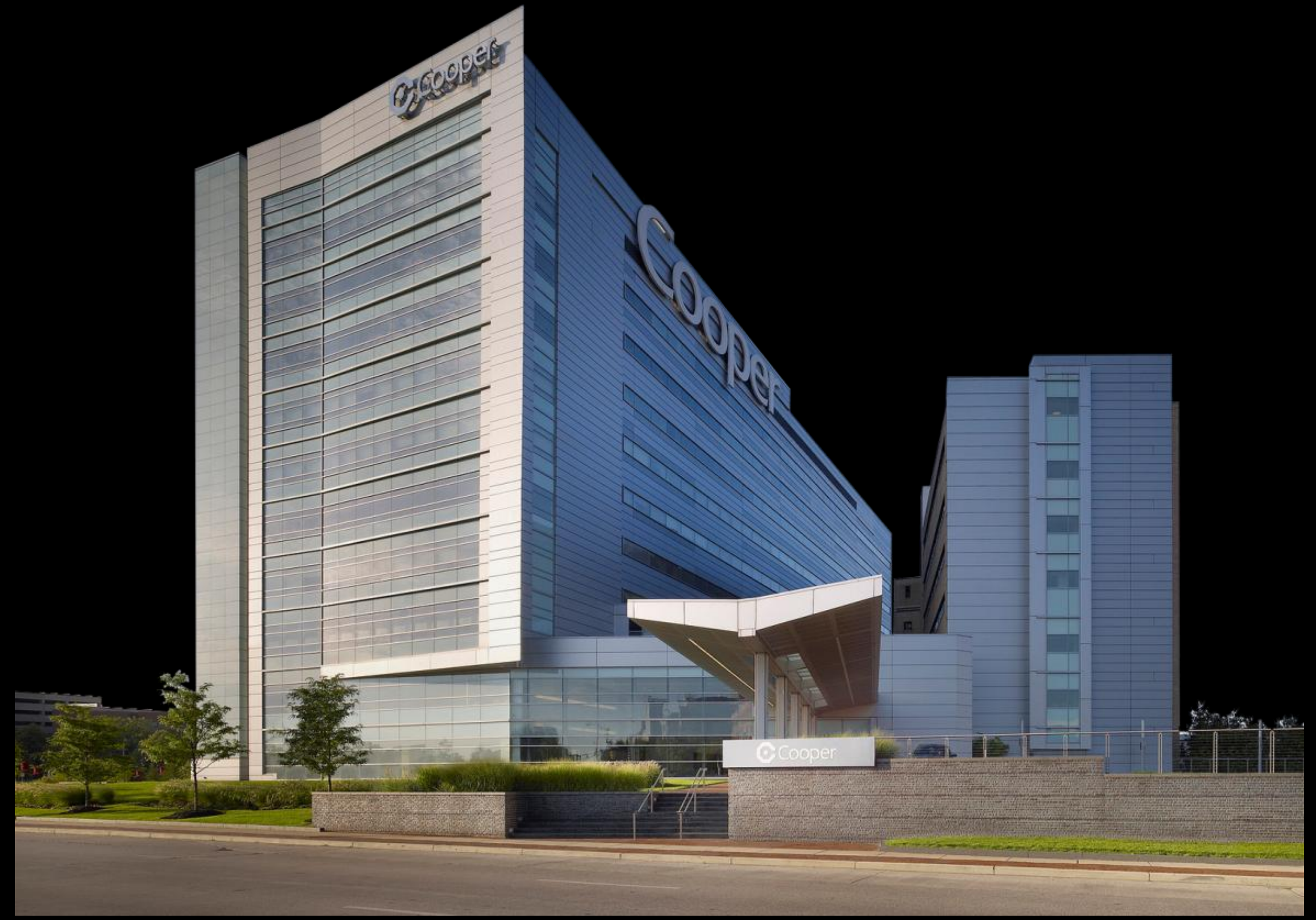
Roberts Pavilion

Cooper University Hospital

Camden, NJ

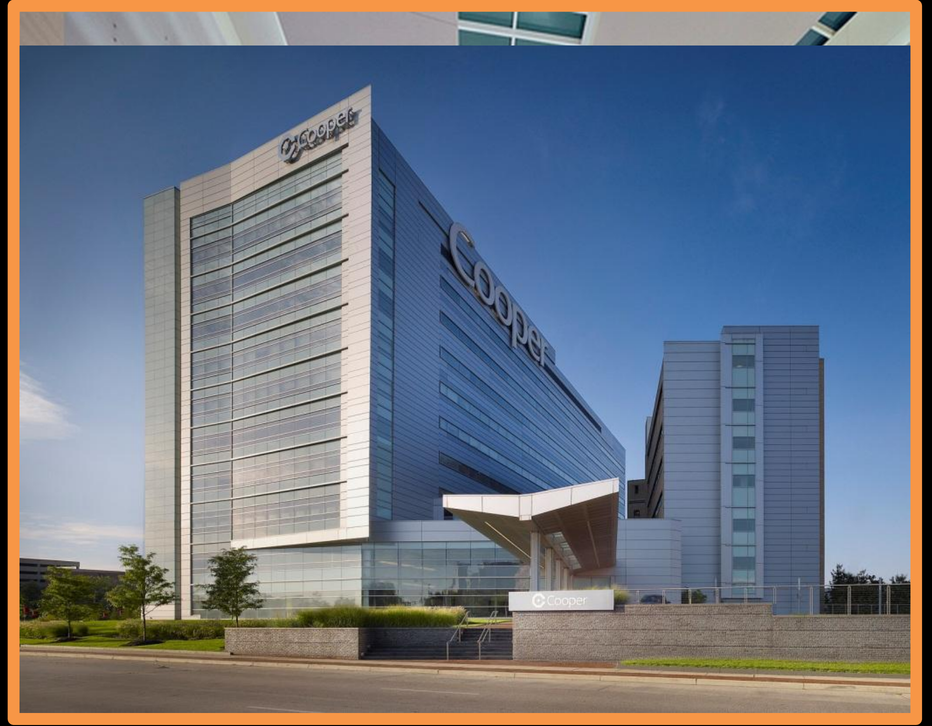


Andrew Voorhees | Structural Option

Faculty Advisor: Dr. Hanagan

Roberts Pavilion

- **Building Introduction**
- Problem Statement & Solution
- Gravity System
  - Slabs
  - Columns
- Lateral System
  - Layout
  - Shear Walls
  - Moment Frames
- Acoustics Breadth
- Construction Breadth
- Conclusions



Introduction

•Architecture & Engineering: EwingCole
•Construction: HSC & Turner Construction

•320,000 GSF
•Project cost - $220 Million
• Completed – December 2008
• 10 Stories
  • Operation suites
  • Clinical cardiology
  • Private patient rooms

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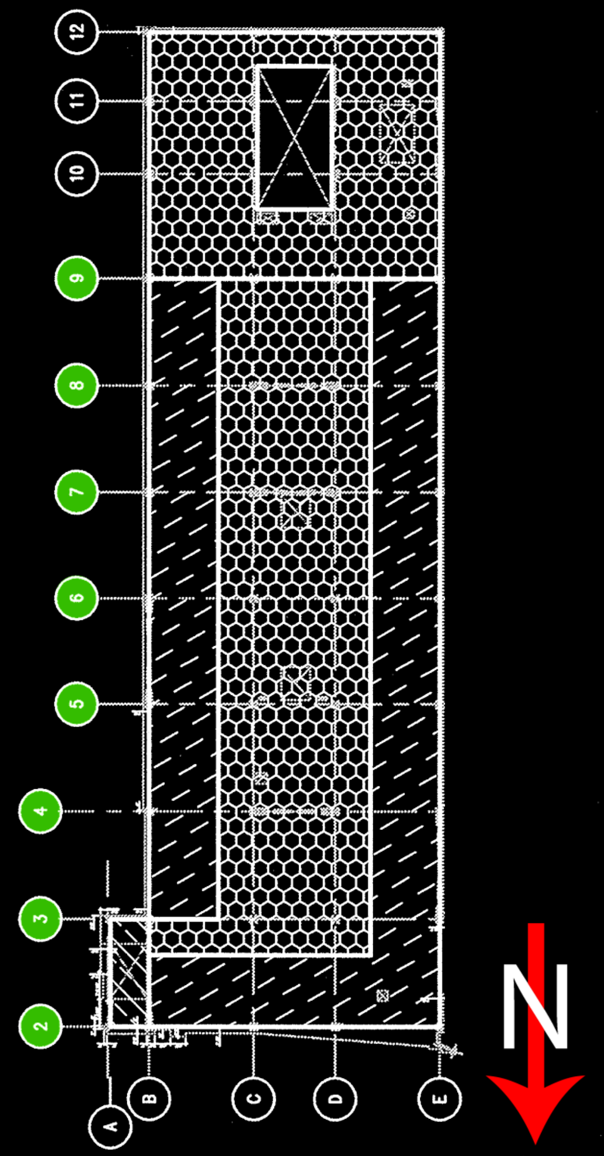
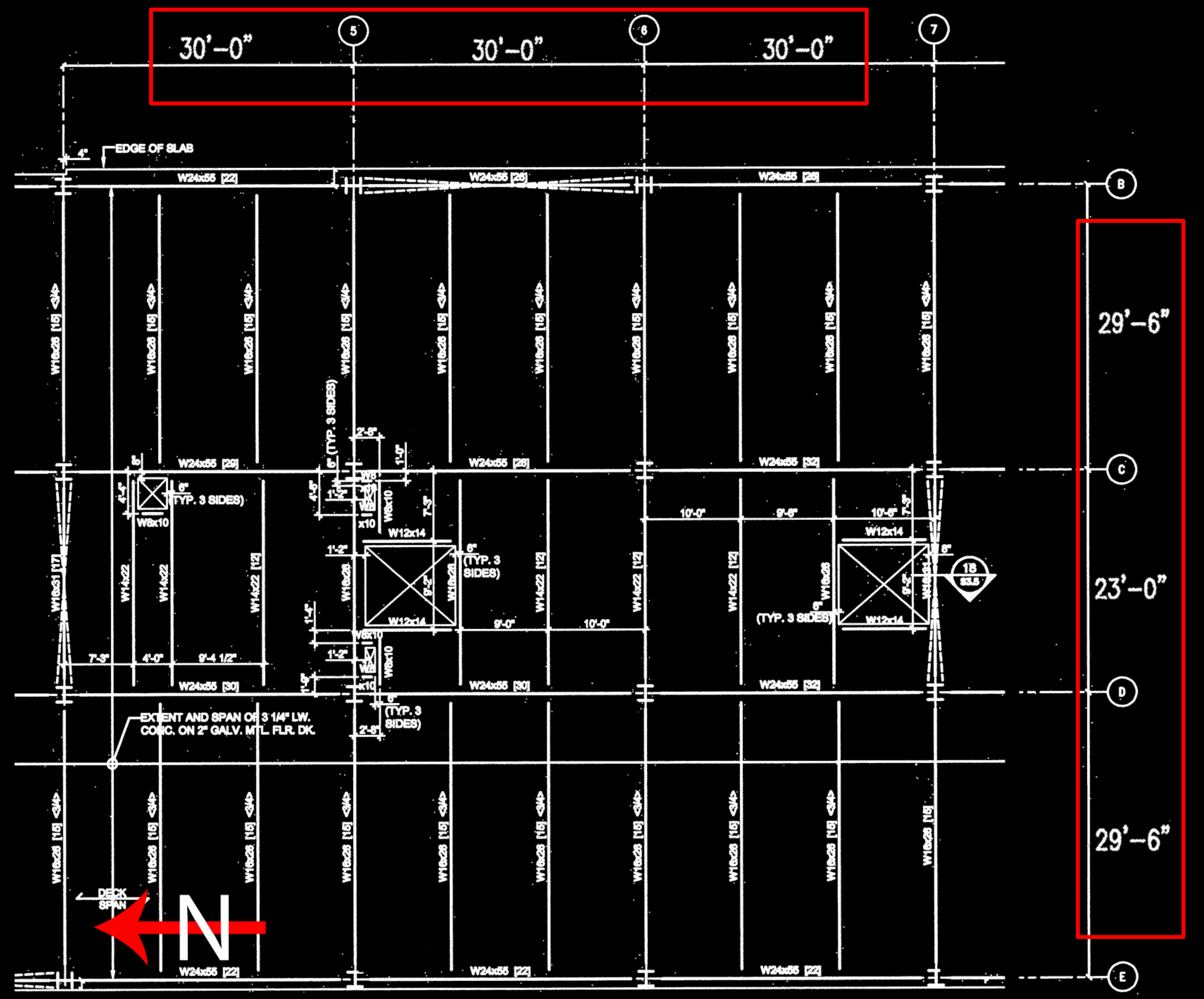


