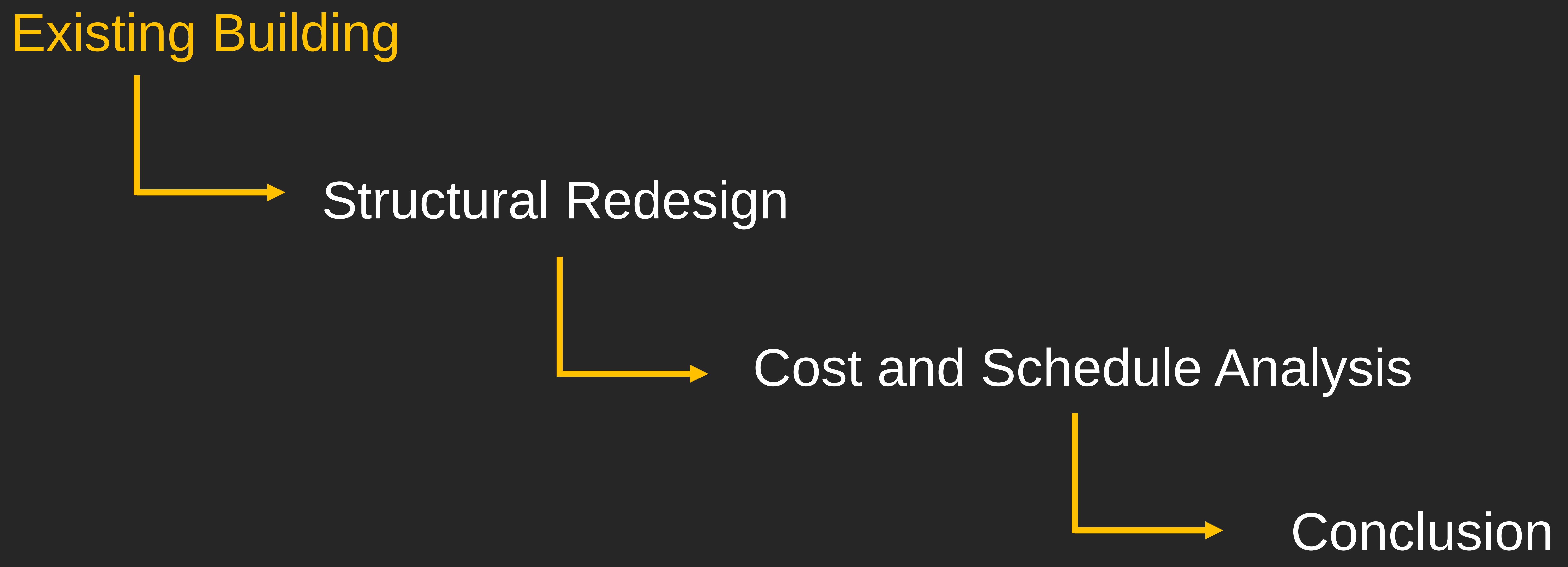
The Brendan Iribe Center for Computer Science and Innovation

College Park, Maryland

Brendan Barrett
Advisor: Dr. Aly Said
Structural Option
April 10, 2017

Brendan Iribe Center for Computer Science and Innovation

I. Building Overview
II. Design Proposal
III. Gravity System
  I. Voided Concrete Slab
  II. Gravity Columns
IV. Lateral System
  I. Shear Wall Layout
  II. Shear Wall Design
V. Construction Breadth
VI. Conclusion



Brendan Iribe Center for Computer Science and Innovation

I. Building Overview
II. Design Proposal
III. Gravity System
  I. Voided Concrete Slab
  II. Gravity Columns
IV. Lateral System
  I. Shear Wall Layout
  II. Shear Wall Design
V. Construction Breadth
VI. Conclusion

Existing Building

→ Structural Redesign

→ Cost and Schedule Analysis

→ Conclusion

Brendan Iribe Center for Computer Science and Innovation

I. Building Overview
II. Design Proposal
III. Gravity System
    I. Voided Concrete Slab
    II. Gravity Columns
IV. Lateral System
    I. Shear Wall Layout
    II. Shear Wall Design
V. Construction Breadth
VI. Conclusion

Existing Building

Structural Redesign

Cost and Schedule Analysis

Conclusion

Brendan Iribe Center for Computer Science and Innovation

Existing Building

→ Structural Redesign

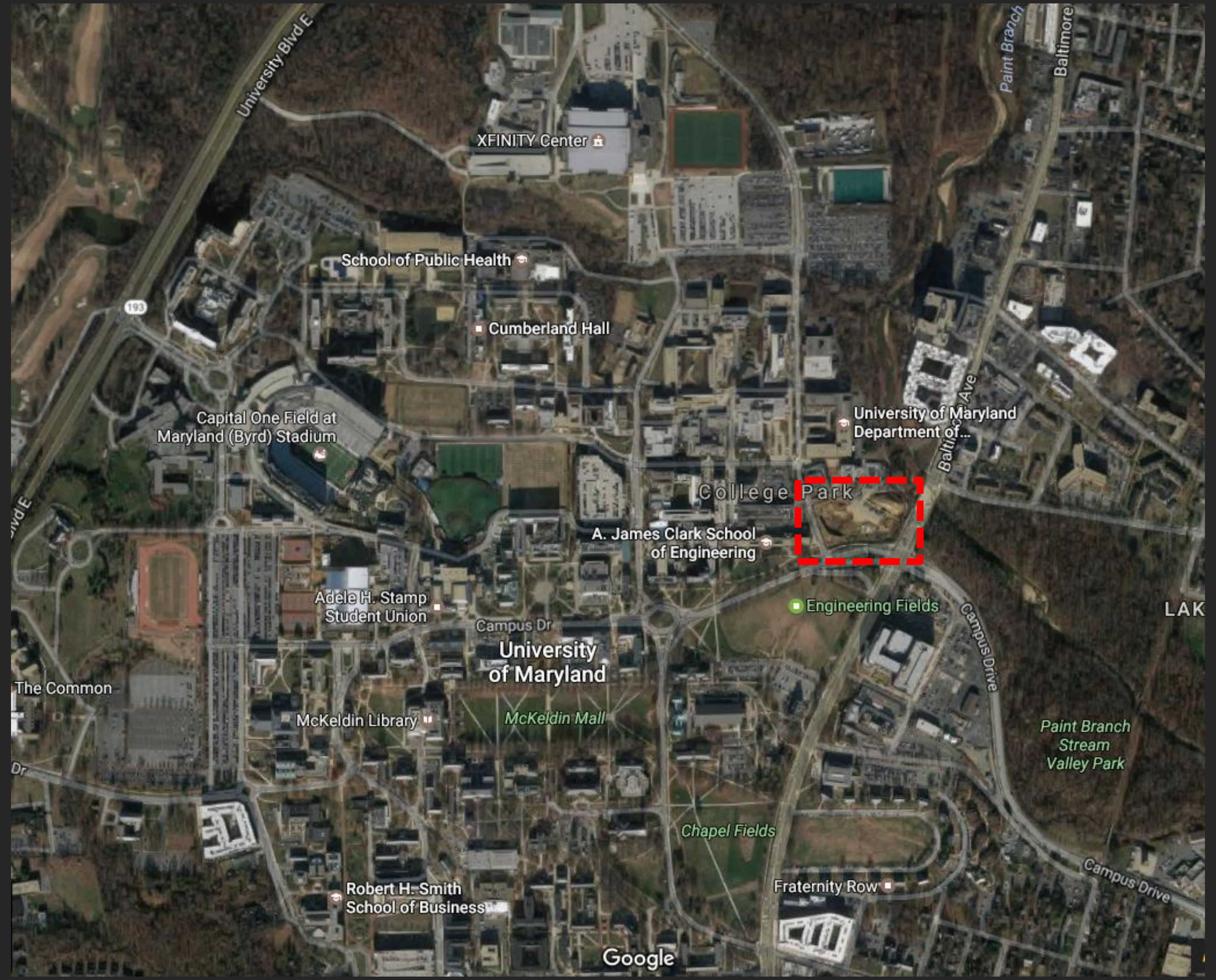
→ Cost and Schedule Analysis

→ Conclusion

Brendan Iribe Center for Computer Science and Innovation

I. Building Overview
II. Design Proposal
III. Gravity System
    I. Voided Concrete Slab
    II. Gravity Columns
IV. Lateral System
    I. Shear Wall Layout
    II. Shear Wall Design
V. Construction Breadth
VI. Conclusion

Site Plan



Brendan Iribe Center for Computer Science and Innovation

Building Statistics

Location	College Park, MD
Use	Higher Education
Size	215,600 sq. ft.
Height	118'-8"
Stories	7
Expected Opening	2018
Architect	HDR Architecture, Inc.
General Contractor	Whiting-Turner
Structural Engineer	Hope Furrer Associates

Brendan Iribe Center for Computer Science and Innovation

I. Building Overview
II. Design Proposal
III. Gravity System
    I. Voided Concrete Slab
    II. Gravity Columns
IV. Lateral System
    I. Shear Wall Layout
    II. Shear Wall Design
V. Construction Breadth
VI. Conclusion

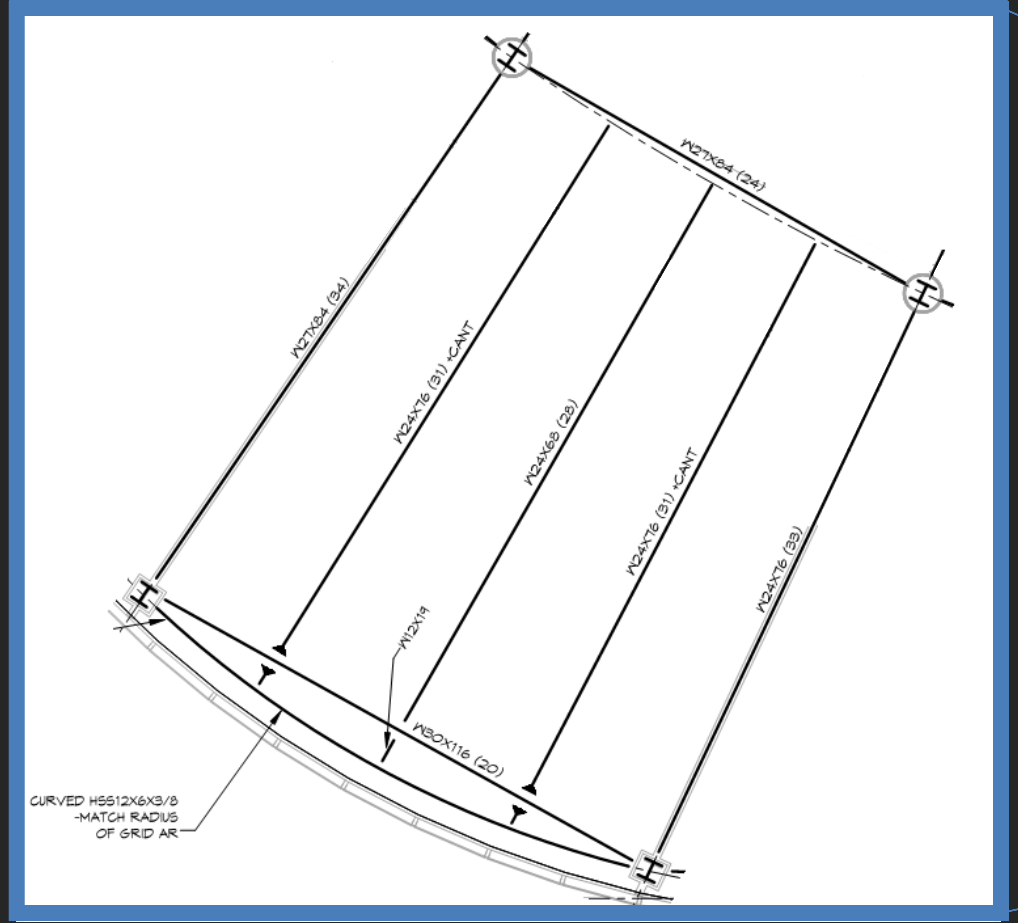
Building Statistics

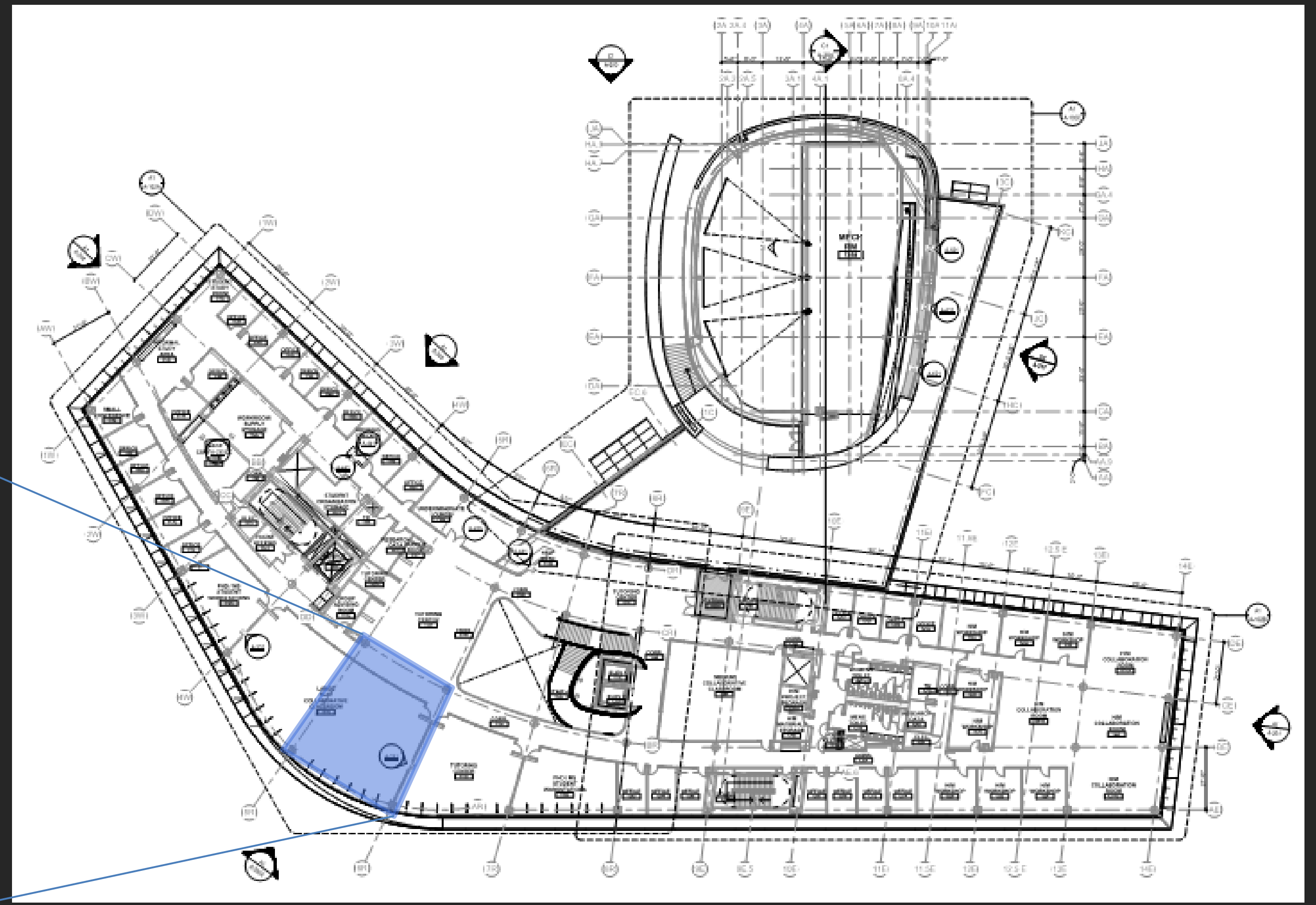
Location	College Park, MD
Use	Higher Education
Size	215,600 sq. ft.
Height	118’-8”
Stories	7
Expected Opening	2018
Architect	HDR Architecture, Inc.
General Contractor	Whiting-Turner
Structural Engineer	Hope Furrer Associates

Brendan Iribe Center for Computer Science and Innovation

I. Building Overview
II. Design Proposal
III. Gravity System
    I. Voided Concrete Slab
    II. Gravity Columns
IV. Lateral System
    I. Shear Wall Layout
    II. Shear Wall Design
V. Construction Breadth
VI. Conclusion

