Tyler Meek – Structural Option

AE Senior Thesis 2011

33 Harry Agganis Way, Boston Ma.

Presentation Outline

Introduction
Existing Structure
Thesis Goals
Structural Depth
(MAE Course Related Study)
Architectural Breadth
Construction Management Breadth
Conclusion
Questions & Comments

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- Introduction

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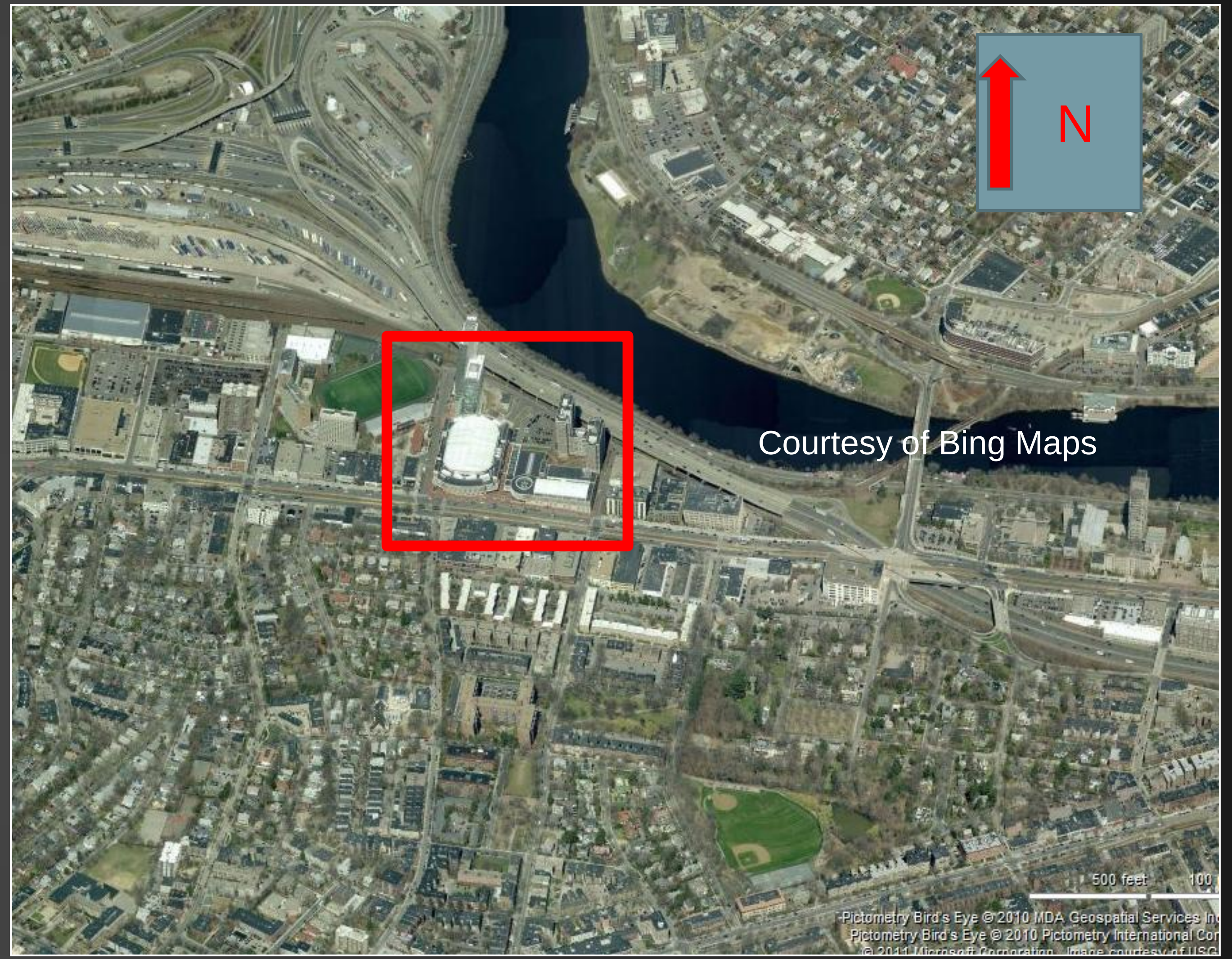
Introduction

33 Harry Agganis Way
"Res Tower II"
Dormitory on BU Campus, JH Student Village
Between Charles River & Commonwealth Ave



Building Statistics

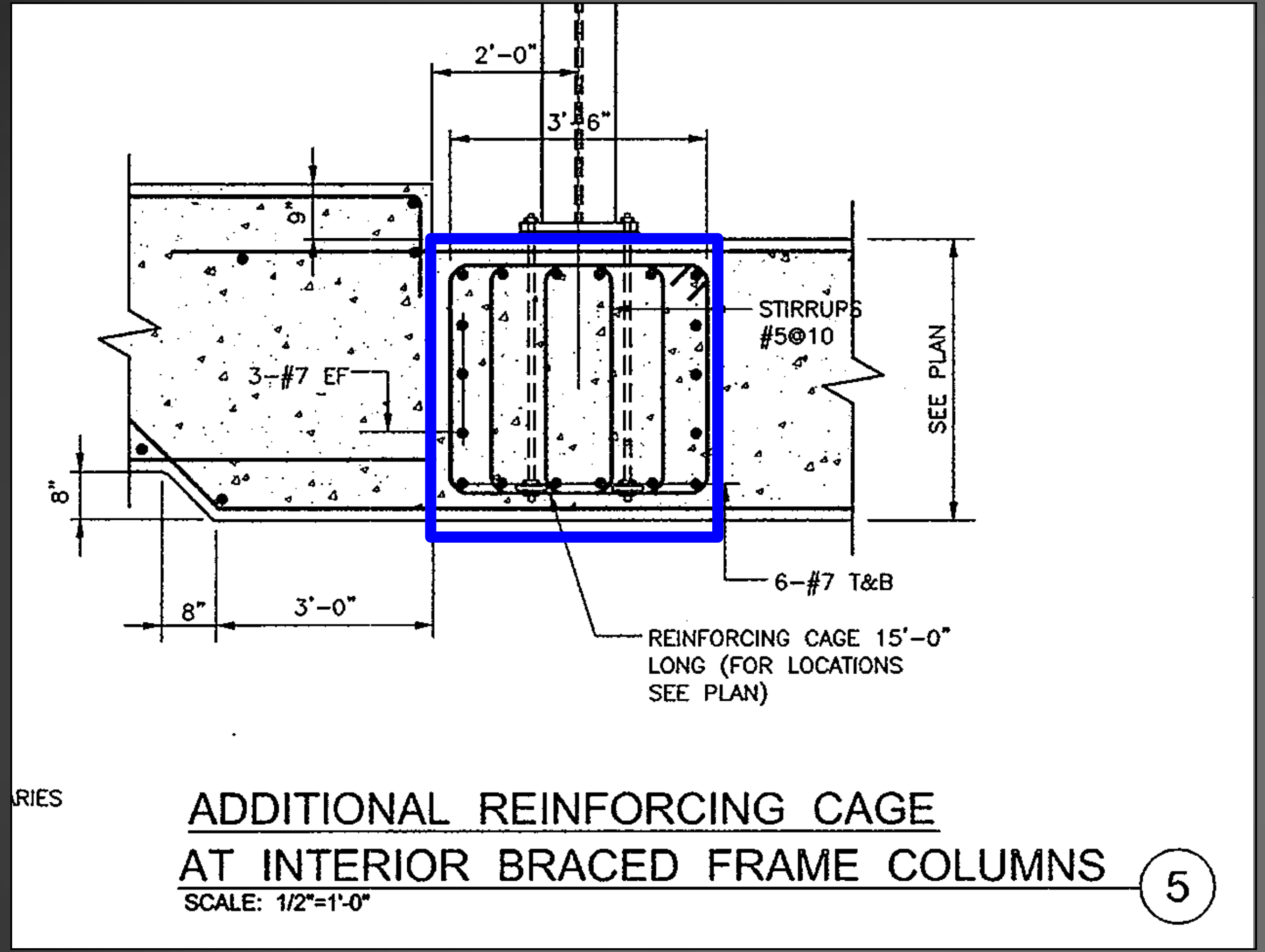
26 Story Dormitory
396,000 sq. ft.
296 ft tall (208 ft shorter section)
Floor plan steps back at floor 19
Main lobby on first floor
Meeting area/observatory on 26th floor

Meeting area/observatory on 26th floor

Project Team

Owner:	Boston University
CM:	Walsh Brothers
Arch/MEP:	Cannon Design
Structural:	Weidlinger Associates

BOSTON UNIVERSITY
CANNONDESIGN
WALSH BROTHERS CONSTRUCTION
WEIDLINGER ASSOCIATES INC



Existing Foundation

Mat foundation with two thicknesses

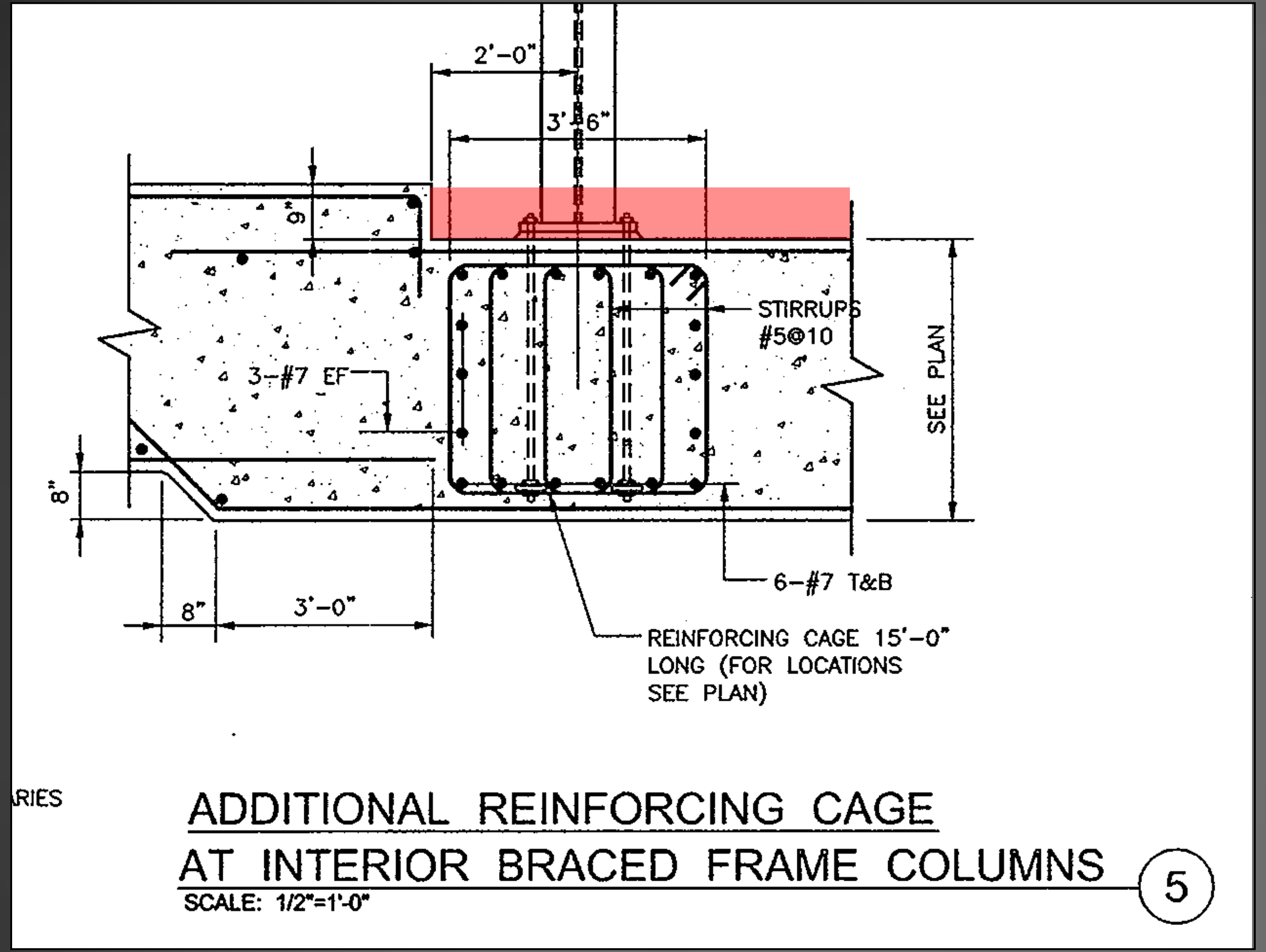
4’-3” supporting taller section

3’-9” supporting shorter section

Typical reinforcement: E-W, #10 @ 10” O.C

N-S, #9 @ 10” O.C

Braced frames anchored to foundation with additional reinforcing cages to increase resistance to uplift.



Existing Foundation

Mat foundation with two thicknesses

4'-3" supporting taller section

3'-9" supporting shorter section

Typical reinforcement: E-W, #10 @ 10" O.C

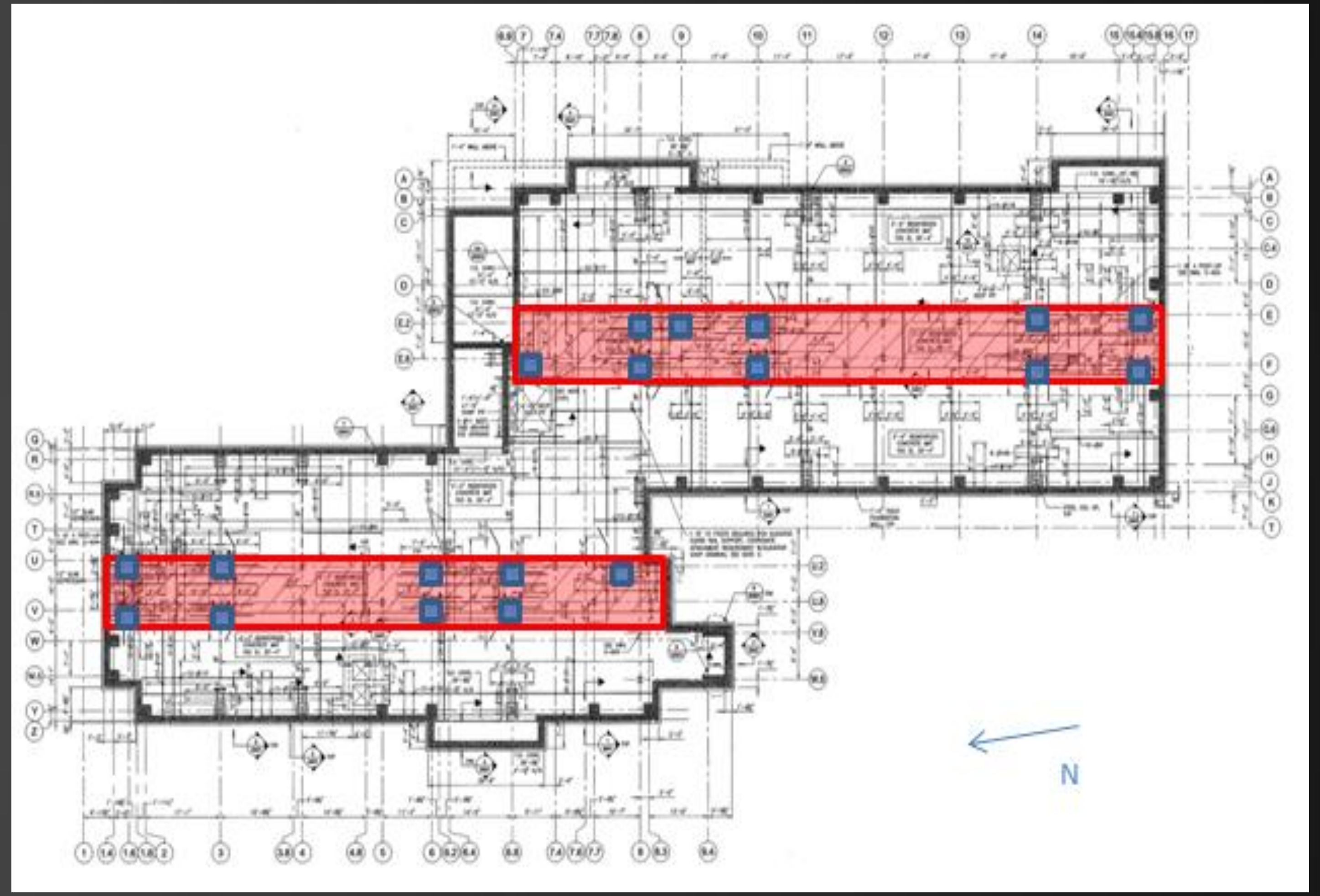
N-S, #9 @ 10" O.C

Braced frames anchored to foundation with additional reinforcing cages to increase resistance to uplift.

9" trench along center of each tower

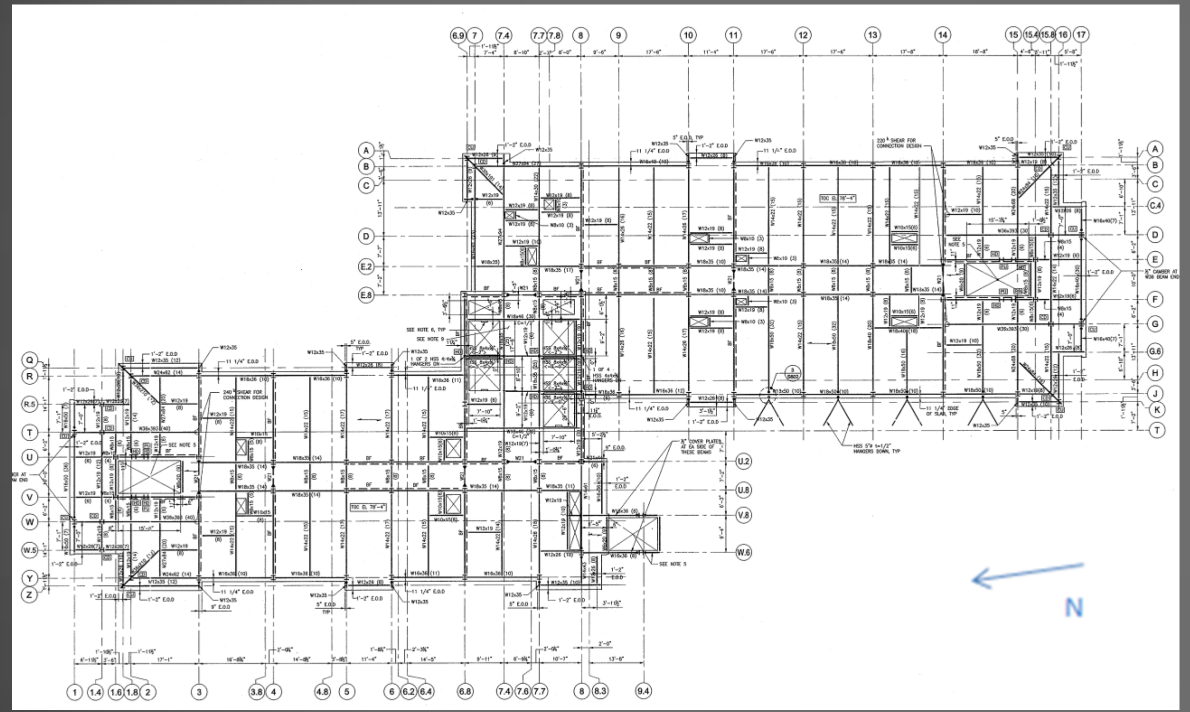
Filled with 4000 psi and reinforced with welded wire fabric after erection of interior columns