Existing Gravity System

- Reinforced piles - 68’ depth
- Composite steel floor
  - 2” 18 – gauge deck
  - 3¼” LW concrete topping
- Wide flange members
- 30’ column spacing typical



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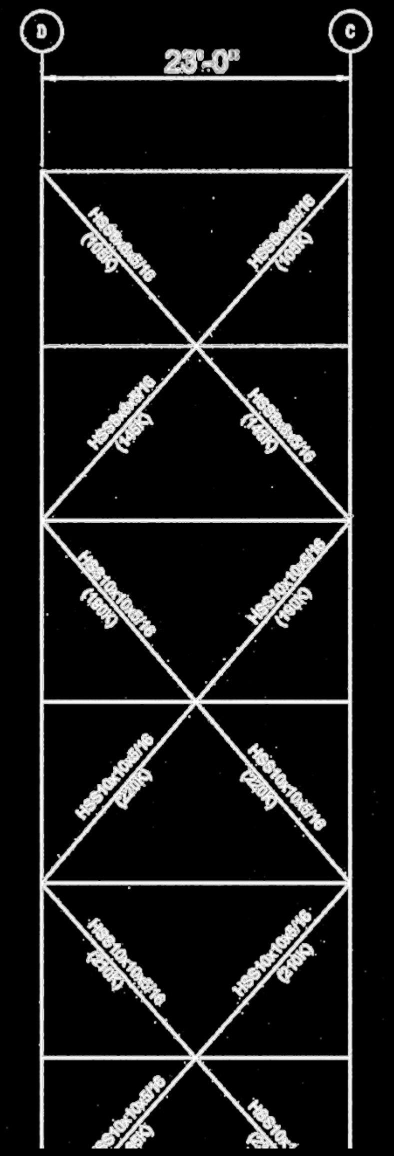

Existing Lateral System

- Concentrically braced frames
  - HSS members
- 4 frames in each direction
- Low impact on architecture
- Torsional irregularity based on center of rigidity

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Problem Statement

- Torsional Irregularities
- Code changes – increased seismic loads
  - Drift issues
- Cost
  - Concrete may be cheaper
  - Lower floor to floor heights

Proposed Solution

- Control drifts
  - Change lateral system to shear walls and moment frames
- Decrease cost
  - Redesign gravity system out of concrete: slabs and columns

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Goals

- Design an alternative structural system
  - Educational value
  - Maintain original conditions
- Evaluate the two systems based on:
  - Feasibility
  - Acoustics
  - Cost
  - Schedule

Proposed Solution

- Control drifts
  - Change lateral system to shear walls and moment frames
- Decrease cost
  - Redesign gravity system out of concrete: slabs and columns

Slab Design

- Two way slab chosen based on smallest floor depth
- Less labor and formwork than one way
- Use of drop panels to decrease required thickness
- Live Load = 80 psf
- Dead Load = 125 psf

- Trial slab thickness of 10”
- Drop panels 10’x10’
  - 2.5” thick
- Adequate for punching shear
- Deflections satisfied by use of ACI 318-11 Table 9.5(c)
- Moments distributed via Direct Design Method
  - Column, Middle, and Beam strips

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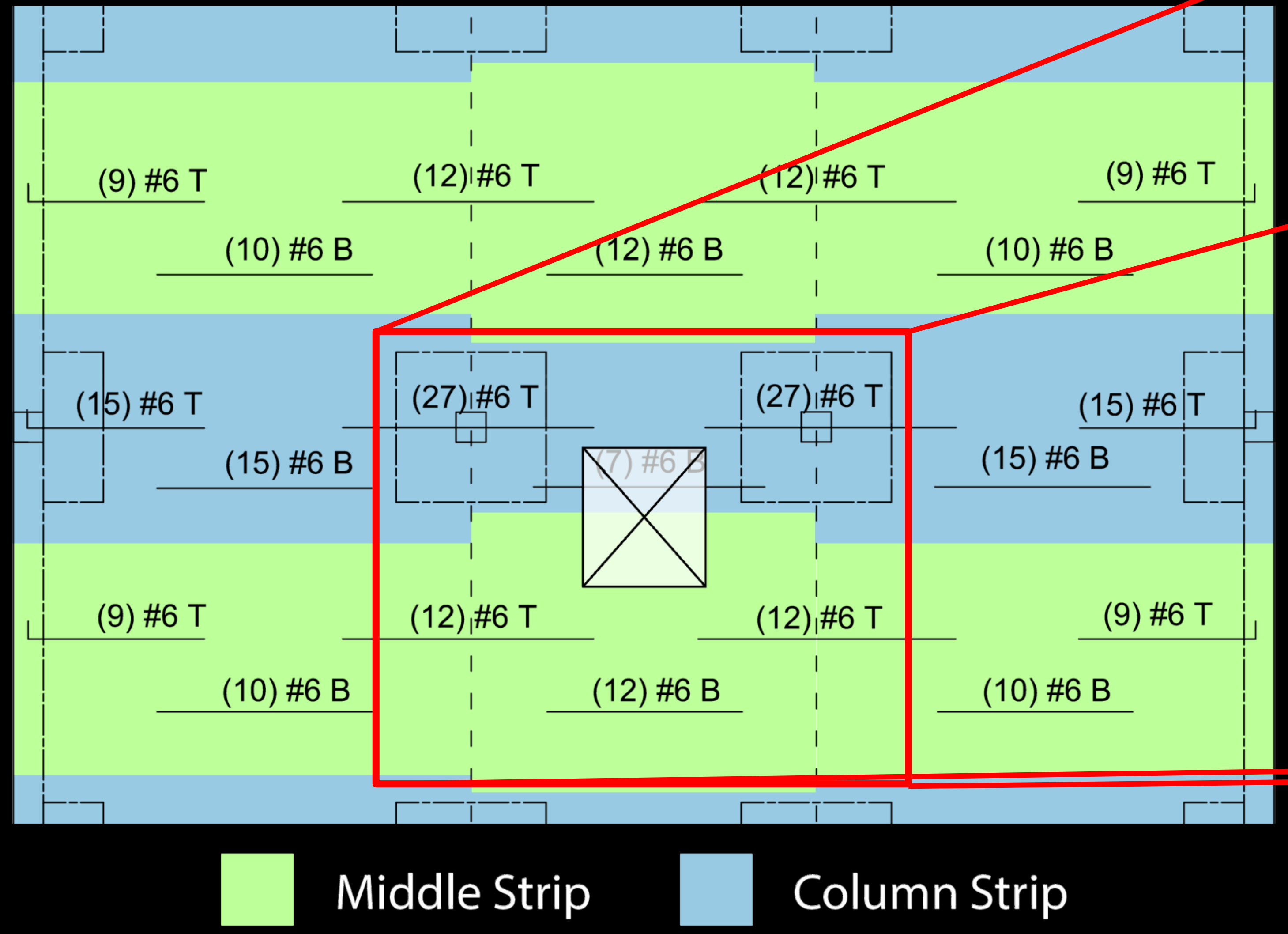
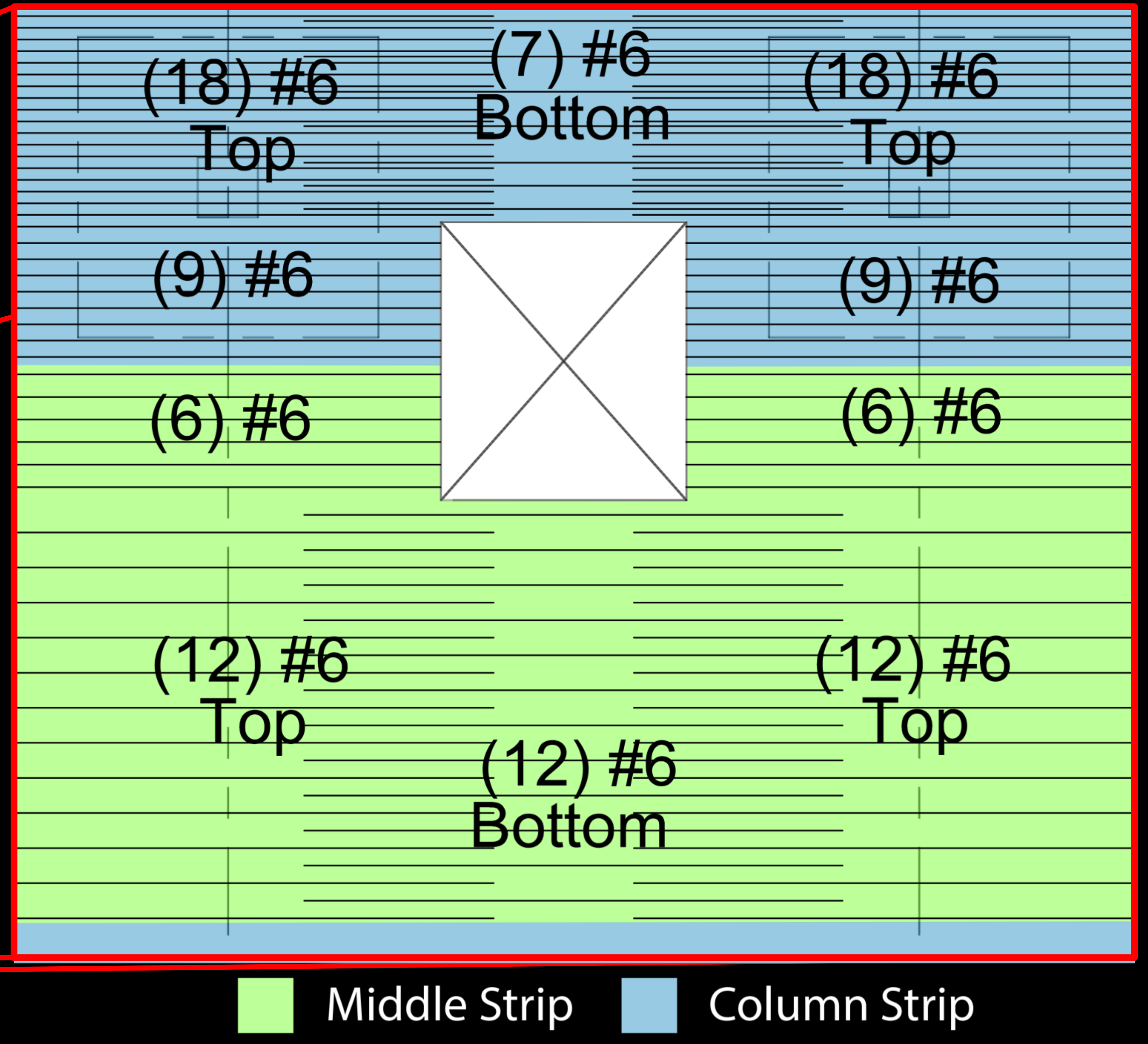
Slab Design





