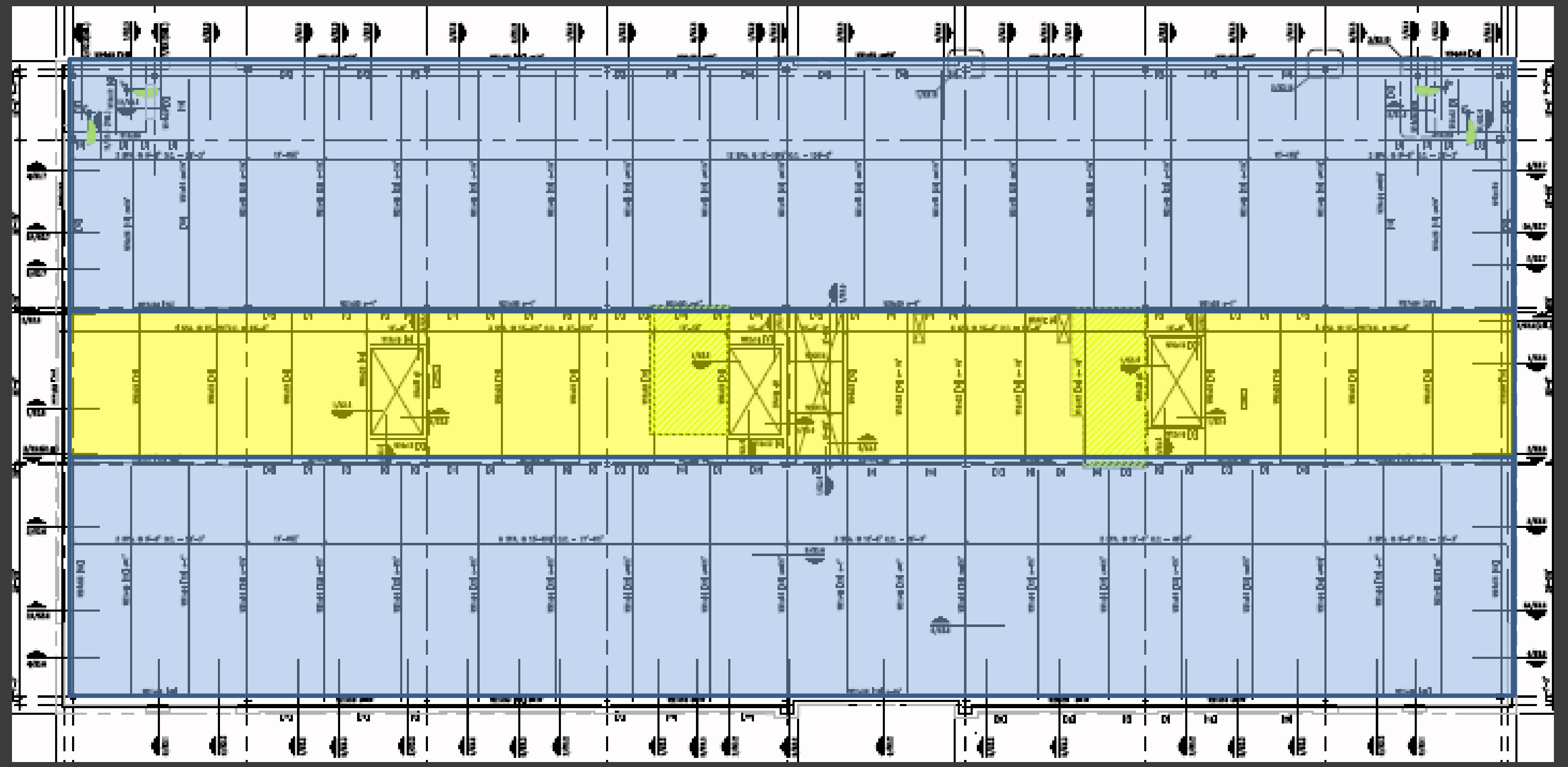
General Information

- Location: Ashburn, VA – 12 miles NW of Dulles International
- Project Type: 5 Story, Multi-Tenant Office Building
- Project Size: ~125,000 SF
- Architect: The M Group Architects
- Structural Engineer: Haynes Whaley Associates
- Owner: Toll Brothers Commercial
- Project Delivery Method: Guaranteed Maximum Price
- Project Duration: September 2006 – July 2007

Gravity System

- 6 ¼” lightweight concrete on 3” composite metal deck, f’c = 3500 psi
- Composite action achieved through the use of shear studs
- W shape steel beams/columns
- Square spread footings with perimeter strip footing, f’c = 4000 psi
- Typical bay sizes
  - 40’-0”x30’-0” exterior bays
  - 26’-2”x30’-0” interior bays



- Introduction
- **Exiting Structural System**
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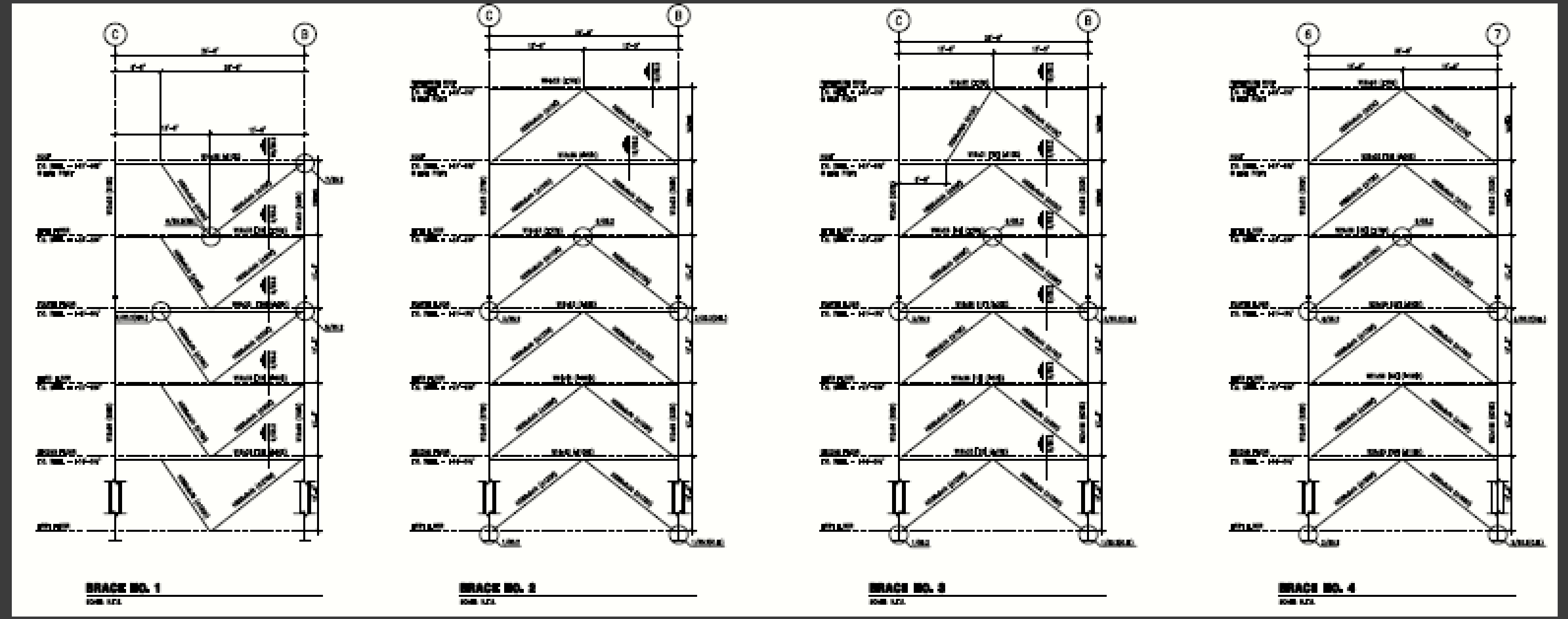
Lateral System