Attempt to increase strength column-to-foundation connection

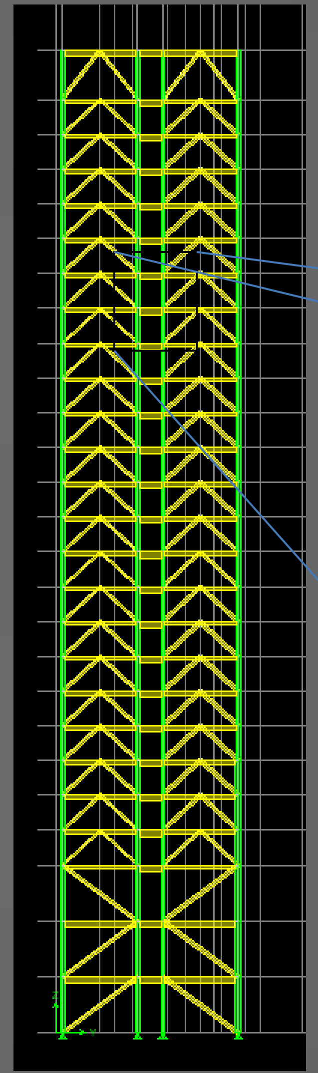


Existing Floor Construction

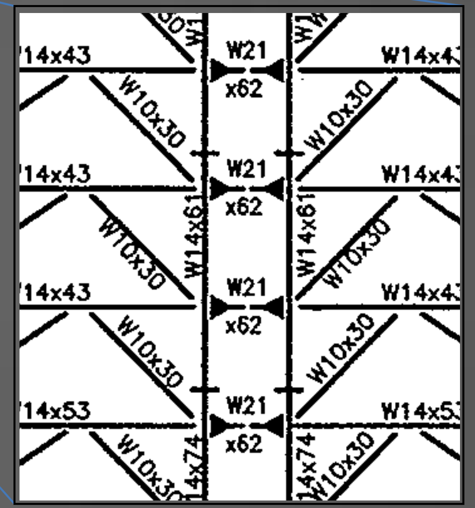
3” 18 gage galvanized steel deck
3 ¼” lightweight concrete topping
6x6 welded wire fabric reinforcement



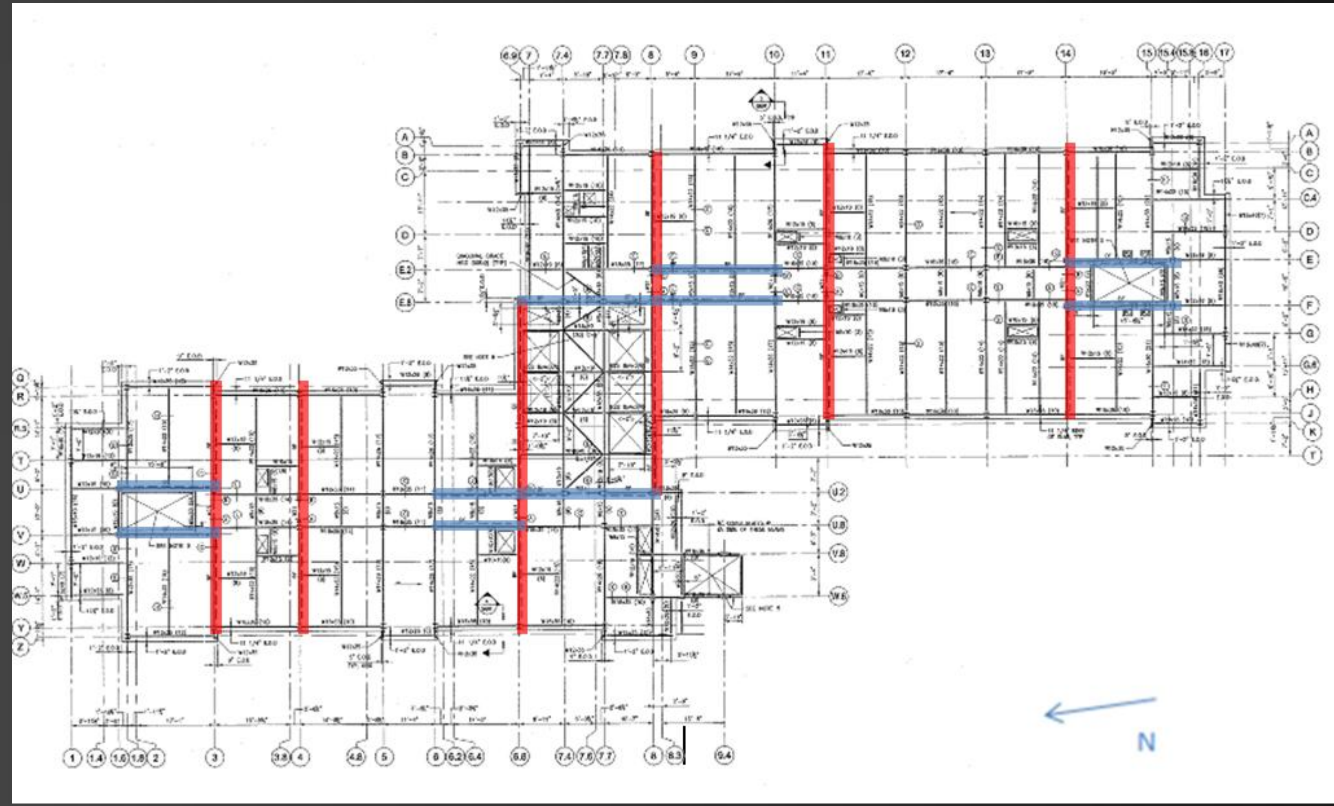
Existing Lateral System



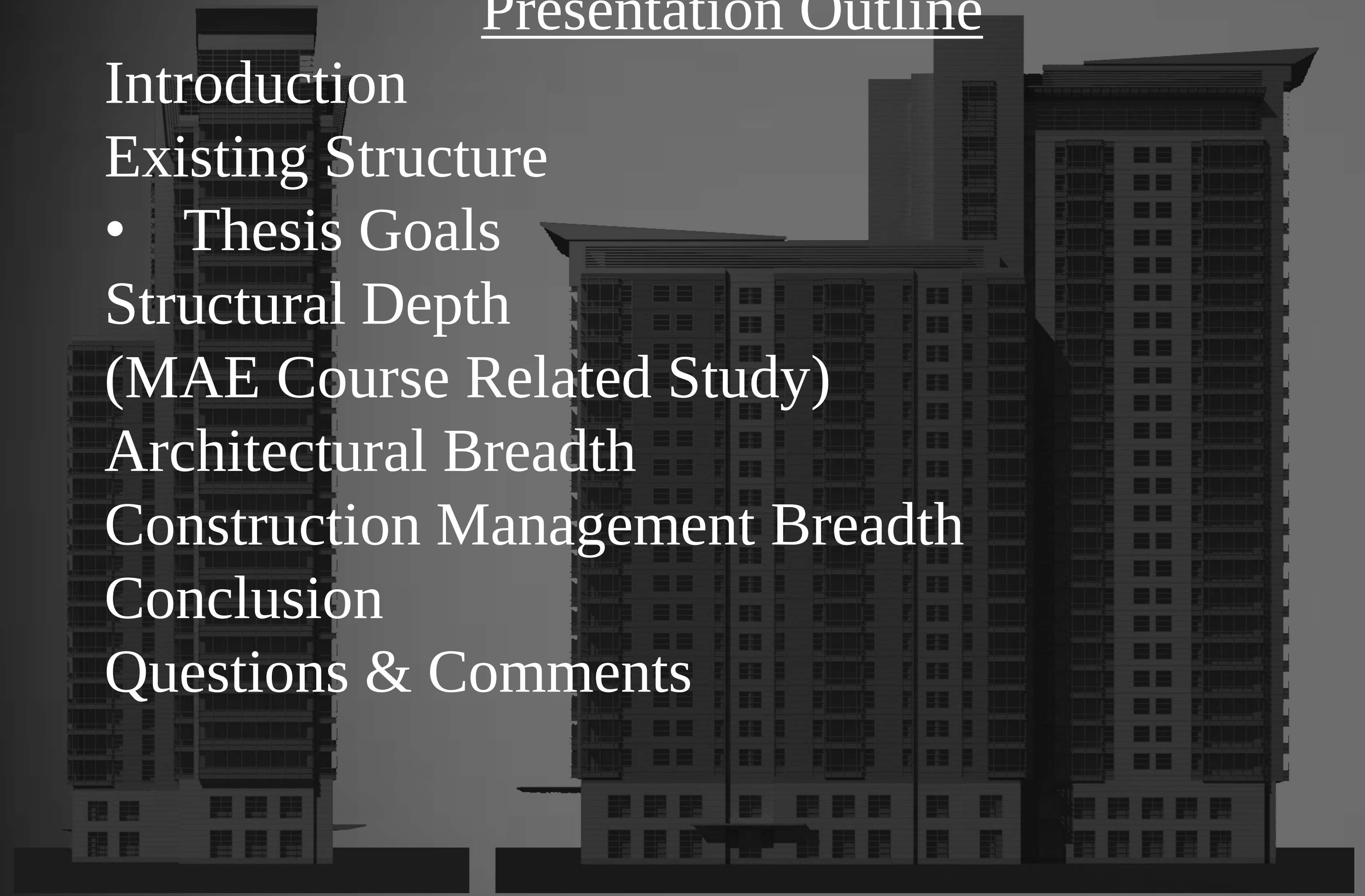
Moment connected concentrically braced frames



Moment connections to increase stiffness while avoiding interruption of main corridor



Red and blue lines represent braced frames running in perpendicular directions



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- Structural Depth
- (MAE Course Related Study)
- Architectural Breadth
- Construction Management Breadth
- Conclusion
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Thesis Goals

Structural Depth

Investigate the most effective use of a Staggered Truss System:

1. Design for gravity loads
2. Gravity and 100% lateral loads
3. Gravity and partial lateral loads
   i. Design new lateral system

Construction Management Study

Create site logistics plan for steel erection phase of project
Estimate a schedule using new design scheme

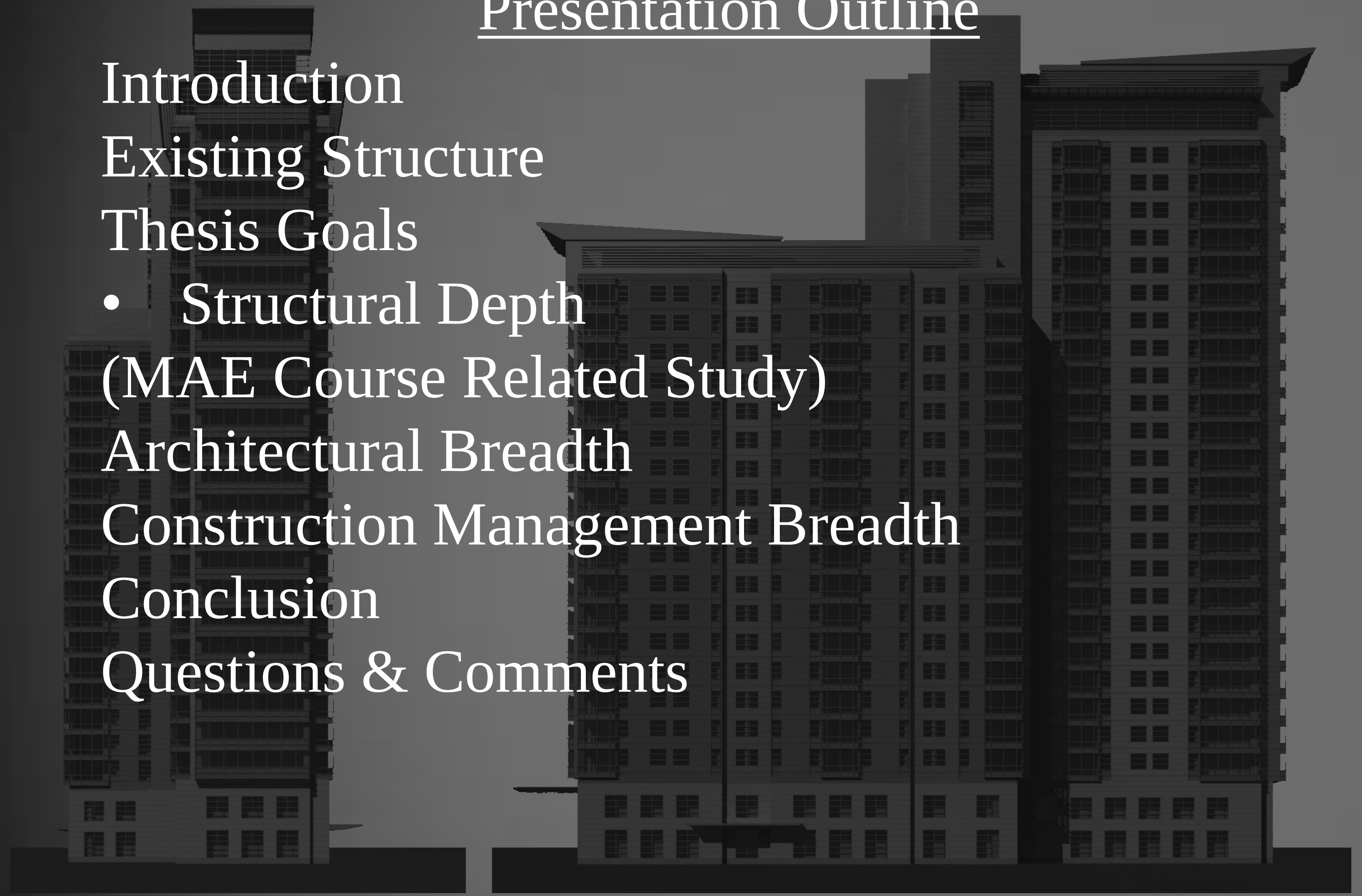
Architectural Study

Document impact of trusses on interior architectural dynamic using rendered images

MAE Course Related Study

Design two typical connections in truss

1. Truss to column design (bolted)
2. Web members to chord members (welded)



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Structural Depth

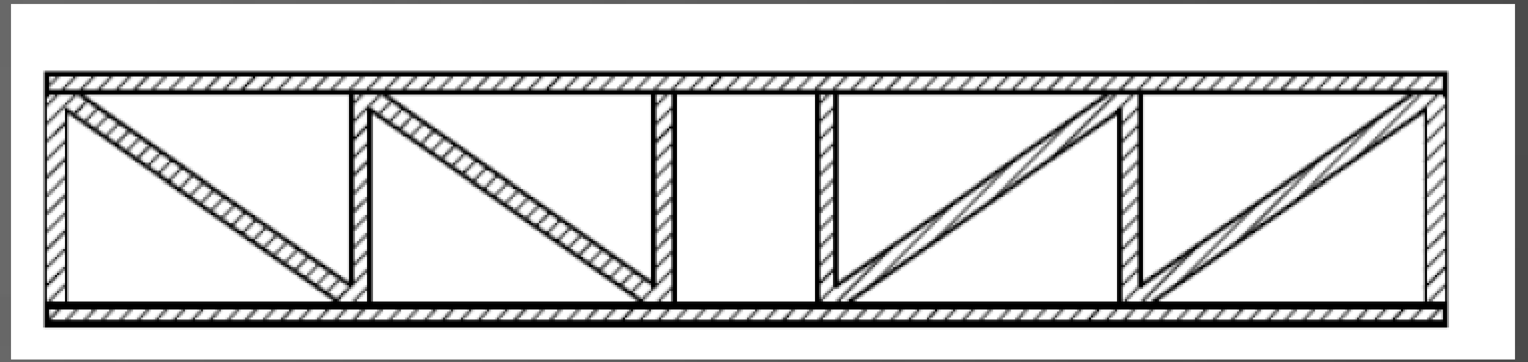
AISC Design Guide 14: *Staggered Truss Framing Systems* provided excellent guidance

Background

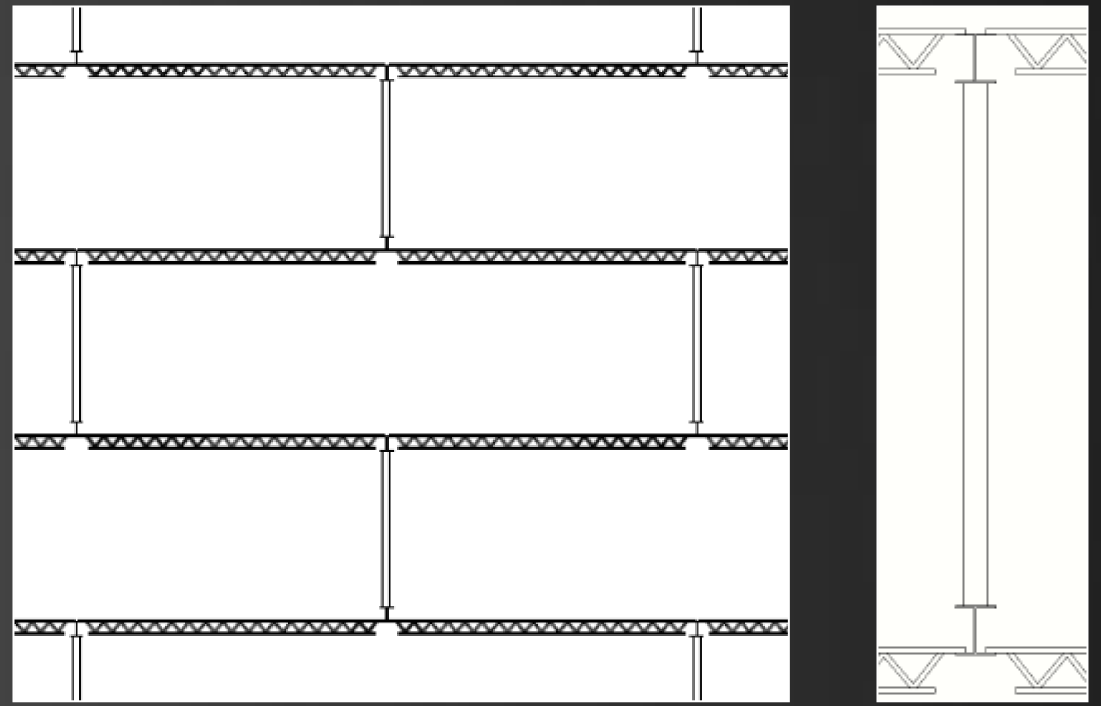
Story deep Vierendeel truss to replace need for interior columns