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Column Design

- 24” x 24” throughout building
- Floor to floor height decreased
- Basement – 2nd Floor
  - f’c = 6000 psi
- 3rd Floor – 10th Floor
  - f’c = 4000 psi

Column	Floor	Location	f'_c	P_u (k)	Reinforcing
C - 6	Basement	Center	6000	2220	(16) - #11’s
C - 6	6th Floor	Center	4000	1230	(12) - #8’s
B - 7	Basement	Edge	6000	1429	(8) - #8’s
B - 2	Basement	Corner	6000	1068	(8) - #8’s

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Lateral System

- Building height decreased
  → Wind loads decreased
- Building weight increased
  → Seismic loads increased
- Seismic controls

Base Shear (kips)				
	Wind N-S	Wind E-W	Seismic N-S	Seismic E-W
Steel	518	2020	1462	1462
Concrete	**443**	**1729**	**1898**	**3138**

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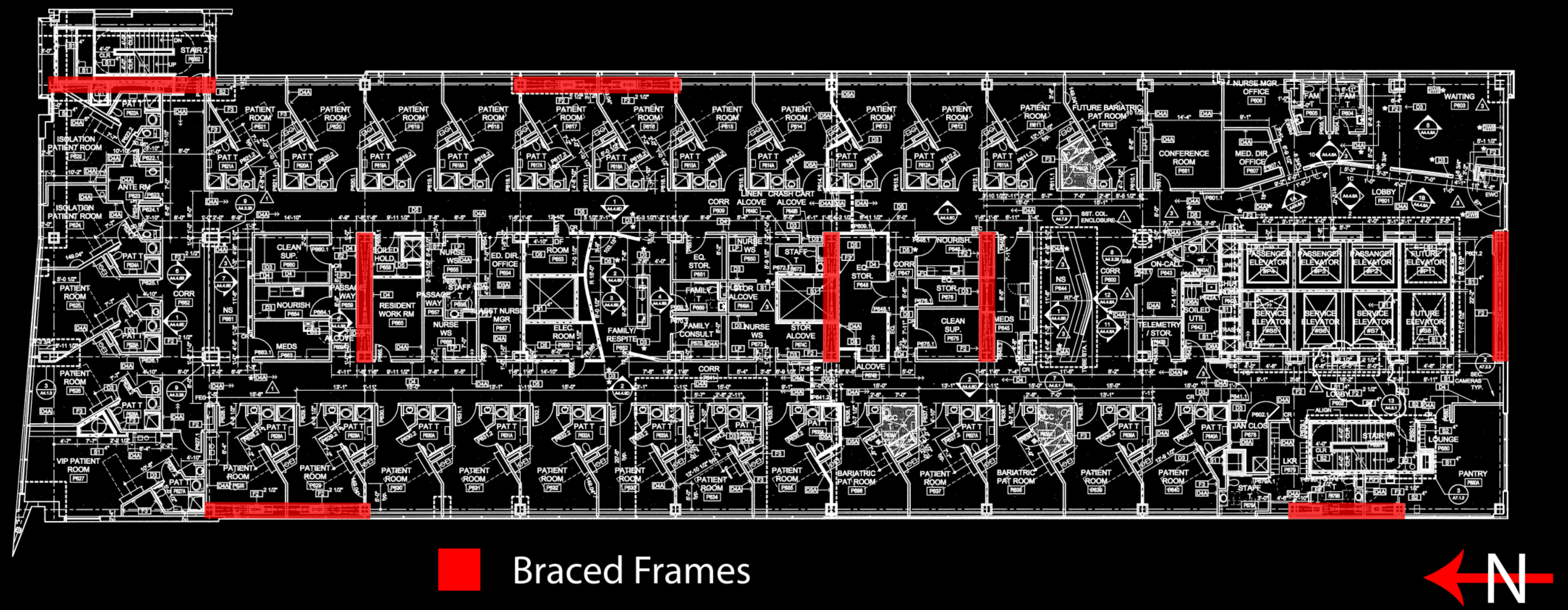
Lateral System Layout



Existing Lateral System

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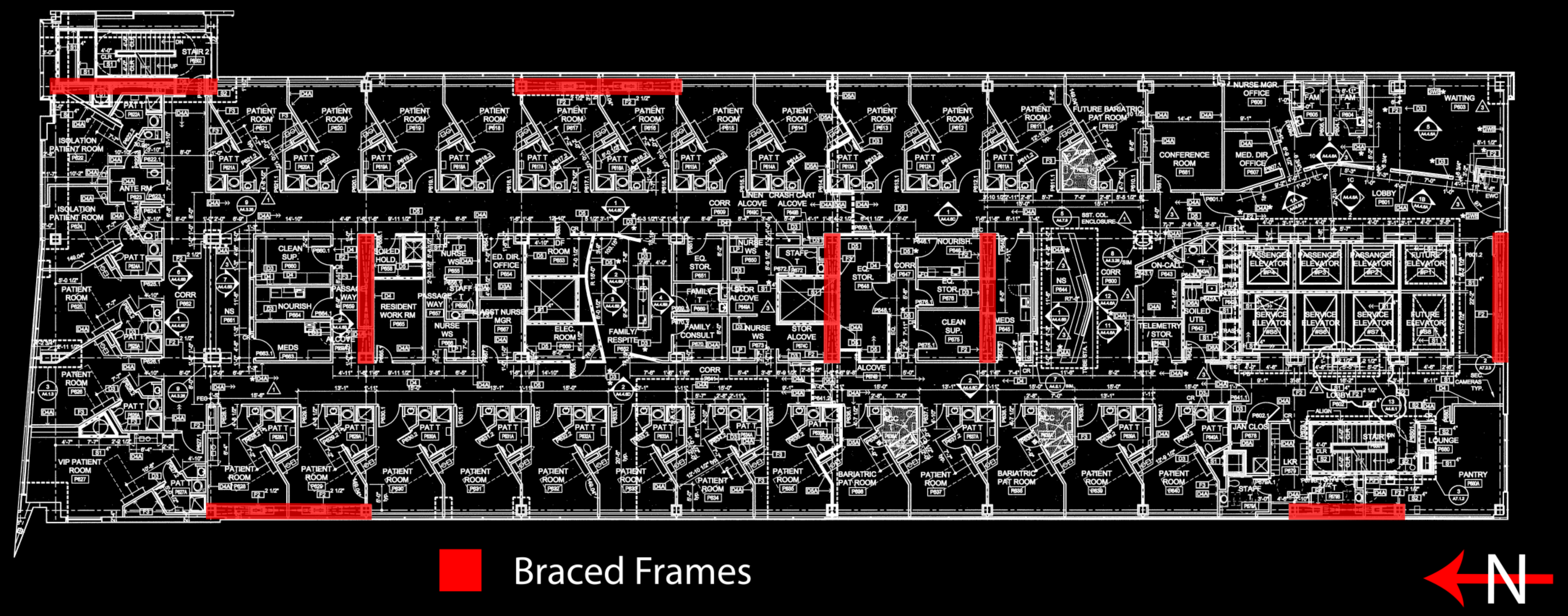

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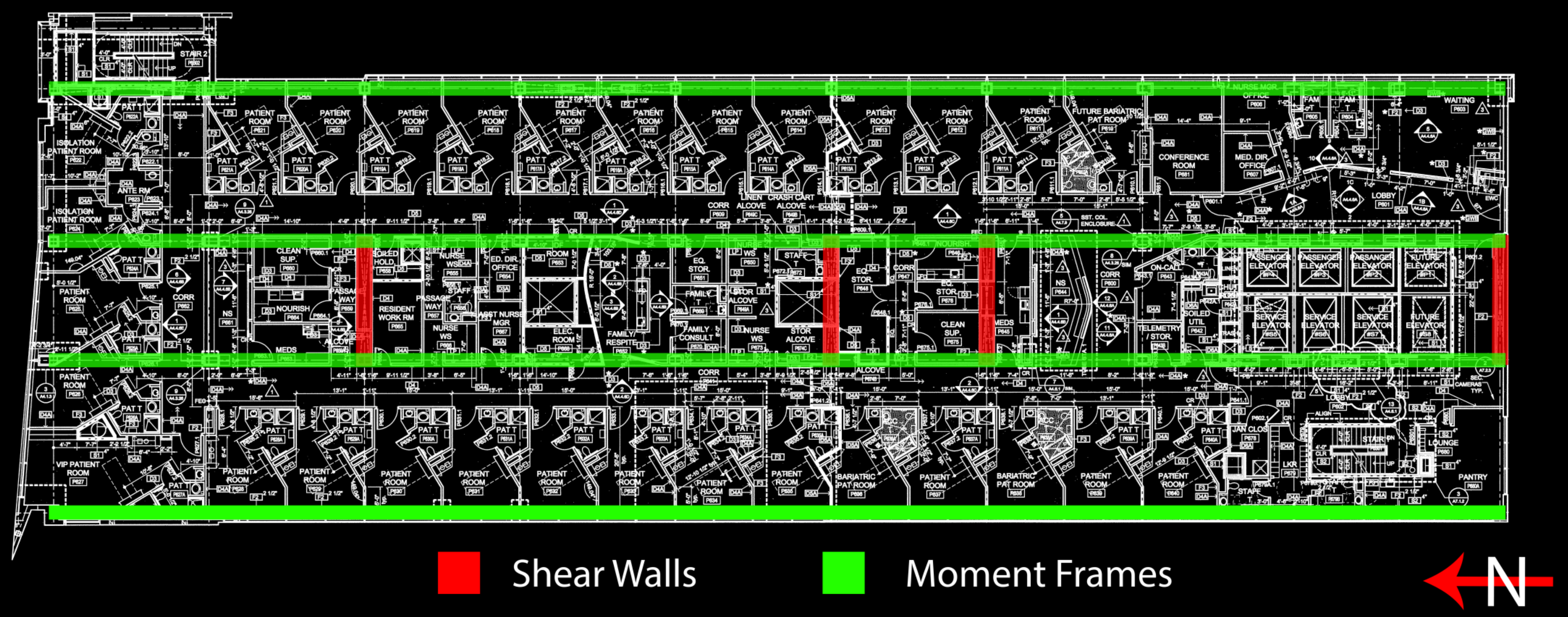

