- Gravity System
- Lateral System
  - Lateral Loads
  - Shear Wall Design
  - Story Drift

Green Roof Breadth
Enclosures Breadth
Conclusion

Lateral System- Lateral Loads

East-West Wind Pressures Now Control

Seismic Pressures		
Level	Force (K)	Overturning Moment (ft-k)
Main Roof	106.58	8882.38
5	63.41	4354.36
4	63.41	3424.14
3	87.77	3276.45
2	75.66	1513.2
Base Shear (K)	**397**	**21450.53**

Wind Pressure North-South		
Floor	**Force (K)**	**Overturning Moment (ft-k)**
roof	39.325	3276.950
5	75.993	5218.444
4	80.988	4373.359
3	79.314	2960.800
2	78.998	1579.962
Base	354.618	17409.515

Wind Pressure East-West		
Floor	**Force (K)**	**Overturning Moment (ft-k)**
roof	46.918	3909.638
5	90.690	6227.687
4	96.636	5218.328
3	94.645	3533.094
2	94.273	1885.466
Base	423.162	20774.213

Corporate Headquarters

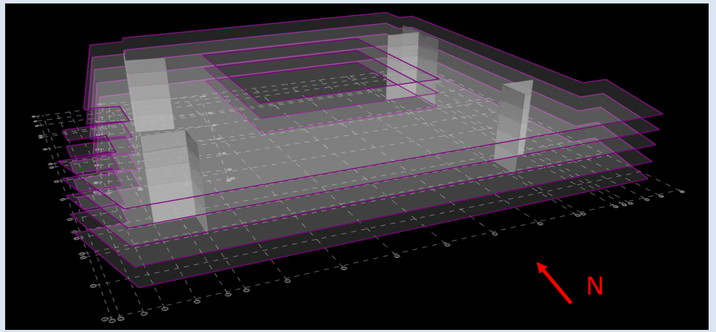
Introduction
Problem Statement and Solution
Structural Depth
- Gravity System
- Lateral System
  - Lateral Loads
  - Shear Wall Design
  - Story Drift

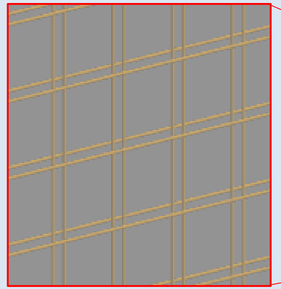
Green Roof Breadth
Enclosures Breadth
Conclusion

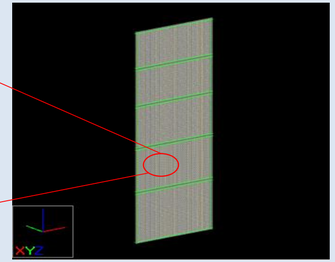
Lateral System- Shear Wall Design

Reinforced Concrete Shear Walls

- Eight reinforced concrete shear walls
- Retained locations of existing lateral system
- Reinforced with minimum reinforcement
- #4's at 12" O.C. horizontal and vertical
- 8" thickness







Corporate Headquarters

Introduction
Problem Statement and Solution
Structural Depth
- Gravity System
- Lateral System
  - Lateral Loads
  - Shear Wall Design
  - Story Drift

Green Roof Breadth
Enclosures Breadth
Conclusion

Lateral System- Story Drift

Wind drift limit

$$\Delta_{allowable} = (83.33'x12"/1')/400 = 2.5"$$

Seismic drift limit

$$\Delta_{allowable} = (14.67'x12"/1') \times 0.02 = 3.52"$$

Redesign Seismic Drift		
	Story Drift (in)	Total Drift (in)
Main Roof	0.136	0.404
Level 5	0.11	0.268
Level 4	0.083	0.158
Level 3	0.052	0.075
Level 2	0.023	0.023

Existing Seismic Drift		
	Story Drift (in)	Total Drift (in)
Main Roof	0.244	0.751
Level 5	0.208	0.507
Level 4	0.158	0.299
Level 3	0.1	0.141
Level 2	0.041	0.041

Redesign Wind Drifts (E-W)		
	Story Drift (in)	Total Drift (in)
Main Roof	0.272	0.816
Level 5	0.222	0.544
Level 4	0.169	0.322
Level 3	0.106	0.153
Level 2	0.047	0.047

Existing Wind Drifts (E-W)		
	Story Drift (in)	Total Drift (in)
Main Roof	0.555	1.764
Level 5	0.488	1.209
Level 4	0.38	0.721
Level 3	0.241	0.341
Level 2	0.1	0.1

Redesign Wind Drifts (N-S)		
	Story Drift (in)	Total Drift (in)
Main Roof	0.194	0.592
Level 5	0.16	0.398
Level 4	0.123	0.238
Level 3	0.079	0.115
Level 2	0.036	0.036