W10 chord members
HSS web members
Gusset plate connections

10 ft floor-to-floor = 9’-6” truss with 6” slab



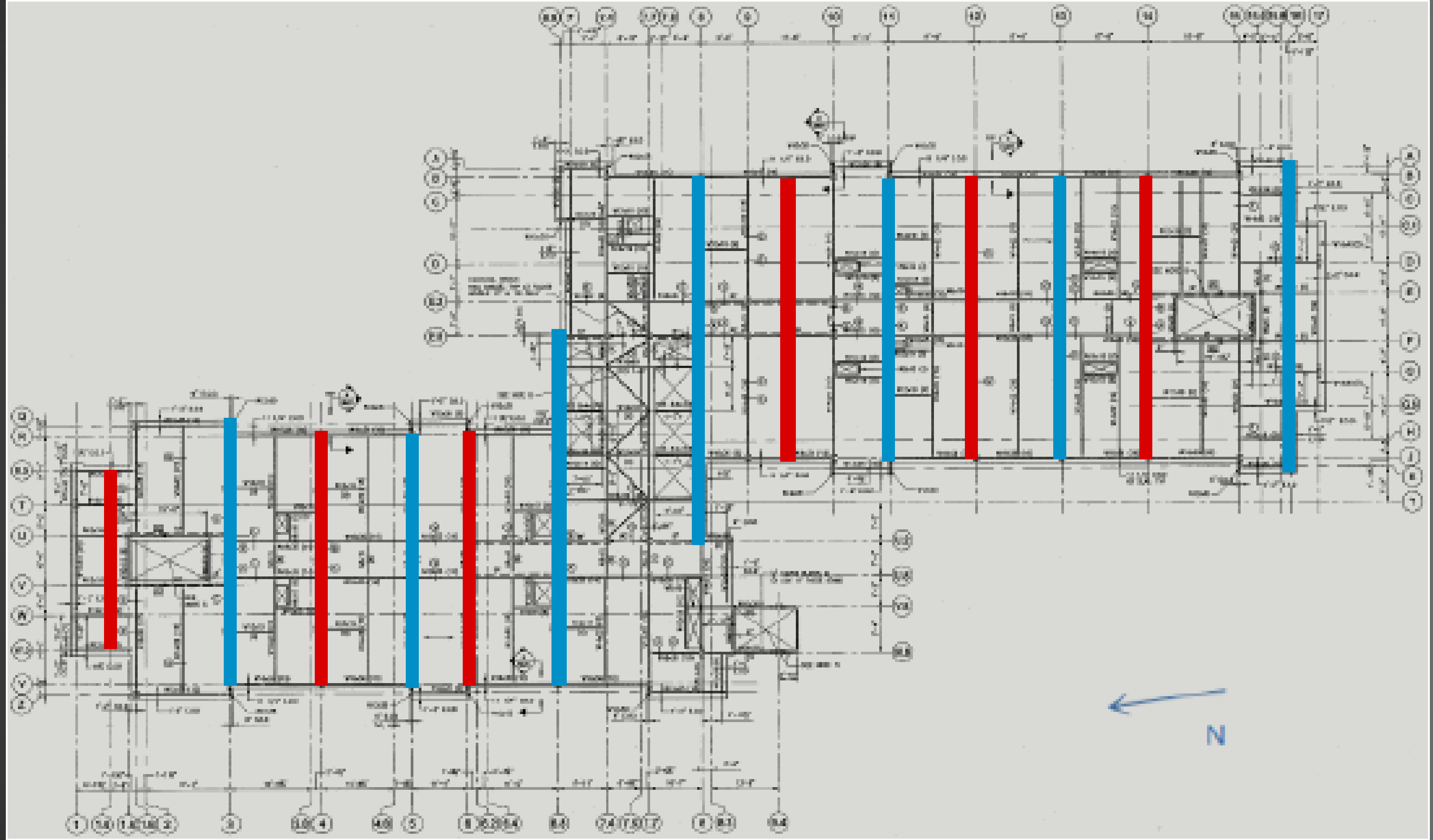
Typical Elevation of Truss



Details of Truss system

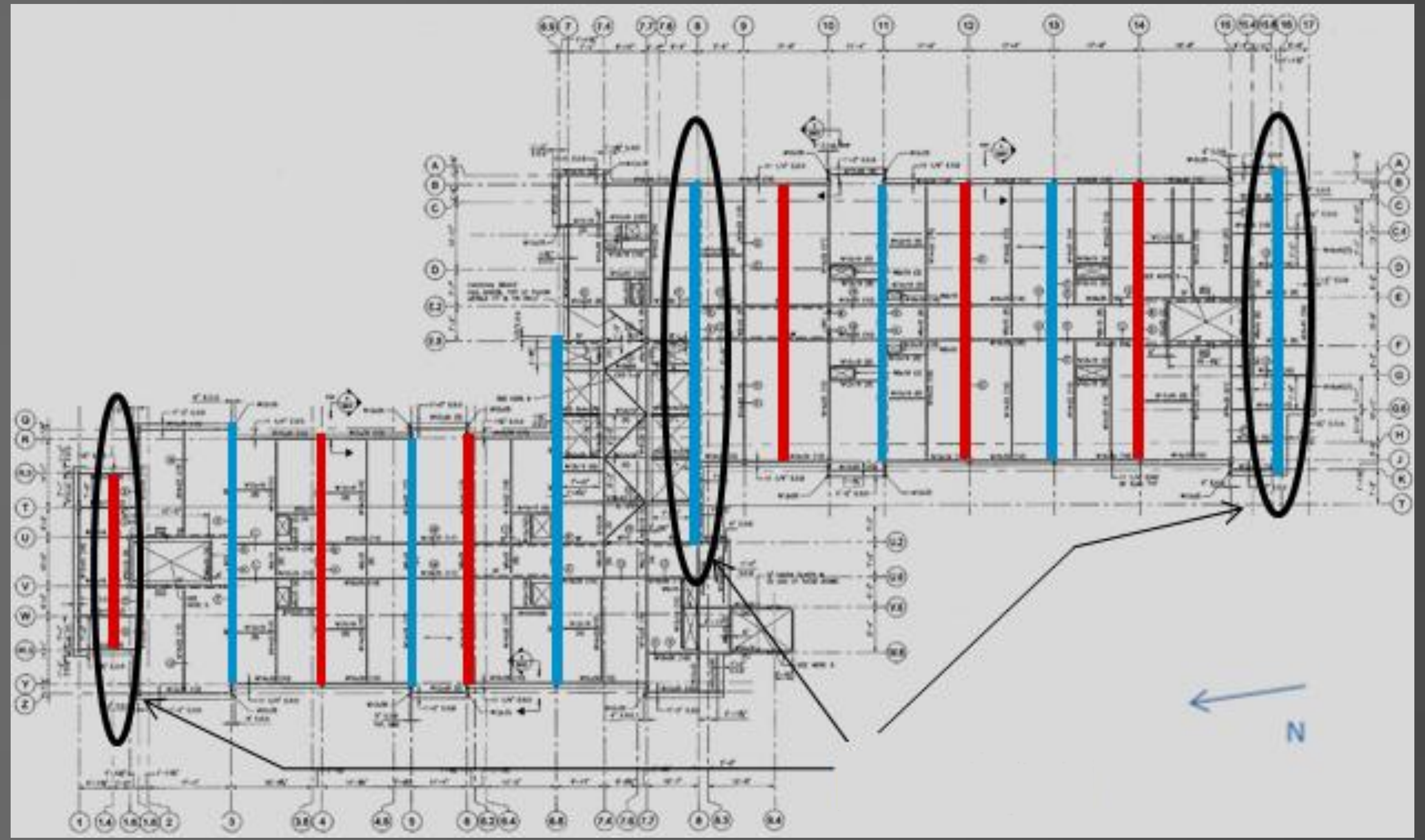
Truss Locations

Original



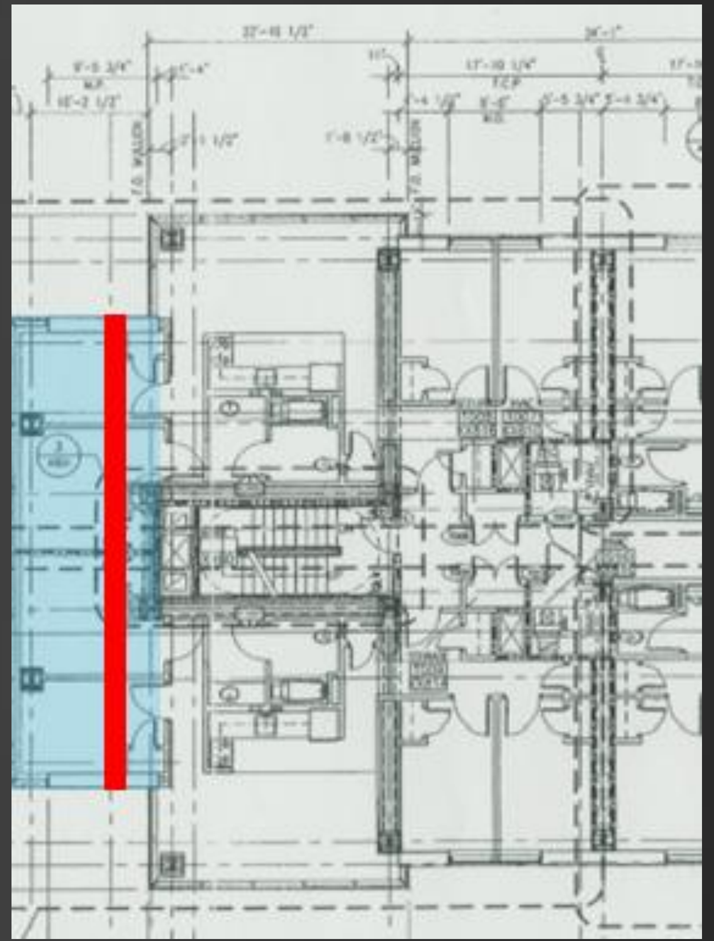
Original Truss Locations

Location Issues



Trusses that require coordination

Architectural Plans



Architectural Issue

Gravity System Design

Design Loads

Live Loads		
	Design Load (psf)	Thesis Load (psf)
Occupancy Type	Mass. State Building Code	IBC 2009 & ASCE7-10
Public Area	100	100
Corridor	80	100
Dwelling Unit	40	40
Loading Dock	250	250
Mechanical Penthouse	150	125
Roof	30	20

Table 1: Live Loads for Res Tower II

Dead Loads	
Material	Load (psf)
Slab	
-Roof Deck	56
-Floor Deck	46
Façade	18
Superimposed	30

Table 2: Dead loads for Res Tower II

$\delta < \ell/240 = 2.96$”

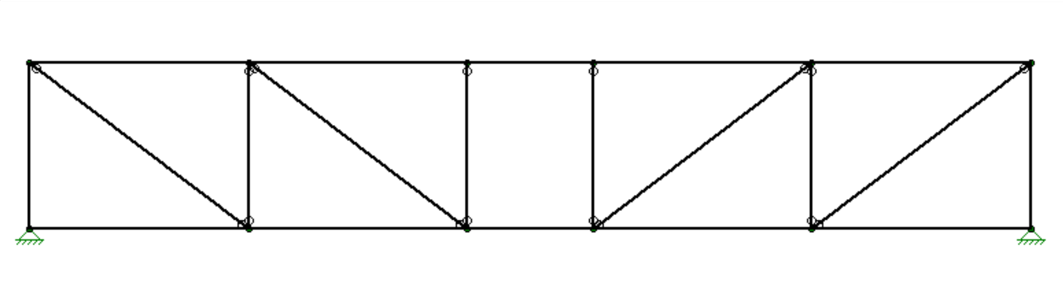
Member Sizes

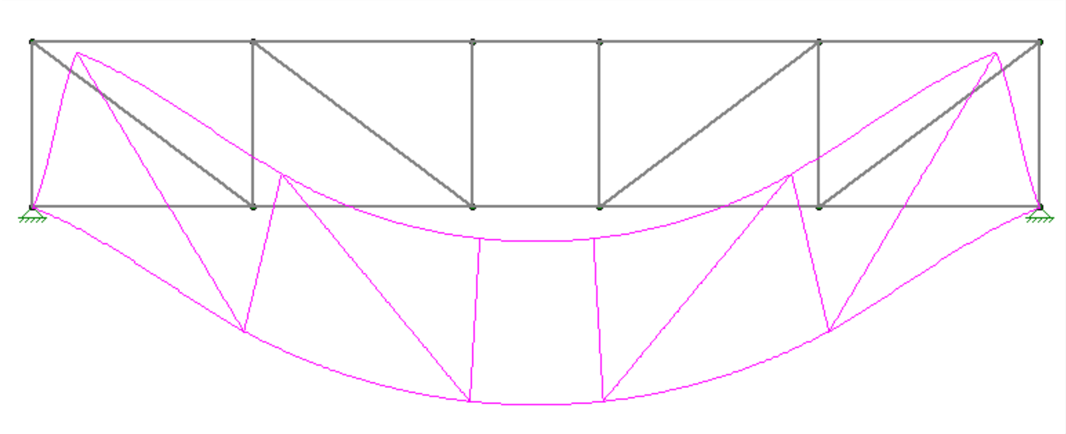
Chord Members – W10 x 33
Web Members – HSS 10 x 5 x 5/16

Secondary Elements

14K4 joists span between trusses
3” 18 gage decking with 3 ¼” LW topping

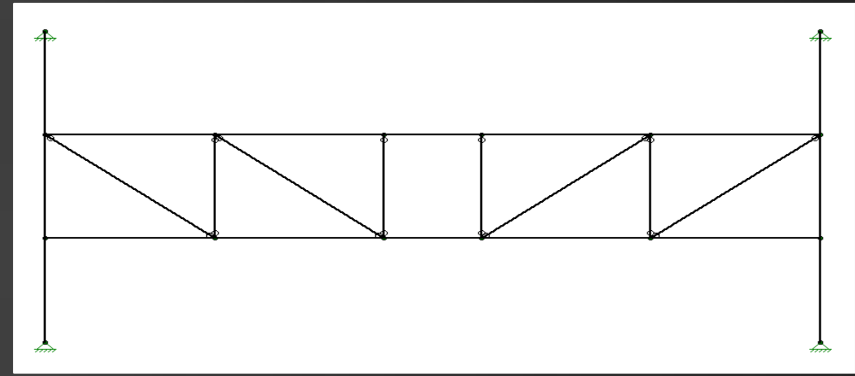
Original RISA Model

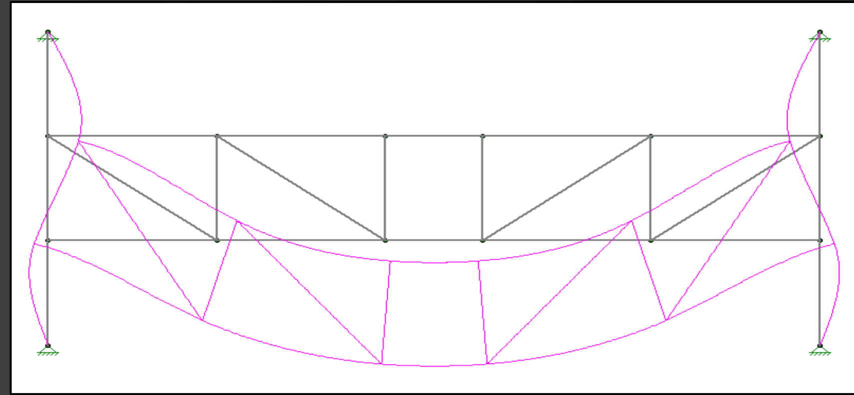




$\delta = 2.41$”

Adjusted RISA Model





$\delta = 1.28$”

MAE Course Related Study

Design Loads

Live Loads		
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Occupancy Type	Mass. State Building Code	IBC 2009 & ASCE7-10
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Dead Loads	
Material	Load (psf)
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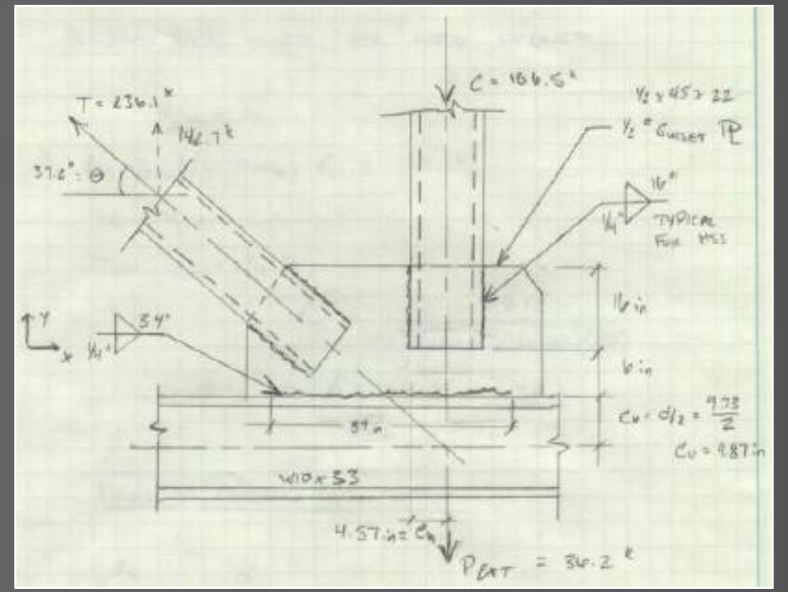
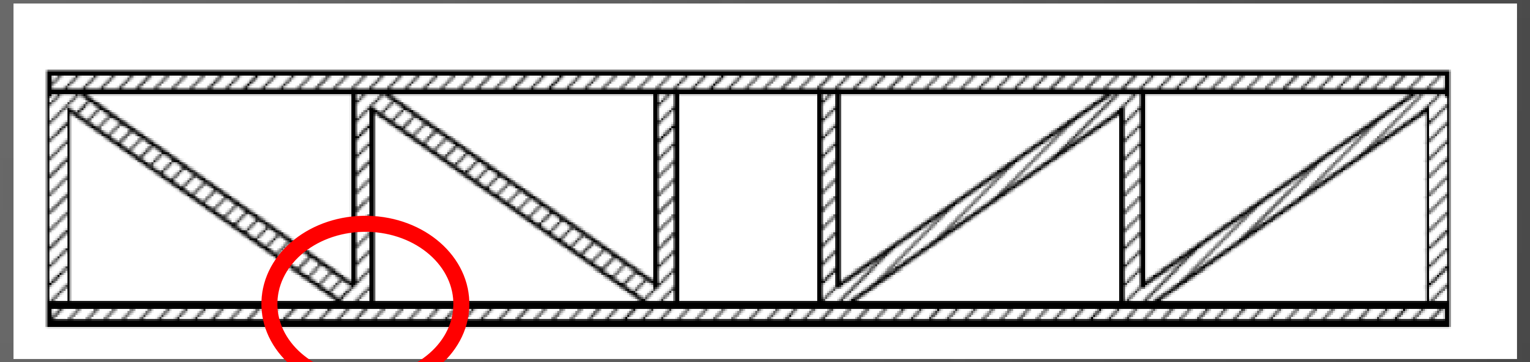
Façade	18
Superimposed	30

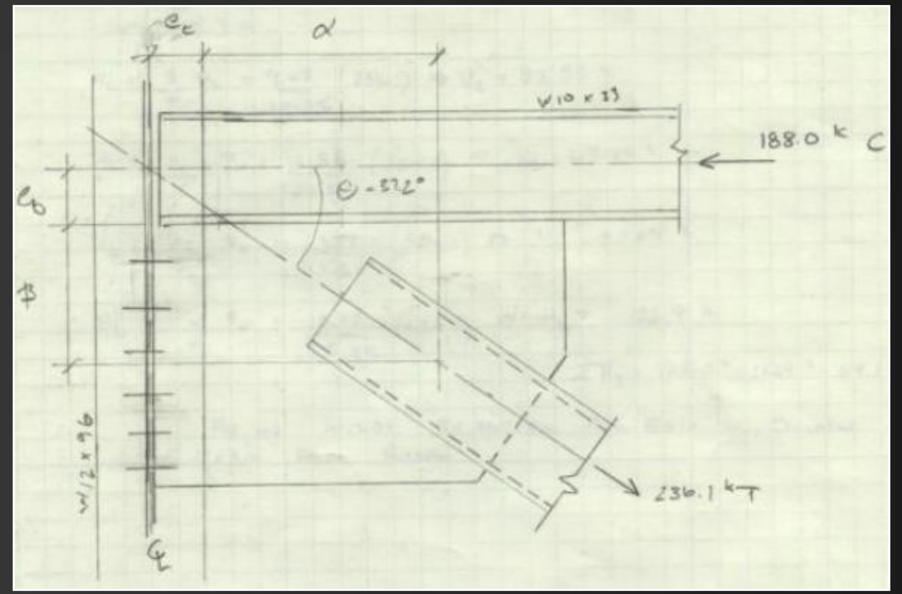
Table 2: Dead loads for Res Tower II

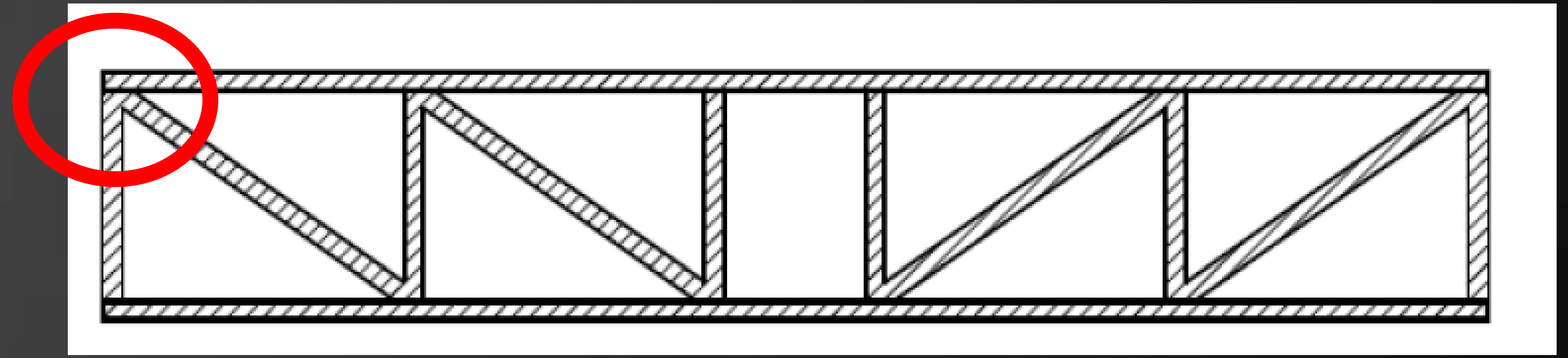
Web Members to Bottom Chord Member





Truss to Column Web





Gravity & Lateral System Investigation

Design Loads

Live Loads		
	Design Load (psf)	Thesis Load (psf)
Occupancy Type	Mass. State Building Code	IBC 2009 & ASCE7-10
Public Area	100	100
Corridor	80	100
Dwelling Unit	40	40
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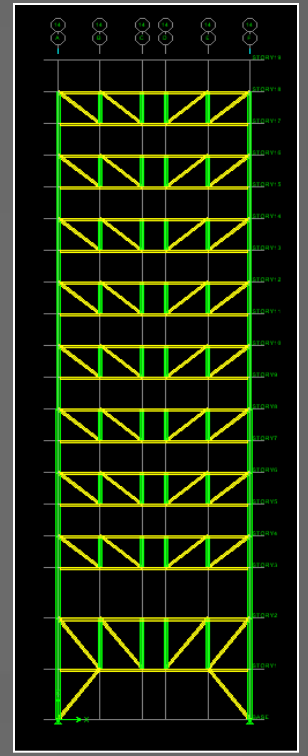
Table 1: Live Loads for Res Tower II