Proposed Lateral System

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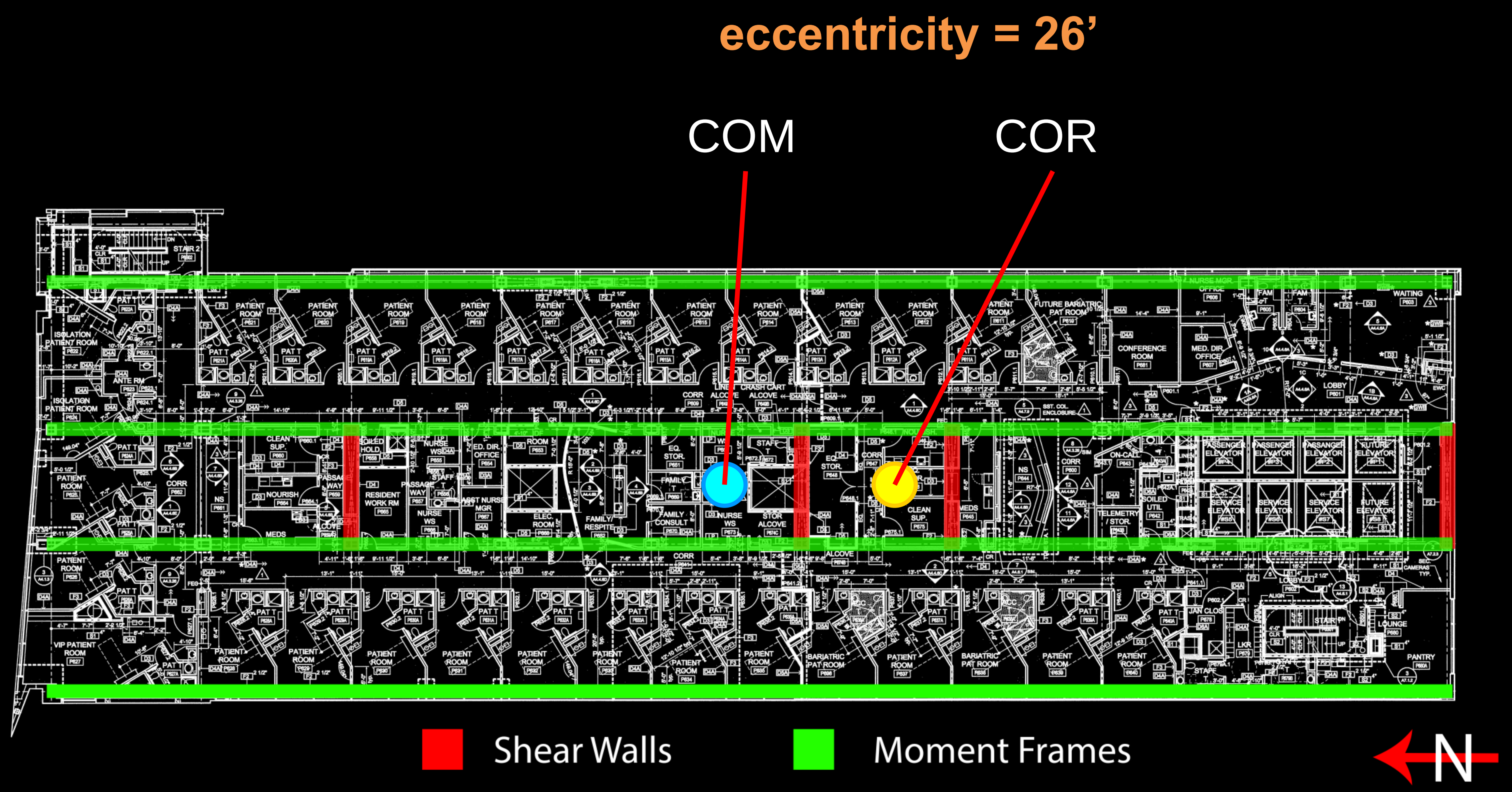
Lateral System Layout

- Shear walls in E-W direction
- Moment frames in N-S direction
  - Exterior Frames: columns & edge beams
  - Interior Frames: columns & slab
- Torsional Irregularity
  - Large eccentricity between COM & COR



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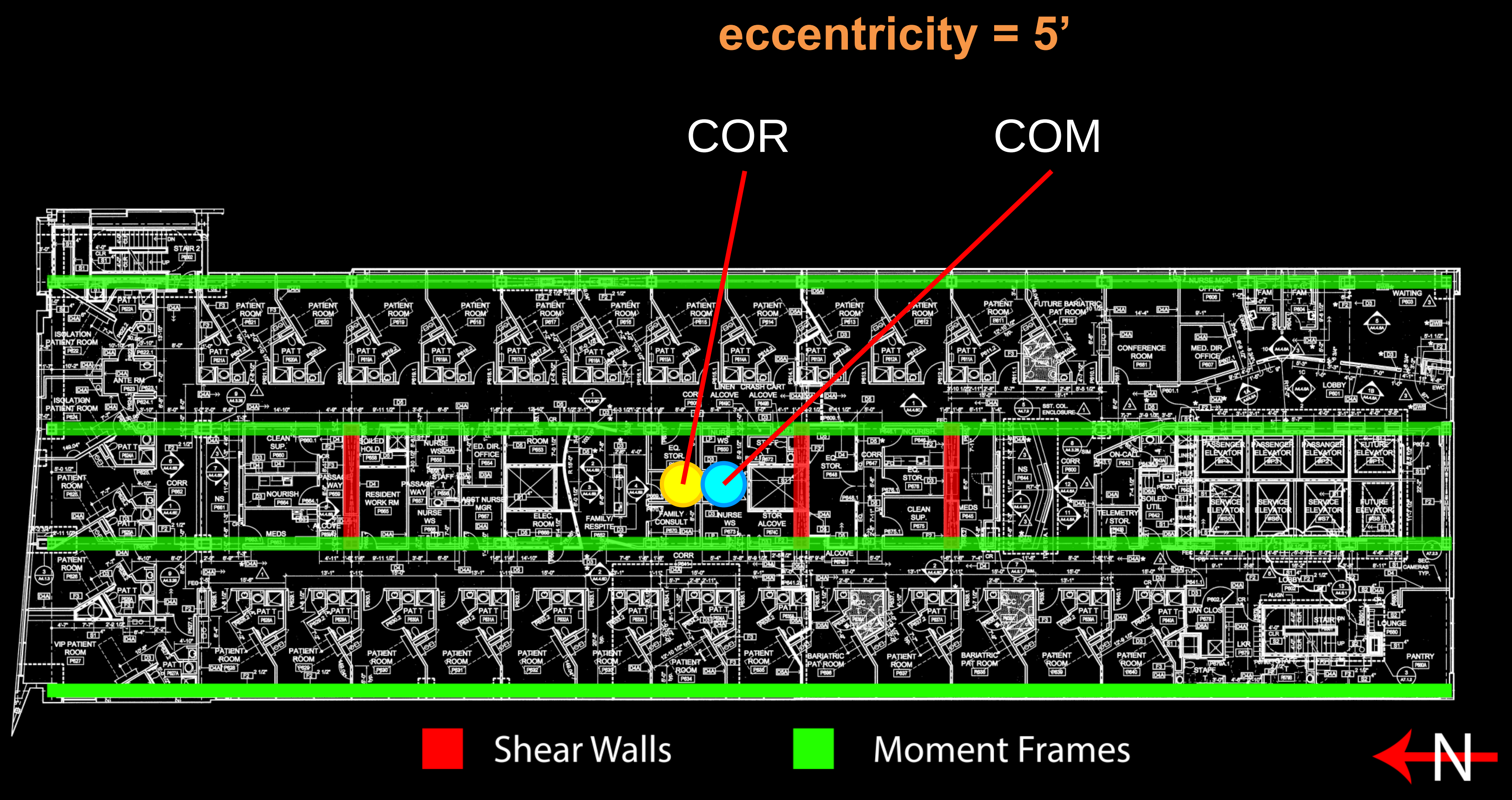

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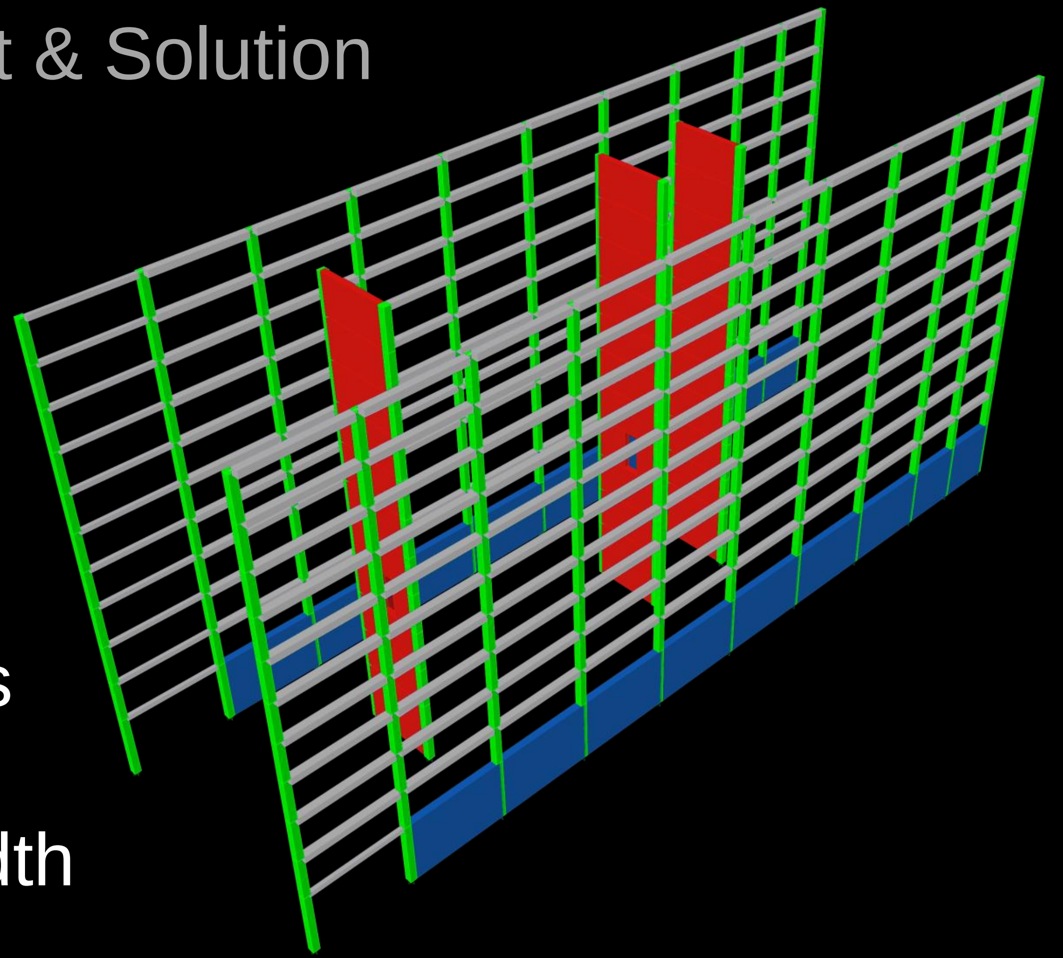
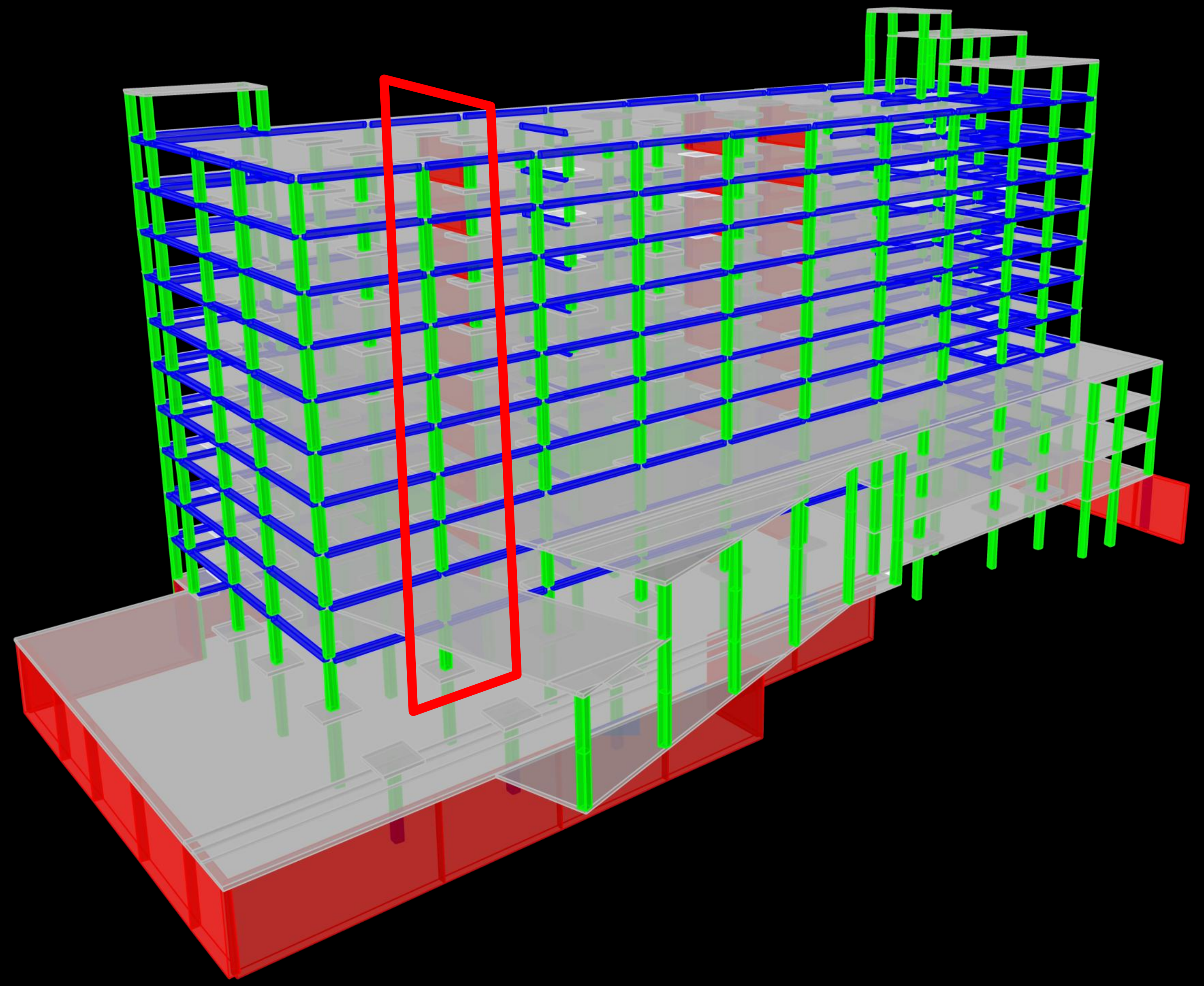