- 4 braced frames
- 3 in the North-South direction
- 1 in East-West direction

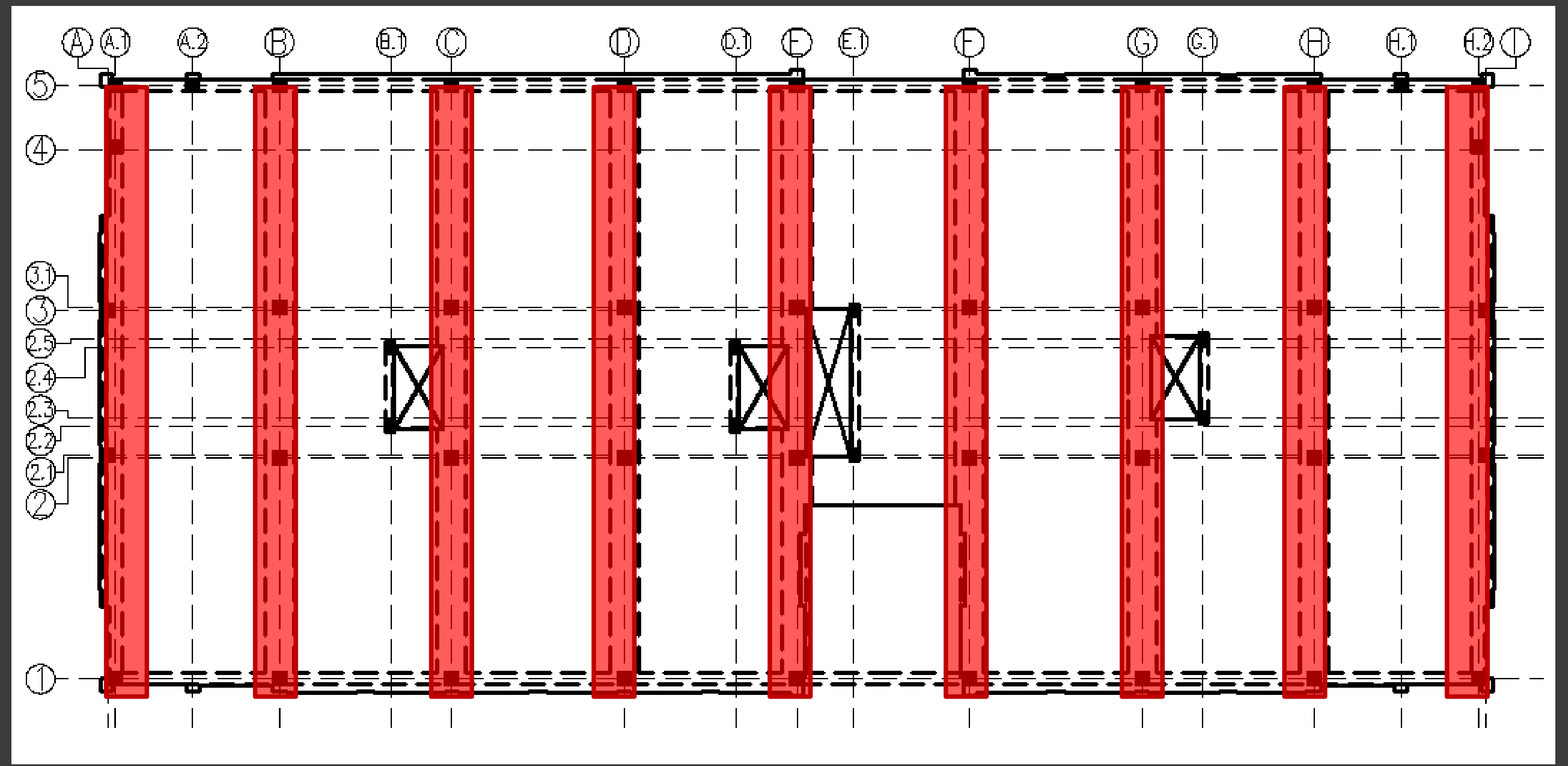


Goals

1. Design structure using post-tensioned concrete
2. Maintain long exterior spans
3. Minimize the floor depth
4. Determine architectural impacts of new system
5. Compare cost and schedules of the original vs. the proposed system

Solution

- Gravity System: One-way, post-tensioned slab supported by wide, shallow post-tensioned girders
- Lateral System: Concrete moment frames



Design of Post-Tensioned Slab

Concrete

- **Normal weight concrete**
- **f'c = 5000 psi**

PT Tendons

- **½" Ø, 7-wire strands**

Post-Tensioned Slab Design Parameters	
Clear Cover	1.0"
Size of Conventional Reinforcement	#4 Bars
Balanced Dead Load	50%-100% £
Precompression Stress	≤ 300psi ¥
Location of Tendon(s) Anchor	¼*L Ж