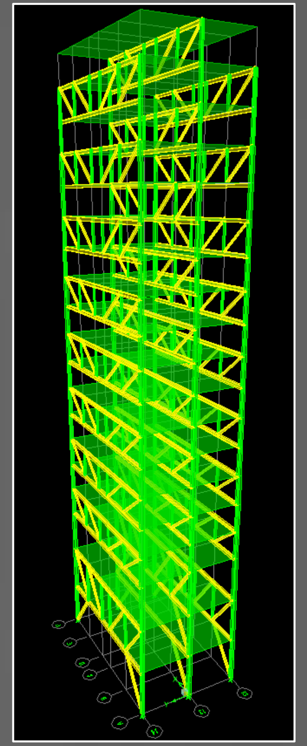
Dead Loads	
Material	Load (psf)
Slab	
-Roof Deck	56
-Floor Deck	46
Façade	18
Superimposed	30

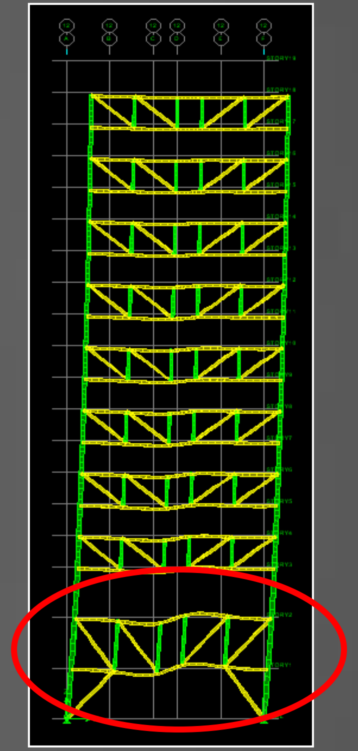
Table 2: Dead loads for Res Tower II

East West	
Floor	Force (k)
1	53.26
2	106.87
3	90.06
4	74.18
5	76.54
6	78.50
7	80.27
8	82.01
9	83.48
10	84.57
11	85.59
12	86.70
13	87.82
14	88.88
15	89.73
16	90.42
17	91.22
18	92.09
19	92.84
20	70.88
21	49.29
22	56.08
23	62.33
24	62.67
25	75.63
26	95.06

Preliminary Models





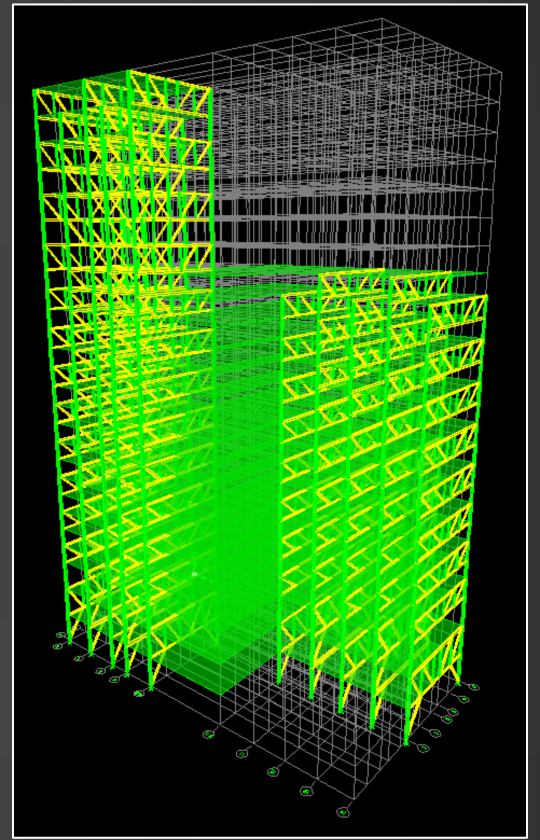


Single bay modeled to find weak points

Multiple bays investigated for interaction and stresses

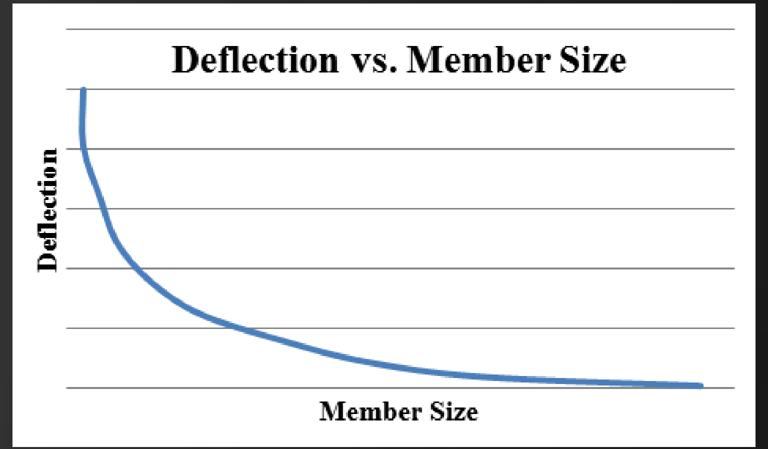
As can be seen from image, the chord members stressed beyond capacity

Full Building Model and Results



For Res Tower II, the staggered truss system is not an efficient system to resist lateral loads

Exponential relationship between stiffness and deflections



New Lateral Loads

North South (X-Direction, Etabs)	
Floor	Force (k)
1	24.22
2	48.61
3	40.96
4	33.74
5	34.81
6	35.70
7	36.51
8	37.30
9	37.97
10	38.47
11	38.93
12	39.44
13	39.94
14	40.43
15	40.81
16	41.13
17	41.49
18	41.89
19	42.23
20	42.53
21	45.91
22	43.72
23	38.41
24	38.61
25	46.58
26	58.54
27	58.90
ROOF	27.76
BASE	1135.55

East West (Y-Direction, Etabs)	
Floor	Force (k)
1	53.26
2	106.87
3	90.06
4	74.18
5	76.54
6	78.50
7	80.27
8	82.01
9	83.48
10	84.57
11	85.59
12	86.70
13	87.82
14	88.88
15	89.73
16	90.42
17	91.22
18	92.09
19	92.84
20	70.88
21	49.29
22	56.08
23	62.33
24	62.67
25	75.63
26	95.06
27	95.65
ROOF	45.09
BASE	2227.72

H/400 = 8.76” at 26th floor
= 5.94” at 19th floor

Designed using Load Case
D + 0.5L + 0.7W

(ASCE7-05 CC1.2)
-Appendix Slide

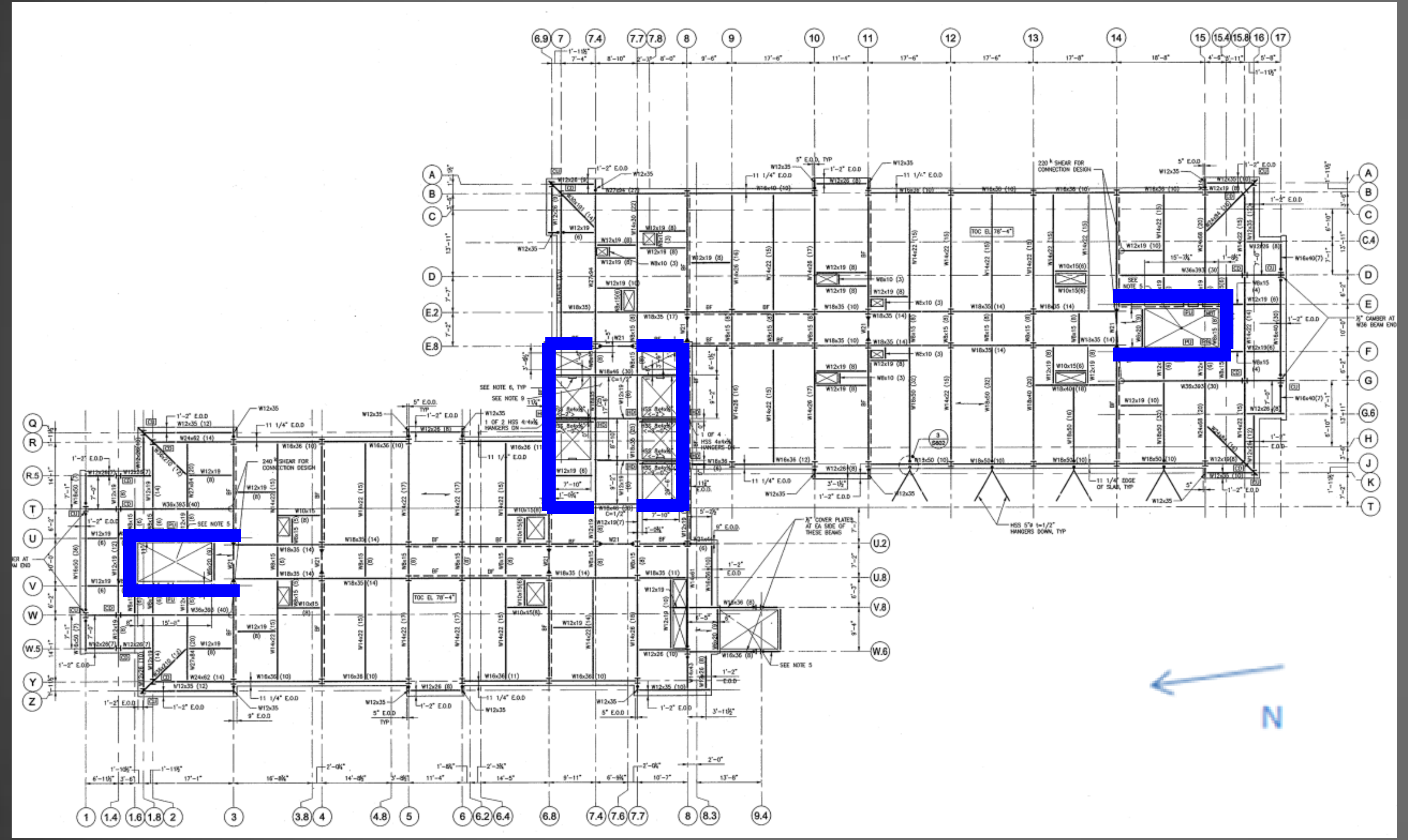
Seismic Design Criteria			
S_{DS} =	0.40615	$T_{model\text{-}x}$ =	2.1424 s
S_{D1} =	0.2263	$T_{model\text{-}y}$ =	1.7839 s
R =	3.25	C_u =	1.474
I =	1.25	T_a =	0.701
T =	1.033 s	C_s =	0.1367

Story Drift Limit (ASCE Table 12.2-1)
Δ_a = 1.80” for 10 ft Floor-to-Floor
2.88” for 16 ft Floot-to-Floor

Seismic	
Floor	Force (k)
1	3
2	6
3	12
4	16
5	22
6	29
7	36
8	43
9	51
10	59
11	67
12	76
13	84
14	93
15	102
16	121
17	131
18	140
19	150
20	160
21	85
22	91
23	96
24	101
25	106
26	114
27	125
ROOF	133
BASE	2350

Most Efficient Lateral Design

Floor Plan



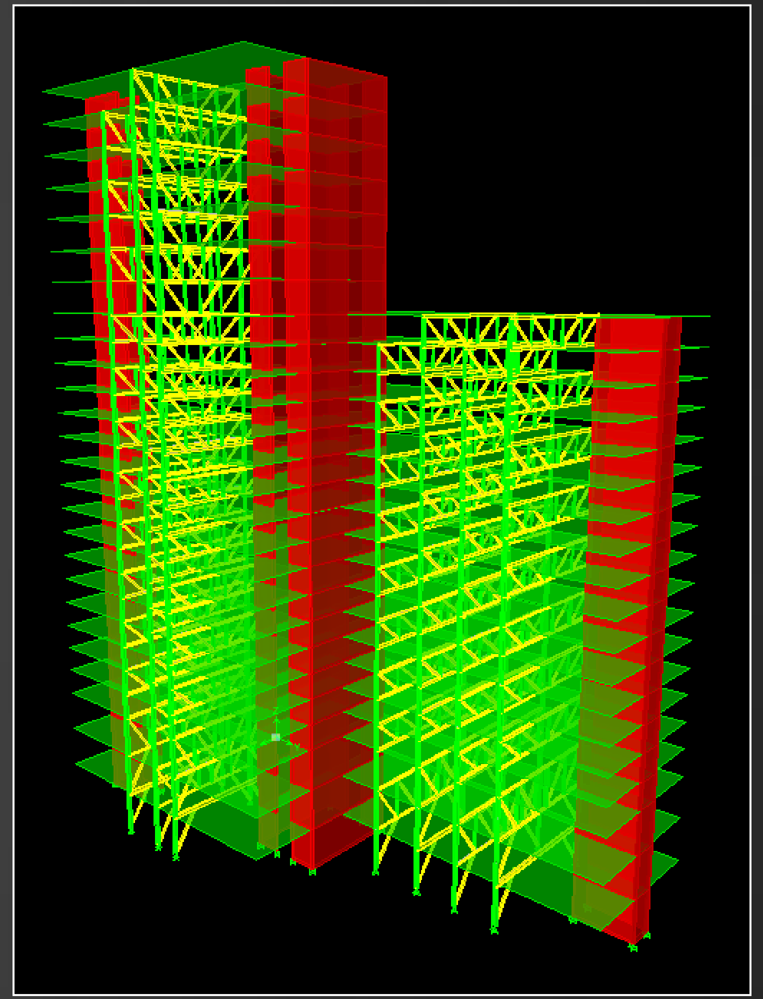
Shear Wall Locations Highlighted

Process

Three main iterations were completed to find the most efficient lateral system:

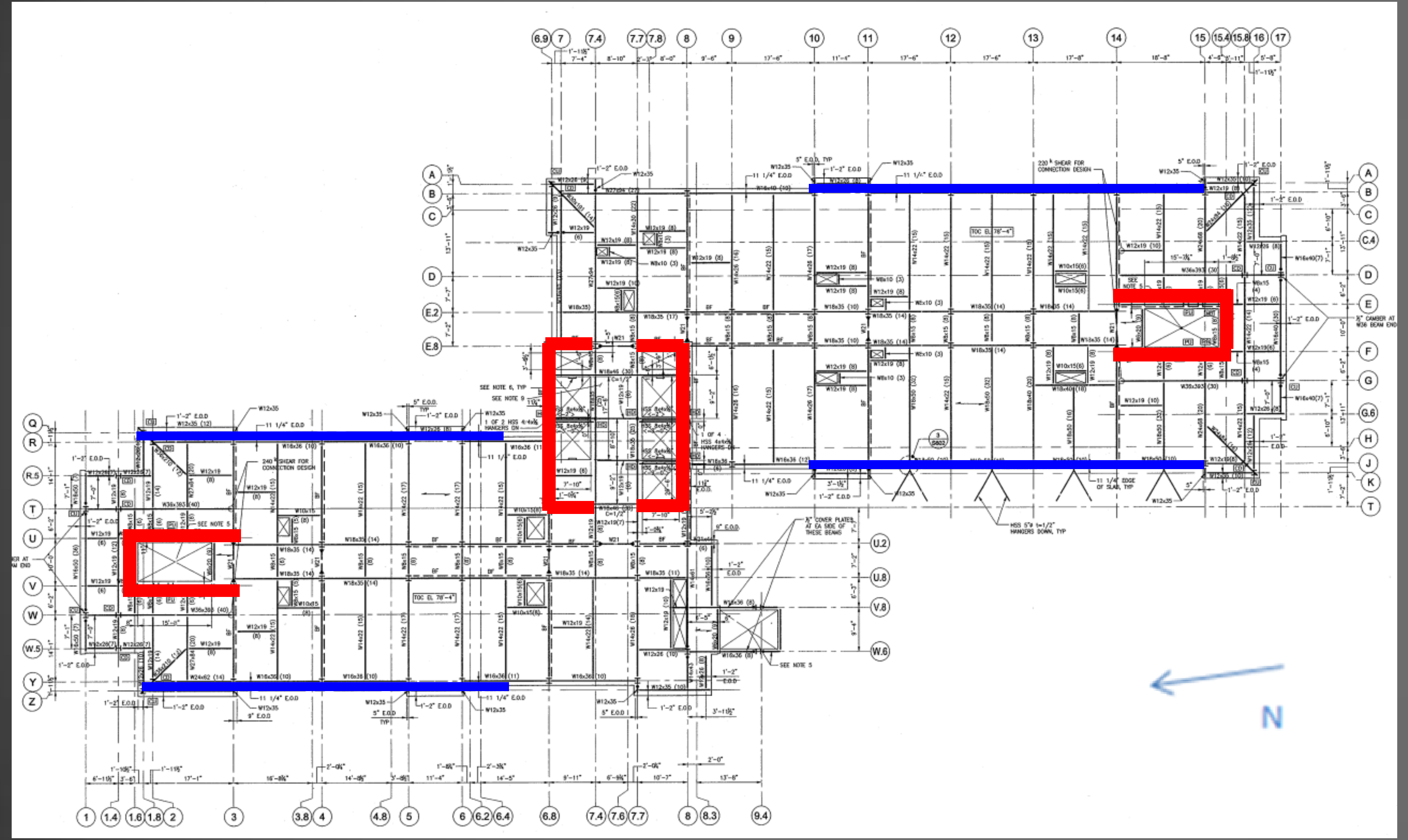
1. 24” shear walls were added around the vertical circulation spaces at the central core and north and south stairwells

Model



Most Efficient Design

Floor Plan



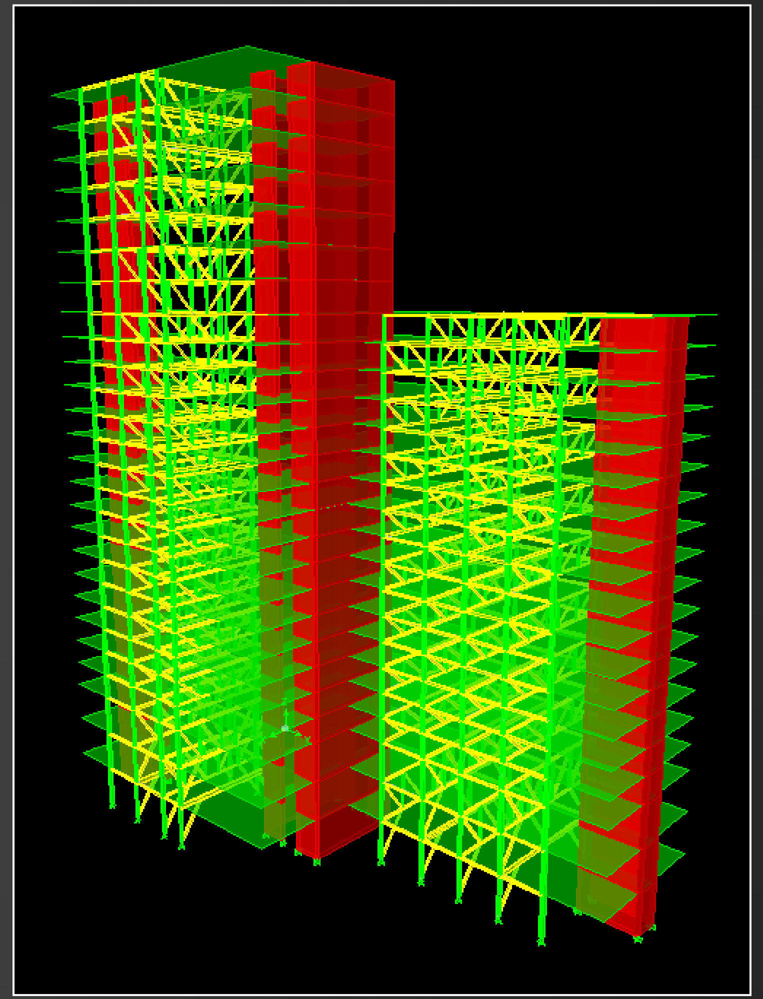
Shear Wall and Moment Frame Locations Highlighted