ETABS Model

- Rigid diaphragm constraints
- Walls neglect out of plane stiffness
- Stiffness modifiers based on ACI 318-11 section 10.10.4.1
- Drift checks



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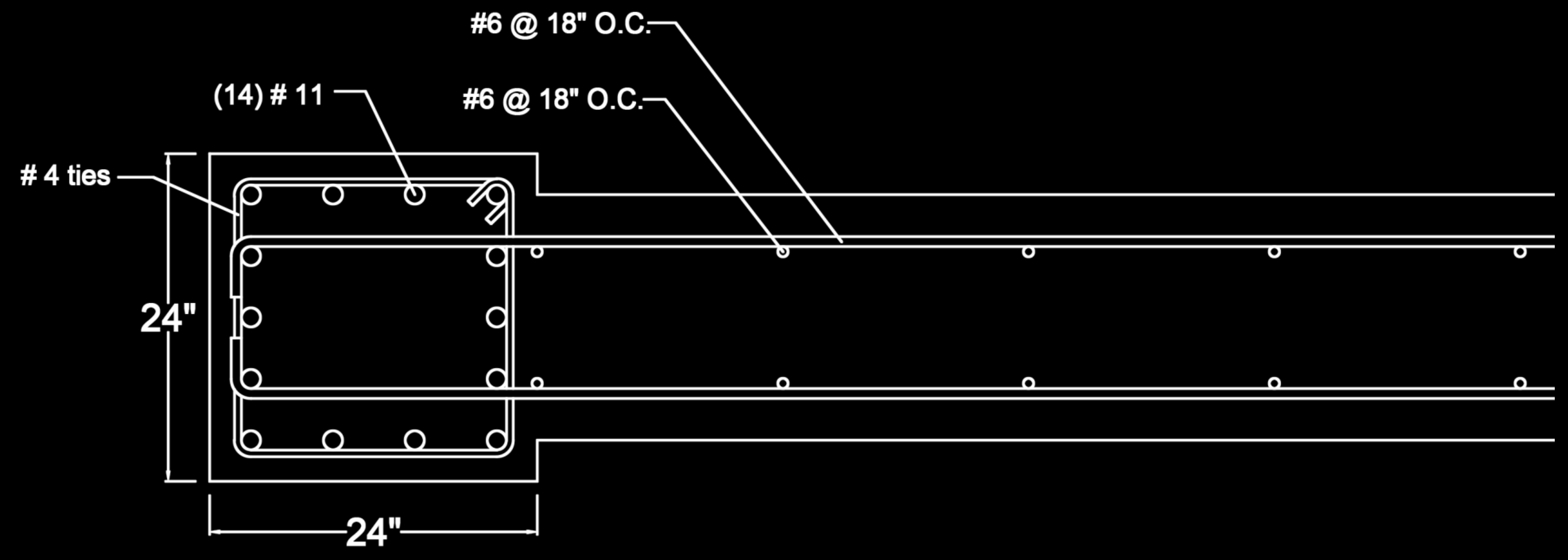
Shear Wall Design



- V = 1038 k
- M = 52,240 ft-k

- Controlling load combination
  0.9D + 1.0E
- Height – 138’
- Width – 25’
- Wall thickness - 18”
- Columns act as boundary elements
- Tension & Compression reinforcing for overturning moment

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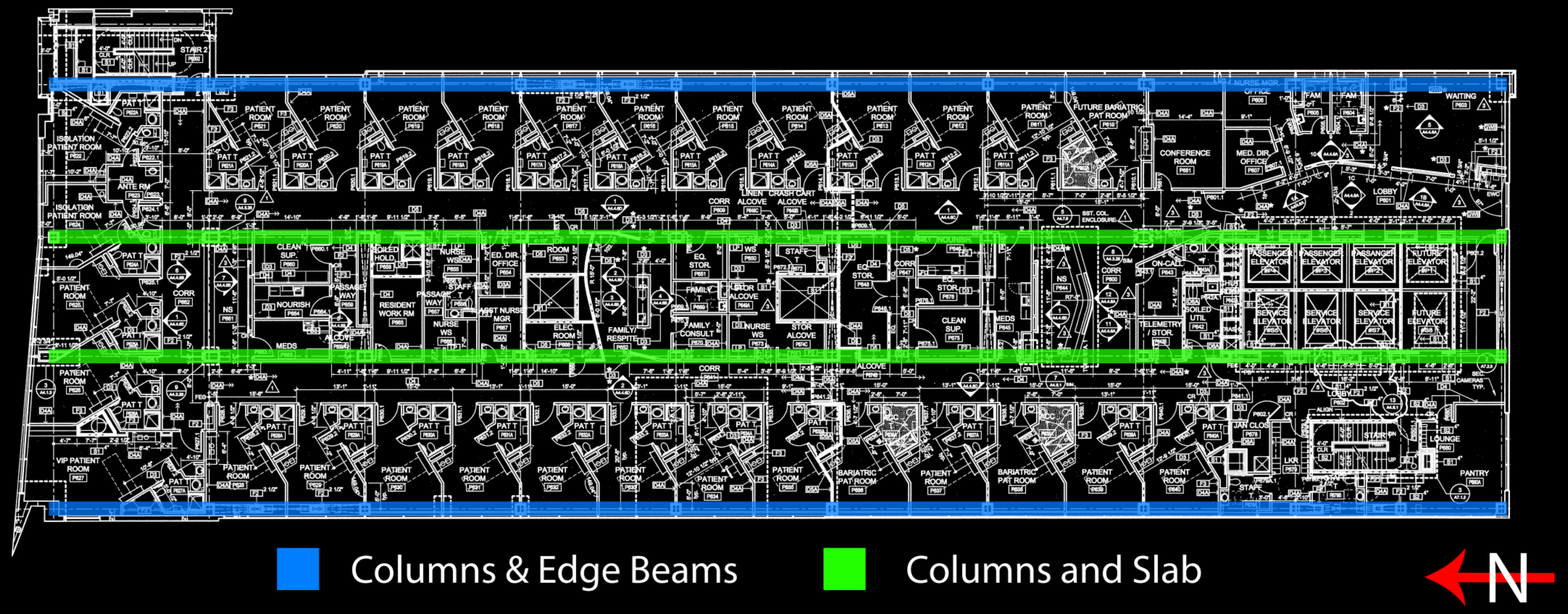
Moment Frame Design

- Drifts checked to find acceptable size
  - Edge beams 24” x 24”
- Portal analysis to verify ETABS output
- Edge frames stiffer than interior frames

Shear (kips)				
	Frame B (Ext)	Frame C (Int)	Frame D (Int)	Frame E (Ext)
Ex + Ext	**663**	**197**	353	661
Ex - Ext	647	195	**354**	**673**



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Moment Frame Design

- Controlling Load Combination
  1.2D + 1.0E + 1.0L
- Edge beam reinforcing
  - (5) - #10 bars top & bottom
  - #4 hoops @ 10”

- Slab reinforcing in addition to gravity loads
  - Column Strip — - Pos: + 0 bars; - Neg: + 6 bars
  - Middle Strip — - Pos: + 0 bars; - Neg: + 1 bar
- Column reinforcing also updated because of laterally induced moments and shear
  - B-7: (8) #8’s → (12) #9’s
  - Tie spacing reduced: 18” → 10”

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Acoustics

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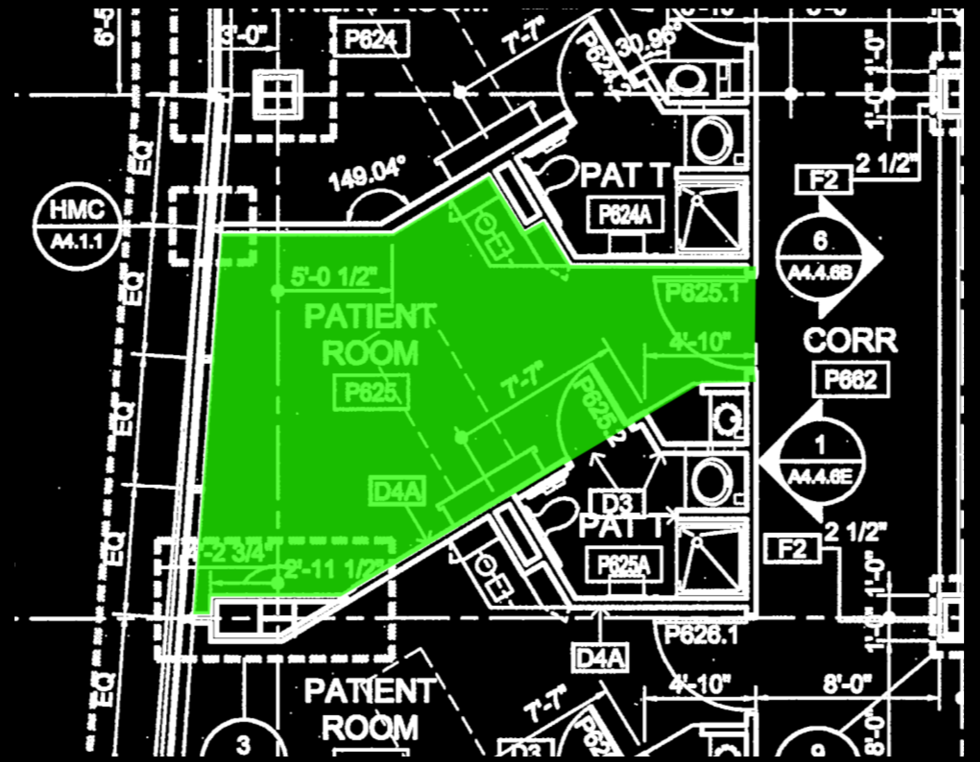
Roof Noise Transmission