Existing Gravity System

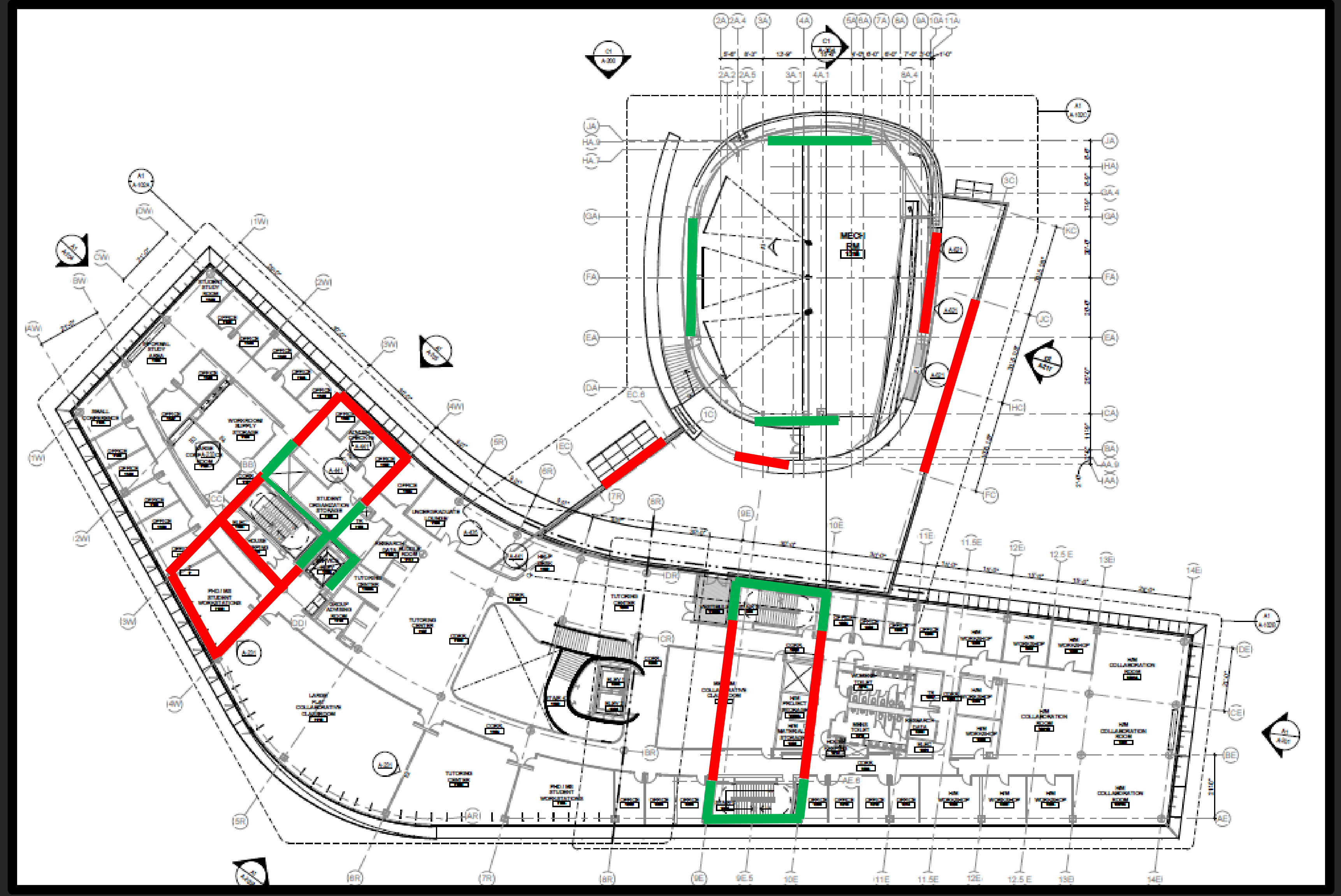




- Composite wide flange girders and columns
- 3 ¼” LW concrete on 3” 20 gage metal deck

Existing Lateral System

- Ordinary Moment Frames and Ordinary Braced Frames
  - Red-Moment Frames
  - Green- Braced Frames
- Typical beam in moment frames are W24s and W27s
- Typical brace are W10s and W12s



Problem Statement

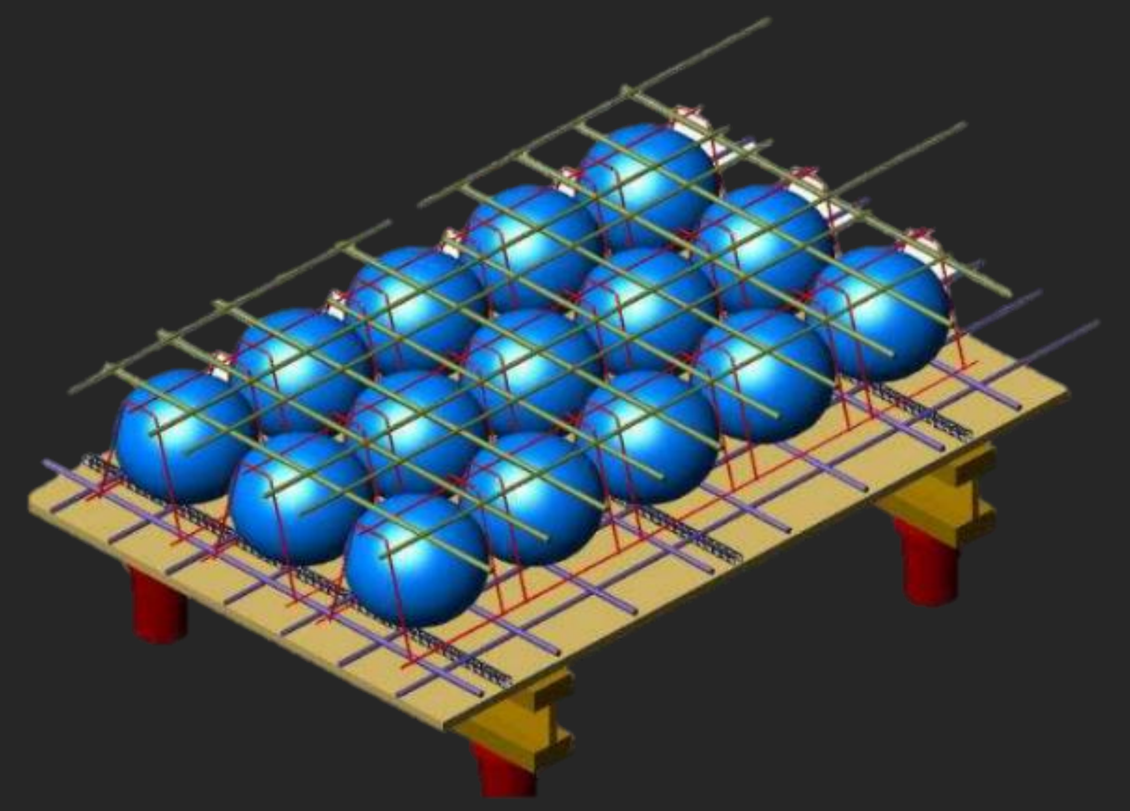
What alternate system could be a feasible design?

Goals

- Reduce structural depth
- Reduce cost
- Maintain open floor plan

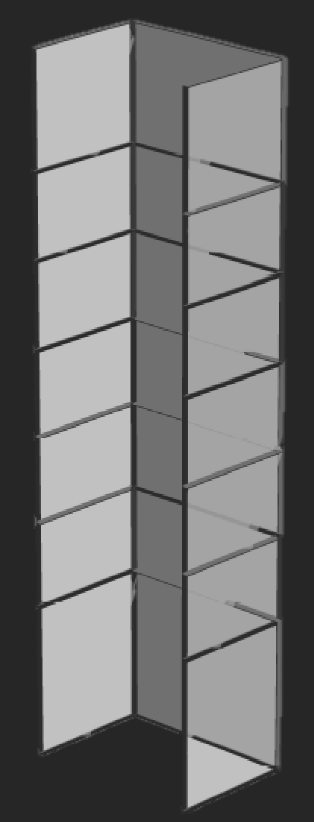
Brendan Iribe Center for Computer Science and Innovation

Gravity System



Voided Concrete Slab

Lateral System

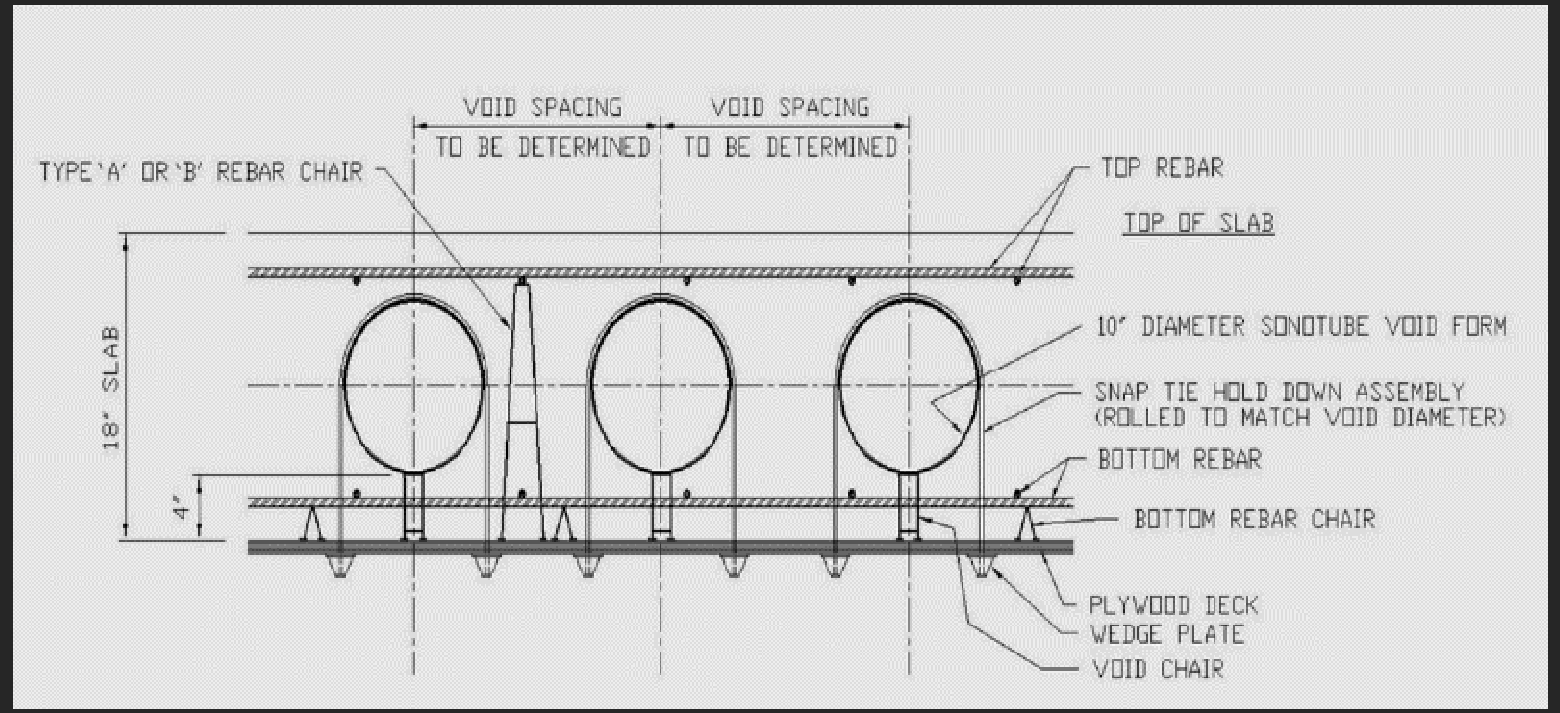


Reinforced Concrete Shear Walls

Gravity Redesign- Voided Slab

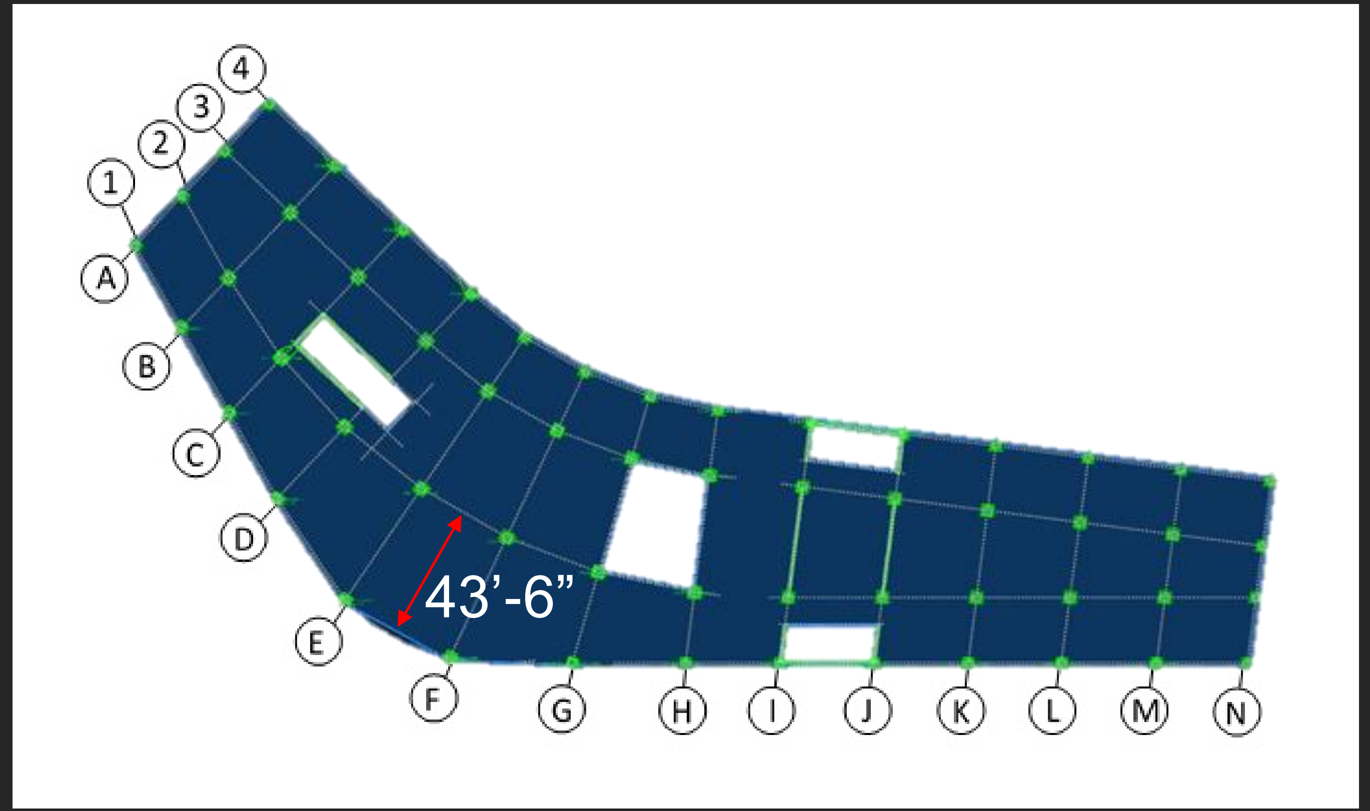
Advantages of a Voided Concrete Slab

- Reduces self weight by ~30-35%
- Reduces structural depth
- Reach longer spans than flat plate slab



Brendan Iribe Center for Computer Science and Innovation

Gravity Redesign- Voided Slab



From Table 8.3.1.1, minimum slab thickness:

$$h_{min} = \frac{l_n}{30} = \frac{(43.5 * 12) - (\frac{30}{2} + \frac{24}{2})}{30} = 16.5"$$

Exterior panel without edge beam without drop panel

Brendan Iribe Center for Computer Science and Innovation

Gravity Redesign- Voided Slab

Cobiax Eco-Line System

Slab depth (in)	17.5
Dead load reduction (psf)	-66
Stiffness correction factor	0.91
Shear reduction factor	0.55
Cage module support height (in)	12 5/8
Void former height (in)	12 3/8
Void former horizontal dimension (in)	12 3/8
Spacing between void formers (in)	1 3/8
Void formers center line spacing (in)	13 3/4
Number of void formers per sq ft	0.76
Concrete displacement per sq ft (cubic ft)	0.44
Void formers per cage module	7
Equivalent area per cage module (sq ft)	9.25