Existing Wind Drifts (N-S)		
	Story Drift (in)	Total Drift (in)
Main Roof	0.409	1.329
Level 5	0.363	0.92
Level 4	0.285	0.557
Level 3	0.188	0.272
Level 2	0.084	0.084

Corporate Headquarters

Introduction
Problem Statement and Solution
Structural Depth
    Gravity System
    Lateral System
Green Roof Breadth
Enclosures Breadth
Conclusion

Green Roof Breadth

Corporate Headquarters

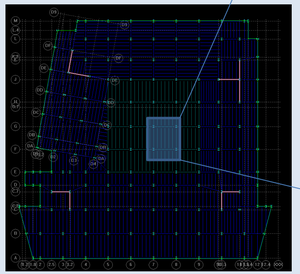
Introduction
Problem Statement and Solution
Structural Depth
Green Roof Breadth
    Loading and Framing
    Design and Materials
Enclosures Breadth
Conclusion

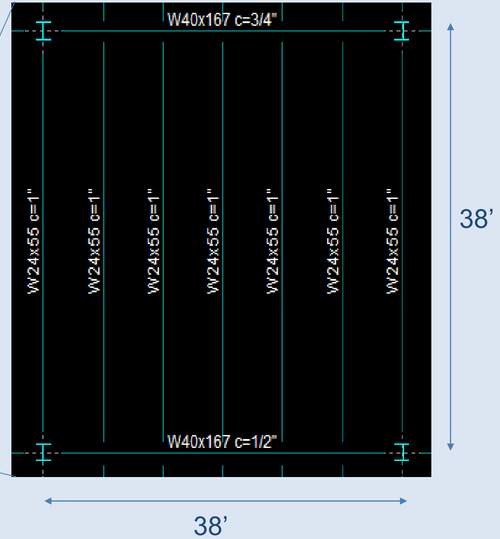
Green Roof Breadth- Loading and Framing

- Tree area removed in order to decrease dead load
- Steel beams and girders necessary to carry load
- Slightly smaller bays (38’x38’)

- Average beam size W24x55
- 6.67’ spacing
- 1” camber

- Average girder size W40x167
- ½” camber





Courtyard Green Roof Dead Loads (PSF)		
Material	Garden Area	Paver Area
Deck	3	3
Concrete Topping	31	31
Vegitation	20	
Engineered Fill (fully saturated)	55	55
Filter Fabric	1	1
Drainage Layer	2	2
Root Barrier	1	1
Waterproofing Membrane	1	1
Planter Allowance	10	10
Concrete Pavers		30
Total	**124**	**134**

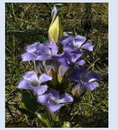
Corporate Headquarters

Introduction
Problem Statement and Solution
Structural Depth
Green Roof Breadth
    Loading and Framing
    Design and Materials
Enclosures Breadth
Conclusion

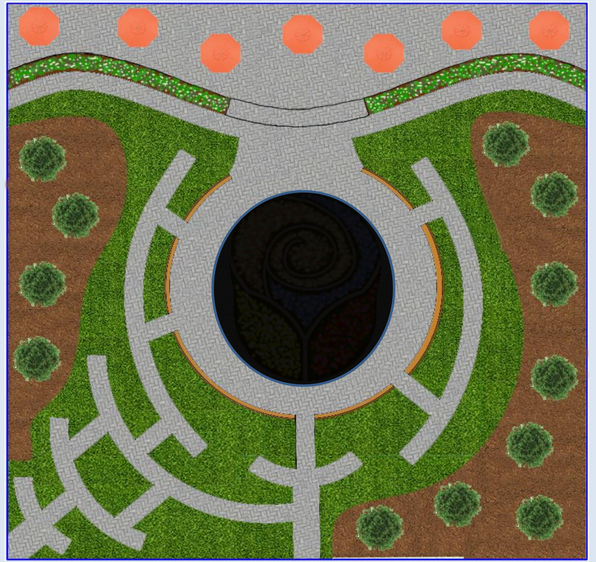
Green Roof Breadth- Design and Materials

- Design focused around new feature planter
- Takes a form symbolic to the building owner
- Features plants local to the building area
- Walkways shown are 5’ wide

- Holland pavers for patio area
  - Easy snow removal due to smooth surface
- Engineered fill
  - Filters rainwater and buffers acid rain



152’



152’

Design obscured for privacy reasons

Introduction
Problem Statement and Solution
Structural Depth
    Gravity System
    Lateral System
Green Roof Breadth
Enclosures Breadth
Conclusion

Enclosures Breadth

Corporate Headquarters

Introduction
Problem Statement and Solution
Structural Depth
Green Roof Breadth
Enclosures Breadth
    Membrane Comparison
    Water Testing and Drainage Plan
Conclusion