Process

Three main iterations were completed to find the most efficient lateral system:

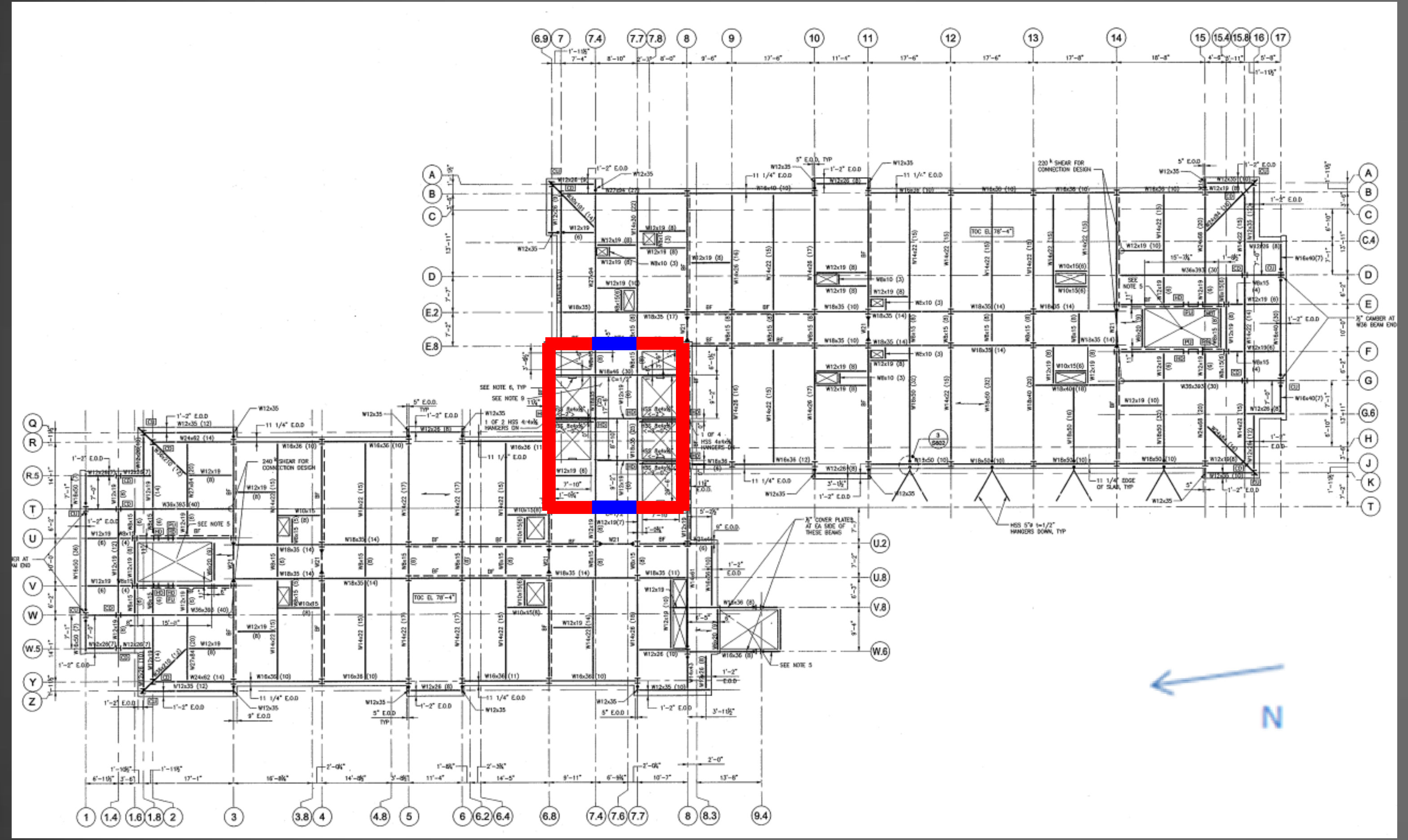
1. 24” shear walls were added around the vertical circulation spaces at the central core and north and south stairwells
2. Moment frames were added through the entire height of the building and shear walls decreased to 16”

Model



Most Efficient Design

Plan



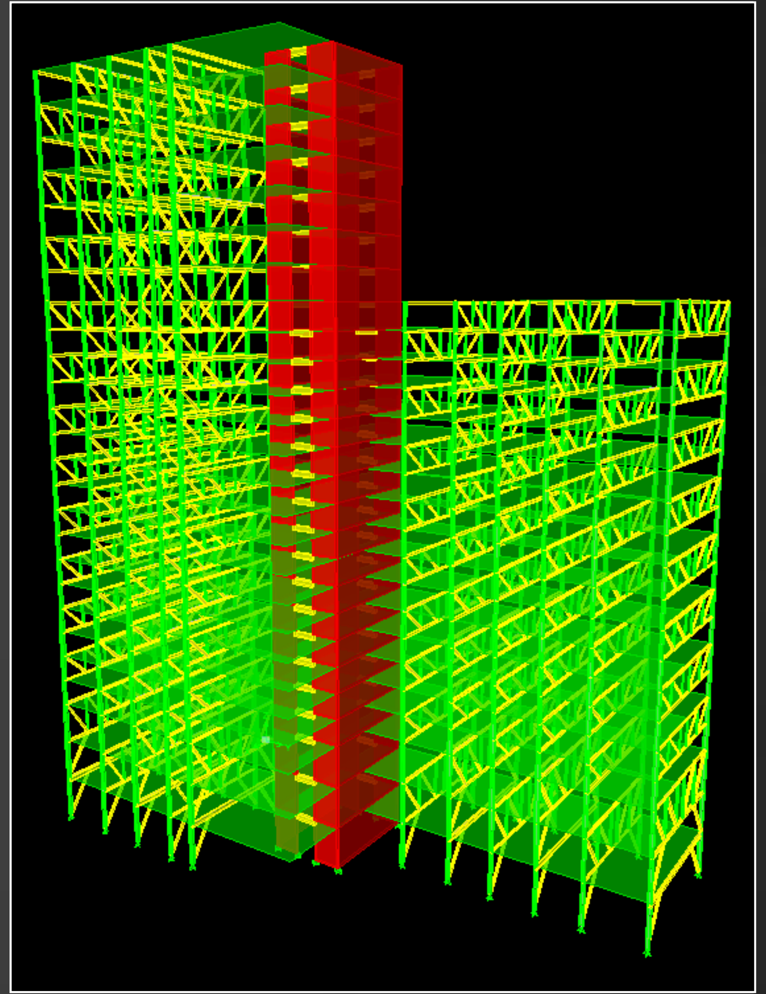
Coupling Beam Locations Highlighted

Process

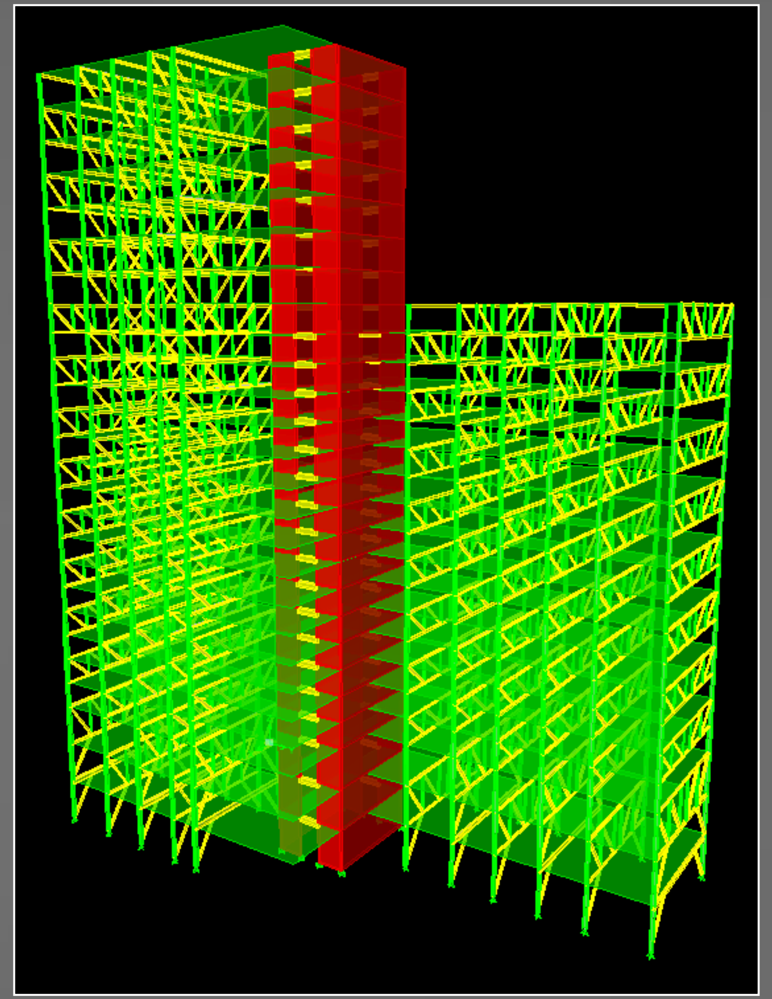
Three main iterations were completed to find the most efficient lateral system:

1. 24” shear walls were added around the vertical circulation spaces at the central core and north and south stairwells
2. Moment frames were added through the entire height of the building and shear walls decreased to 16”
3. Moment frames were removed from the system as well as the north and south shear wall

Model



Staggered Truss System Summary



Model A: 16” shear walls with coupling beams and staggered truss system

Gravity

W10x33 Continuous Top and Bottom Chord Members

HSS10x5x5/56 Diagonal and Vertical Web Members

Columns ranging in size from W12x279 to W12x79 with splices at every 4th floor

14K4 Joists span from Truss to Truss

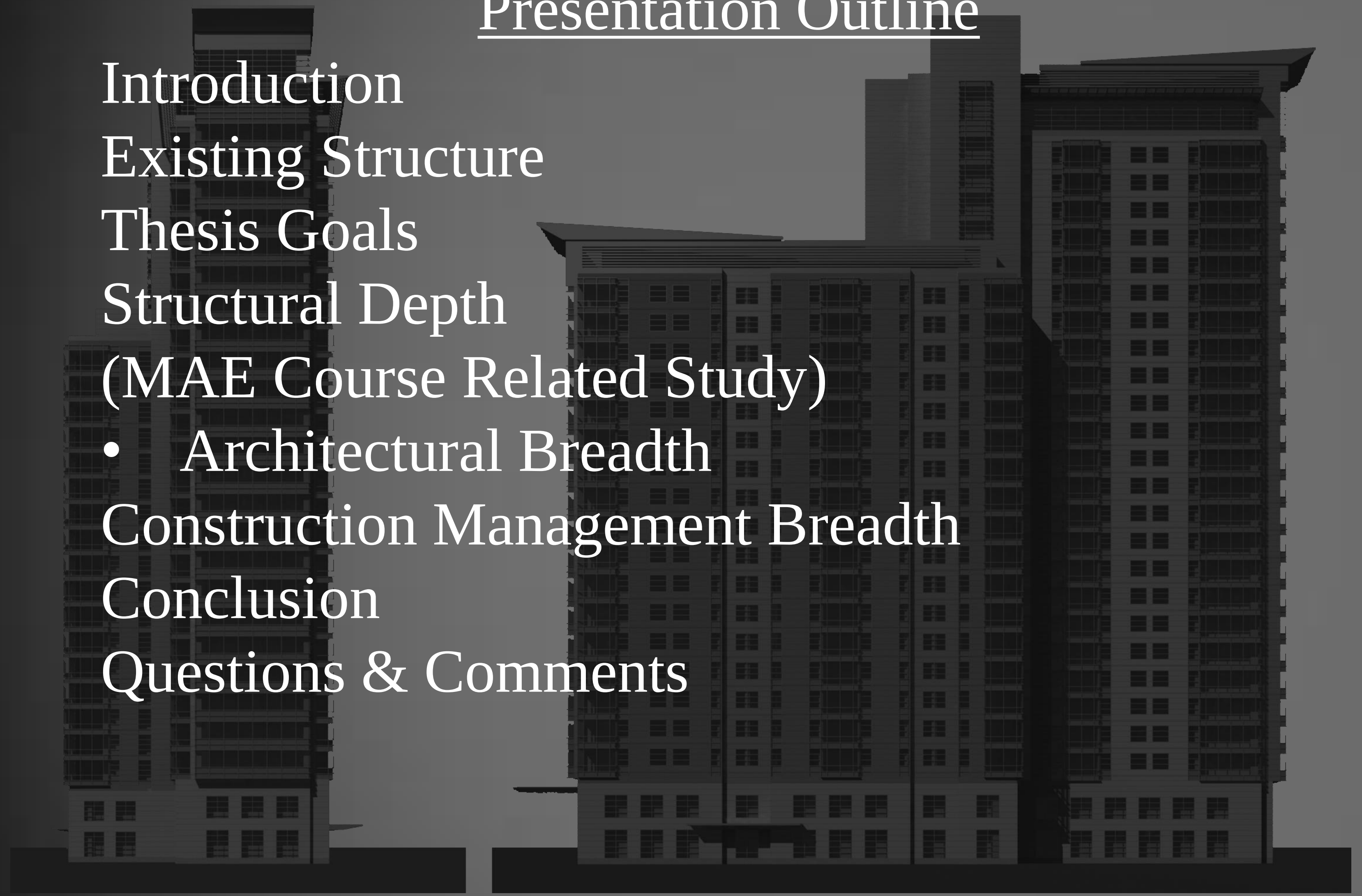
3” 18 gage decking with 3 ¼” LW topping spans from Joist to Joist

Lateral

16” Shear Walls with 16”x24” Coupling Beams located at Central Core (Vertical Circulation Area)

Stiffness from Staggered Truss System

Drift values in appendix slide



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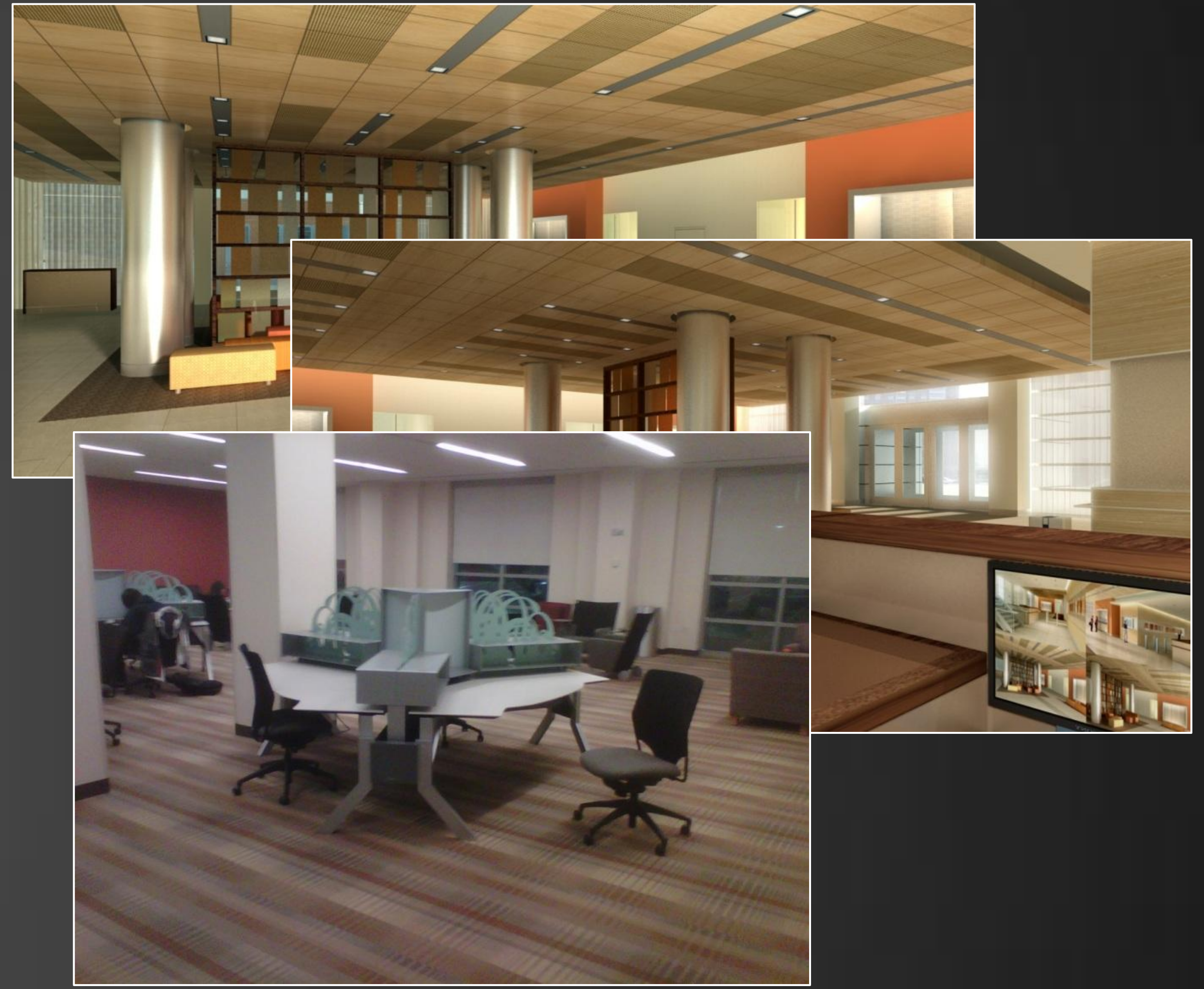
Architectural Breadth

Areas of Concern

Meeting area/observatory on 26th floor

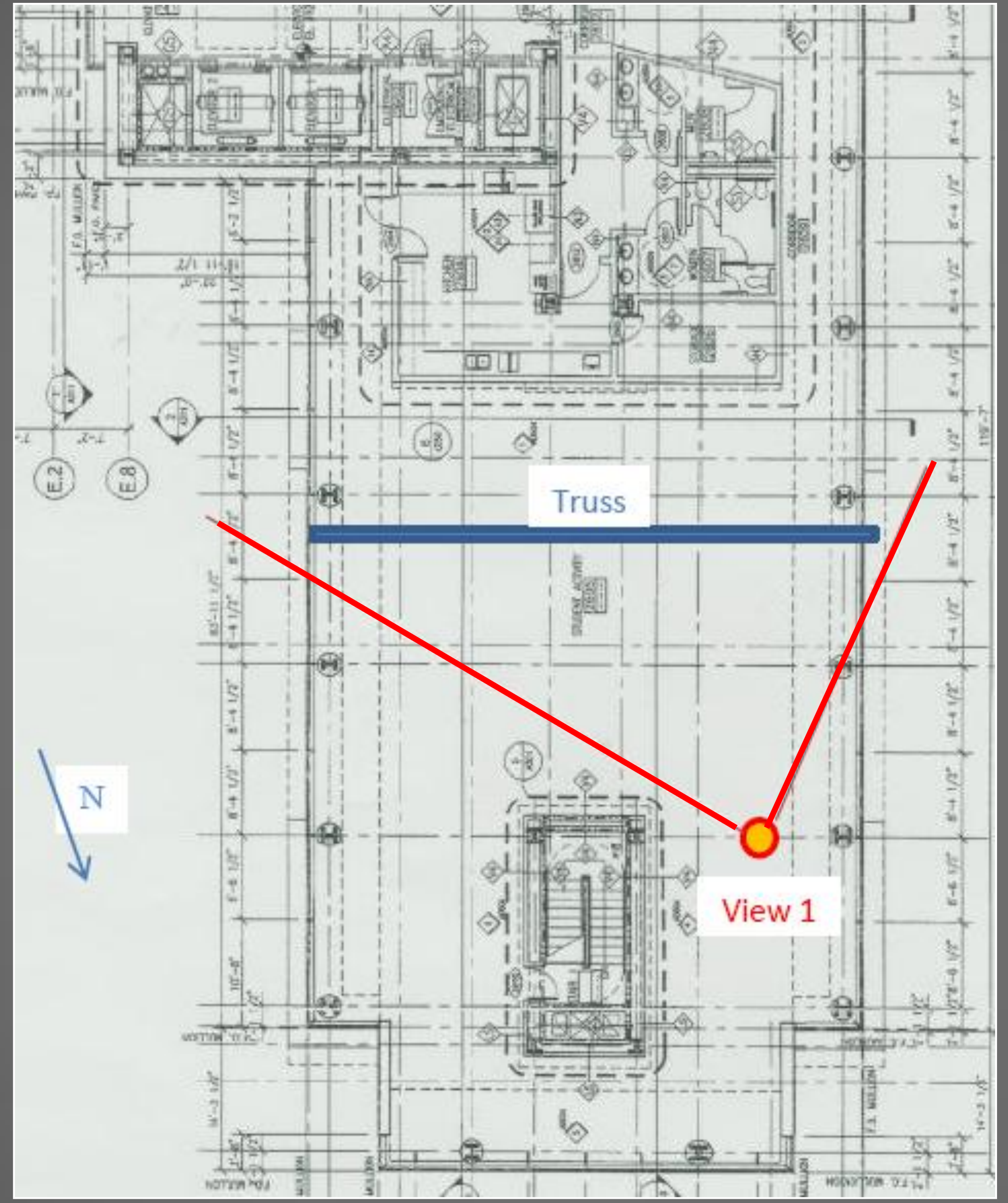
Main Lobby

Large study area on 2nd floor



Renderings:
compliments of Cannon Design
Special thanks to Claire Kuehnel for photos