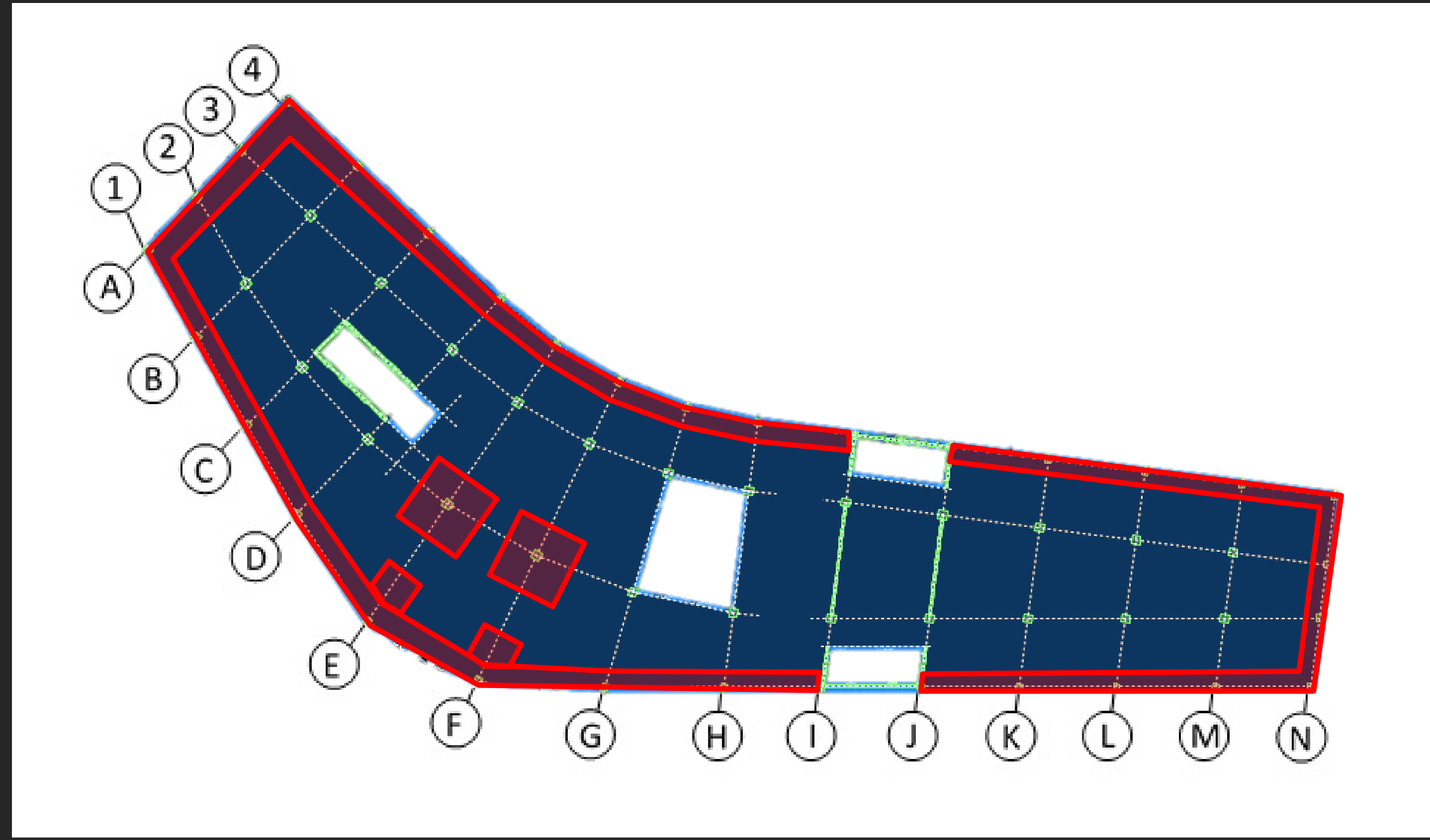
17.5” slab depth

Reduced dead load = 66 psf

New slab weight

$$= \frac{17.5 * 150}{12} - (.7 * 66) = 172.5\,psf$$

Gravity Redesign- Voided Slab



Solid slab required in two locations:

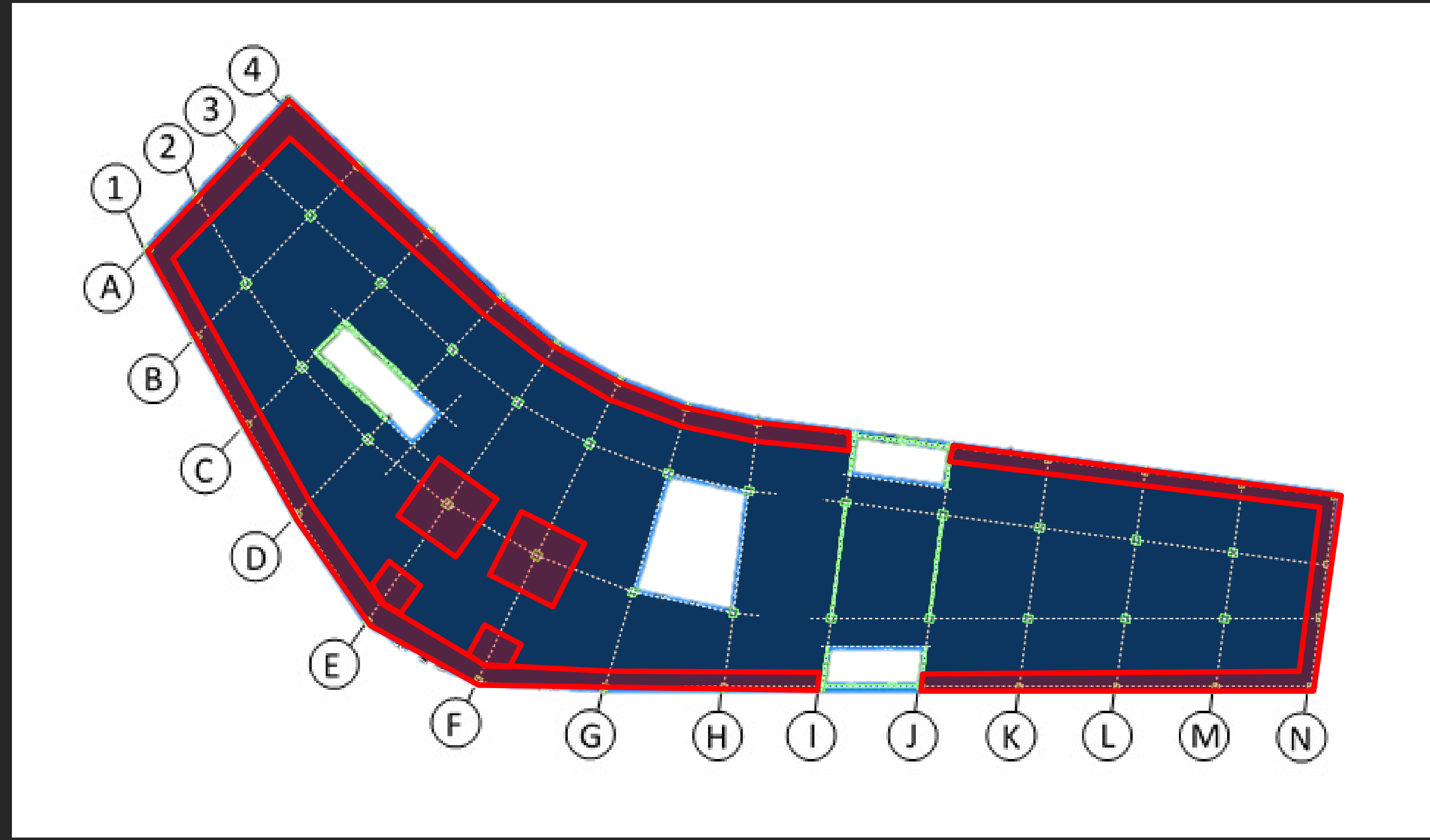
1) Perimeter of floor plate

2) Around columns where voided slab can't resist total shear stress

$$Solid\ slab = Trib\ area - \frac{(Shear\ reduction\ factor)(Allowable\ shear)}{Total\ factored\ uniformaly\ dist.load}$$

Brendan Iribe Center for Computer Science and Innovation

Gravity Redesign- Voided Slab



Column E1= 200 ft^2

Column E2= 450 ft^2

Column F1= 166 ft^2

Column F2= 450 ft^2

Gravity Redesign- Voided Slab

Cobiax Eco-Line System

Slab depth (in)	17.5
Dead load reduction (psf)	-66
Stiffness correction factor	0.91
Shear reduction factor	0.55
Cage module support height (in)	12 5/8
Void former height (in)	12 3/8
Void former horizontal dimension (in)	12 3/8
Spacing between void formers (in)	1 3/8
Void formers center line spacing (in)	13 3/4
Number of void formers per sq ft	0.76
Concrete displacement per sq ft (cubic ft)	0.44
Void formers per cage module	7
Equivalent area per cage module (sq ft)	9.25