10th Floor Patient Room

- Steel roof vs. concrete slab
- Chiller located on roof above
- Absorption 211 sabins
- Aim for RC-30

Patient Room 10th Floor							
Frequency (Hz)	**125**	**250**	**500**	**1000**	**2000**	**4000**
Chiller, L_1	85	87	87	90	98	91
Concrete TL	63	72	84	92	104	105
NR	62	71	83	91	103	104
L_2	23	16	4	0	0	0
Steel TL	41	52	52	71	75	78
NR	40	51	51	70	74	77
L_2	45	36	36	20	24	14
RC-30	45	40	35	30	25	20
NR Req	40	47	52	60	73	71
TL Req	**41**	**48**	**53**	**61**	**74**	**72**

- Steel TL too low at 500 Hz

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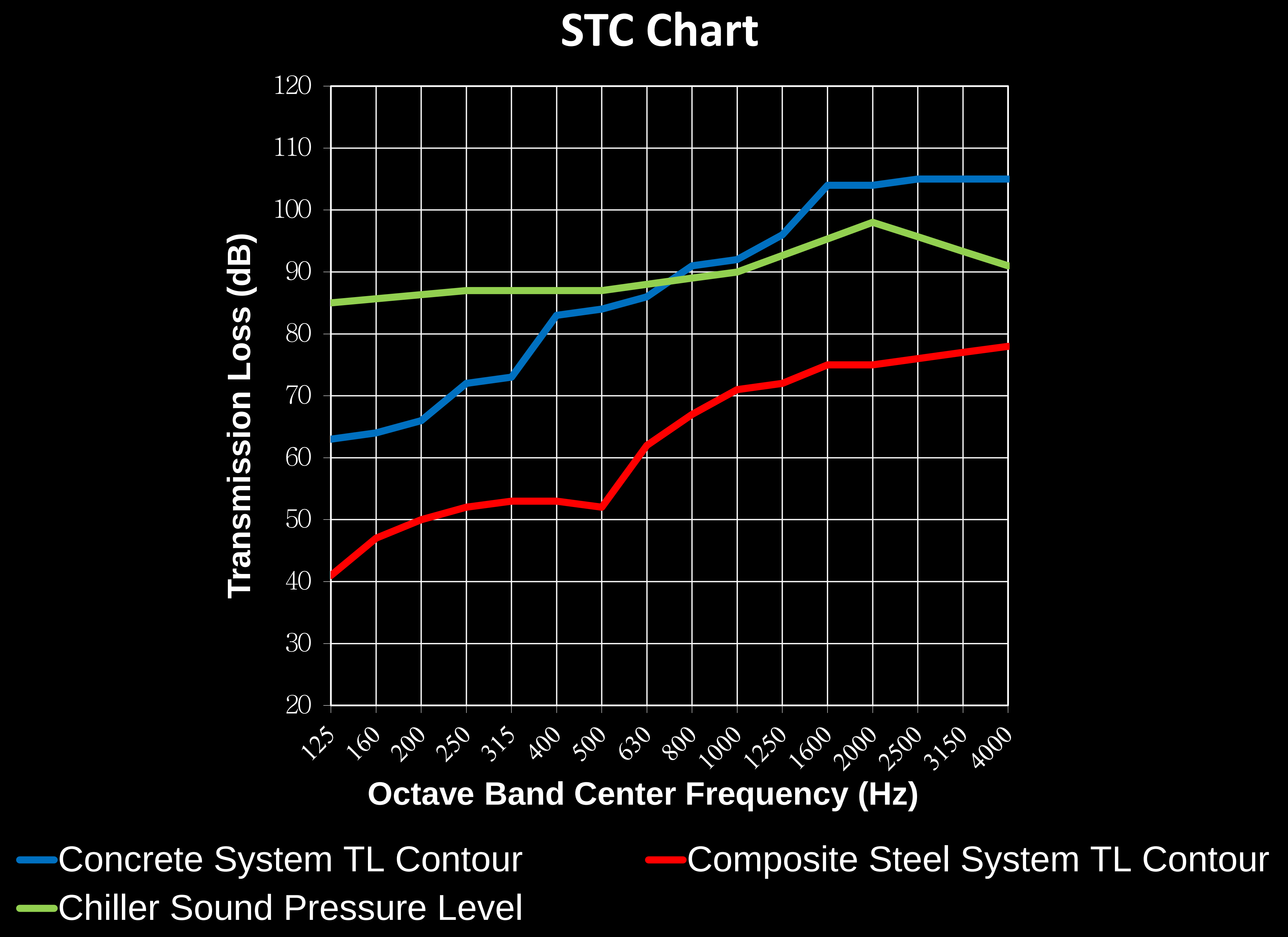

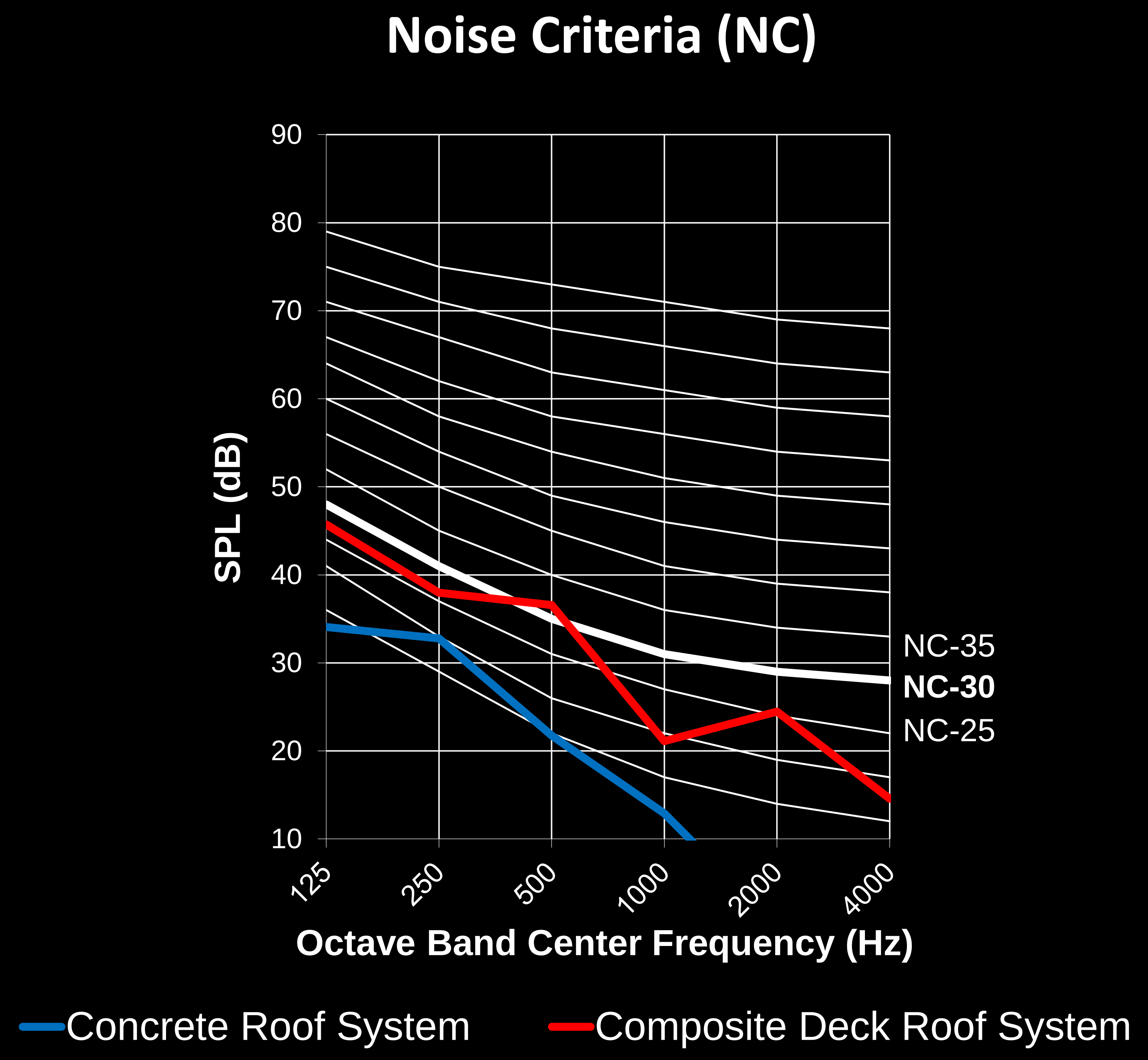

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Construction

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Steel Cost

- Steel cost calculated by tonnage
- Structure cost - 4% of total project cost
- Structural members - 67% of total cost

Steel Cost Breakdown	
Beams	$ 3,669,945
Columns	$ 2,054,205
Braces	$ 300,814
Fireproofing	$ 791,217
Steel Decking	$ 992,154
Conc Topping	$ 879,998
Placing Conc	$ 93,752
Finishing Conc	$ 247,320
Total	$ 9,029,405

$ 28.22 per SF

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Concrete Cost

- No fireproofing for concrete structure
- Formwork – 56% of total cost
- Reinforcing steel – 20% of total cost
- **7% cost savings over steel**
- **1' per floor decrease = 7750 SF of façade savings**

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Conc Topping	$ 879,998
Placing Conc	$ 93,752
Finishing Conc	$ 247,320
Total	$ 9,029,405

$ 28.22 per SF

Concrete Cost Breakdown	
Formwork	$ 4,684,332
Conc Vol	$ 1,254,047
Placing	$ 438,709
Finishing	$ 376,472
Reinf Steel	$ 1,653,306
Total	$ 8,406,867

$ 26.27 per SF

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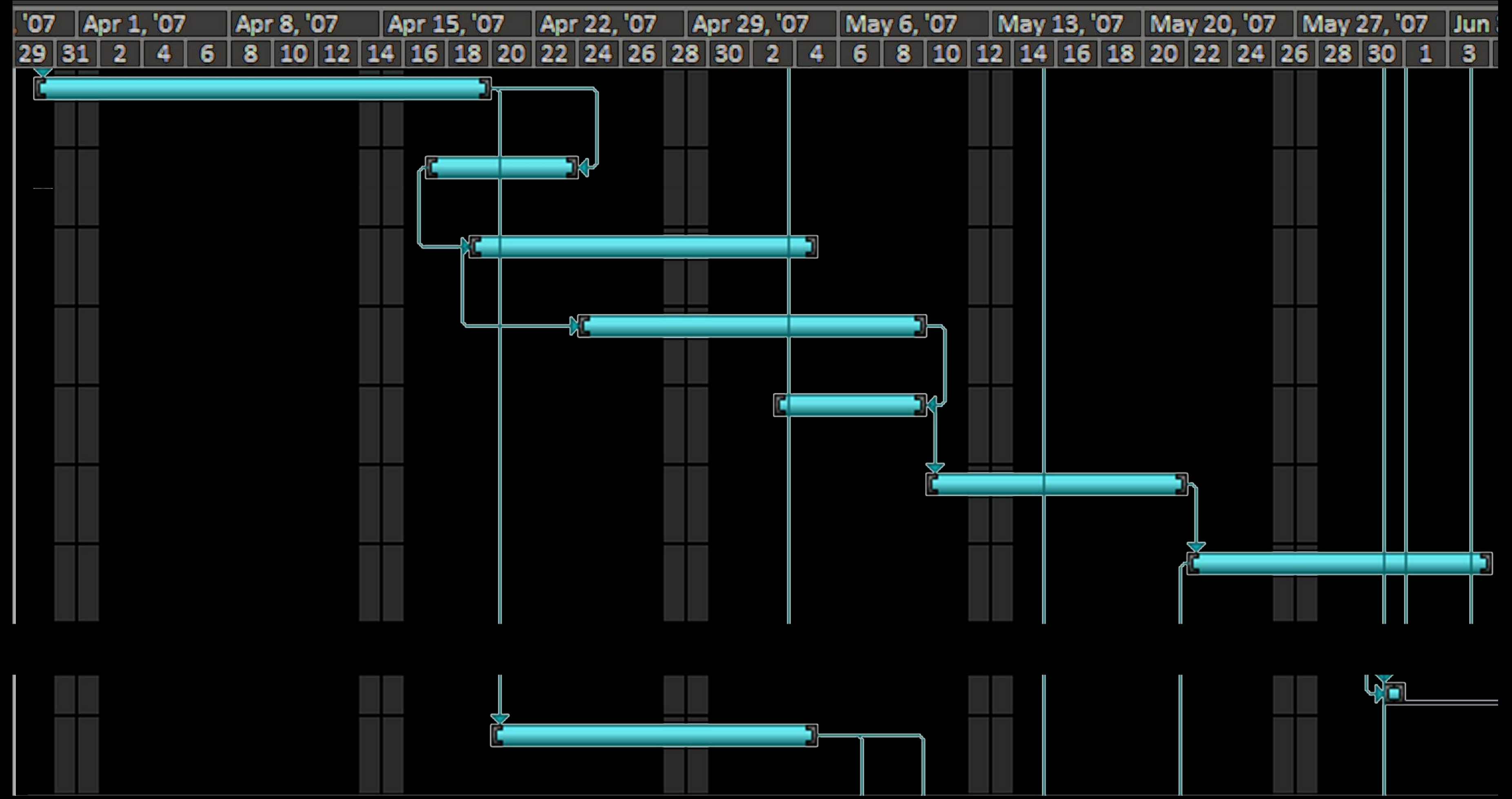
Steel Schedule