£ To avoid extreme upward camber

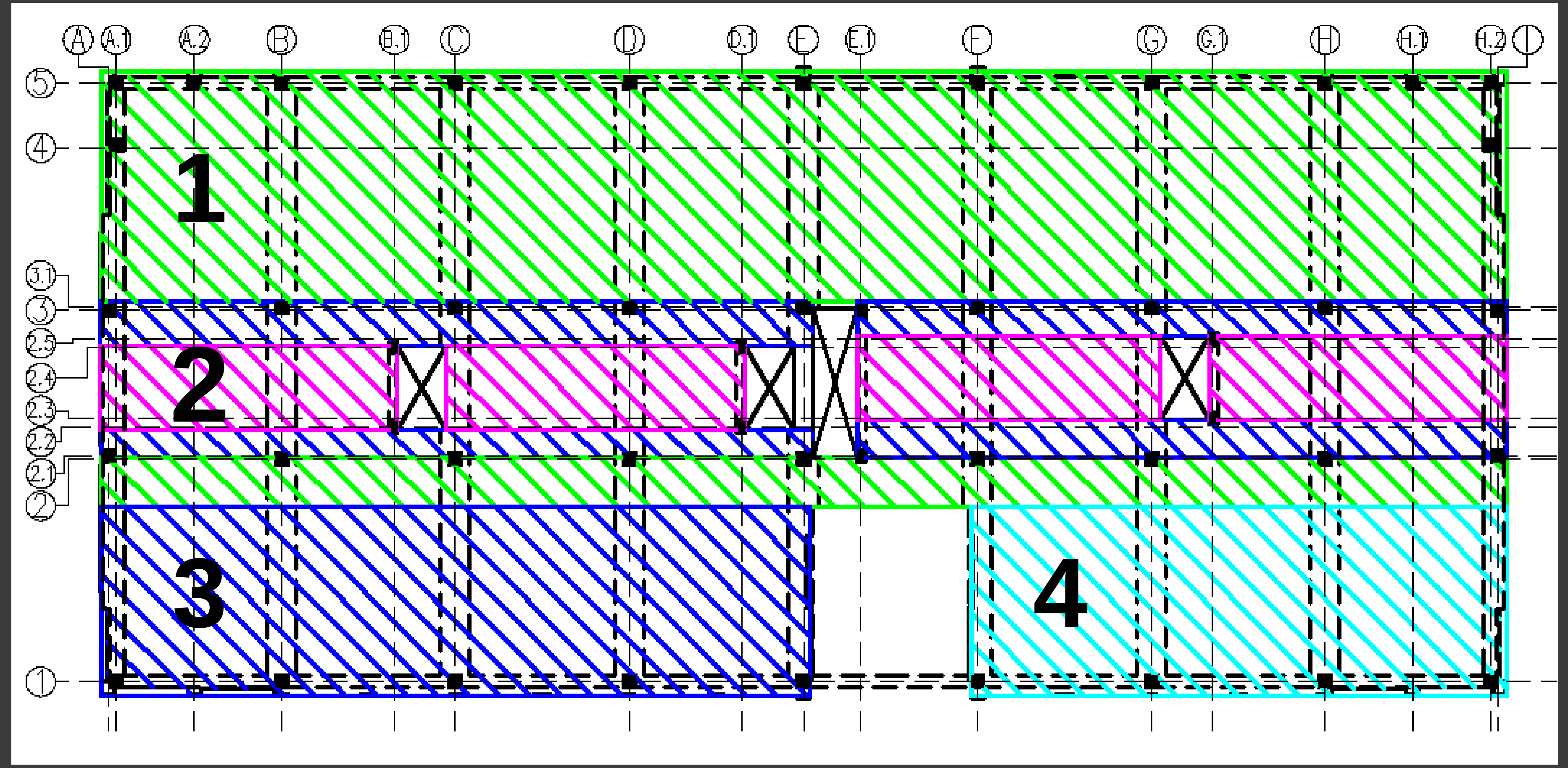
¥ To avoid cracking due to creep

Ж To avoid reinforcement congestion

Design of One-Way Post-Tensioned Slab

Design Zones

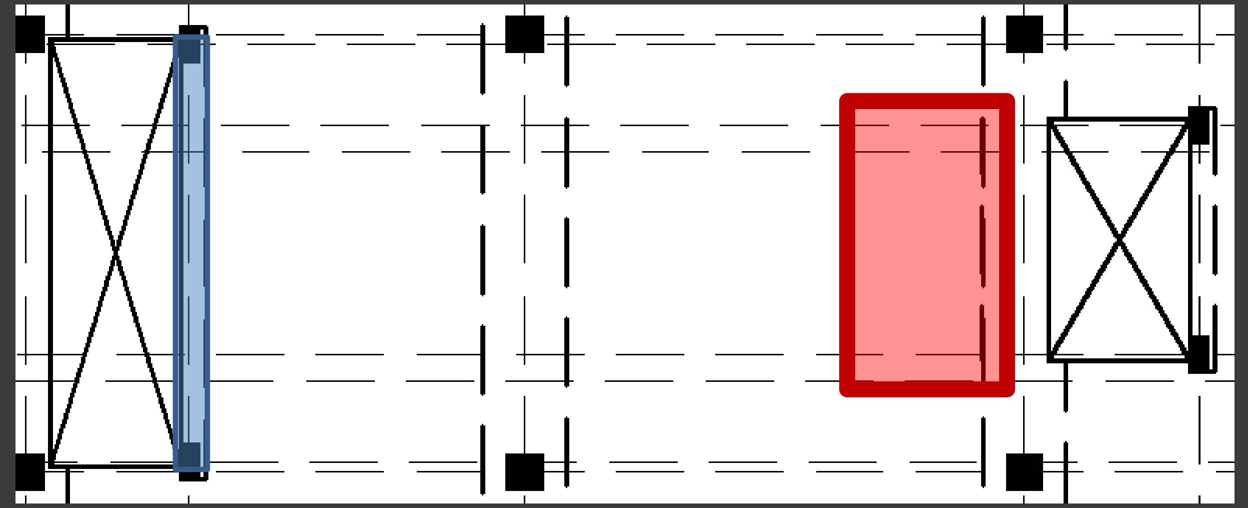
- Slab divided into different areas based on:
  1. Number of spans
  2. Length of Spans
- 4 individual zones

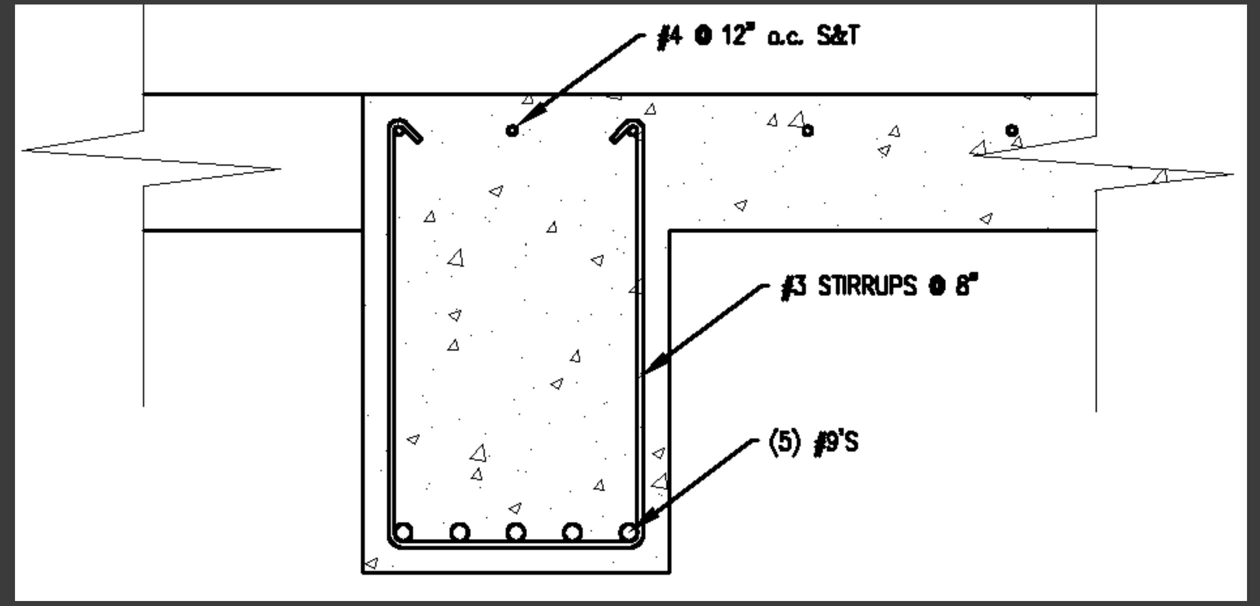


Design of One-Way Post-Tensioned Slab

Design of Zone 2

- Introduce Normally Reinforced Concrete Beam
  - 18”x20”
  - f’c = 5000 psi
  - (5) #9’s – flexural reinforcement
  - (2) legs of #3 @ 8” – shear reinforcement