17.5” slab depth

Reduced dead load = 66 psf

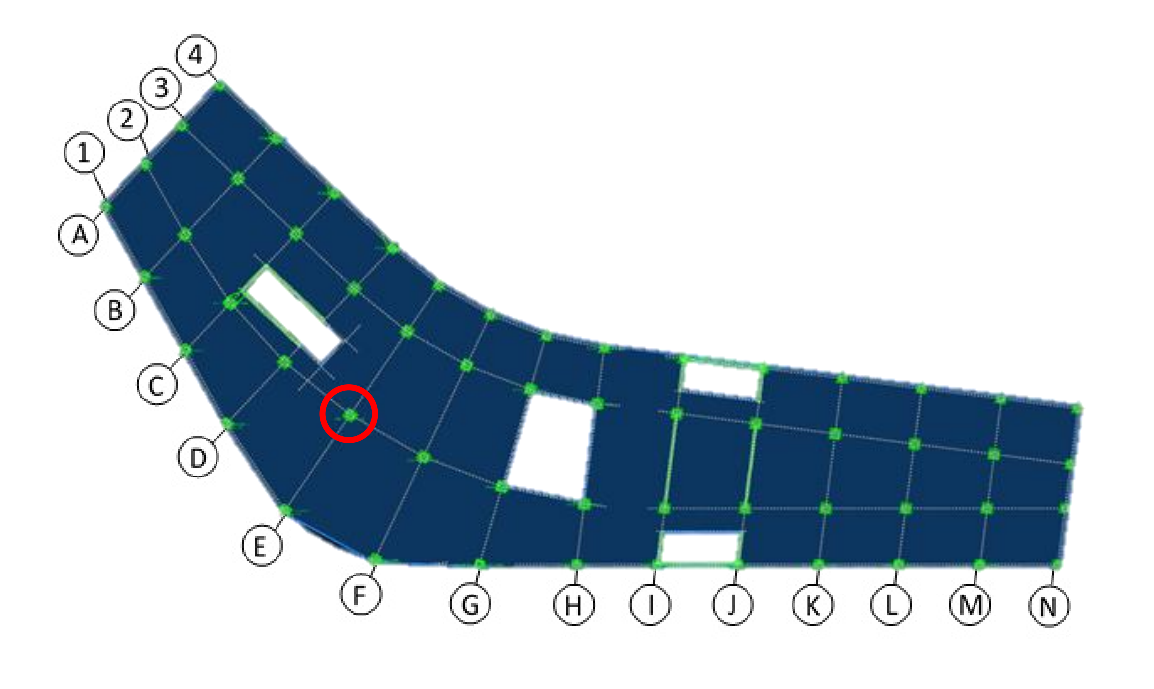
New slab weight

$$= \frac{17.5 * 150}{12} - (.7 * 66) = 172.5\, psf$$

Brendan Iribe Center for Computer Science and Innovation

Gravity Redesign- Voided Slab

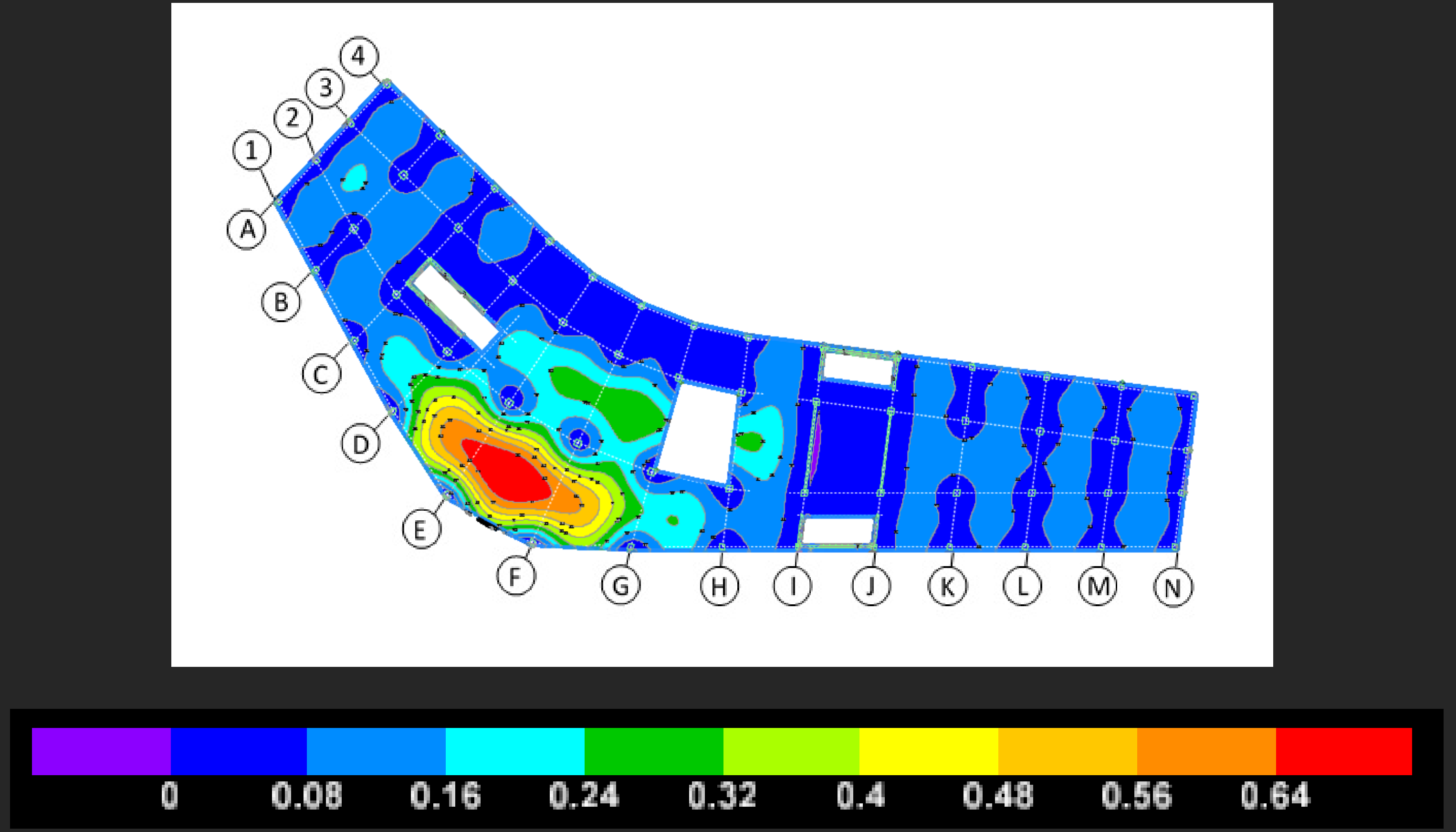
Punching Shear



ΦV_c = 189.7 psi > V_u = 159.5 psi ∴ OK

Deflection

Max = 0.77" < Allowable = L/480 = 1.08" ∴ OK

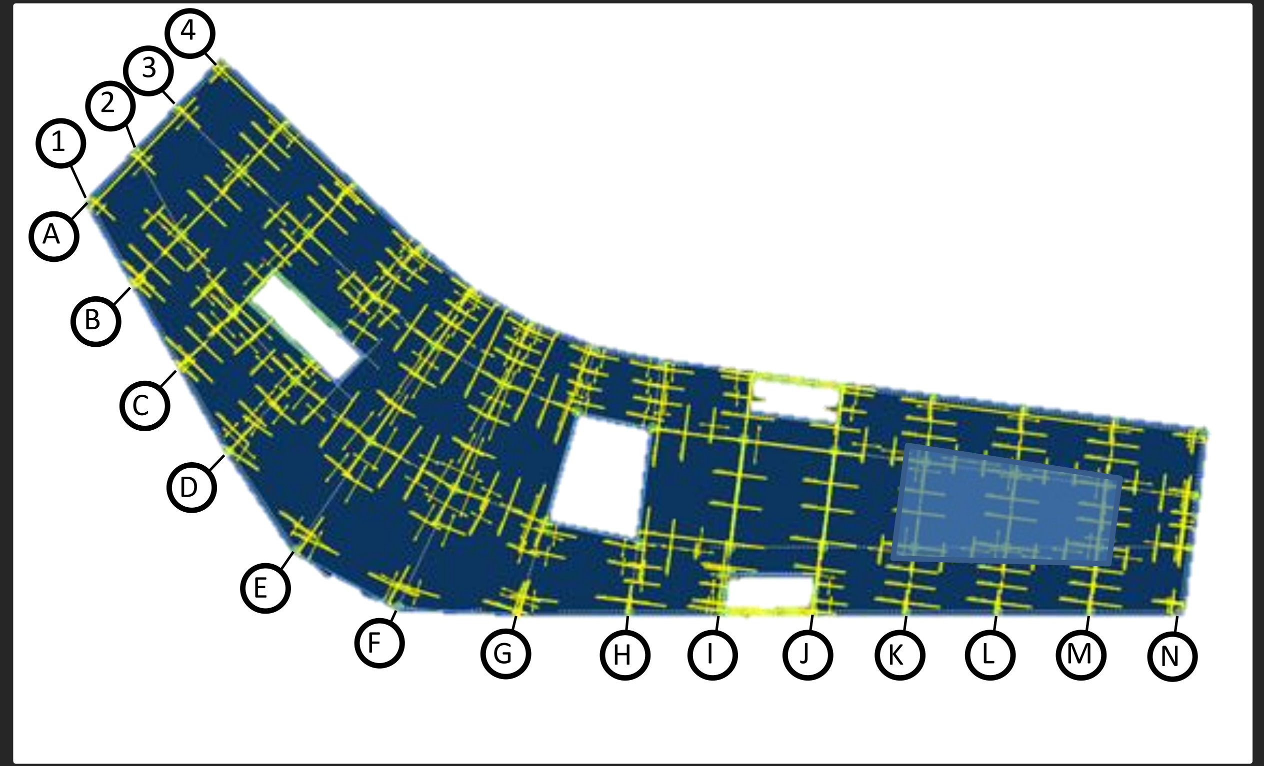


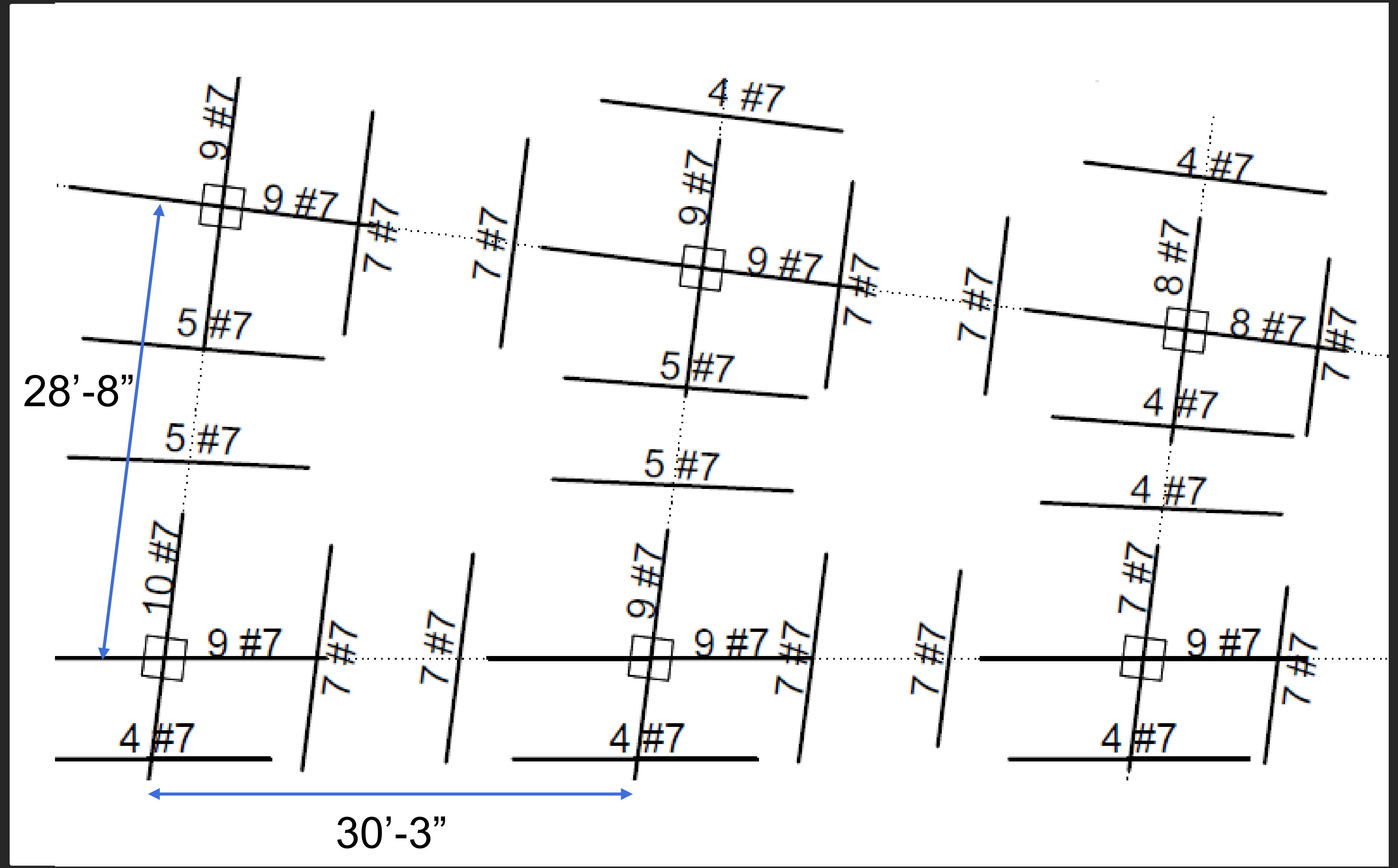
Brendan Iribe Center for Computer Science and Innovation

I. Building Overview
II. Design Proposal
III. Gravity System
  I. Voided Concrete Slab
  II. Gravity Columns
IV. Lateral System
  I. Shear Wall Layout
  II. Shear Wall Design
V. Construction Breadth
VI. Conclusion

Gravity Redesign- Voided Slab

Top Reinforcement



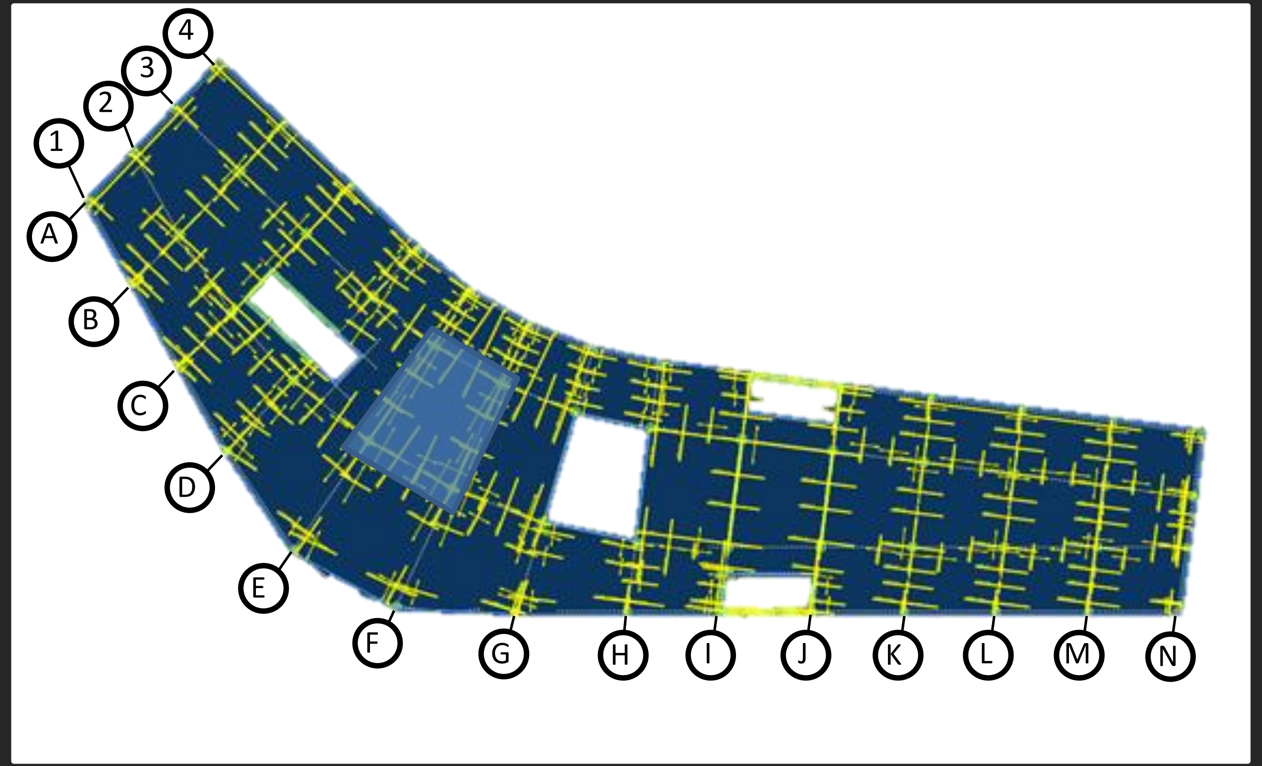


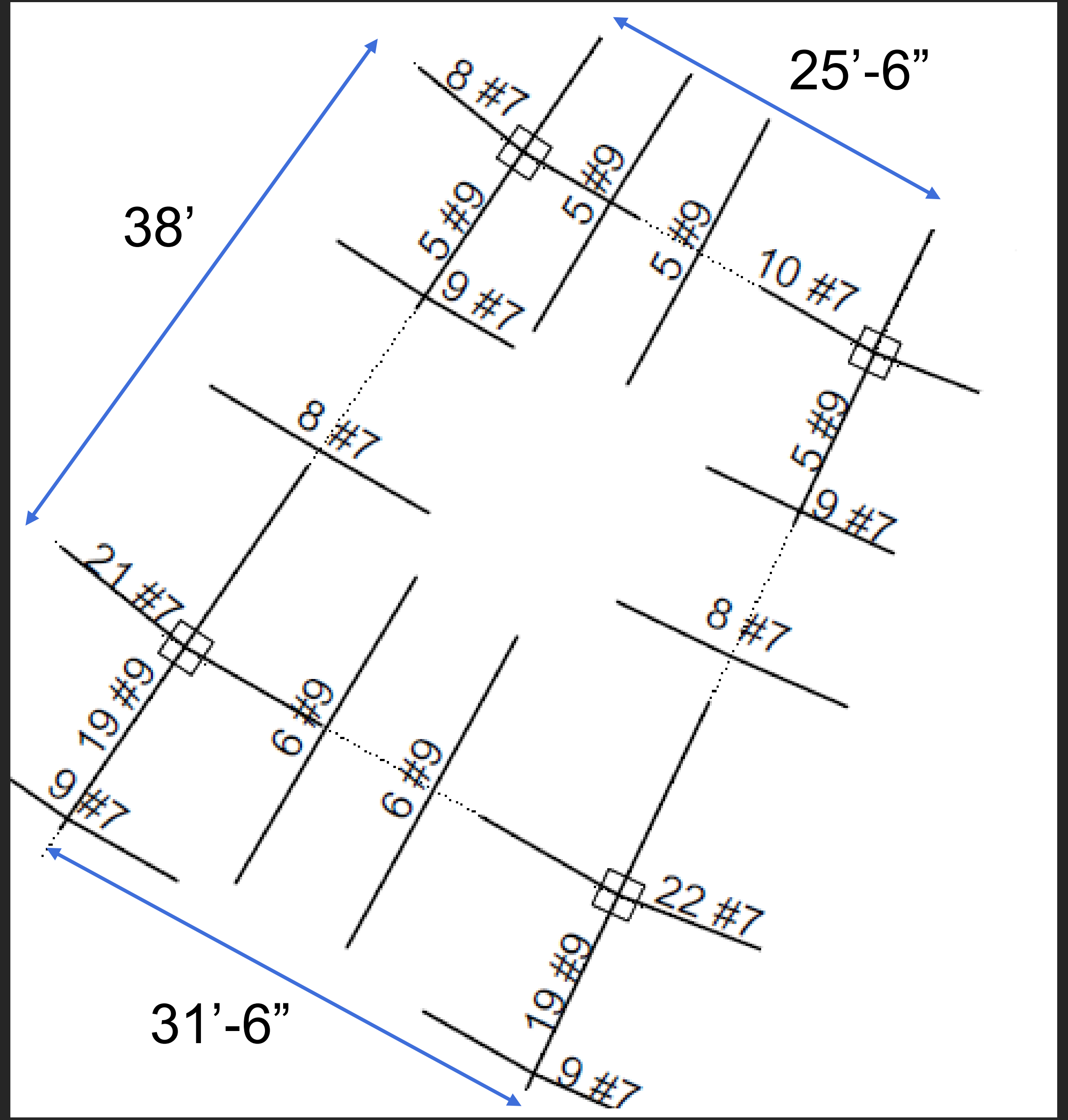
Brendan Iribe Center for Computer Science and Innovation

I. Building Overview
II. Design Proposal
III. Gravity System
  I. Voided Concrete Slab
  II. Gravity Columns
IV. Lateral System
  I. Shear Wall Layout
  II. Shear Wall Design
V. Construction Breadth
VI. Conclusion

Gravity Redesign- Voided Slab

Top Reinforcement



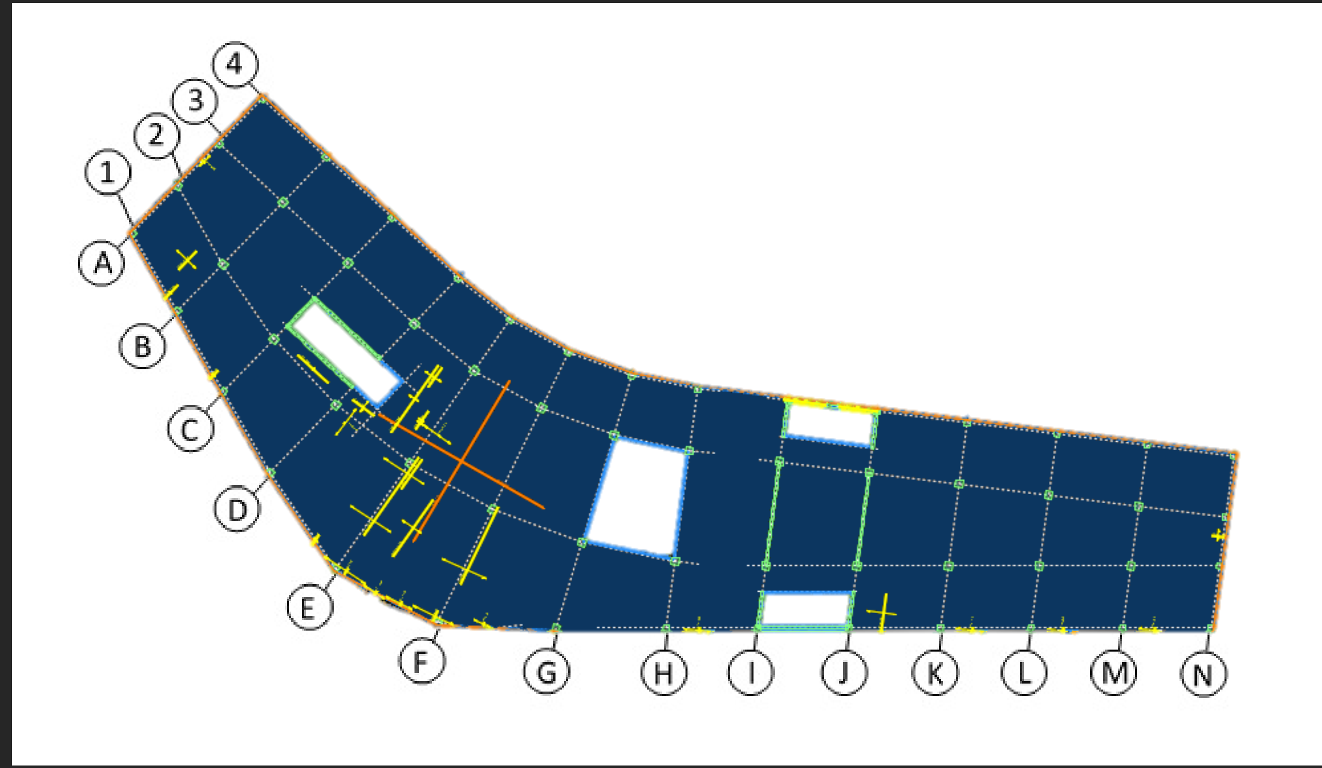


Brendan Iribe Center for Computer Science and Innovation

I. Building Overview
II. Design Proposal
III. **Gravity System**
  I. **Voided Concrete Slab**
  II. Gravity Columns
IV. Lateral System
  I. Shear Wall Layout
  II. Shear Wall Design
V. Construction Breadth
VI. Conclusion