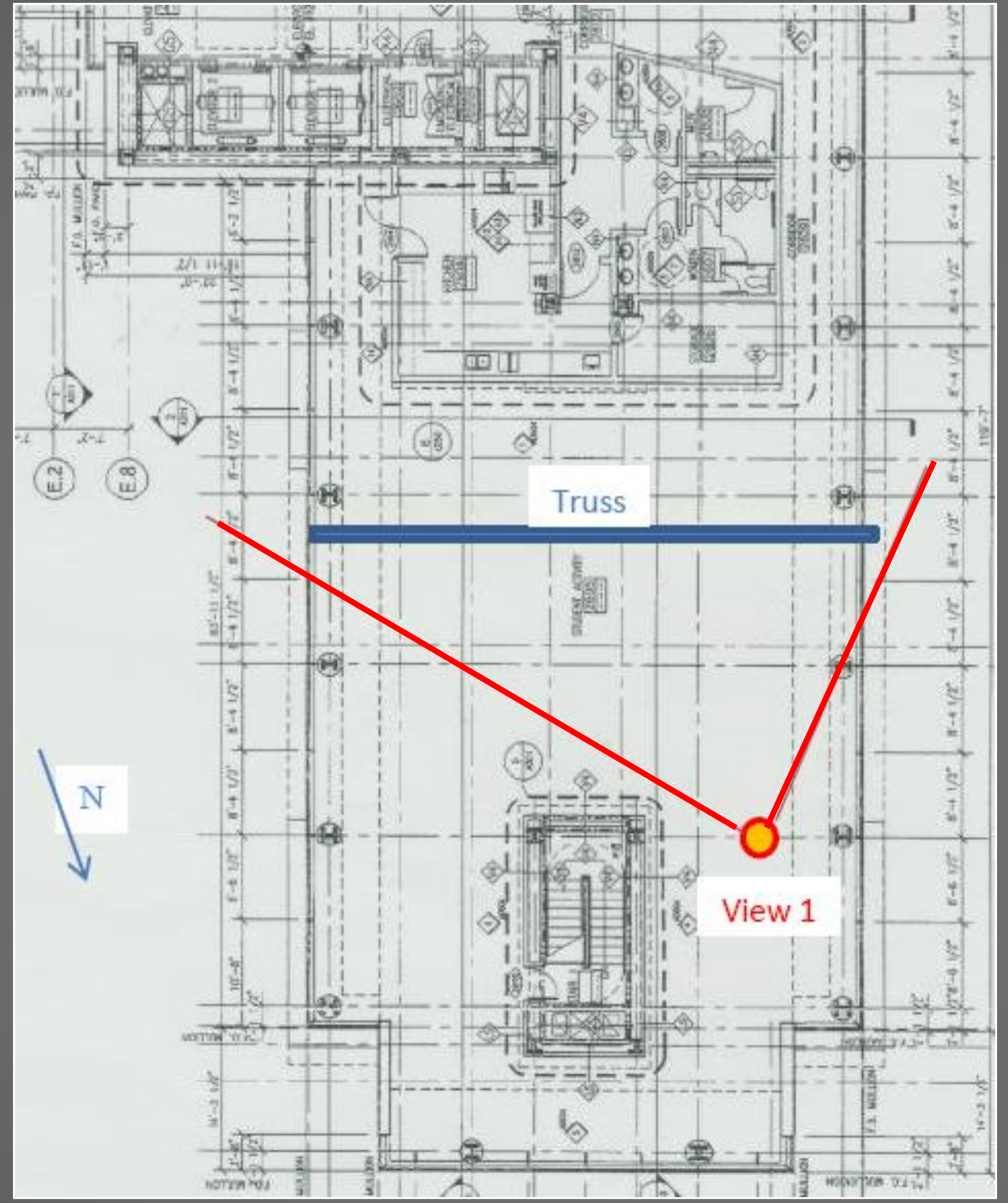
26^{th} floor Meeting Area/Observatory



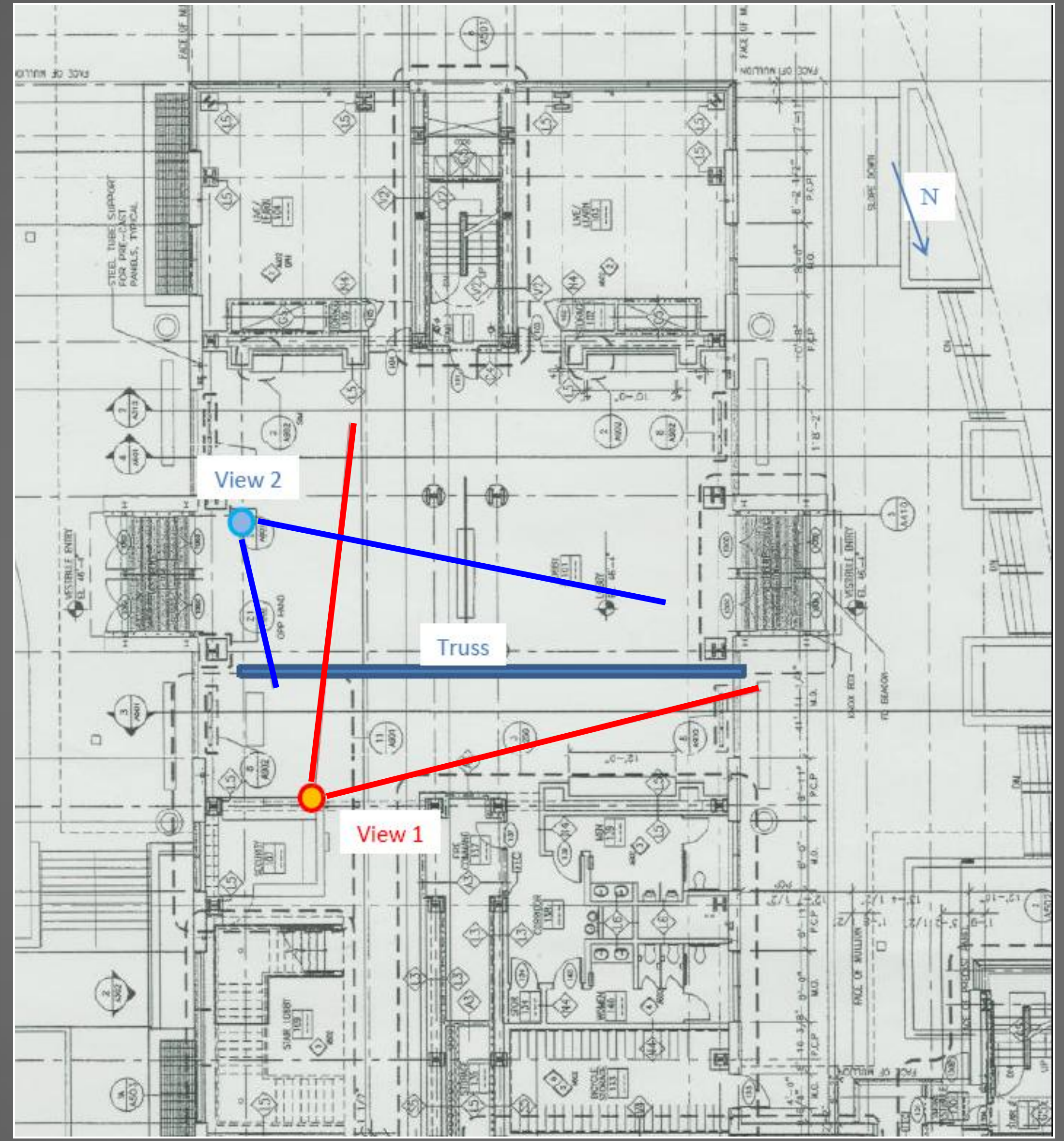
Existing Conditions

With Truss

26th floor Meeting Area/Observatory



Main lobby on First Floor



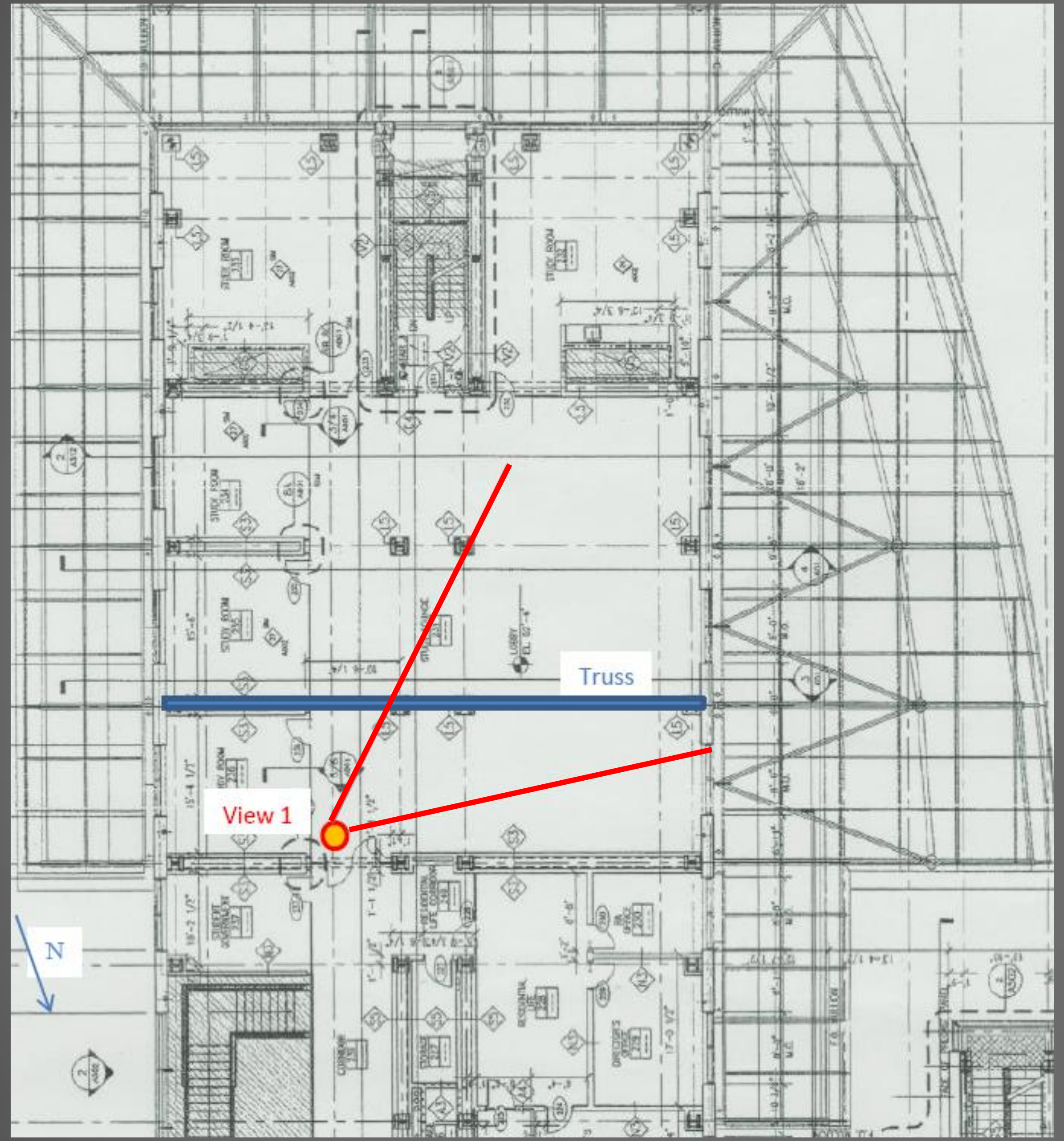
View 1

View 1

View 2

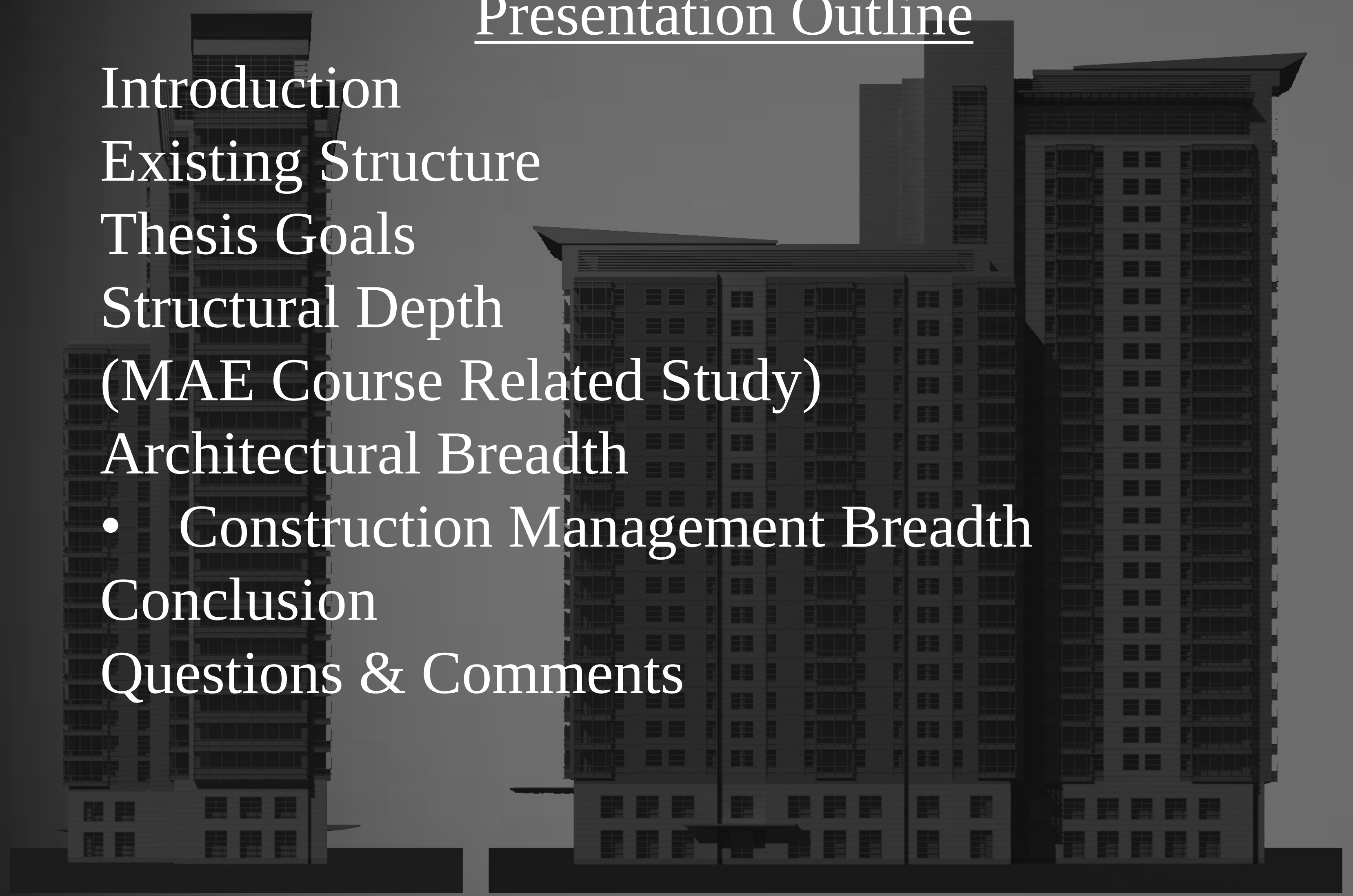
View 2

Large Study on 2nd Floor



Existing Conditions

With Truss



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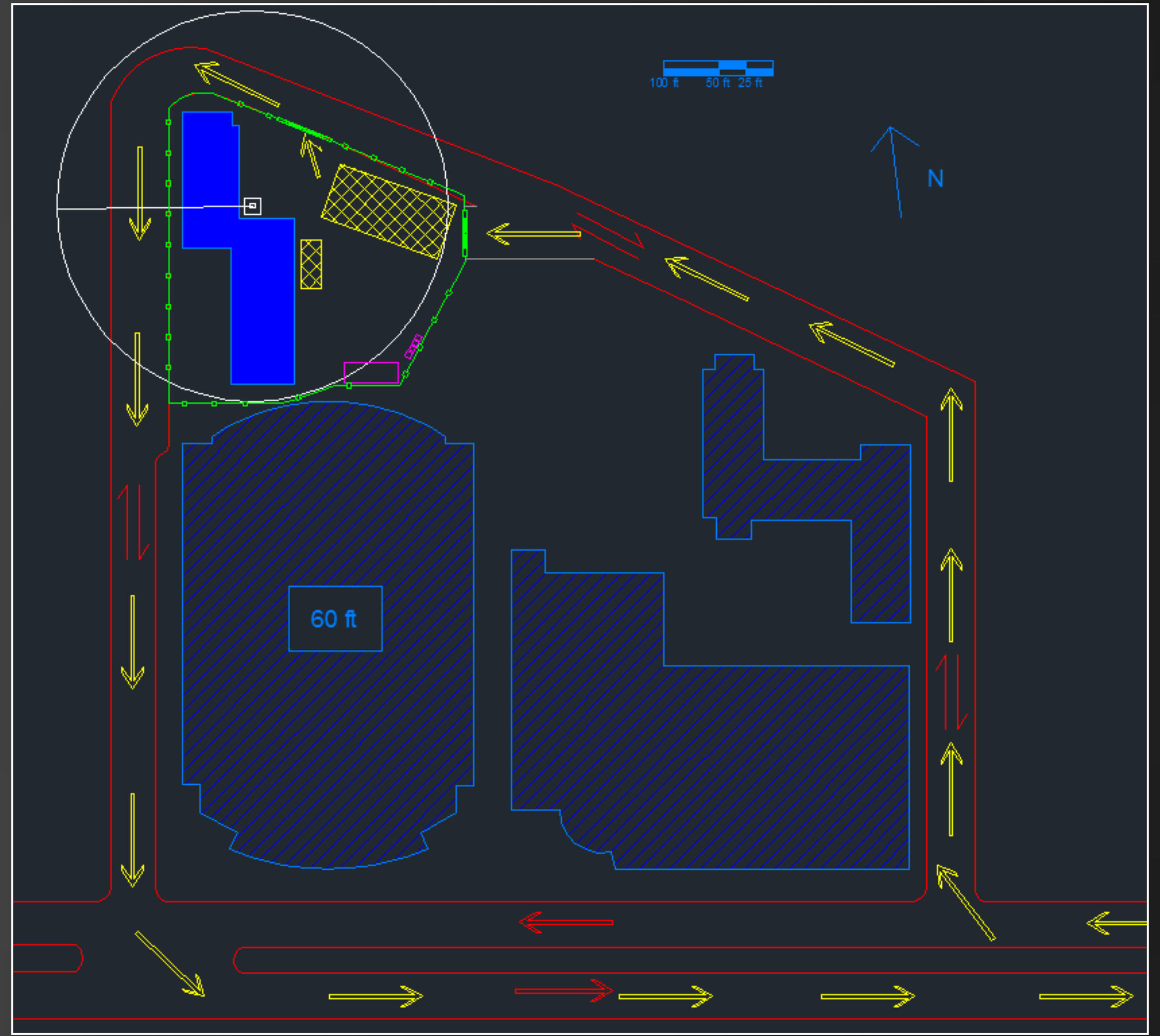
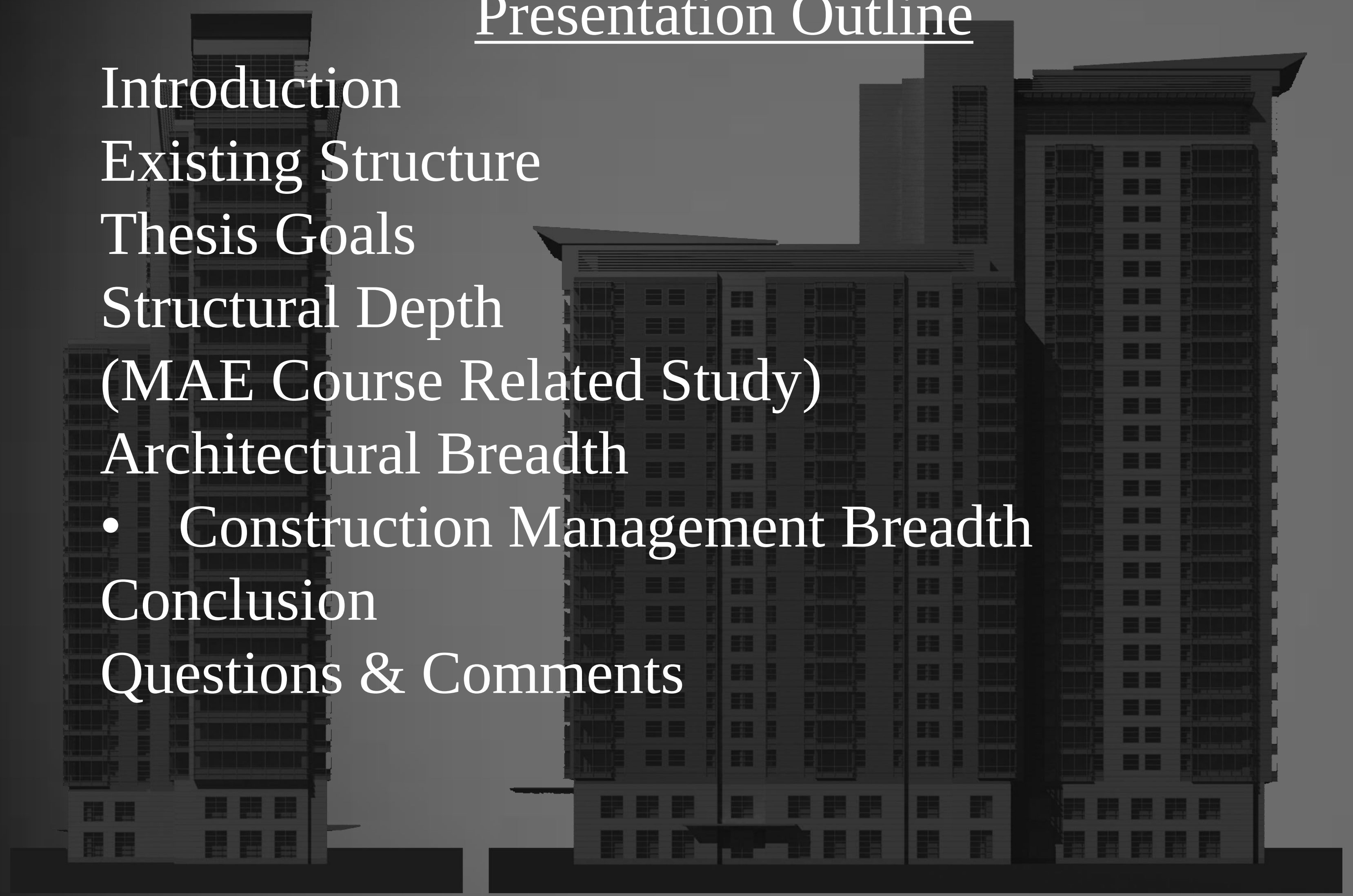
Construction Management Breadth

Site Logistics

Schematic plan of site before construction to evaluate surrounding environment
Delivery routes and onsite storage locations determined
Crane selection