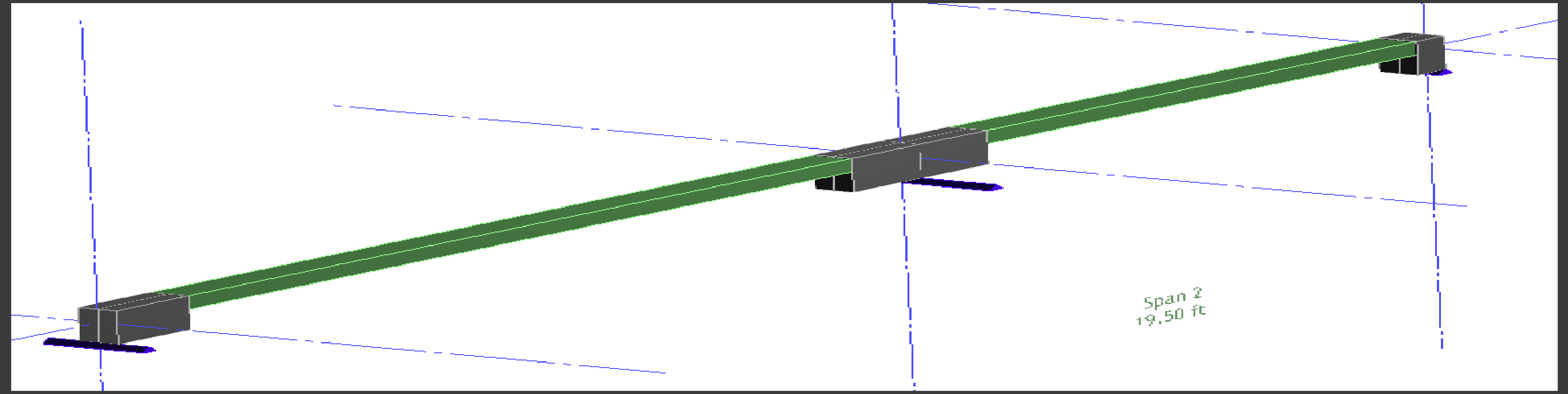


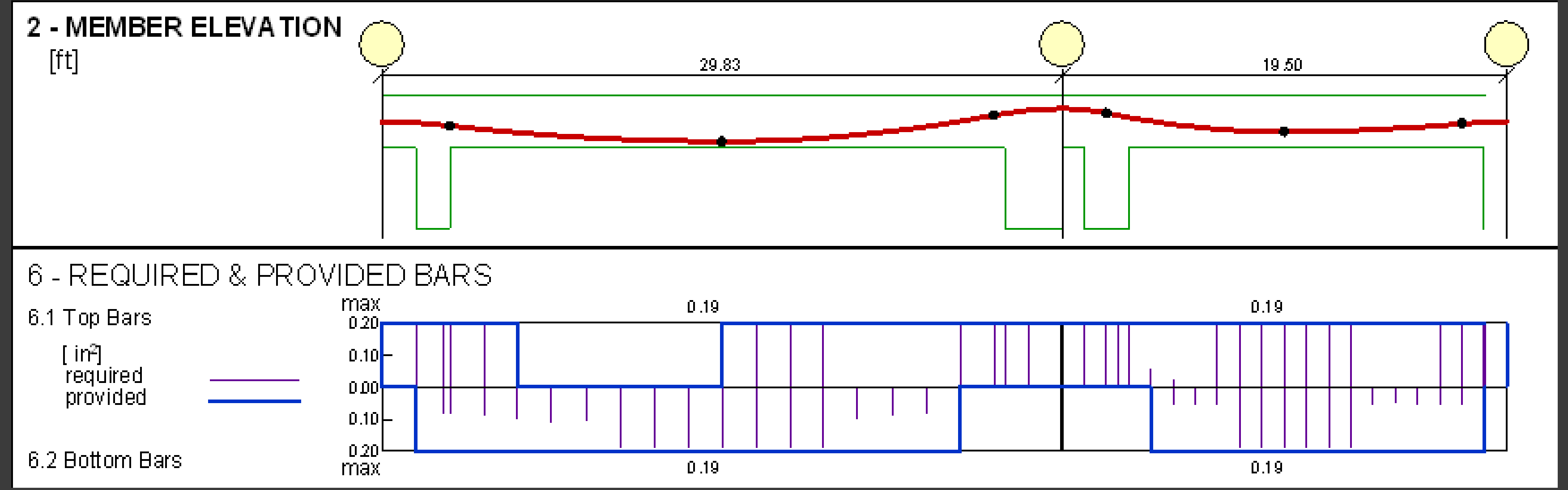
Design of Gravity System

Design of One-Way Post-Tensioned Slab

Design of Zone 2

- Live load reductions per ASCE 7-05 § 4.8
- Preliminary Size
  - L/45 – continuous spans: (30*12) / 45 → h = 8"
- f'c = 5000 psi
- Fe = 28.8 kips/ft (2 tendons per foot width)
- Increased span 2 tendon height at mid-distance due to high tension stress at initial loading
- (1) #4 per foot; T – over supports, B - midspan

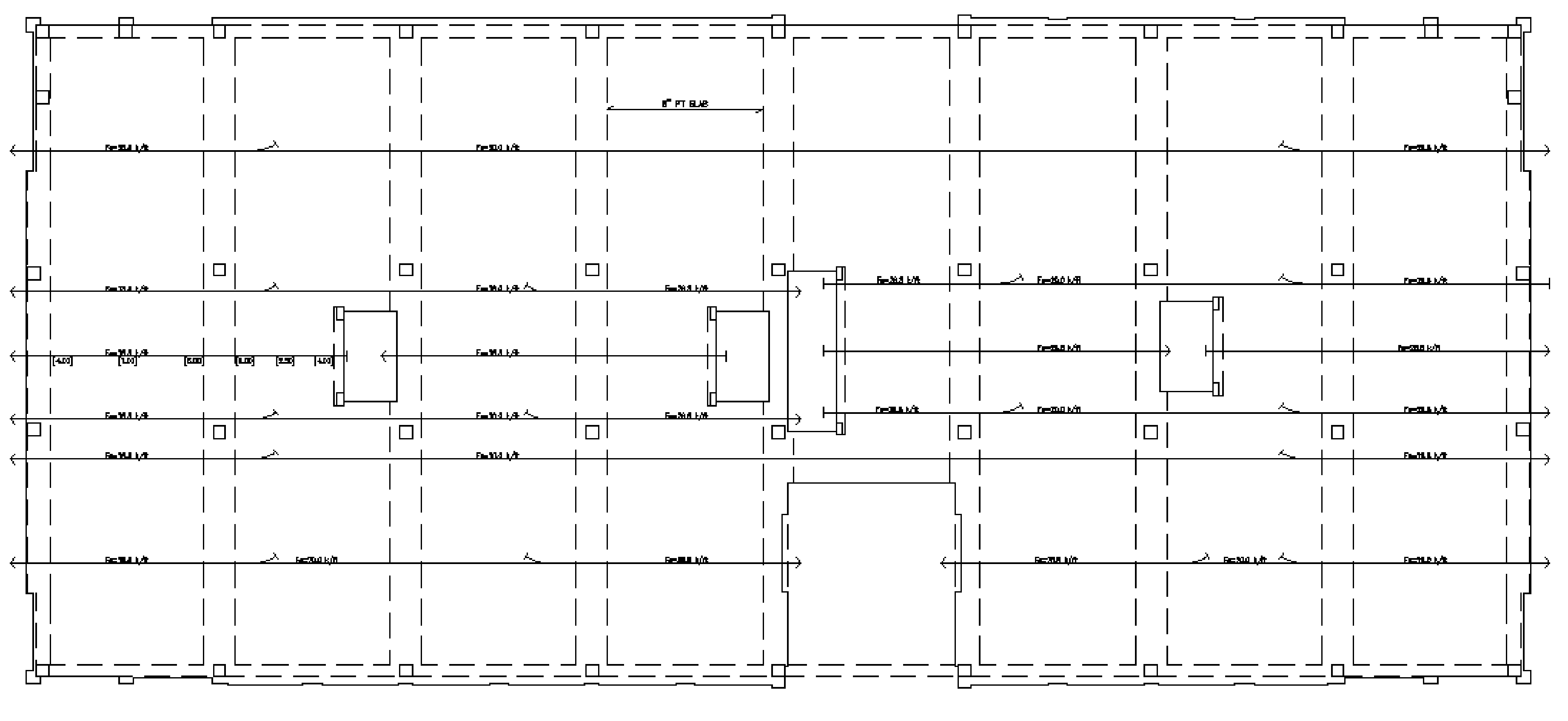




Design of One-Way Post-Tensioned Slab

Zone 1, 3, and 4

- Fe = 28.8 kips/ft in exterior bays
- Fe = 20.9 kips/ft in interior bays
- Tendon heights:
  - At supports: 7.0”
  - At mid-span: 1.0”
- Deflections were not an issue
  - Max deflection = 0.53” in exterior spans
- #4 @ 12” perpendicular to tendons for S&T