Gravity Redesign- Voided Slab

Bottom Reinforcement

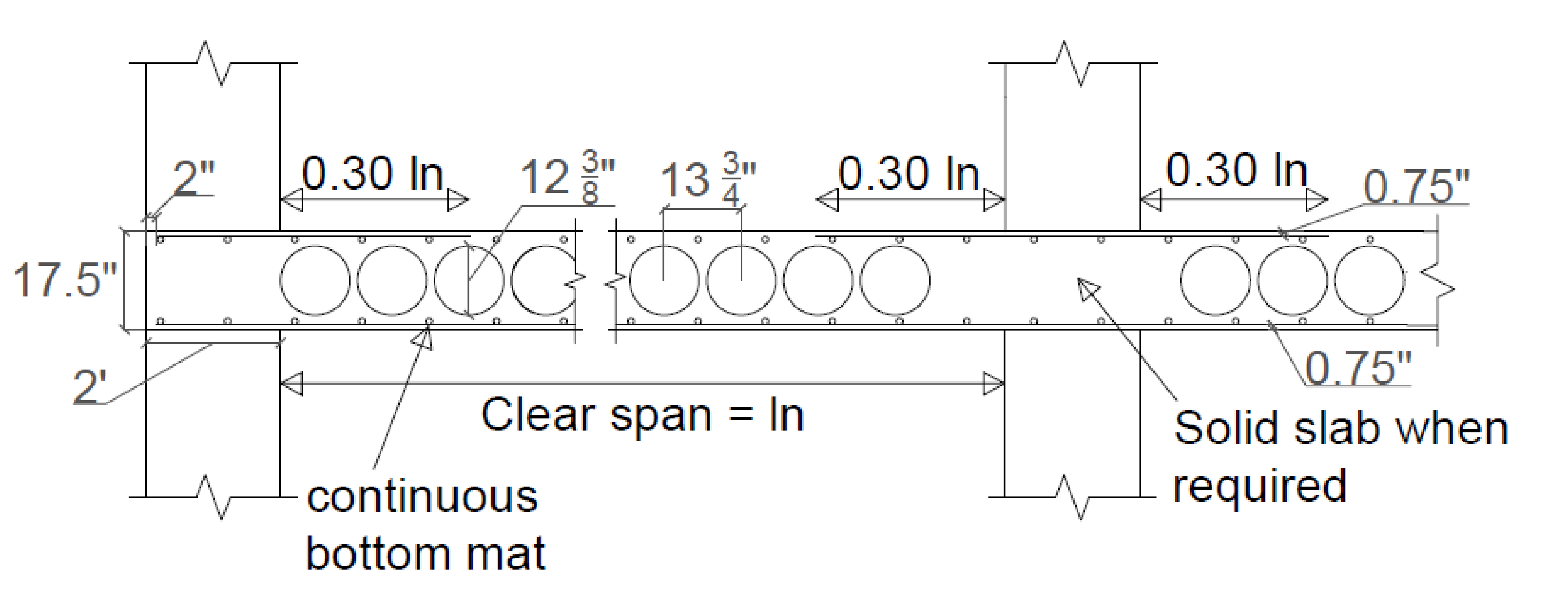


Mat of #7@12” each way

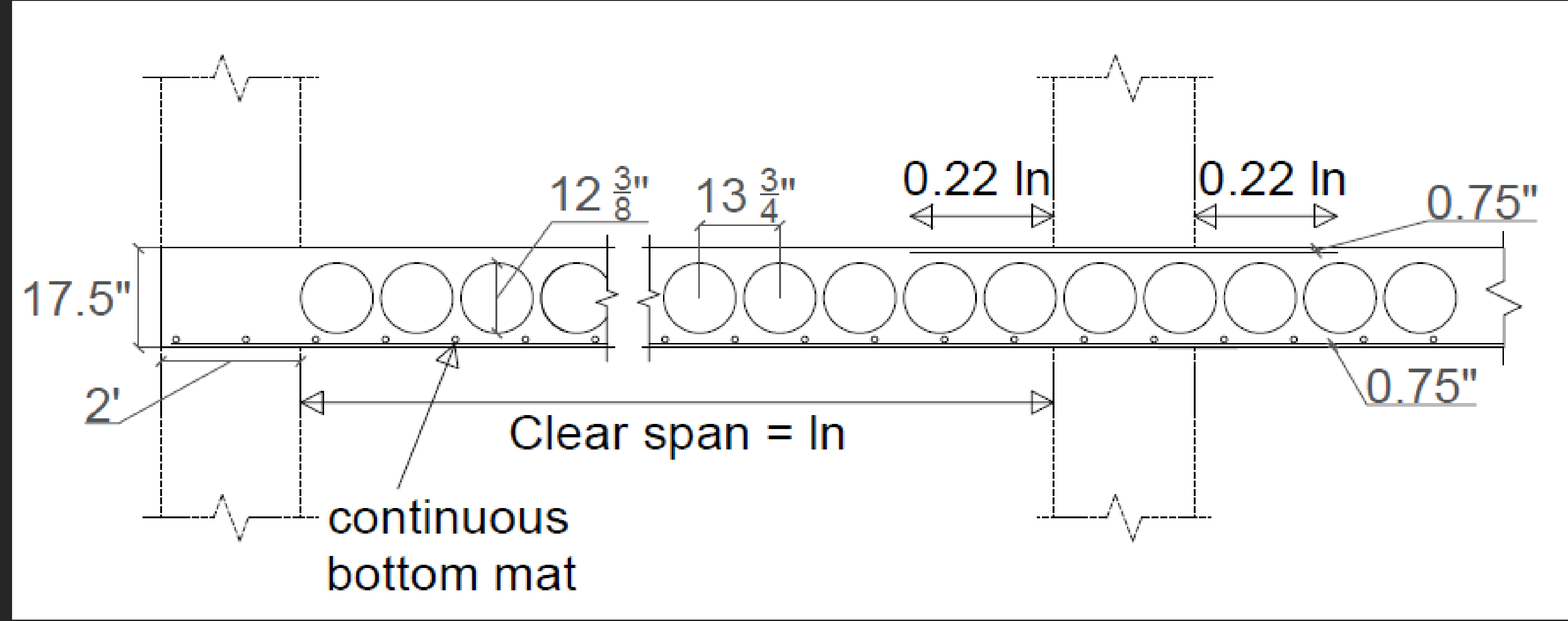
- 15’ strip → 9 in^2
  - A_{smin} = 5.31 in^2

Brendan Iribe Center for Computer Science and Innovation

Gravity Redesign- Voided Slab



Column Strip

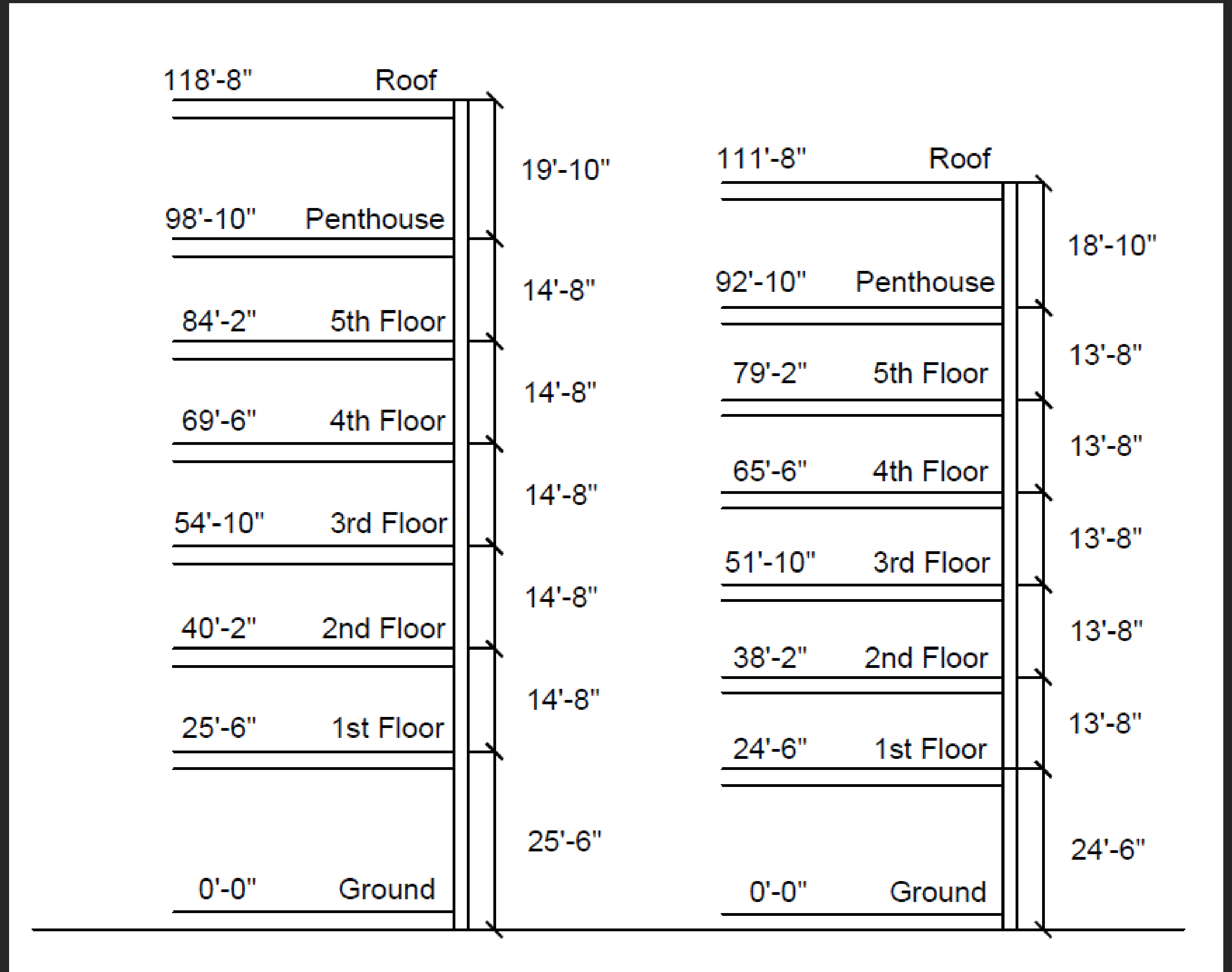


Middle Strip

Brendan Iribe Center for Computer Science and Innovation

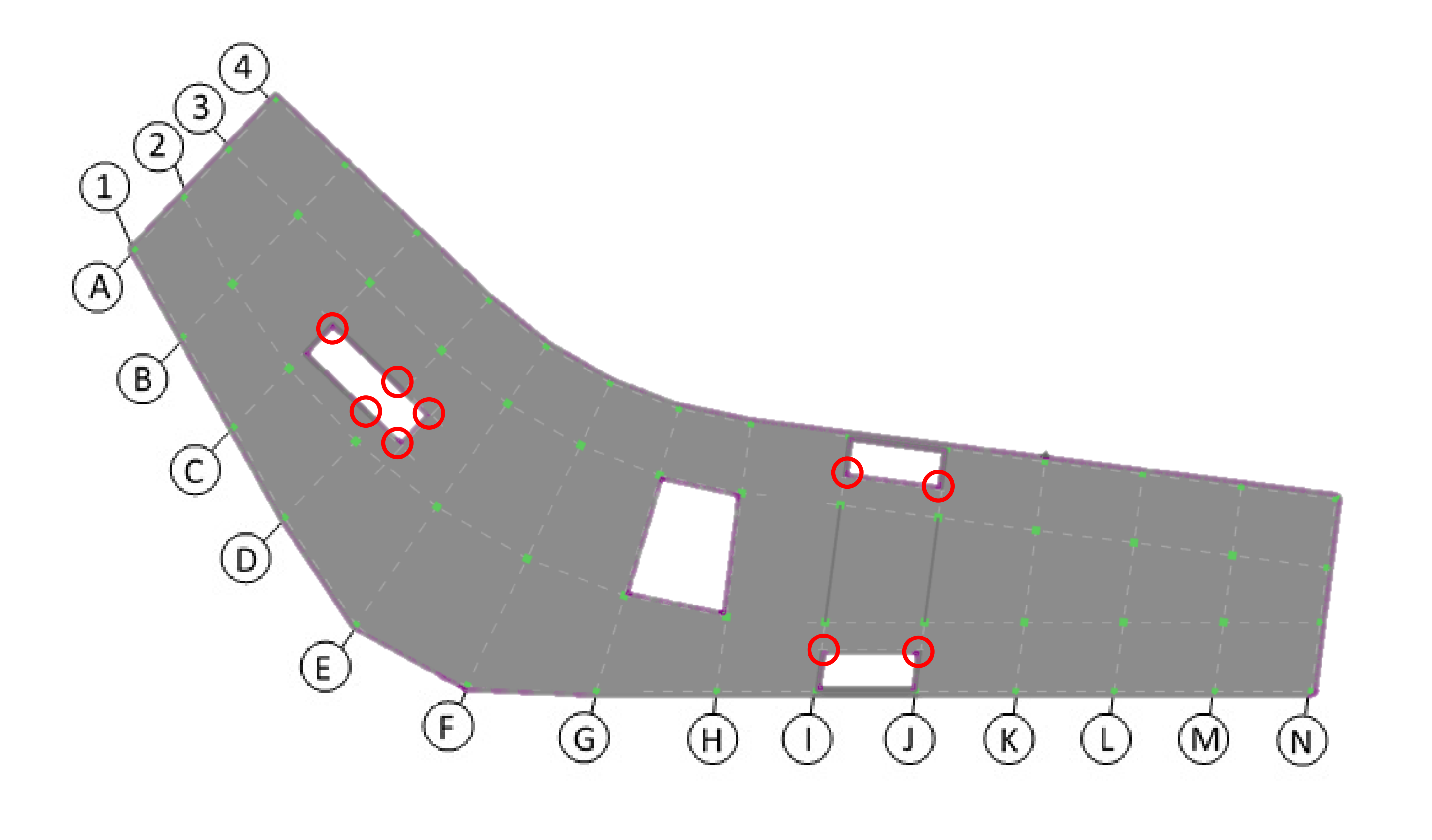
Gravity Redesign- Voided Slab

- Height decreases by 7’
  - ~6% of the building height
- Reduce costs of façade, ductwork, and pipes



Brendan Iribe Center for Computer Science and Innovation

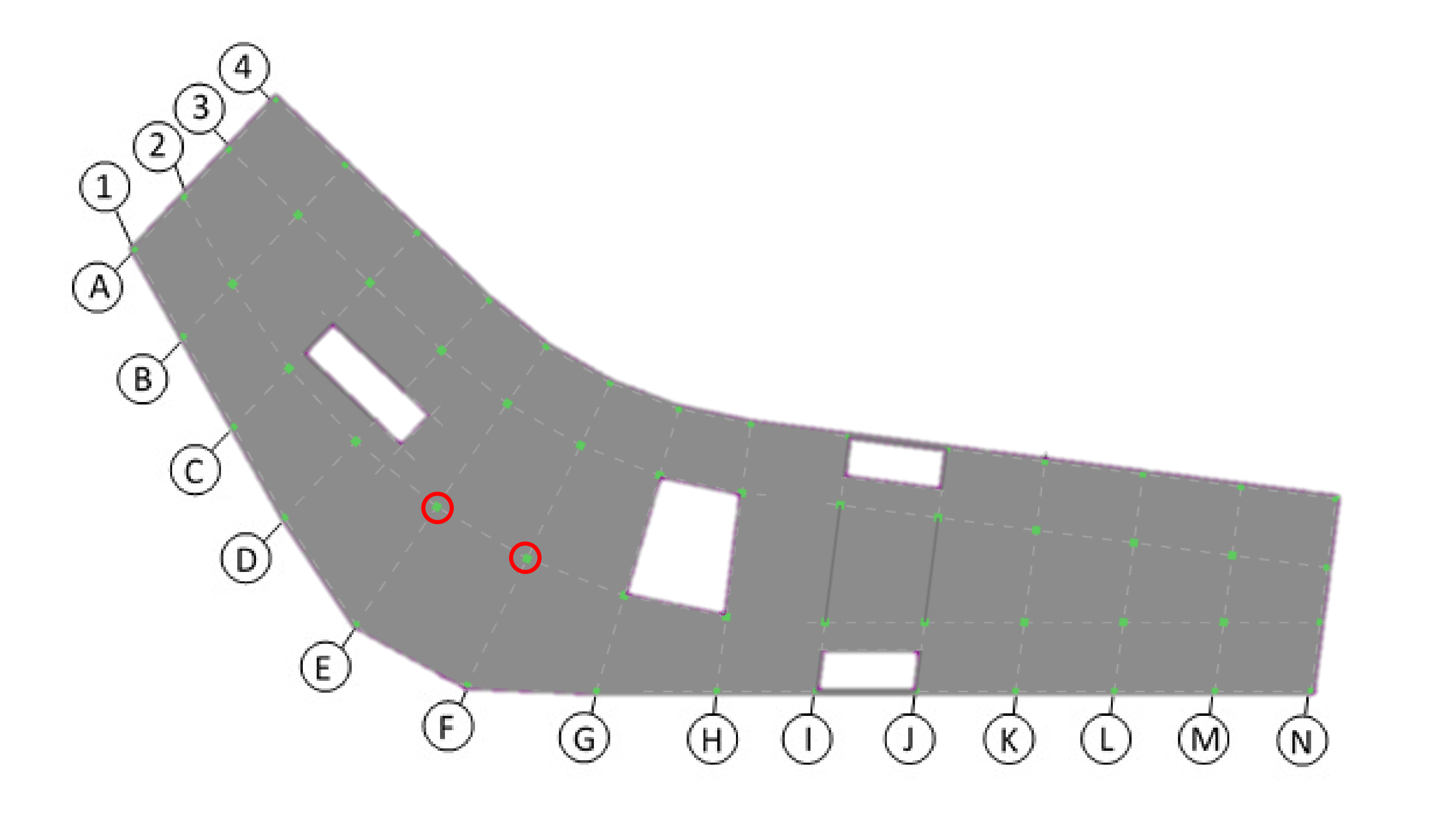
Gravity Redesign- Columns



- Column locations remain the same
- 9 columns removed that were part of existing lateral system
- f'c= 8000 psi to keep column sizes reasonable