- Construction length – 188 days
- February '07- October '07

	Task Name	Durat	Predecessors
506	Install Structural Steel (3) Columns 4-8, Floors Base-4th	15 days	495
507	Plumb Structure Columns 4-8, Floors Base-4th	5 days	506FF+2 days
508	Detail and Moment Con Col 4-8, Flr's Base-4th	12 days	507SS+2 days
509	Metal Decking and Studs Col 4-8, Flr's Base-4th	12 days	508SS+3 days
510	Perimeter and Opening Protection Cols 4-8, Flr's 1st-4th	5 days	509FF
511	HVAC Rough in Slab on Metal Deck Col's 4-8, Flr's 1st-3rd	8 days	510
512	Reinforcement Steel & Mesh Col's 4-8, Flr's 1st-3rd	10 days	511
519	Pour Stair #1 Basement - 4th Floor	1 day	513SS,505
520	Install Structural Steel (3a) Column's 1-4 Flr's Base-4th	11 days	506



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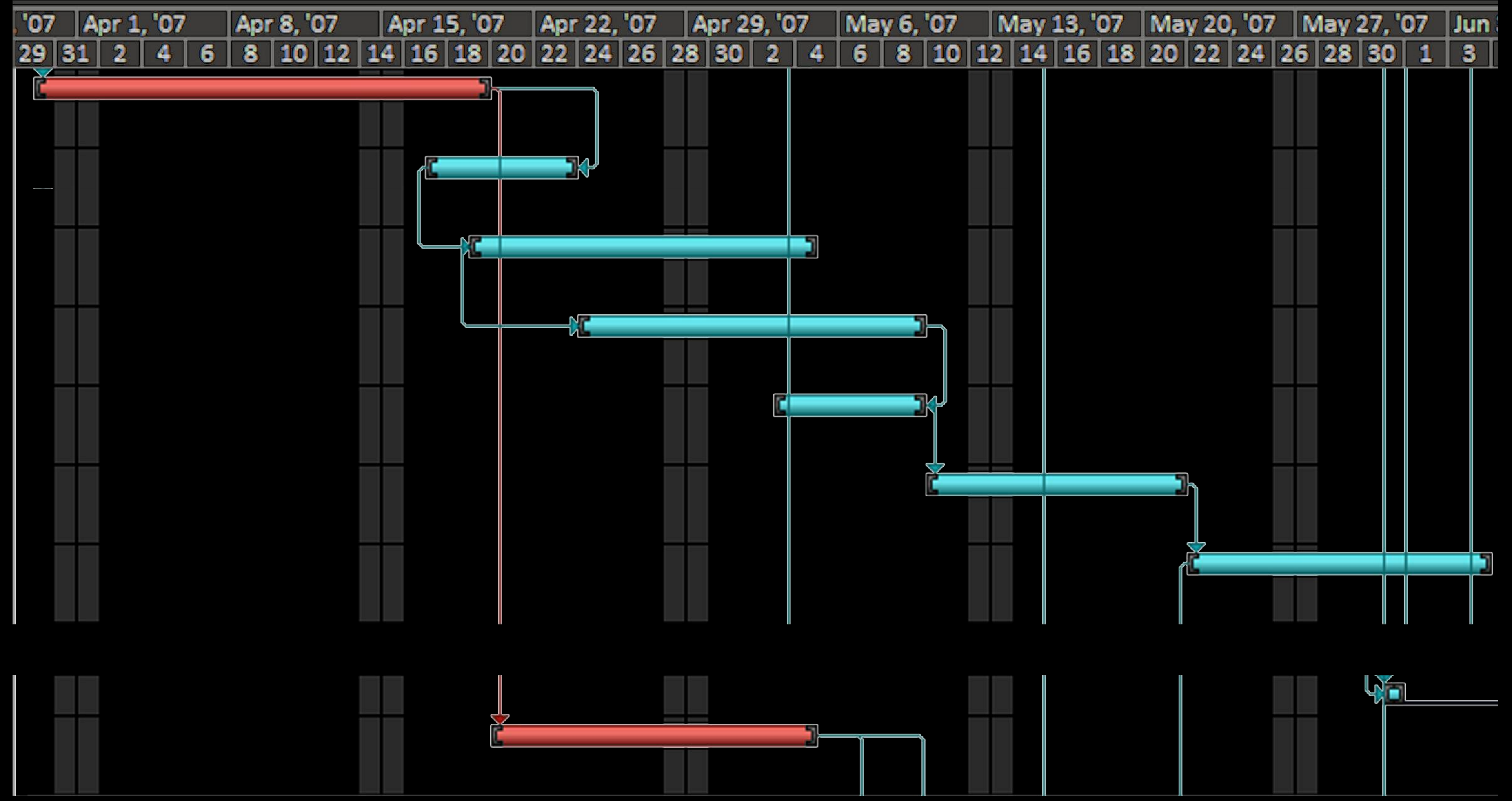

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Concrete Schedule

- Construction length – 260 days
- February '07-February '08
- 14 weeks longer than steel

Gantt Chart

	Task Name	Dura	Predecessors
502	Set Steel Reinforcing, Columns and Walls, 2nd Floor	4 days	499SS+1 day
503	Form Columns and Walls, 2nd Floor	6 days	502SS+2 days
504	Pour Columns and Walls, 2nd Floor	2 days	503FF+1 day
505	Form Slab, 3rd Floor	9 days	504SS+1 day
506	Set Steel Reinforcing, Slab, 3rd Floor	5 days	505FF+1 day
507	Pour Slab, 3rd Floor	7 days	506SS+1 day
508	Perimeter and Opening Protection, Slab, 3rd Floor	2 days	507
509	Finish Columns and Walls, 2nd Floor	5 days	507FS+10 days
510	Finish Slab, 2nd Floor	4 days	507FS+10 days
511	Set Steel Reinforcing, Columns and Walls, 3rd Floor	4 days	508SS+1 day
512	Form Columns and Walls, 3rd Floor	6 days	511SS+2 days
513	Pour Columns and Walls, 3rd Floor	2 days	512FF+1 day
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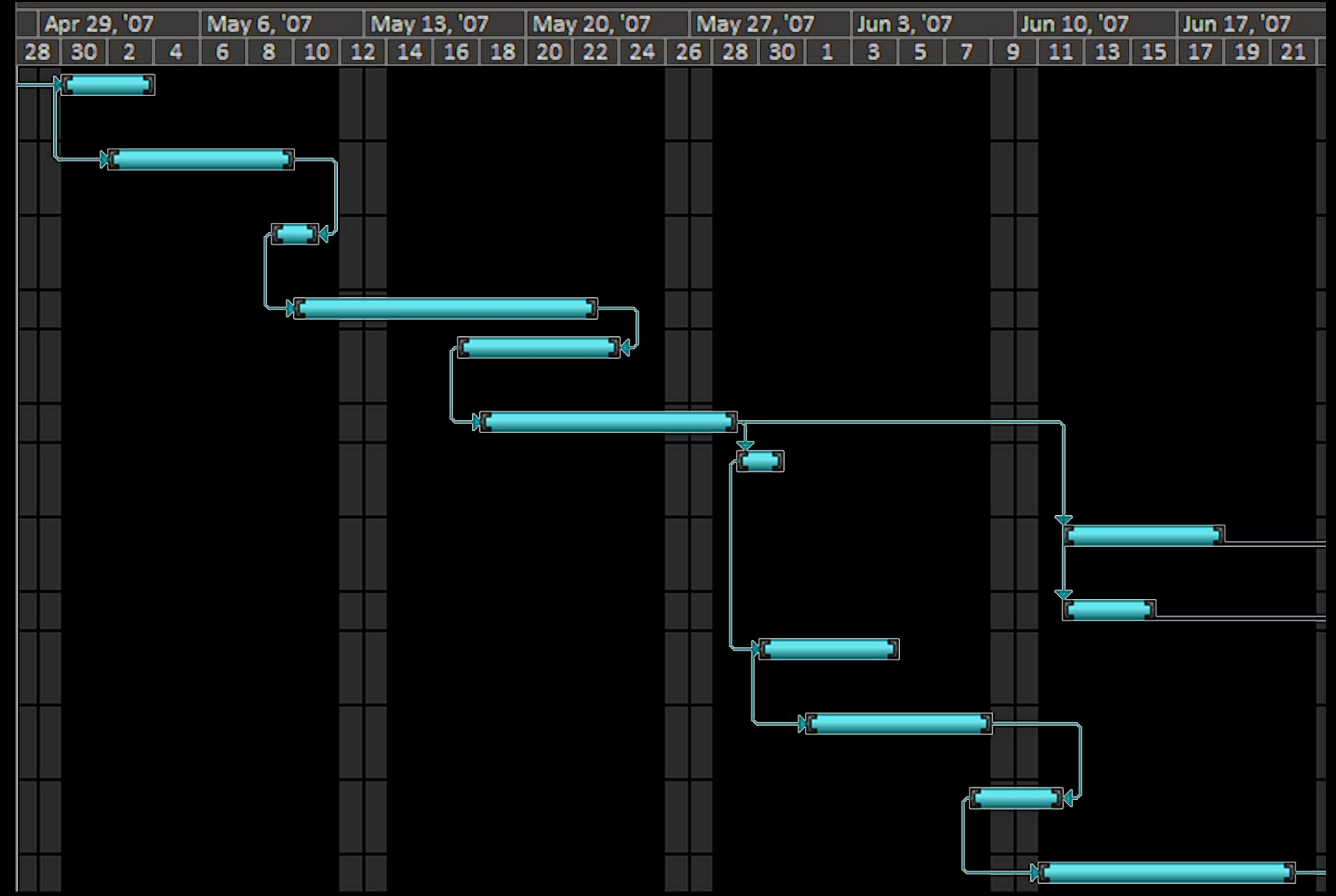