Enclosures Breadth

American Hydrotech MM6125

- Resists animal droppings (+)
- No material failure in 50 years (+)
- Performed well in fertilizer resistance test (+)
- Can only be installed through trained Hydrotech professionals (-)

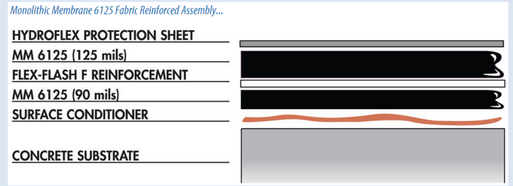
Barret Company ram-Tough 250

- Highest flash point (+)
- Highest softening point (+)
- Not tested for fertilizer resistance and animal droppings (-)

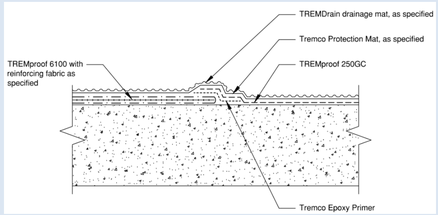
Tremco TREMproof 6100

- Manufactured near the project site (+)
- Second highest flash point (+)
- Performed well in a pinhole test (+)
- Requires special authorization to be applied over lightweight concrete topping (-)

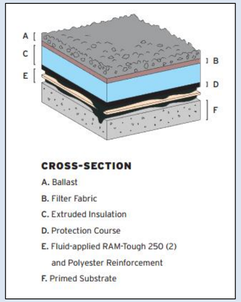
Membrane Comparison



MM6125



TREMproof 6100



ram-Tough 250

Corporate Headquarters

Introduction
Problem Statement and Solution
Structural Depth
Green Roof Breadth
Enclosures Breadth
Membrane Comparison
Water Testing and Drainage Plan
Conclusion

Enclosures Breadth

Leakage Test- ASTM D7281-07

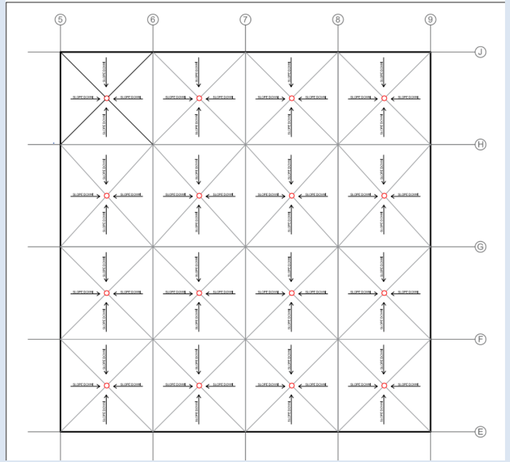
- Requires leakage test apparatus
- 7 day test procedure under 6” of water
- Utilizes pressurized air (6.9 kPa)

Flood Test- ASTM D5957-98

- Courtyard test
- Performed after membrane installation
- Requires drains to be plugged
- 24-72 hour test
- 1-4” water

New Drainage Plan

- one drain per bay
- 16 drains total
- 1520 sq ft of membrane area per drain
- Tie drains into existing system



Water Testing and Drainage Plan

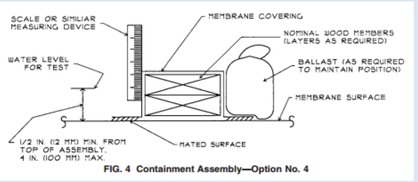


FIG. 4 Containment Assembly—Option No. 4

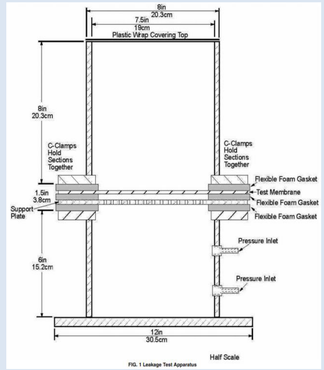


FIG. 1 Leakage Test Apparatus

Corporate Headquarters

Introduction
Problem Statement and Solution
Structural Depth
Green Roof Breadth
Enclosures Breadth
Conclusion

Conclusion

- More office space was created on the upper three floors of the building
  - Approximately 2,000 sq ft per floor, 6,000 sq ft total
- new gravity and lateral system were created
- Total drift and story drift decreased
- Courtyard green roof redesigned
- New watertight assembly chosen

Corporate Headquarters

Introduction
Problem Statement and Solution
Structural Depth
Green Roof Breadth
Enclosures Breadth
Conclusion

Acknowledgements

RTKL Corporation

WJE Cleveland

AE Faculty
Heather Sustersic

AE 2015

Family and Friends

Image Courtesy: RTKL

Corporate Headquarters

Introduction
Problem Statement and Solution
Structural Depth
Green Roof Breadth
Enclosures Breadth
Conclusion

Questions

Image Courtesy: RTKL and The Village Newspaper

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Structural Option

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