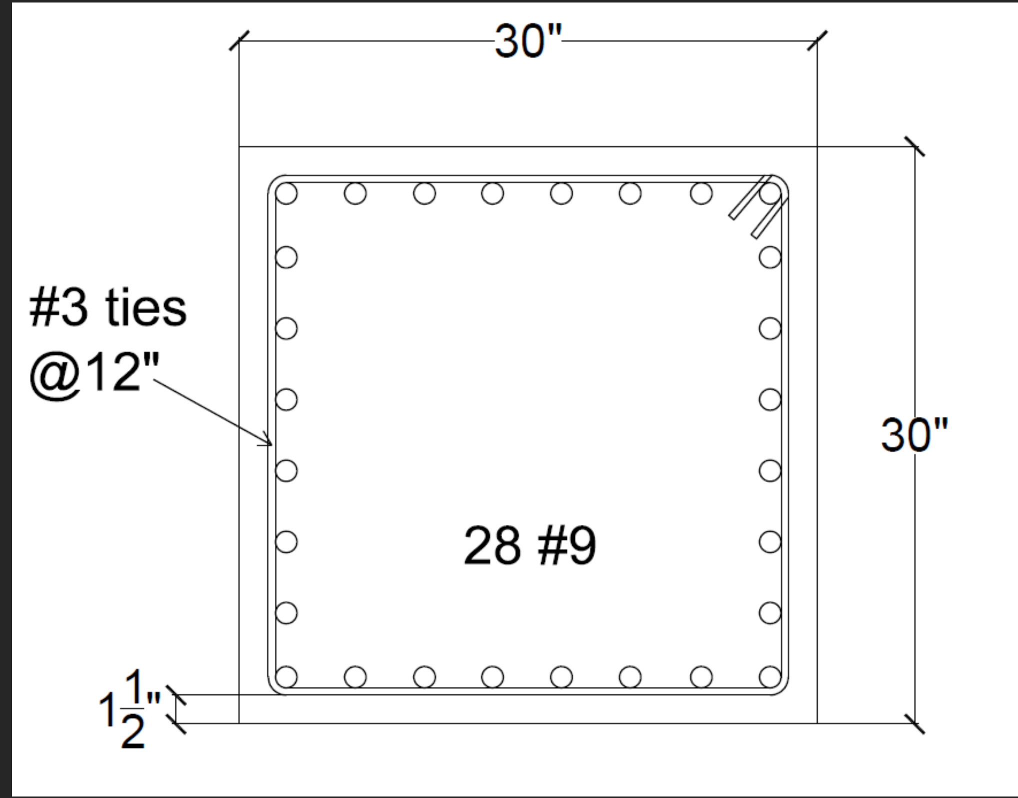
Brendan Iribe Center for Computer Science and Innovation

Gravity Redesign- Columns

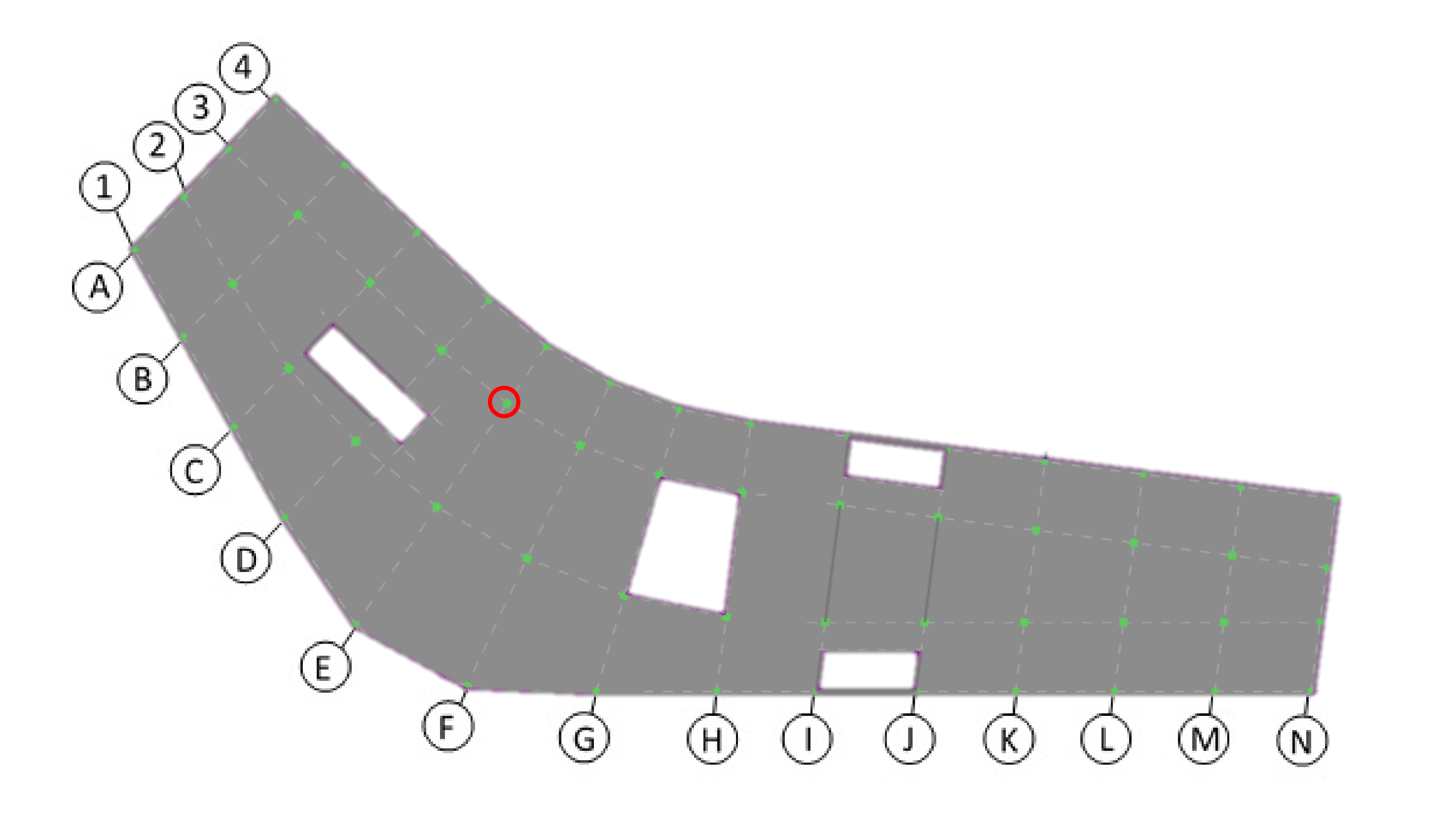


Columns E2 and F2

P_u= 3900 kips
From ACI 22.4.2.2 → Trial Size 30x30
Longitudinal Reinforcement 28#9
Transverse Reinforcement #3 ties @12"



Gravity Redesign- Columns



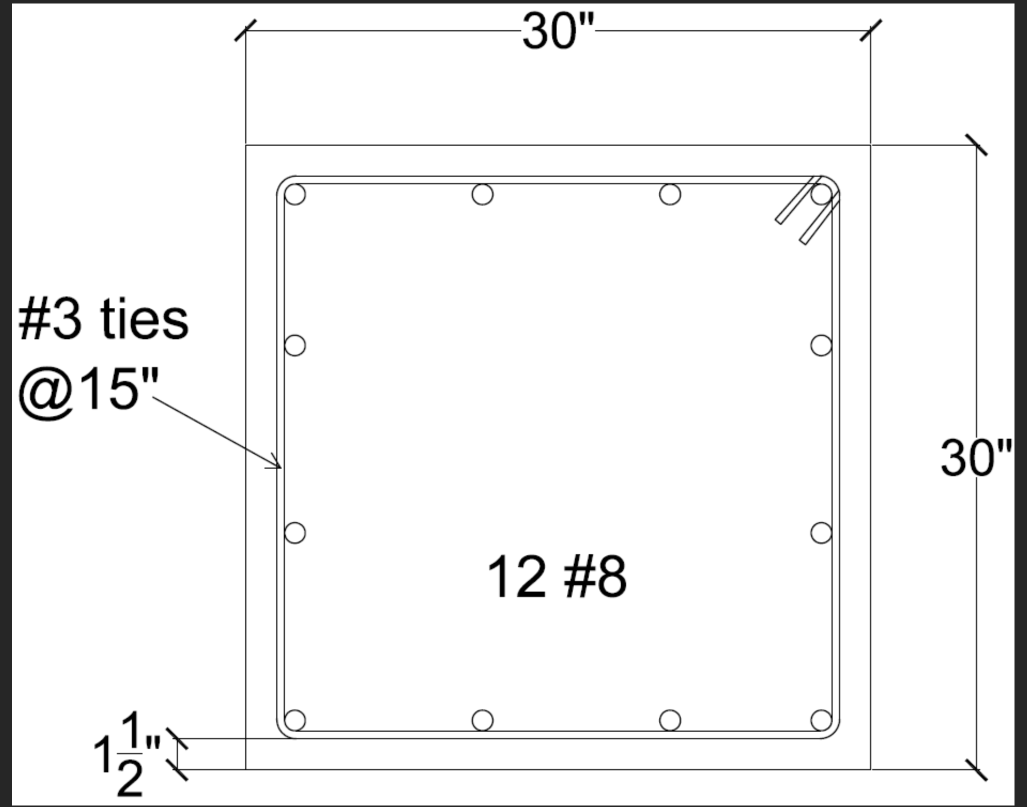
Interior Column

P_u= 2133 kips

A_s min = 9 in^2

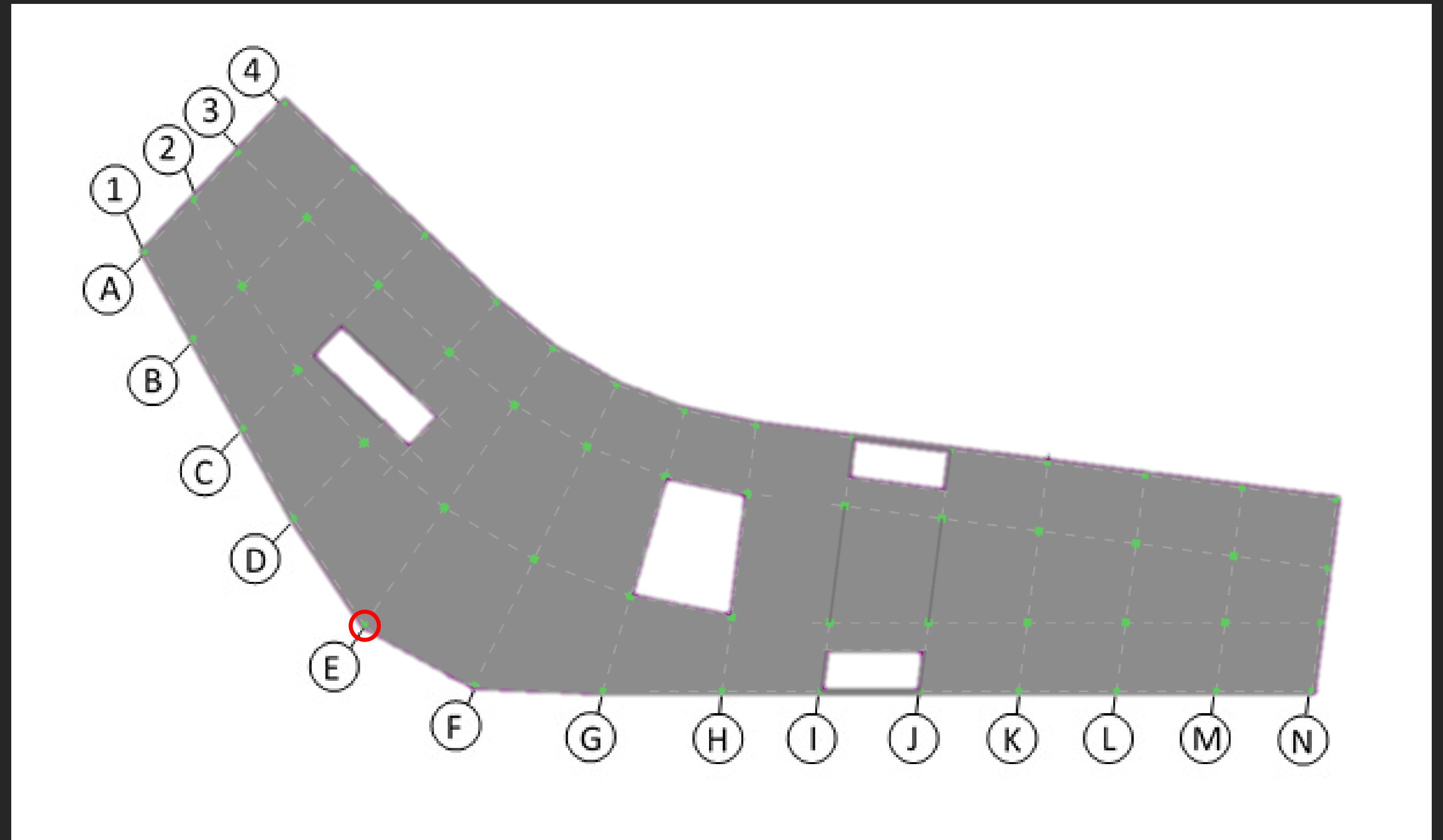
Long. Reinforcement 12#8 (9.48 in^2)

Transverse Reinforcement #3 ties @15"



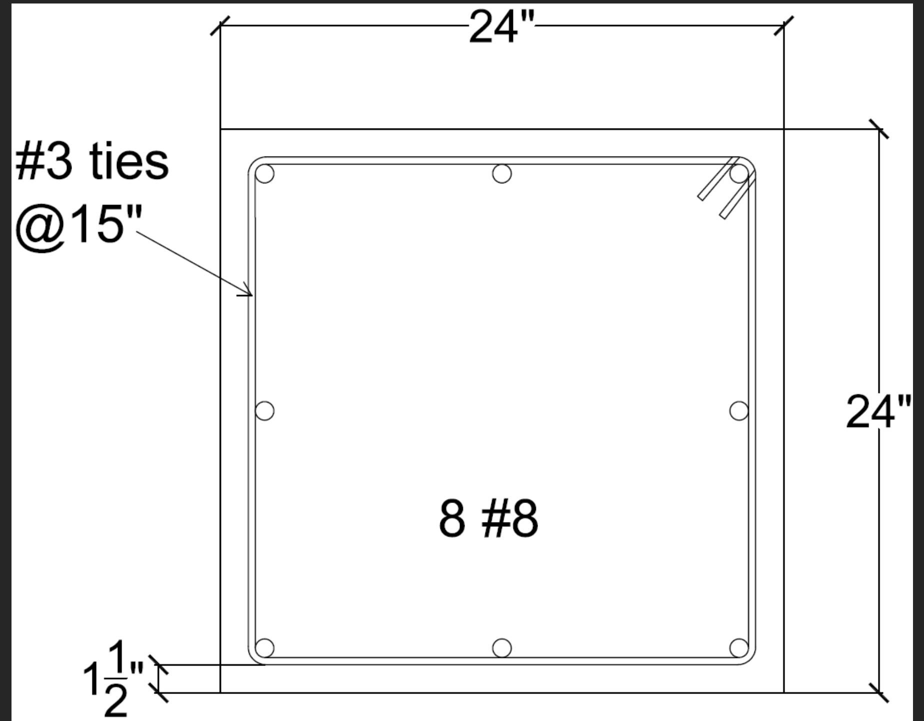
Brendan Iribe Center for Computer Science and Innovation