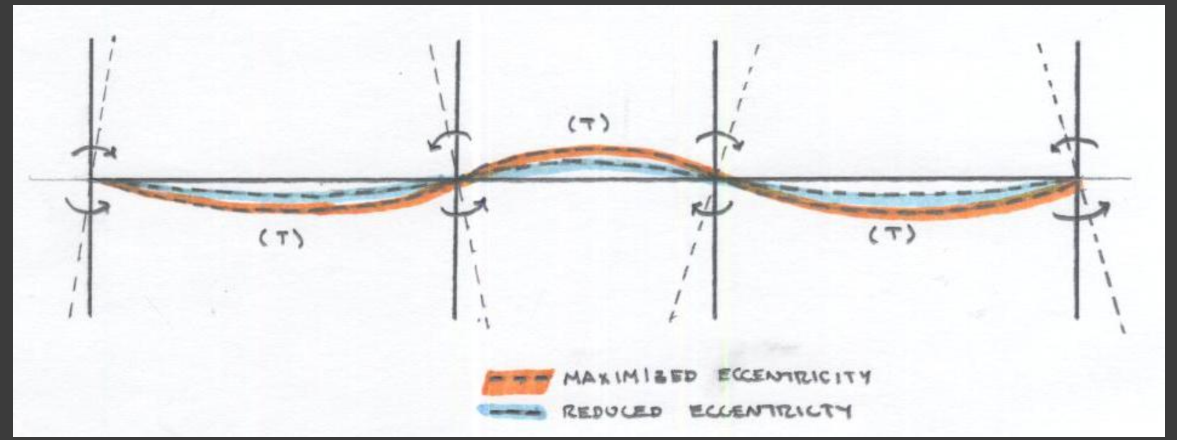


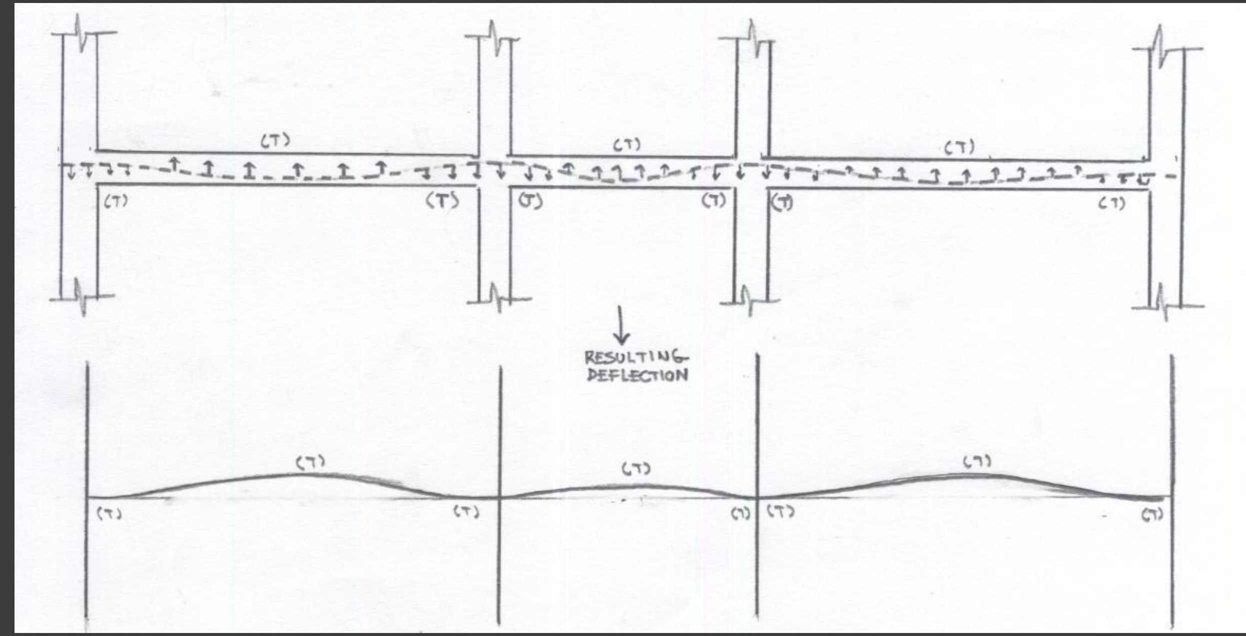
Design of Post-Tensioned Girders

- Banded tendons to provide high PT force
  - 7 tendons per 2 ¾” conduit

Method

- Reduce tension at midspan in exterior bays by decreasing drape eccentricity in the middle span
- Reduce bottom fiber tension at supports by decreasing tendon height over columns

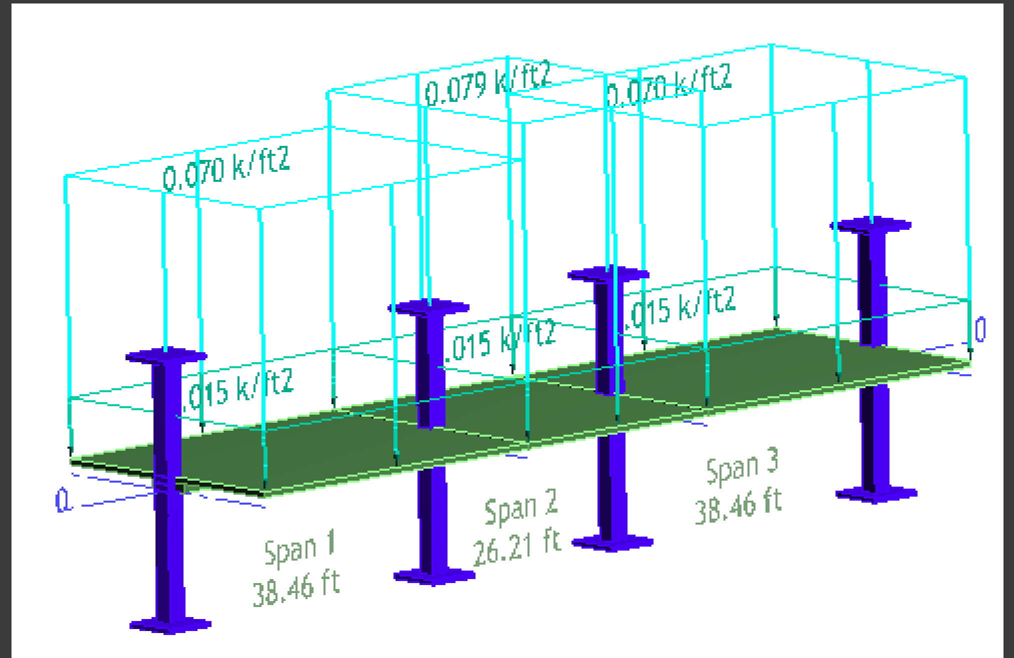


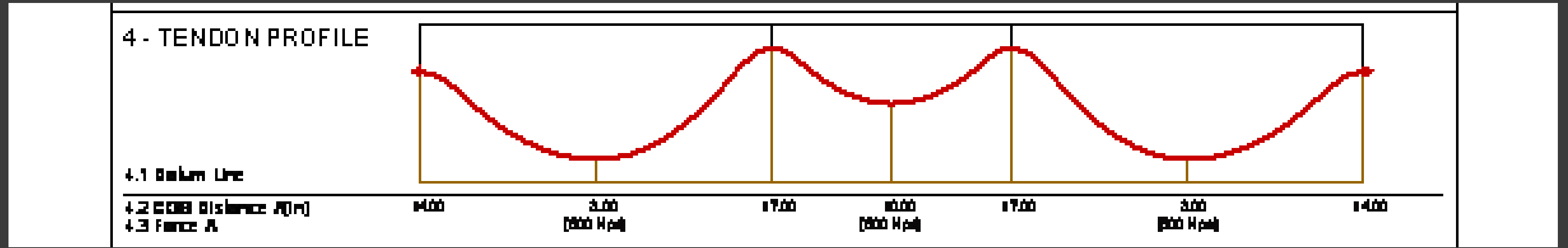


Design of Post-Tensioned Girders

Design of Typical Girder

- **Preliminary Size: 60" x 20"**
- **PT force = 600 kips**
- **Required number of tendons = 23**
- **Max deflection = 0.18" in exterior spans**