Site Logistics Plan



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Existing Structure
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Structural Depth
(MAE Course Related Study)
Architectural Breadth
- Construction Management Breadth

Conclusion
Questions & Comments

Construction Management Breadth

Site Logistics

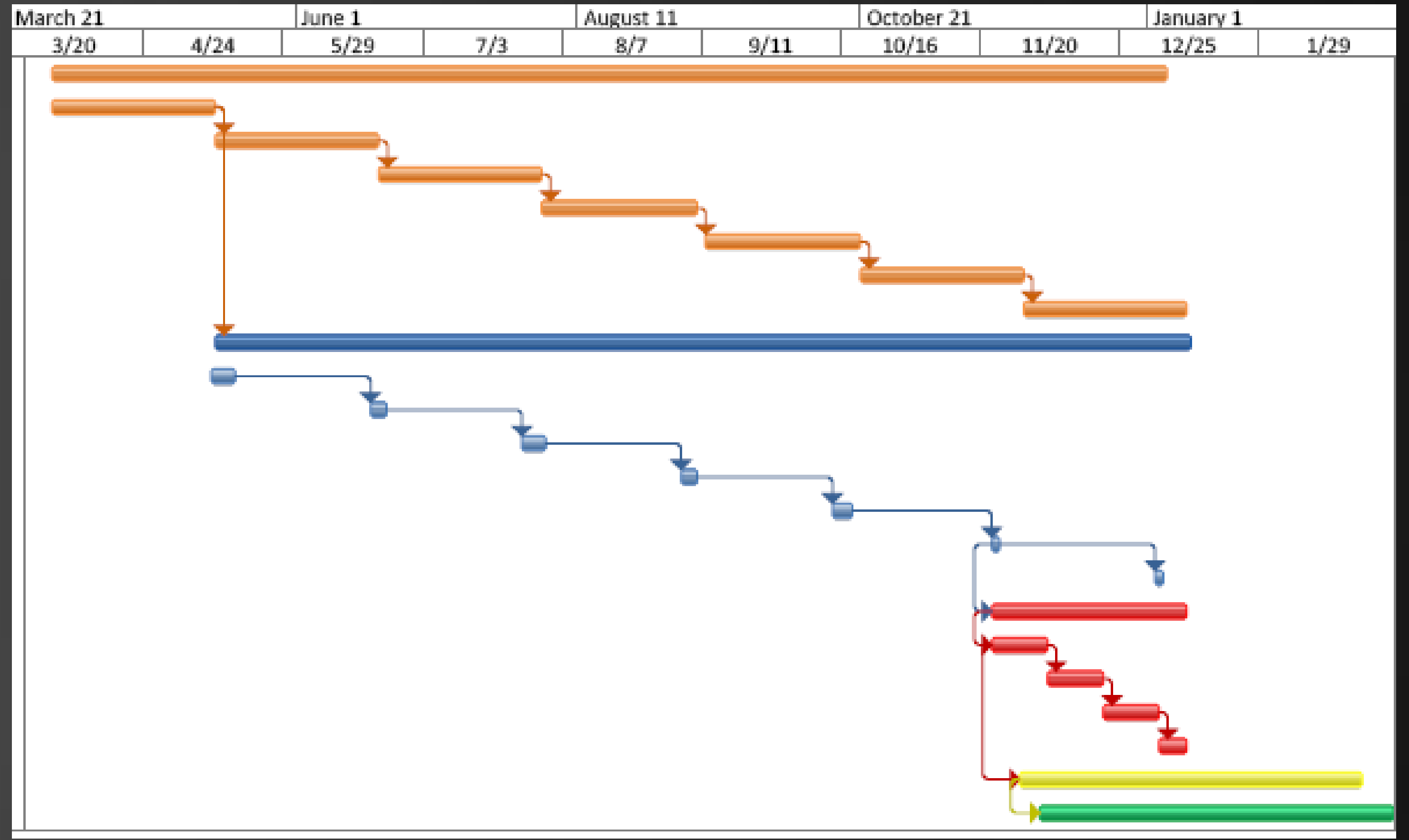
Schematic plan of site before construction to evaluate surrounding environment
Delivery routes and onsite storage locations determined
Crane selection

Construction Schedule

Five stages

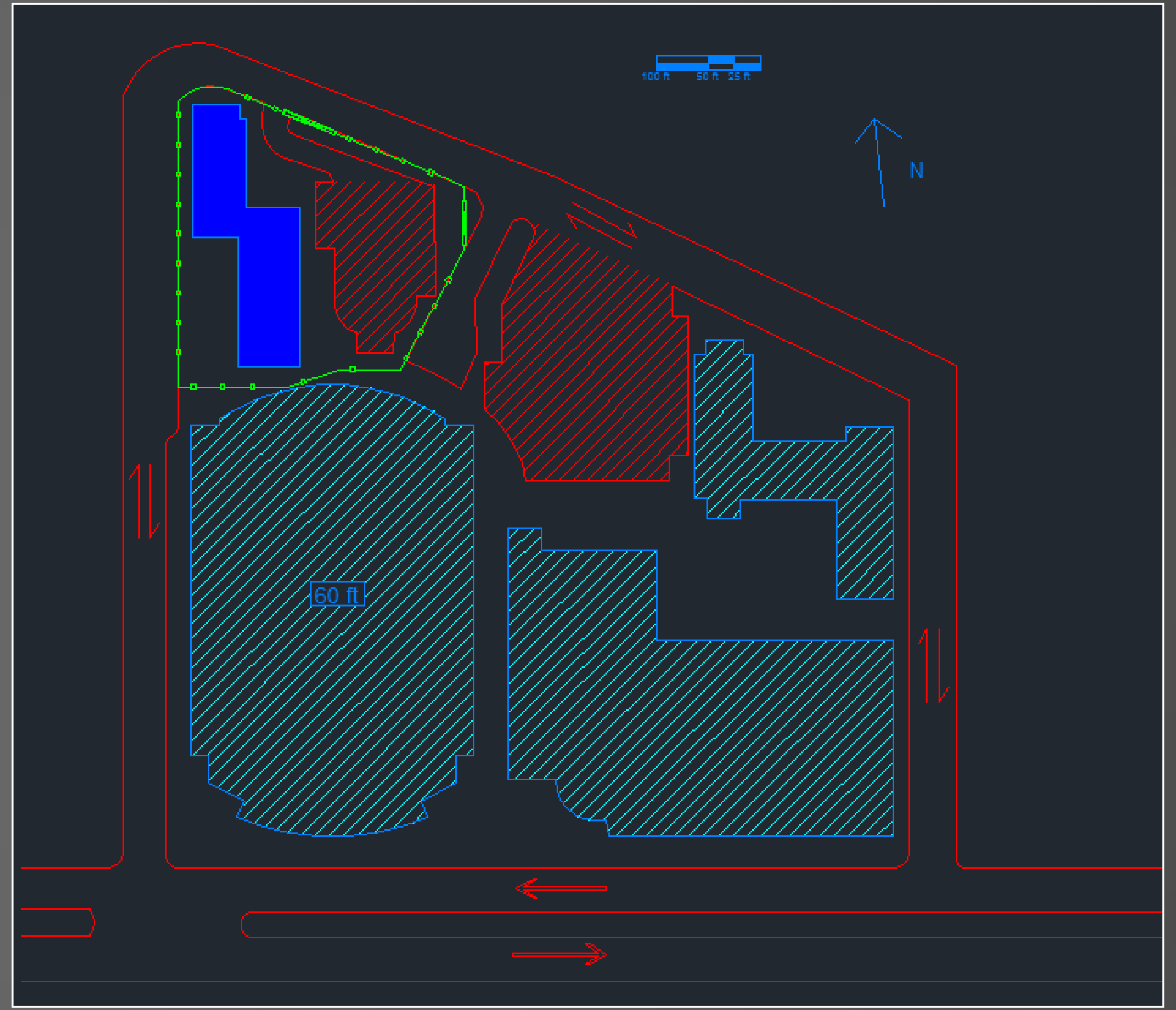
1. Shear walls
2. Steel framing (trusses and columns)
3. Joists
4. Decking
5. Slab

(Not covered in presentation, appendix slide)