Gravity Redesign- Columns



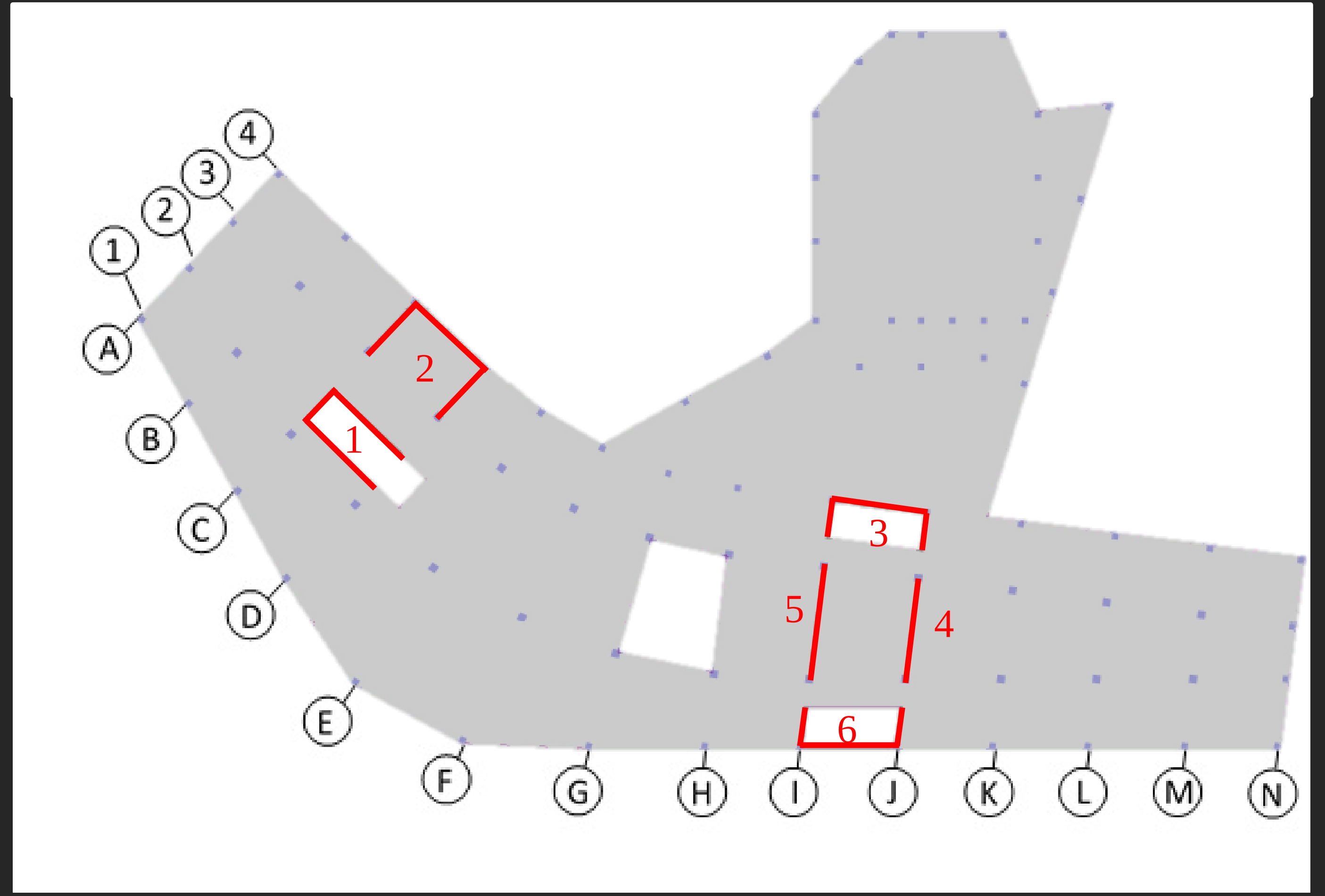
Exterior Column

P_u= 1751 kips
From ACI 22.4.2.2 → Trial Size 24x24
A_s min = 5.76 in^2
Long. Reinforcement 8#8 (6.32 in^2)
Transverse Reinforcement #3 ties @15"



Brendan Iribe Center for Computer Science and Innovation

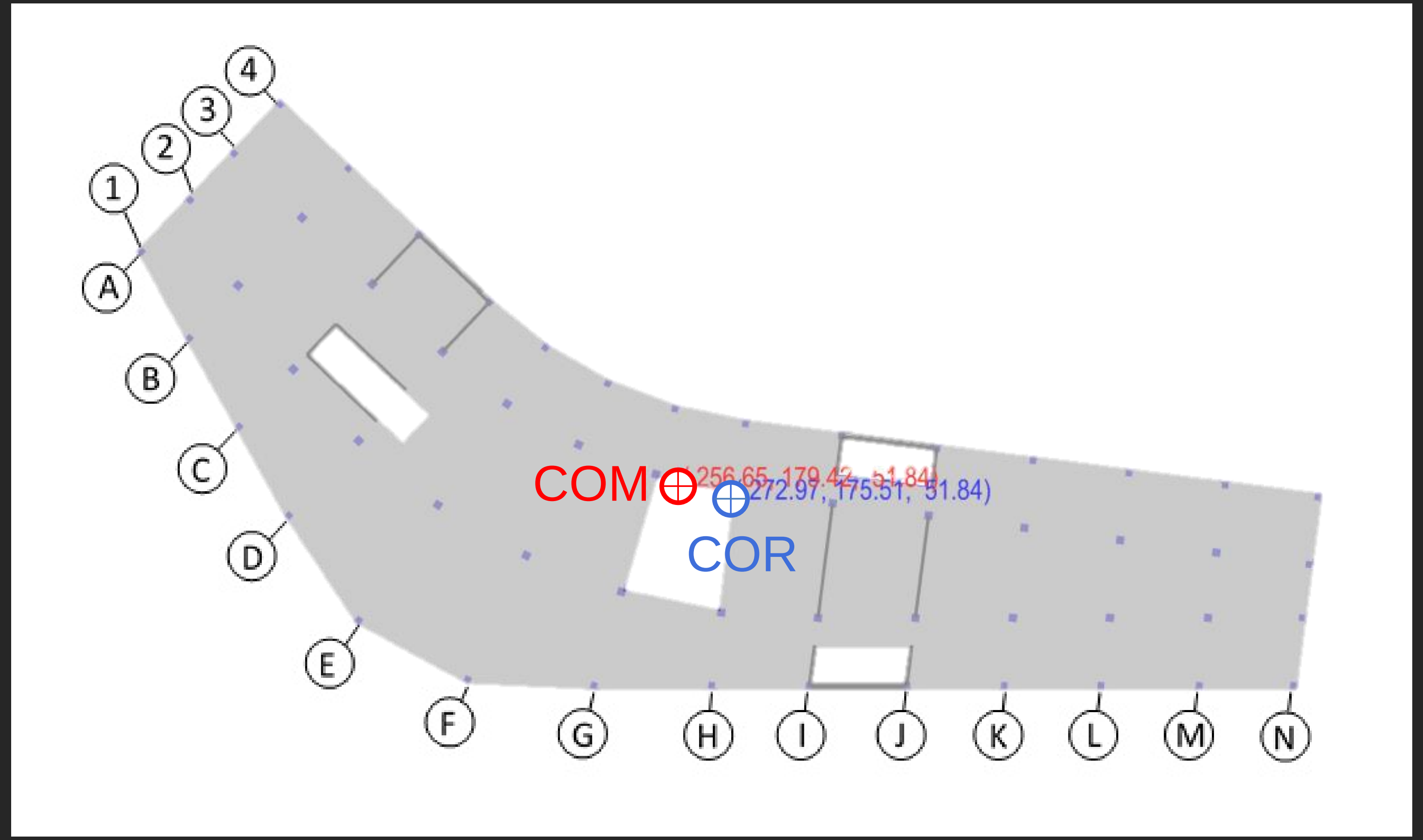
Lateral Redesign- Shear Walls



- Shear walls remain in the same locations as moment frames
- Thickness = 12”
  - ACI 11.3 → 1/25 unsupported height
- f’c= 4000 psi

Brendan Iribe Center for Computer Science and Innovation

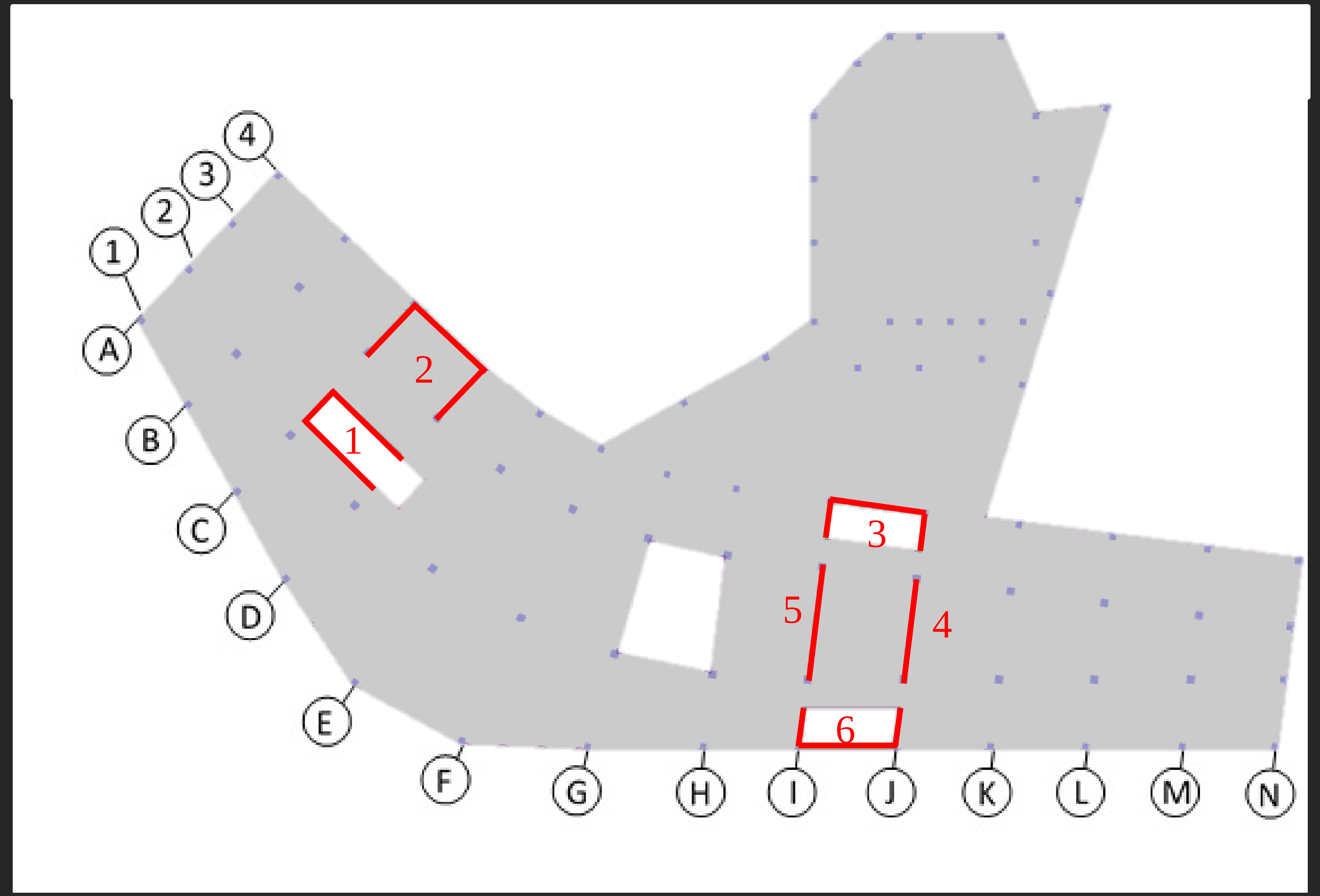
Lateral Redesign- Shear Walls



- COR and COM off 16’ in the x direction and 4’ in the y direction
- Helps minimize torsional deformations

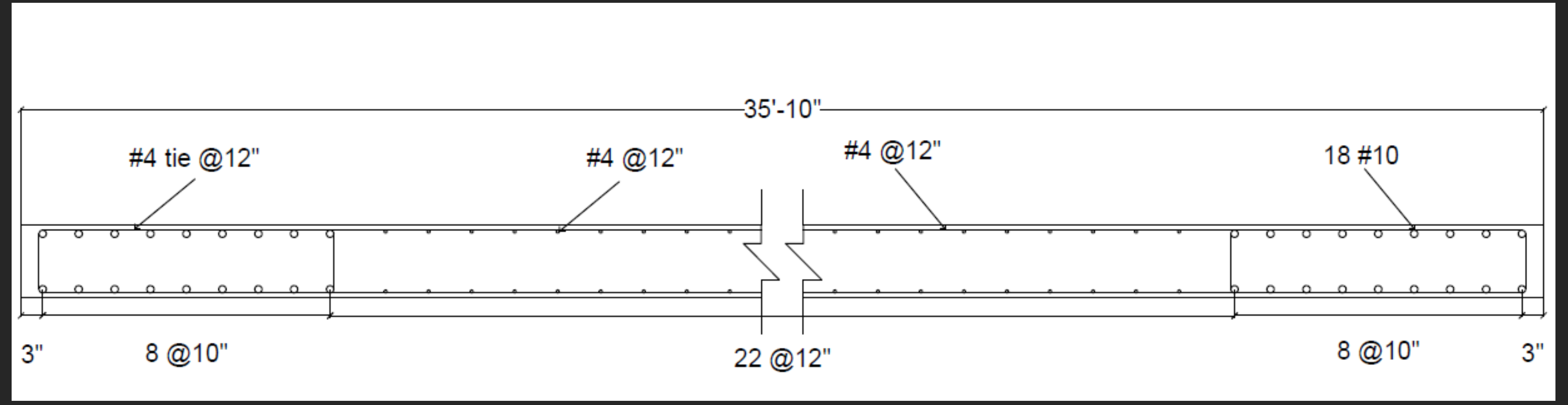
Brendan Iribe Center for Computer Science and Innovation

Lateral Redesign- Shear Walls



Shear Wall #5 Design

Controlling Load Combination: 0.9D – 1.4E



Shear Wall	Length	Horizontal RFT	Vertical RFT	Flexural/Axial RFT
1	Short- 13.17' Long-30'	#5@12"	#5@12"	8 #7@9"
2	Short- 21' Long- 30'	#5@12"	#5@12"	8 #10@9"
3	Short- 12.5' Long- 30'	#5@12"	#5@12"	8 #8@9"
4	32'	#4@12"	#4@12"	14 #10@9"
5	35.83'	#4@12"	#4@12"	18 #10@10"
6	Short- 12.67' Long- 30.25'	#5@12"	#5@12"	10 #9@9"

Brendan Iribe Center for Computer Science and Innovation

Lateral Redesign- Shear Walls

$\Delta_{allowable,wind}$ = H/400

Story	LdC	Displacement X in	Displacement Y in
Roof	W15	0.3678	-0.7119
	W16	0.3193	-0.1761
	W17	0.0078	2.2212
	W18	0.2158	-0.0929
	W19	0.4554	0.6201
	W20	0.2317	-1.5082
	W21	0.4377	-0.6036
	W22	0.2453	1.5338
	W23	0.2700	-2.1998
	W24	0.0776	-0.0624

$\Delta_{allowable,wind} = 3.35'' > 2.22'' \therefore OK$

$\Delta_{allowable,seismic}$ = 0.015h_{sx}

Story	LdC	Displacement X in	Displacement Y in
Roof	E5	3.0337	2.2321
	E6	2.4186	1.0743
	E7	0.1192	2.6197
	E8	1.3476	4.9320