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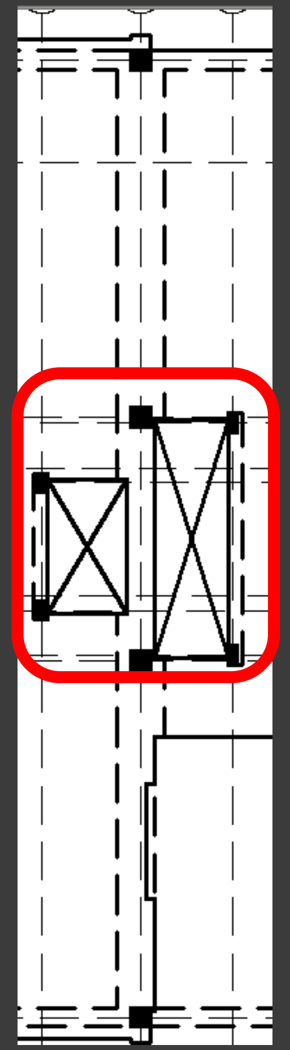
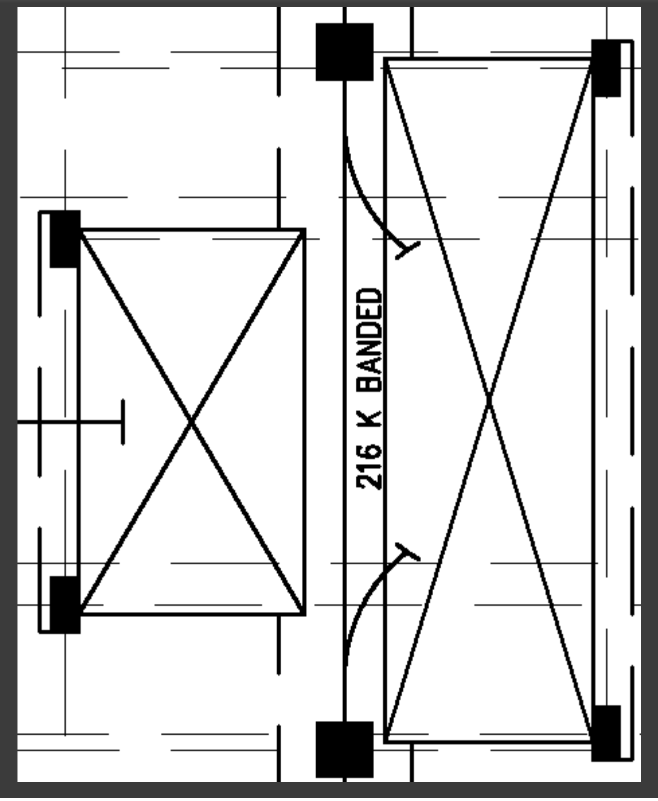
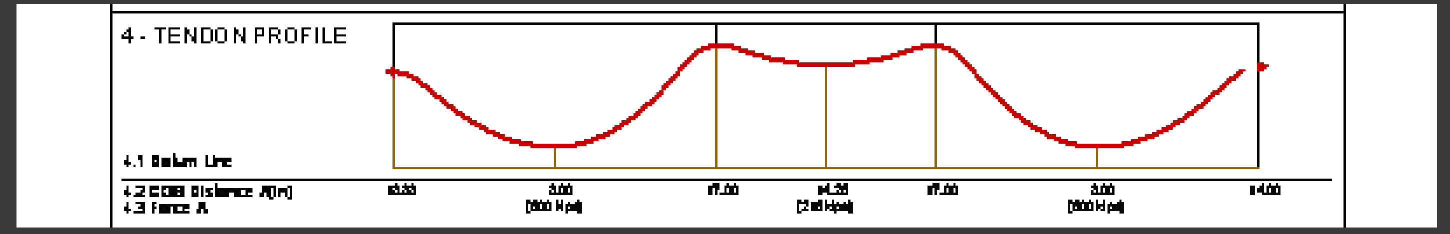
Design of Post-Tensioned Girders

Design of Girder Adjacent to Elevator Openings

- **Narrow cross section increased the precompression stress much greater than 300 psi**
- **Extend tendon group entirely continuously through the girder**
- **Provide tendons in exterior bays to balance dead load**
  - **Run off extra tendons through slab openings**
- **Required PT Force = 500/216/600 kips**
- **Required Number of Tendons = 19/9/23**
- **Maximum deflection in span 3 = 0.19"**







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Design of Concrete Moment Frames

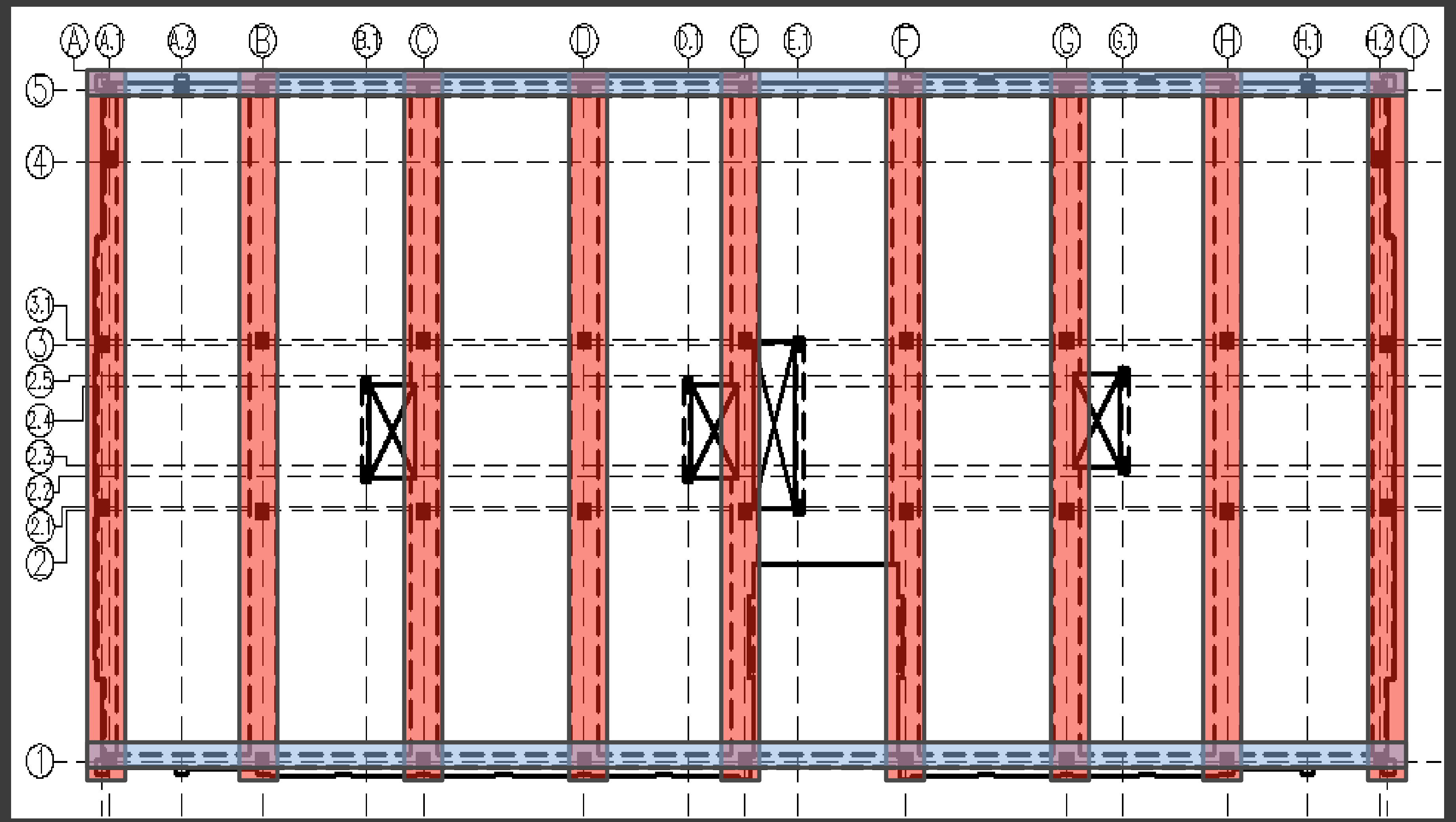
- 9 in north-south direction
- 2 in east-west direction