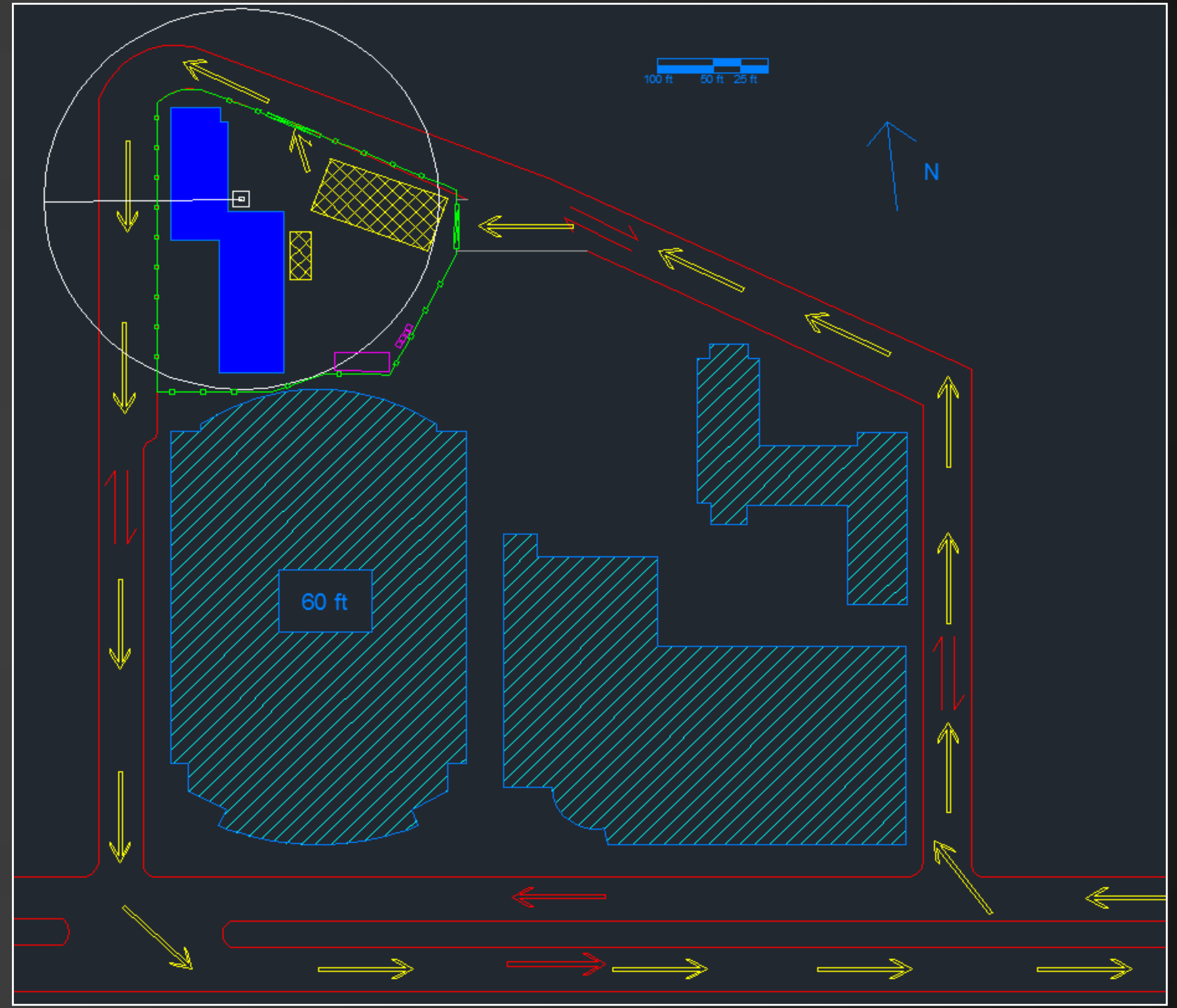


Site Logistics Plan

Symbol Key



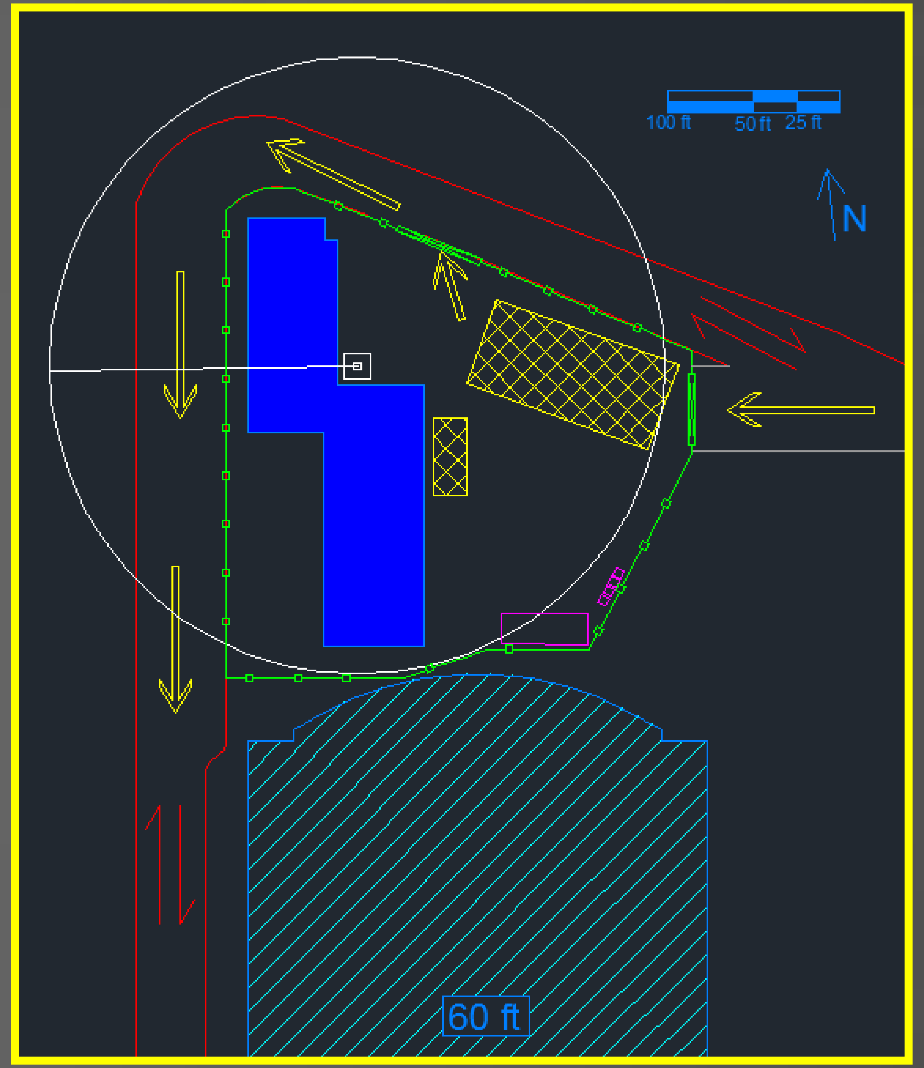
Existing Conditions with fence



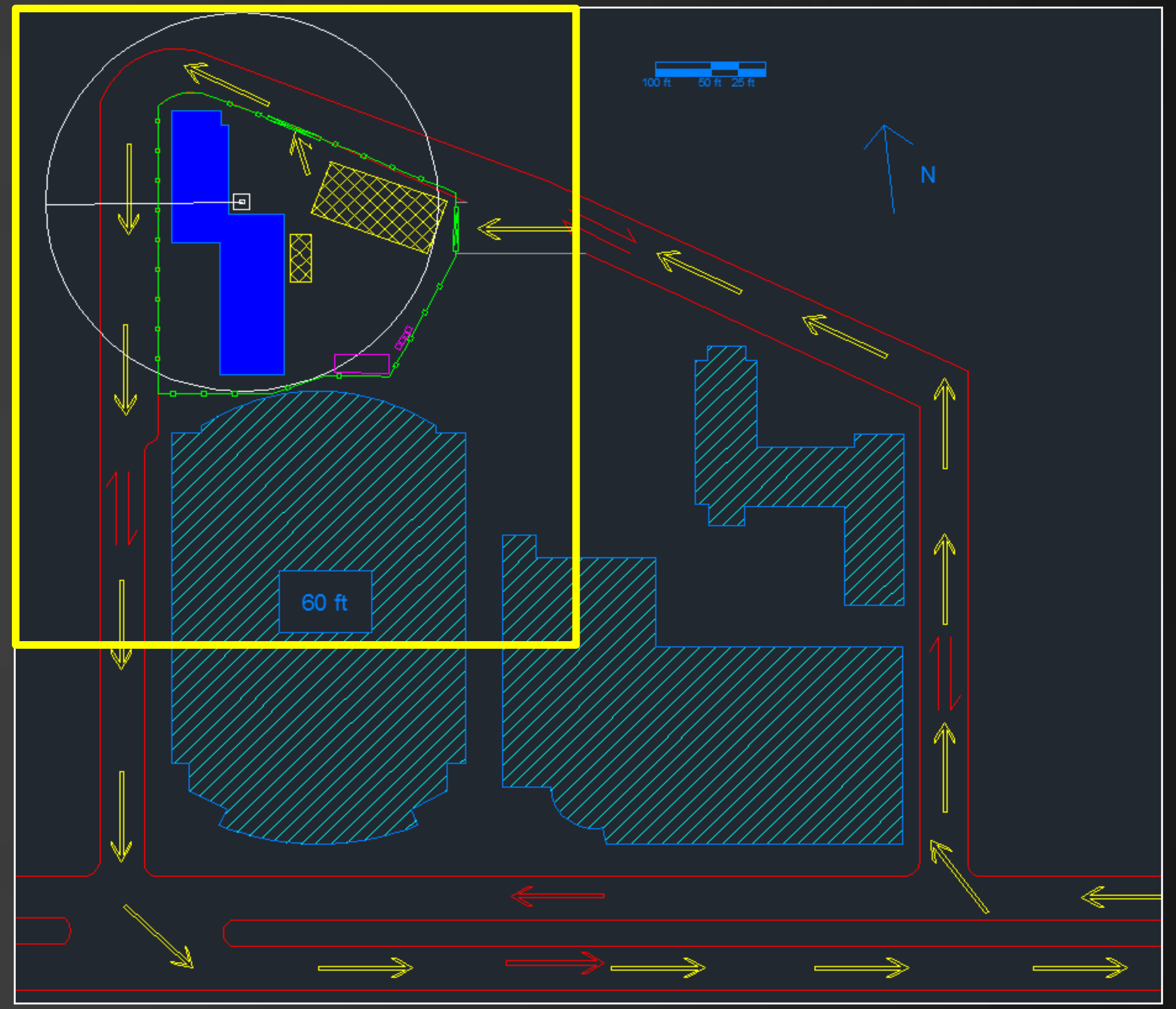
During Construction

Site Logistics Plan

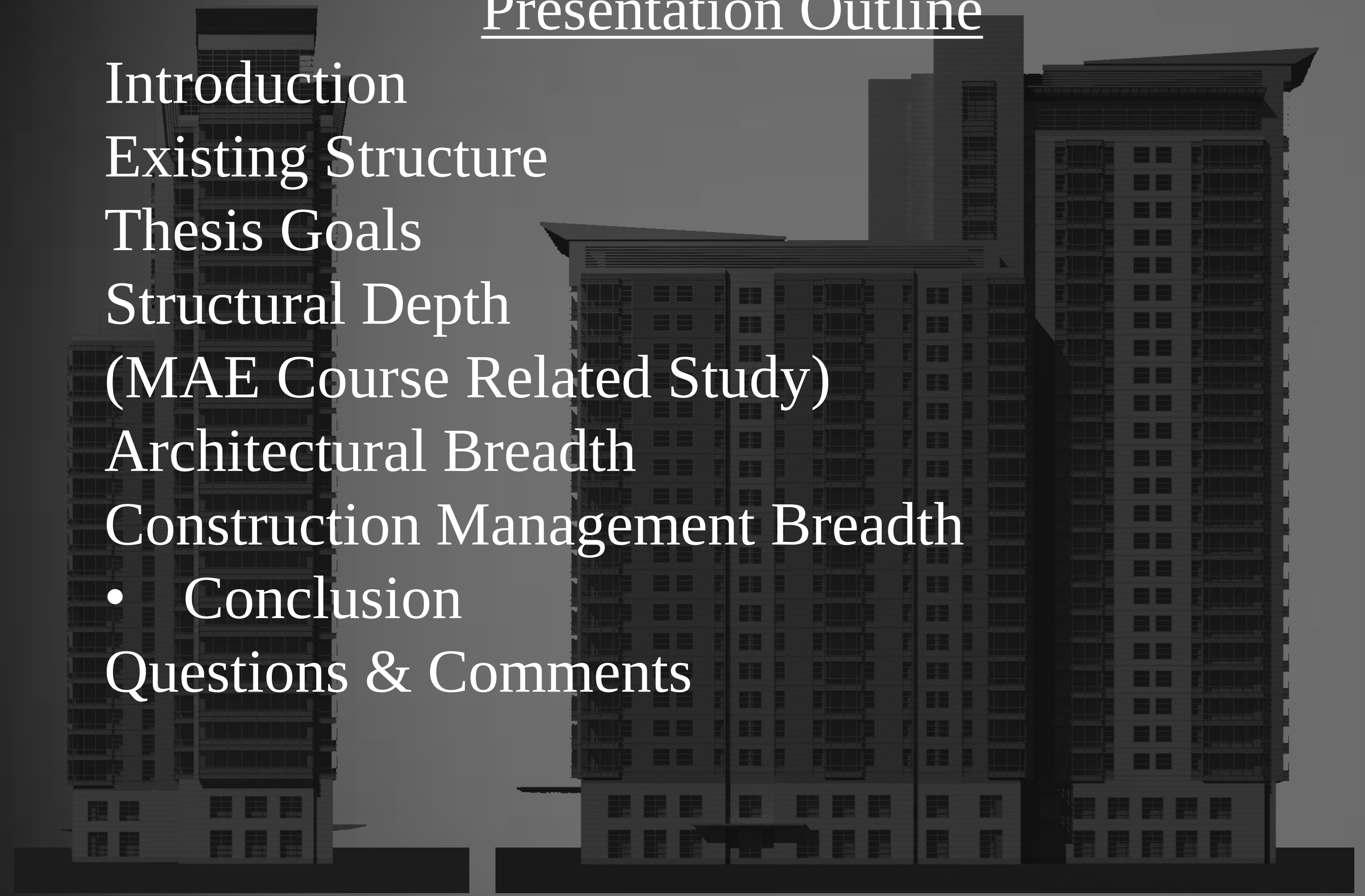
Symbol Key



Site Plan



During Construction



Presentation Outline

Introduction
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Conclusions

Staggered Truss System

Staggered truss system successfully designed and efficiently implemented for Res Tower II.

Not a practical way to resist lateral loads for this particular structure.

Coupled shear walls added to central vertical circulation space to increase stiffness

Impact on Other Disciplines

Architectural

This system allows for very open floor plans because no interior load carrying elements are required (columns, bearing walls)
A good deal of coordination is required between the architect and structural designer to take full advantage of this system's qualities (proven in architectural breath study)

Construction Management

A staggered truss system requires lead time to allow for prefabrication of trusses

Due to the scale of trusses a detailed site logistics plan and construction schedule must be maintained to avoid delayed construction

Impact on Other Disciplines

Mechanical/Electical

The staggered truss system offers an increased plenum space because the structure does not need to be as deep as typical composite steel framing

Because gaps and openings exist within the structure itself, on site adjustments and inter-disciplinary coordination can allow ductwork or wring to be done through these openings

Lighting

The staggered truss system allows for an increase in daylighting capabilities by pulling the structure away from the exterior of the building

Without the need for interior walls daylight is allowed to penetrate deeper into the space.

Exposing the trusses in public spaces would provide an opportunity for creative lighting schemes or for the creation of a display space

Acknowledgements

Cannon Design

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Family

Thank you for allowing me to make my own decisions and mistakes along the way. Even you may not have understood exactly what I have been working on, you have given more than you know.

Friends

Thank you for putting up with me over the years. I cannot believe how lucky I was to find such a great group of people to spend almost every hour of my time with.

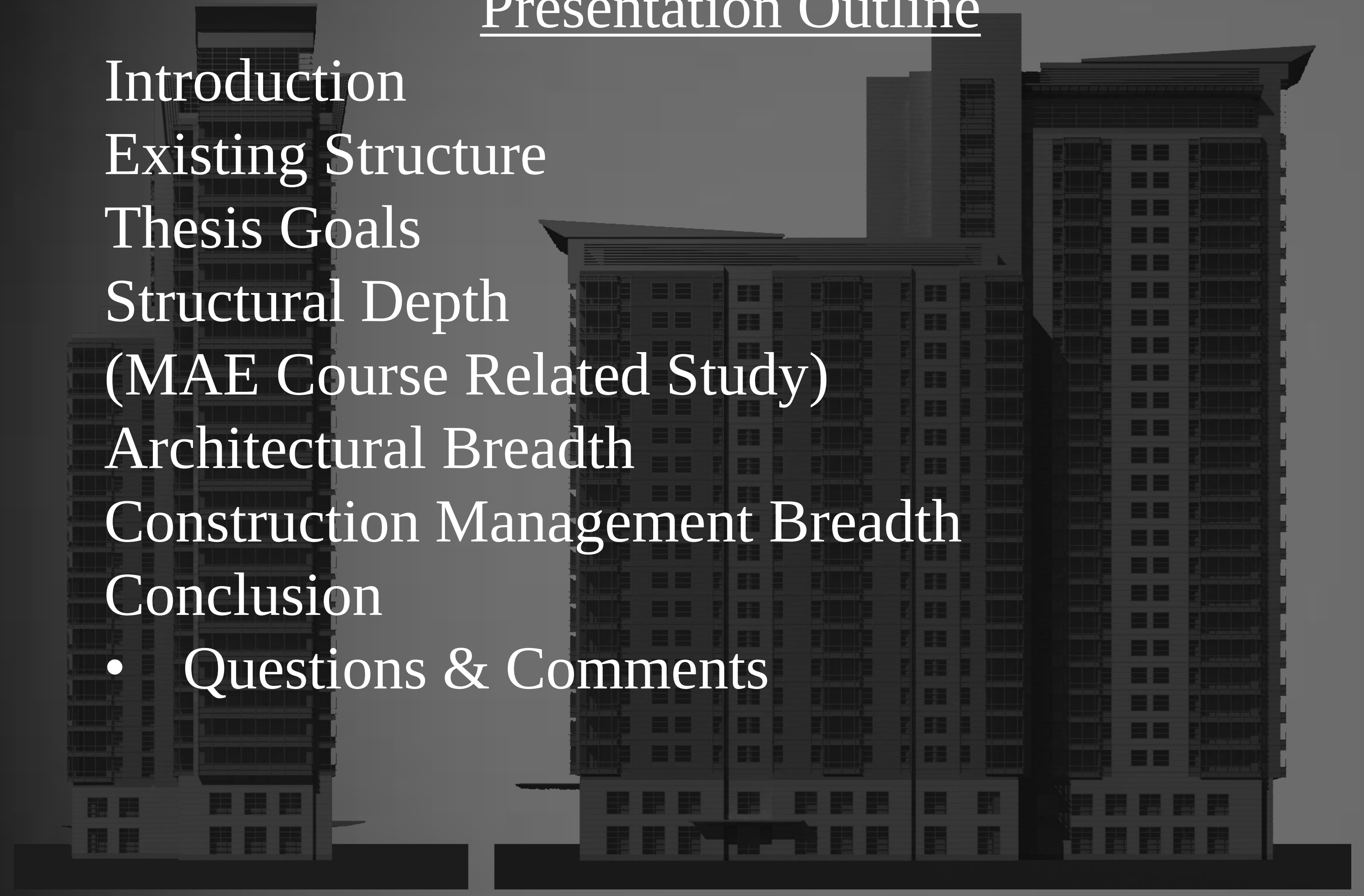
Thanks to all of those of you WHO helped me enjoy my last year of school.

God

I have been blessed in many aspects of my life and am very thankful for it. I hope I can use my talents for His glory.

Faculty

Dr. Boothby
Dr. Hanagan
Dr. Geschwindner
Prof. Bob Holland
Ryan Solnosky



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Questions and Comments

ASCE 7-05 CC. 1.2

CC.1.2 Drift of Walls and Frames. Drifts (lateral deflections) of concern in serviceability checking arise primarily from the effects of wind. Drift limits in common usage for building design are on the order of 1/600 to 1/400 of the building or story height [Ref. CC-7]. These limits generally are sufficient to minimize damage to cladding and nonstructural walls and partitions. Smaller drift limits may be appropriate if the cladding is brittle. An absolute limit on interstory drift may also need to be imposed in light of evidence that damage to non-structural partitions, cladding and glazing may occur if the interstory drift exceeds about 10 mm (3/8 in.) unless special detailing practices are made to tolerate movement [Refs. CC-6, CC-8]. Many components can accept deformations that are significantly larger.

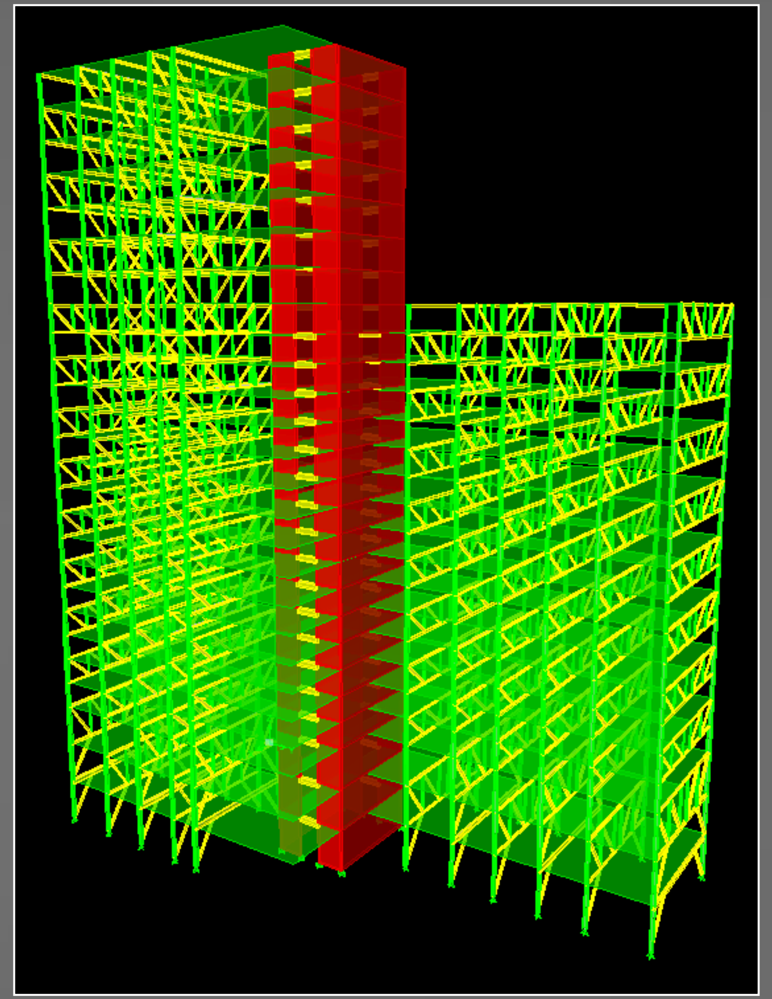
Use of the factored wind load in checking serviceability is excessively conservative. The load combination with an annual probability of 0.05 of being exceeded, which can be used for checking short-term effects, is

$$D + 0.5L + 0.7W \qquad \text{(CC-3)}$$

obtained using a procedure similar to that used to derive Eqs. CC-1a and CC-1b. Wind load, W, is defined in Chapter 6. Due to its transient nature, wind load need not be considered in analyzing the effects of creep or other long-term actions.

Deformation limits should apply to the structural assembly as a whole. The stiffening effect of nonstructural walls and partitions may be taken into account in the analysis of drift if substantiating information regarding their effect is available. Where load cycling occurs, consideration should be given to the possibility that increases in residual deformations may lead to incremental structural collapse.

Lateral Deflections



Model A: 16” shear walls with coupling beams and staggered truss system

Seismic X		
Story	UX (in)	Interstory Drift (in)
26	7.2889	0.3945
25	6.8944	0.393
24	6.5014	0.393
23	6.1084	0.3925
22	5.7159	0.3915
21	5.3244	0.3896
20	4.9348	0.3868
19	4.548	0.3188
18	4.2292	0.3167
17	3.9125	0.3131
16	3.5994	0.3086
15	3.2908	0.303
14	2.9878	0.2963
13	2.6915	0.2885
12	2.403	0.2794
11	2.1236	0.2689
10	1.8547	0.2571
9	1.5976	0.2437
8	1.3539	0.2288
7	1.1251	0.2124
6	0.9127	0.1943
5	0.7184	0.1746
4	0.5438	0.1531
3	0.3907	0.196
2	0.1947	0.1296
1	0.0651	0.0651

Seismic Y		
Story	UY (in)	Interstory Drift (in)
26	16.5868	0.6187
25	15.9681	0.6305
24	15.3376	0.6453
23	14.6923	0.6623
22	14.03	0.6805
21	13.3495	0.6983
20	12.6512	0.7152
19	11.936	0.6069
18	11.3291	0.6205
17	10.7086	0.6346
16	10.074	0.648
15	9.426	0.6596
14	8.7664	0.6692
13	8.0972	0.6755
12	7.4217	0.6789
11	6.7428	0.6788
10	6.064	0.6751
9	5.3889	0.6674
8	4.7215	0.6554
7	4.0661	0.6389
6	3.4272	0.617
5	2.8102	0.5894
4	2.2208	0.5555
3	1.6653	0.7995
2	0.8658	0.5974
1	0.2684	0.2684

Story Drift Limit (ASCE Table 12.2-1)

Δ_a = 1.80” for 10 ft Floor-to-Floor

2.88” for 16 ft Floot-to-Floor

R = 3.25 for Concentrically Braced Frames

R = 5 for Reinforced Concrete Shear Walls

Wind Y		
Story	UY (in)	H/400 (in)
26	8.1914	8.76
25	7.9036	8.4
24	7.6097	8.04
23	7.3081	7.68
22	6.998	7.32
21	6.6793	6.96
20	6.3524	6.6
19	6.0179	6.24
18	5.7343	5.94
17	5.4449	5.64
16	5.1488	5.34
15	4.8458	5.04
14	4.536	4.74
13	4.2198	4.44
12	3.8978	4.14
11	3.5709	3.84
10	3.24	3.54
9	2.9065	3.24
8	2.5718	2.94
7	2.2377	2.64
6	1.9064	2.34
5	1.5804	2.04
4	1.263	1.74
3	0.9579	1.44
2	0.5077	0.96
1	0.1613	0.48

Construction Schedule

Five stages

1. Shear walls
2. Steel framing (trusses and columns)
3. Joists
4. Decking
5. Slab

Task Name	Duration	Start	Finish
Shear Walls	200 days	Fri 4/1/11	Thu 1/5/12
Pour floors 1-4 and cure	29 days	Fri 4/1/11	Wed 5/11/11
Pour floors 5-8 and cure	29 days	Thu 5/12/11	Tue 6/21/11
L9-12	29 days	Wed 6/22/11	Mon 8/1/11
L13-16	29 days	Tue 8/2/11	Fri 9/9/11
L17-20	29 days	Mon 9/12/11	Thu 10/20/11
L21-24	29 days	Fri 10/21/11	Wed 11/30/11
L24-26	29 days	Thu 12/1/11	Tue 1/10/12
Truss and Columns	175 days	Thu 5/12/11	Wed 1/11/12
L1-4	4 days	Wed 5/11/11	Mon 5/16/11
L5-8	4 days	Mon 6/20/11	Thu 6/23/11
L9-12	4 days	Thu 7/28/11	Tue 8/2/11
L13-16	4 days	Tue 9/6/11	Fri 9/9/11
L17-20	3 days	Fri 10/14/11	Tue 10/18/11
L21-24	2 days	Wed 11/23/11	Thu 11/24/11
L25-26	2 days	Tue 1/3/12	Wed 1/4/12
Joists	35 days	Wed 11/23/11	Tue 1/10/12
L1-7	10 days	Wed 11/23/11	Tue 12/6/11
L8-14	10 days	Wed 12/7/11	Tue 12/20/11
L15-21	10 days	Wed 12/21/11	Tue 1/3/12
L22-26	5 days	Wed 1/4/12	Tue 1/10/12
Decking	62 days	Wed 11/30/11	Thu 2/23/12
Slab	65 days	Mon 12/5/11	Fri 3/2/12