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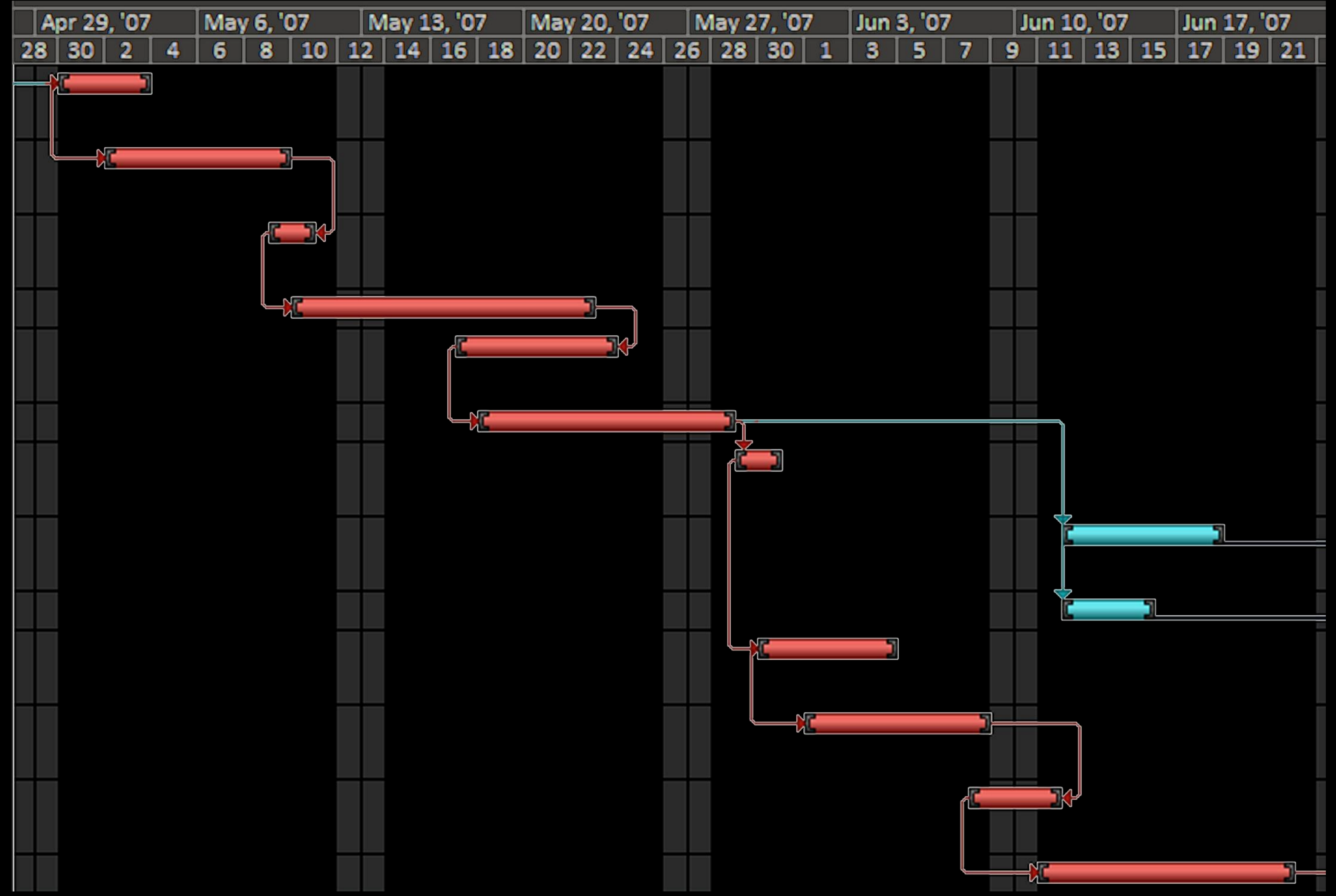
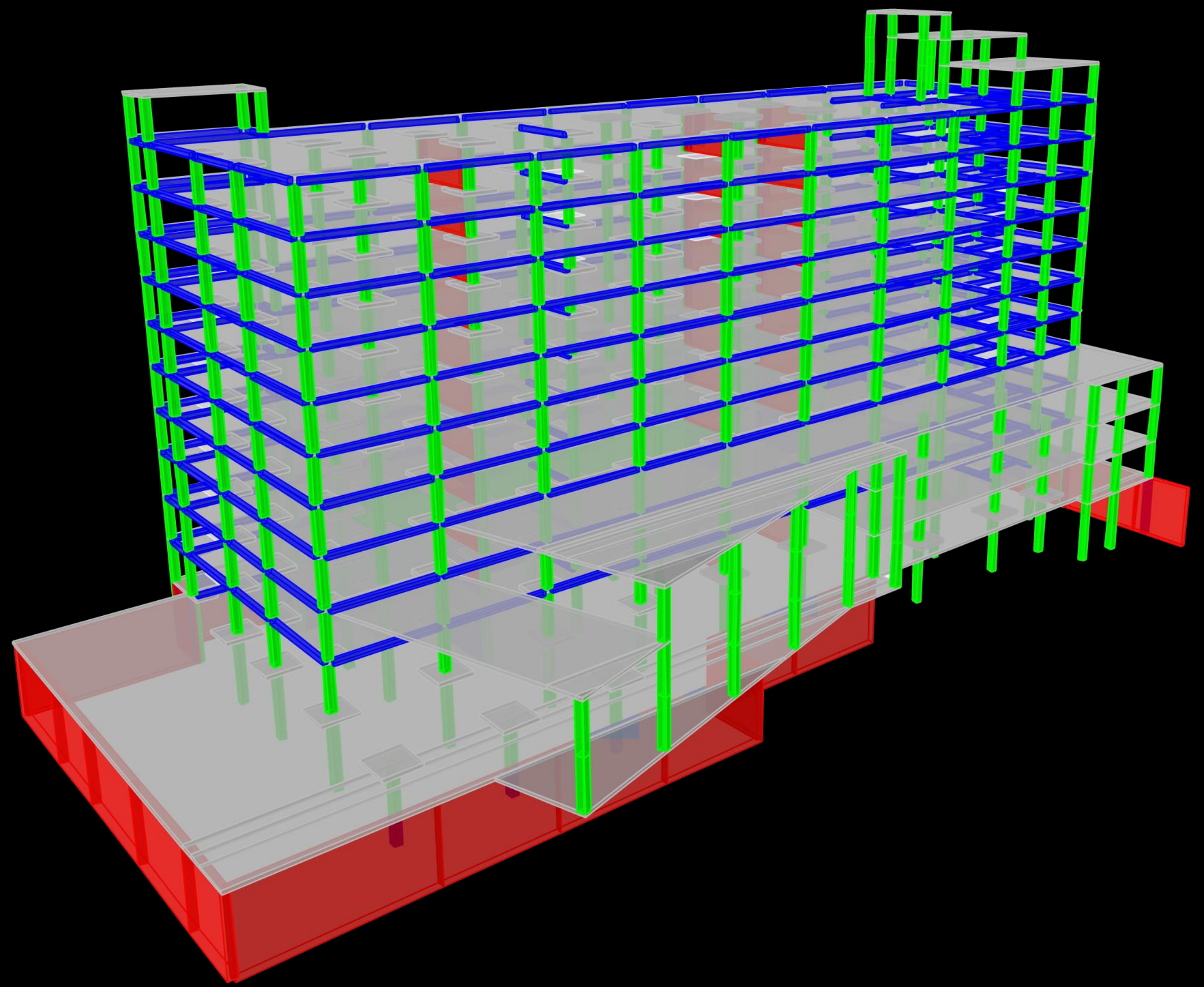


Conclusions

Redesign Recap

- Designed a feasible alternative to steel structure while minimally impacting the architecture
- Controlled lateral displacements
- Provided better acoustical performance
- Decreased cost slightly



Acknowledgements

Special Thanks to:

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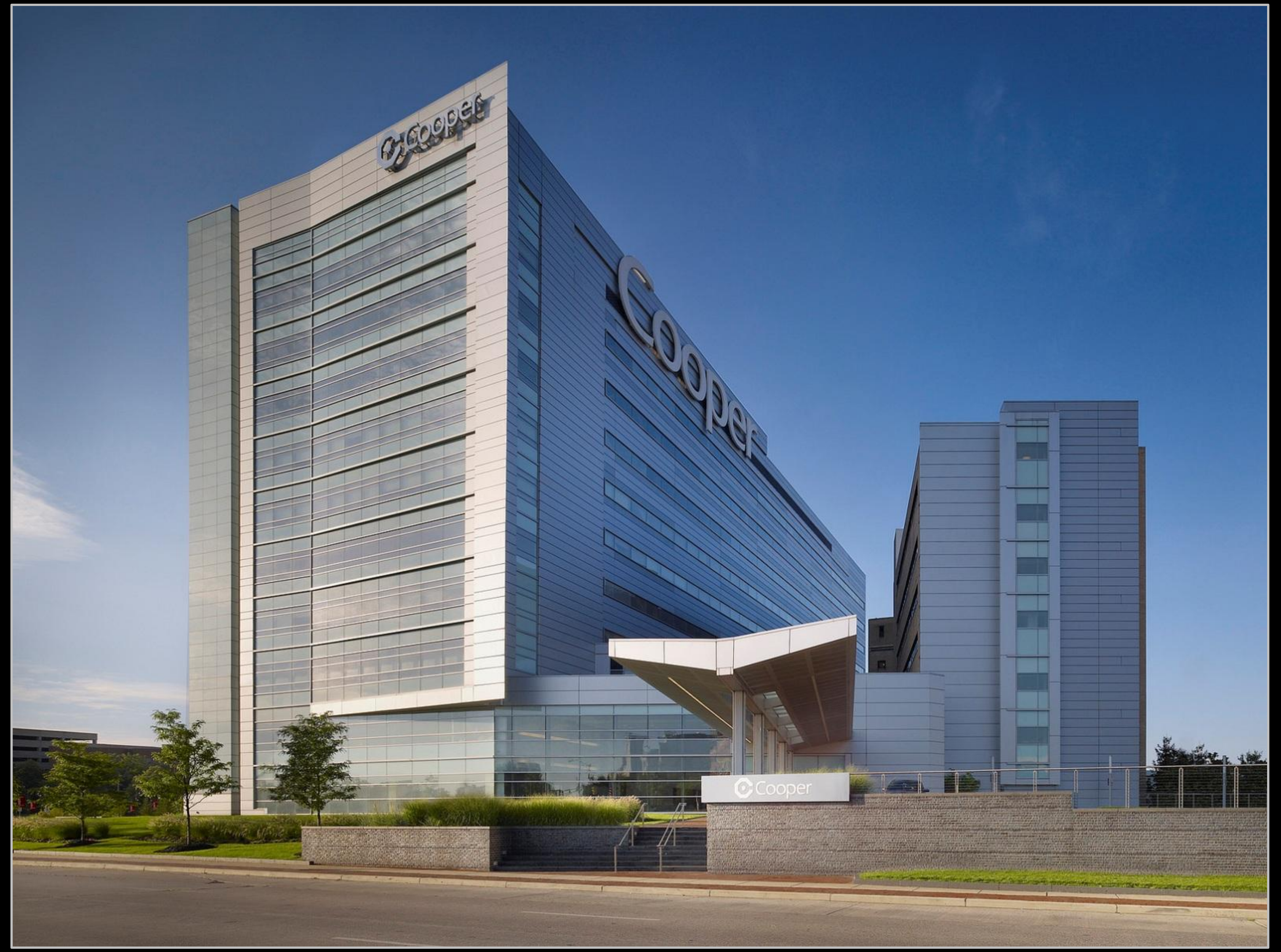
- The AE Faculty
- My family, friends, and classmates



Questions & Comments?