Deflection/Story Drift Limitations

- L/400 – wind
- $0.015 * h_{sx}$ – seismic

ETABS Model

- Property Modifiers
  - 0.70 – columns
  - 0.40 – beams



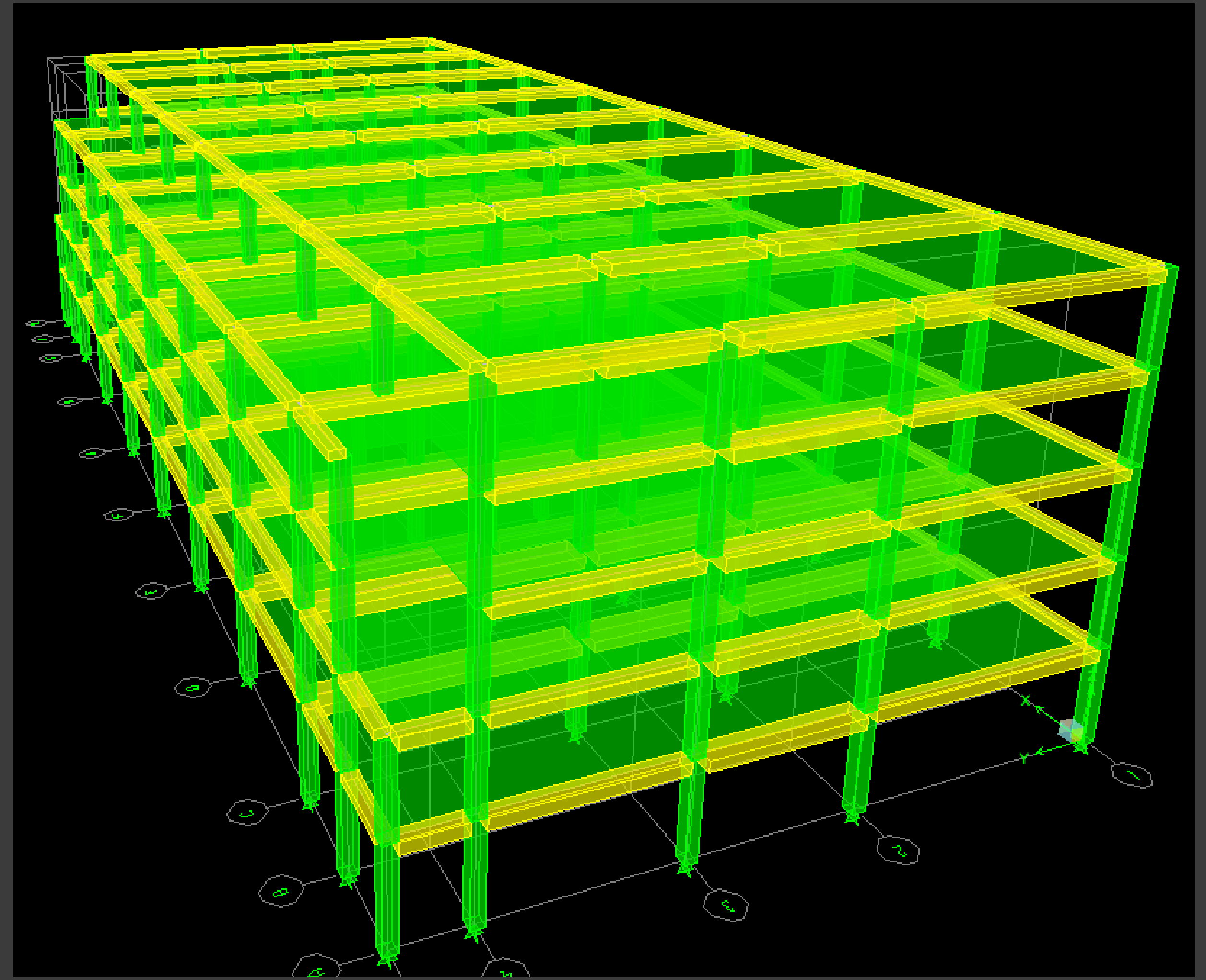
Design of Concrete Moment Frames

Lateral Displacement Due to Wind					
Lateral Displacement/Story Drift in X Direction					
Floor	Height (ft)	Displacement (in)	Allowable Displacement (in)*	Story Drift (in)	Allowable Story Drift (in)*
RF	68.32	0.921	2.05	0.05	0.40
5	54.99	0.868	1.65	0.10	0.40
4	41.66	0.772	1.25	0.14	0.40
3	28.33	0.637	0.85	0.19	0.40
2	15	0.444	0.45	0.44	0.45
Lateral Displacement/Story Drift in Y Direction					
Floor	Height (ft)	Displacement (in)	Allowable Displacement (in)*	Story Drift (in)	Allowable Story Drift (in)*
RF	68.32	1.40	2.05	0.18	0.40
5	54.99	1.22	1.65	0.21	0.40
4	41.66	1.01	1.25	0.26	0.40
3	28.33	0.751	0.85	0.31	0.40
2	15	0.442	0.45	0.44	0.45

Seismic Story Drift									
Story Drift - X Direction					Story Drift - Y Direction				
Floor	Story Height	Displacement	Story Drift	Allowable Drift*	Floor	Story Height	Displacement	Story Drift	Allowable Drift*
RF	13.33	3.04	0.35	3.2	RF	13.33	0.589	0.026	3.2
5	13.33	2.69	0.44	3.2	5	13.33	0.563	0.055	3.2
4	13.33	2.25	0.55	3.2	4	13.33	0.508	0.083	3.2
3	13.33	1.70	0.7	3.2	3	13.33	0.425	0.126	3.2
2	15	1.00	1.00	3.6	2	15	0.299	0.299	3.6