$\Delta_{allowable,seismic} = 20.1'' > 4.93'' \therefore OK$

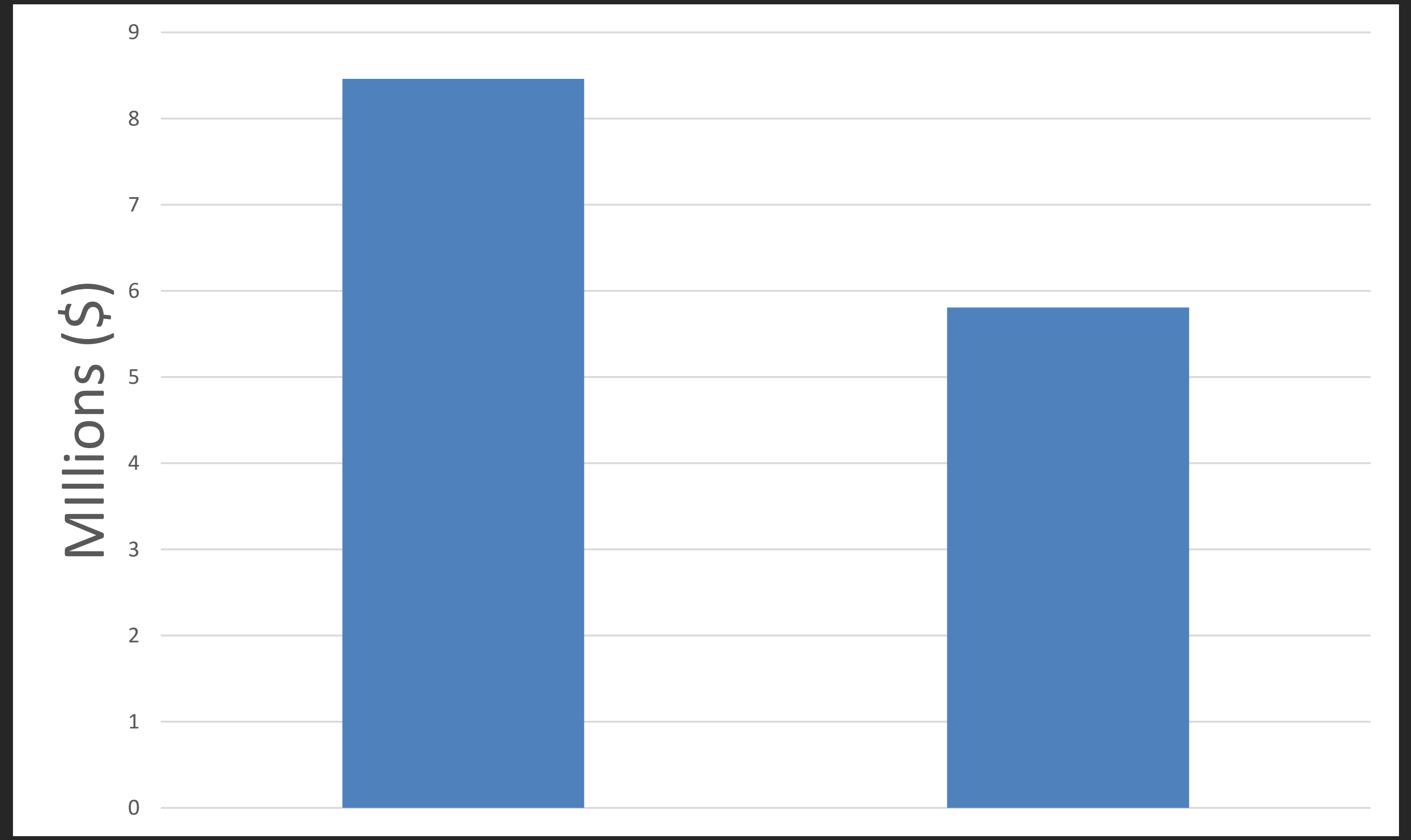
Brendan Iribe Center for Computer Science and Innovation

Construction Breadth

<u>Existing</u> Composite Steel	$ 8,462,332.20
<u>Redesign</u> Voided Slab	$ 5,807,487.37

* Using RS Means 2017

Cost Comparison



Existing Redesign

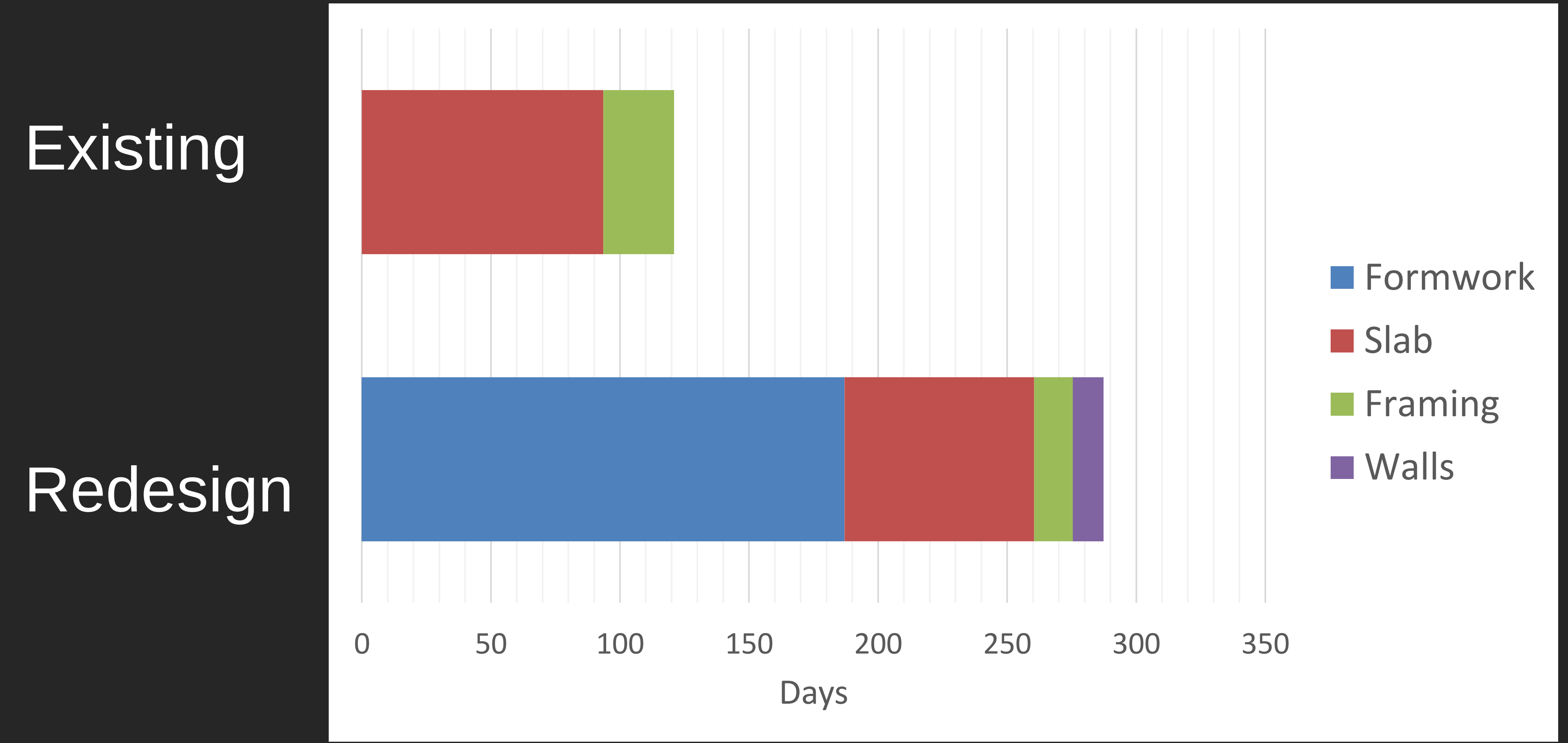
31 % decrease

Brendan Iribe Center for Computer Science and Innovation

Construction Breadth

Existing	
Decking	93.5
Framing	27.5
Total	121 days
Redesign	
Slab	73.5
Columns	15
Walls	11.7
Formwork	187
Total	287.3 days

Schedule Comparison



137 % increase

Brendan Iribe Center for Computer Science and Innovation

I. Building Overview
II. Design Proposal
III. Gravity System
  I. Voided Concrete Slab
  II. Gravity Columns
IV. Lateral System
  I. Shear Wall Layout
  II. Shear Wall Design
V. Construction Breadth
VI. Conclusion

Goals Achieved?

Reduce structural depth ✓
Reduce cost ✓
Maintain open floor plan ✓

Drawbacks

Increase in structural weight
Increase in foundation
Longer construction schedule

Acknowledgements

Special thanks to:

- The engineers at Hope Furrer Associates
- Dr. Aly Said, Thesis Advisor
- The AE Faculty
- Friends and family

Brendan Iribe Center for Computer Science and Innovation

I. Building Overview
II. Design Proposal
III. Gravity System
  I. Voided Concrete Slab
  II. Gravity Columns
IV. Lateral System
  I. Shear Wall Layout
  II. Shear Wall Design
V. Construction Breadth
VI. Conclusion

I. Building Overview

II. Design Proposal

III. Gravity System

IV. Lateral System

V. Construction Breadth

VI. Conclusion

Column E2

	Dead (psf)	SW Slab (psf)	SW Column (k)	Live (psf)	Snow (psf)	1.4D	1.2D+1.6L+0.5Lr	Total (k)
Roof	73	172.5	17.65	30	24.25	**502.45**	497.394	502.45
Penthouse	10	172.5	12.8	100	0	373.07	**563.02**	1065.47
5th	10	172.5	12.8	100	0	373.07	**563.02**	1628.49
4th	10	172.5	12.8	100	0	373.07	**563.02**	2191.51
3rd	10	172.5	12.8	100	0	373.07	**563.02**	2754.53
2nd	10	172.5	12.5	100	0	372.65	**562.66**	3317.19
1st	10	172.5	30	100	0	397.15	**583.66**	3900.85

Column E1

	Dead (psf)	SW Slab (psf)	SW Column (k)	Live (psf)	Snow (psf)	1.4D	1.2D+1.6L+0.5Lr	Total (k)
Roof	73	173.5	11.3	30	24.25	**240.14**	237.03	240.14
Penthouse	10	173.5	8.2	100	0	178.47	**256.97**	497.11
5th	10	173.5	8.2	100	0	178.47	**256.97**	754.08
4th	10	173.5	8.2	100	0	178.47	**256.97**	1011.05
3rd	10	173.5	8.2	100	0	178.47	**256.97**	1268.02
2nd	10	173.5	8.2	100	0	178.47	**256.97**	1524.99
1st	10	173.5	14.7	100	0	187.57	**264.77**	1789.76

$$\text{Solid area around column} = \text{Tributary area of column} - \frac{(\text{Shear reduction factor})(\text{Allowable direct shear force})}{\text{Total factored unifromly distributed load}}$$

$$\Phi V_c = \Phi 4\lambda\sqrt{f'c}b_0d = 0.75(4)(1)\sqrt{4000} * 2[(30 + 16.375) * 2] * \left(\frac{16.375}{1000}\right) = 576.3\ kips$$

$$\text{Solid area arond columm} = 1286 - \frac{0.55 * 576.3}{\frac{379}{1000}} = 449.6\ ft^2$$

Column	Column size	Tributary Area (ft^2)	b_0 (ft)	ΦV_C	Vu	Solid Area (ft^2)
A1	24x24	216	161.5	501.77	79.31	n/a
A2	30x30	395	185.5	576.34	146.78	n/a
A3	30x30	374	185.5	576.34	138.82	n/a
A4	24x24	182	161.5	501.77	66.43	n/a
B1	24x24	405	161.5	501.77	150.94	n/a
B2	30x30	763	185.5	576.34	286.25	n/a
B3	30x30	754	185.5	576.34	282.84	n/a
B4	24x24	330	161.5	501.77	122.52	n/a
C1	24x24	501	161.5	501.77	187.33	n/a
C2	30x30	670	185.5	576.34	251.00	n/a
C3	30x30	833	185.5	576.34	312.78	n/a
C4	24x24	338	161.5	501.77	125.55	n/a
D1	24x24	623	161.5	501.77	233.57	n/a
D2	30x30	749	185.5	576.34	280.94	n/a
D3	30x30	769	185.5	576.34	288.52	n/a
D4	24x24	303	161.5	501.77	112.29	n/a
E1	24x24	929	161.5	501.77	349.54	200.84
E2	30x30	1286	185.5	576.34	484.46	449.63
E3	30x30	757	185.5	576.34	283.97	n/a
E4	24x24	270	161.5	501.77	99.78	n/a
F1	24x24	894	161.5	501.77	336.28	165.84
F2	30x30	1286	185.5	576.34	484.46	449.63
F3	30x30	774	185.5	576.34	290.42	n/a
F4	24x24	272	161.5	501.77	100.54	n/a
G1	24x24	710	161.5	501.77	266.54	n/a
G2	30x30	690	185.5	576.34	258.58	n/a
G3	30x30	542	185.5	576.34	202.49	n/a
G4	24x24	238	161.5	501.77	87.65	n/a

Column	Column size	Tributary Area (ft^2)	b_0 (ft)	ΦV_C	Vu	Solid Area (ft^2)
H1	24x24	497	161.5	501.77	185.81	n/a
H2	30x30	582	185.5	576.34	217.65	n/a
H3	30x30	602	185.5	576.34	225.23	n/a
H4	24x24	291	161.5	501.77	107.74	n/a
I1	24x24	233	161.5	501.77	85.76	n/a
I2	30x30	836	185.5	576.34	313.91	n/a
I3	30x30	732	185.5	576.34	274.50	n/a
I4	24x24	230	161.5	501.77	84.62	n/a
J1	24x24	220	161.5	501.77	80.83	n/a
J2	30x30	815	185.5	576.34	305.96	n/a
J3	30x30	825	185.5	576.34	309.75	n/a
J4	24x24	223	161.5	501.77	81.97	n/a
K1	24x24	445	161.5	501.77	166.10	n/a
K2	30x30	614	185.5	576.34	229.78	n/a
K3	30x30	622	185.5	576.34	232.81	n/a
K4	24x24	307	161.5	501.77	113.80	n/a
L1	24x24	427	161.5	501.77	159.28	n/a
L2	30x30	595	185.5	576.34	222.58	n/a
L3	30x30	706	185.5	576.34	264.64	n/a
L4	24x24	318	161.5	501.77	117.97	n/a
M1	24x24	433	161.5	501.77	161.56	n/a
M2	30x30	571	185.5	576.34	213.48	n/a
M3	30x30	559	185.5	576.34	208.93	n/a
M4	24x24	393	161.5	501.77	146.40	n/a
N1	24x24	231	161.5	501.77	85.00	n/a
N2	30x30	292	185.5	576.34	107.74	n/a
N3	30x30	315	185.5	576.34	116.46	n/a
N4	24x24	176	161.5	501.77	64.15	n/a

Reinforcement Summary

Longitude Direction

			M_u	A_s	Ram Reinforcing	OK?
End span	Column Strip	Exterior negative	-595	8.29	14#9 = 14.0	OK
		Positive	709.4	9.79	mat** + 6#7 = 15.0	OK
		Interior negative	-1212.9	17.3	19#9 =19.0	OK
	Middle Strip	Exterior negative	0	0	-	
		Positive	480.6	7.25*	mat** + 1#7 = 12.0	OK
		Interior negative	-389	7.25*	12#9 =12.0	OK
Interior span	Column Strip	Positive	480.6	7.25*	mat** + 1#7 = 12.0	OK
		Negative	-1121.4	15.8	24#9 = 24.0	OK
	Middle Strip	Positive	320.4	7.25*	mat** = 11.4	OK
		Negative	-366.2	7.25*	22#9 =22.0	OK

Latitude Direction

			M_u	A_s	Ram Reinforcing	OK?
Interior span	Column Strip	Positive	485.3	7.18*	mat** = 11.4	OK
		Negative	-1132.4	16.1	31#7 = 18.6	OK
	Middle Strip	Positive	323.6	7.18*	mat** = 11.4	OK
		Negative	-369.8	7.18*	17#6 = 10.2	OK

* denotes A_s min is used

** mat consits of #7@12" each way

Table 10: Wind in north-south direction comparison

		Calculated	RAM	
Level	Height (ft)	Fy (kips)	Fy (kips)	% error
1st Floor	24.5	189.26	193.82	2.35
2nd Floor	38.17	145.28	148.92	2.44
3rd Floor	51.8	152.44	156.53	2.61
4th Floor	65.6	158.17	162.71	2.79
5th Floor	79.17	163.9	167.99	2.43
Penthouse	92.83	200.04	205.85	2.82
Roof	111.68	119.56	121.55	1.64
	Base Shear	1128.65	1157.37	2.48

Table 11: Wind in east-west direction comparison

		Calculated	RAM	
Level	Height (ft)	Fx (kips)	Fx (kips)	% error
1st Floor	24.5	124.39	105.32	18.11
2nd Floor	38.17	95.48	72.98	30.83
3rd Floor	51.8	75.85	66.41	14.21
4th Floor	65.6	78.71	68.88	14.27
5th Floor	79.17	81.56	71.57	13.96
Penthouse	92.83	99.54	88.21	12.84
Roof	111.68	59.5	52.57	13.18
	Base Shear	615.03	525.94	16.94

Table 12: Seismic story shear comparison

		Calculated	RAM	
Level	Height (ft)	Fx (kips)	Fx (kips)	% error
1st Floor	24.5	108.6	114.57	5.21
2nd Floor	38.17	178.28	188.93	5.64
3rd Floor	51.8	173.25	190.59	9.10
4th Floor	65.6	227.04	246.17	7.77
5th Floor	79.17	282.6	302.86	6.69
Penthouse	92.83	343.62	373.14	7.91
Roof	111.68	548.08	574.59	4.61
	Base Shear	1861.47	1990.85	6.50