* Limited to $0.020h_{sx}$

- **Torsion : Threshold 54.4 ft-kips, Tu = 25.3 ft-kips**



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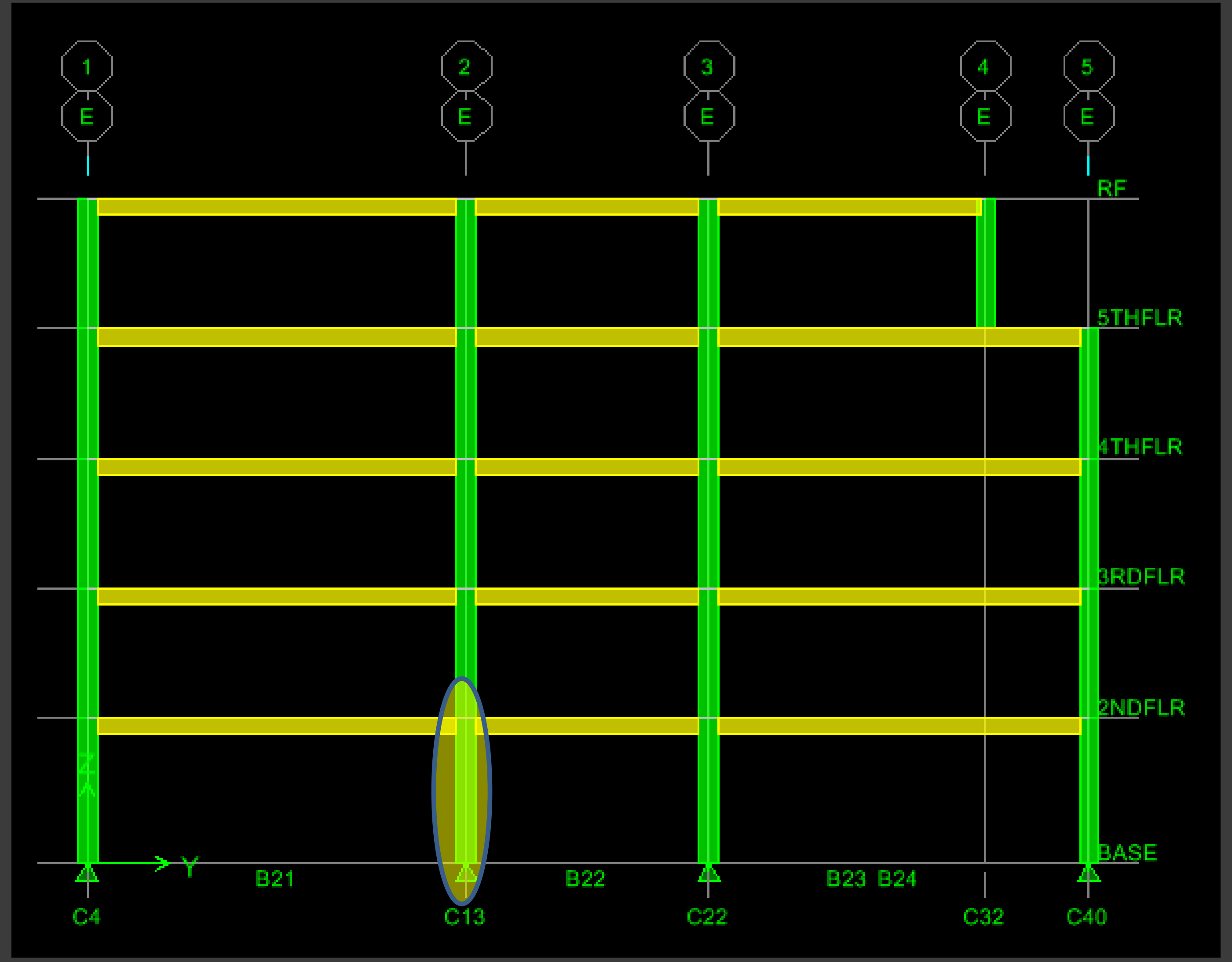
Design of Typical Interior Column

Axial Load at Top of Column	
Dead Load	Live Load
1064 kips	352 kips
Moments at Top of Column	
Seismic	Wind
82.3 ft-kips	128 ft-kips

- **Load Combination: 1.2D + 1.6W + L**

Pu	Mu
1651 ft-kips	205 ft-kips

- **Summary: f'c = 6000 psi, As = (8) # 10's → ρ = 1.76% ≤ 2.00%**



Construction Management Breadth

- Cost Comparison

Post-Tensioned Structure				
Type	Bare Material	Bare Labor	Bare Equipment	Bare Total
Formwork	$ 47,806.46	$120,116.04	$ -	$ 212,626.50
Reinforcement	$ 73,170.58	$ 19,391.44	$ -	$ 92,562.03
PT Tendons	$ 19,207.93	$ 29,909.49	$ 48.00	$ 49,666.22
Concrete	$ 131,523.38	$ -	$ -	$ 131,523.38
Placing Concrete	$ -	$ 10,192.37	$ 4,352.92	$ 14,545.29
Finishing Concrete	$ -	$ 4,826.00	$ 1,524.00	$ 6,350.00
Sub Total	$ 271,708.36	$184,435.34	$ 5,924.92	$ 507,273.42
Total	$ 507,273.42			

Steel Structure				
Type	Bare Material	Bare Labor	Bare Equipment	Bare Total
Structural Steel	$ 259,979.09	$ 18,381.13	$ 4,854.64	$ 282,851.36
Reinforcement	$ 5,204.46	$ 4,744.72	$ -	$ 9,949.18
Concrete	$ 61,806.06	$ -	$ -	$ 61,806.06
Placing Concrete	$ -	$ 4,413.24	$ 1,883.70	$ 6,296.94
Finishing Concrete	$ 6.35	$ -	$ 4,826.00	$ 1,524.00
Sub Total	$ 326,995.96	$ 27,539.09	$ 11,564.34	$ 362,427.54
Total	$ 362,427.54			

	Cost Comparison Per Floor	
	Steel	PT Concrete
Total Cost	$367,000.00	$501,000.00
Cost per SF	$14.45	$19.72

Construction Management Breadth

- **Schedule Comparison**

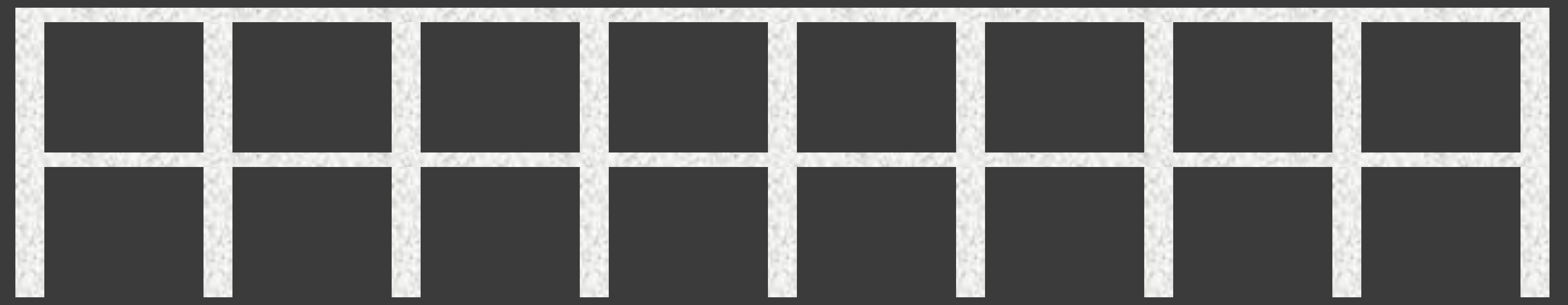
  Steel Structure

  - **35 piece of steel per day**
  - **Erect beams after decking two floors below is installed**

  Post-Tensioned Structure

  - **Divided slab into 3 phases**
  - **Sequenced trades to accelerate schedule**

Construction Time	
Steel	Concrete
50 days	70 days



Conclusion

- **Long exterior spans were maintained**
- **The floor depth was minimized**
- **PT system took longer to construct and cost more**

Recommendation

- **Because the construction time and cost increased, the original structure design is most efficient.**
- **Switching to PT concrete would not be a viable solution**

Acknowledgments

- **Toll Brothers Commercial**
- **The M Group Architects**
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Questions