FMC Tower

Structural Design Challenges

David O'Connell, SE

Associate, Thornton Tomasetti

SEAoP Annual Conference,
Harrisburg, PA

June 4, 2015

FMC Tower

2900 Walnut St, Philadelphia

Owner	Brandywine Realty Trust
Design Architect	Pelli-Clark-Pelli Architects
Architect of Record	BLT Architects
Contractor	Turner Construction
Concrete	Madison Concrete
Steel	Samuel Grossi and Sons

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FMC Tower

2900 Walnut St, Philadelphia

GSF	1,000,000 ft^2
Height	720 ft
Core	40 ft x 110 ft
Total Steel	5000 tons
Core Concrete	15,000 cubic yards
Total Concrete	40,000 cubic yards

18 residential floors @ ~15,000 ft^2

28 office floors @ ~25,000 ft^2

20 elevators

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FMC Tower

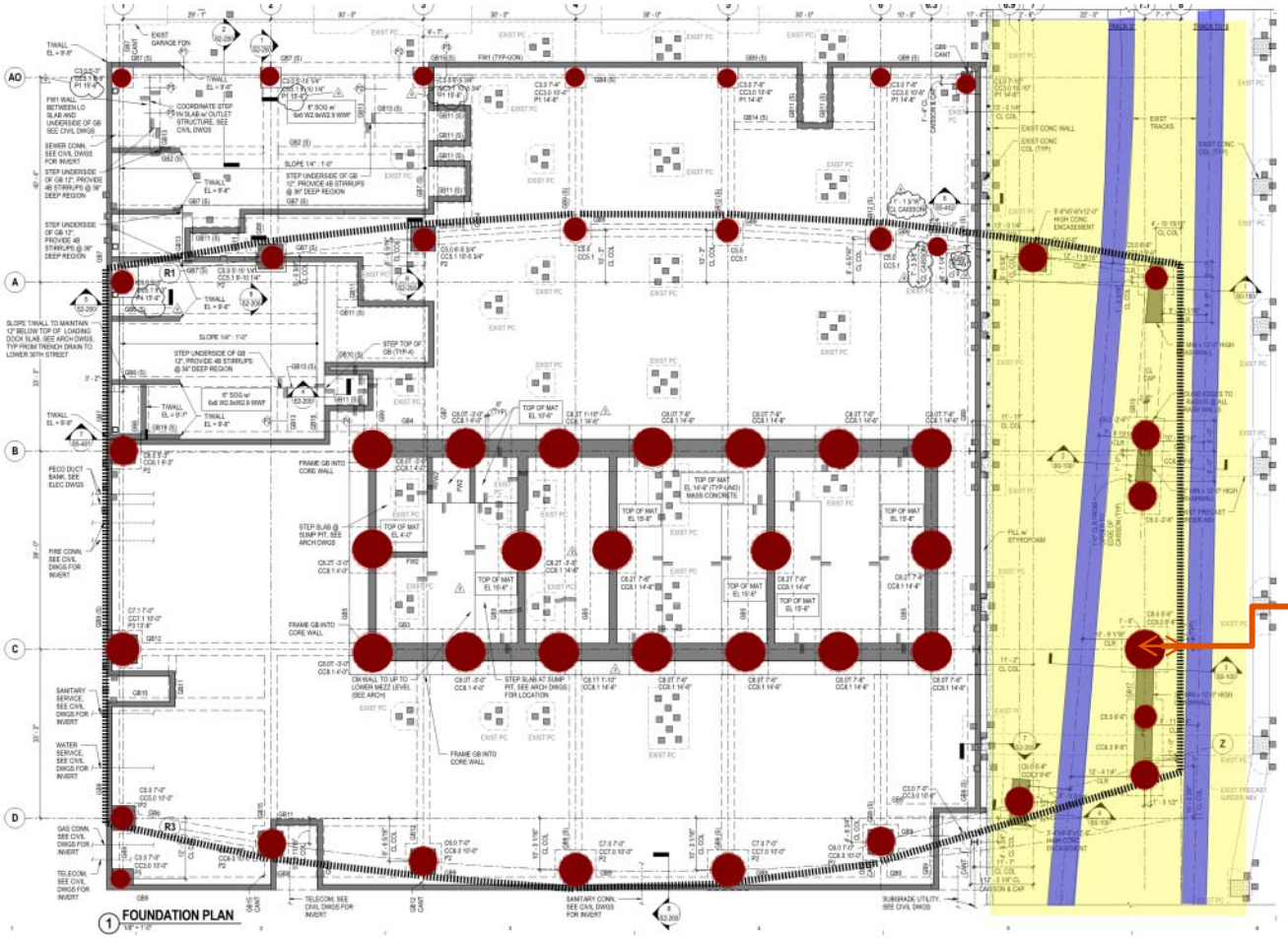
2900 Walnut St, Philadelphia

Design	September, 2013
Construction	August, 2014
Occupancy	June, 2016

Summary of Presentation

- Description of FMC Tower
- Choice of structural system
- Transfer floor design
- Vertical and horizontal movement and mitigation
- Occupant comfort

Foundation Plan



Caissons:

51 total, 19 under core, 8 within Amtrak ROW

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Dealing with Cocoon

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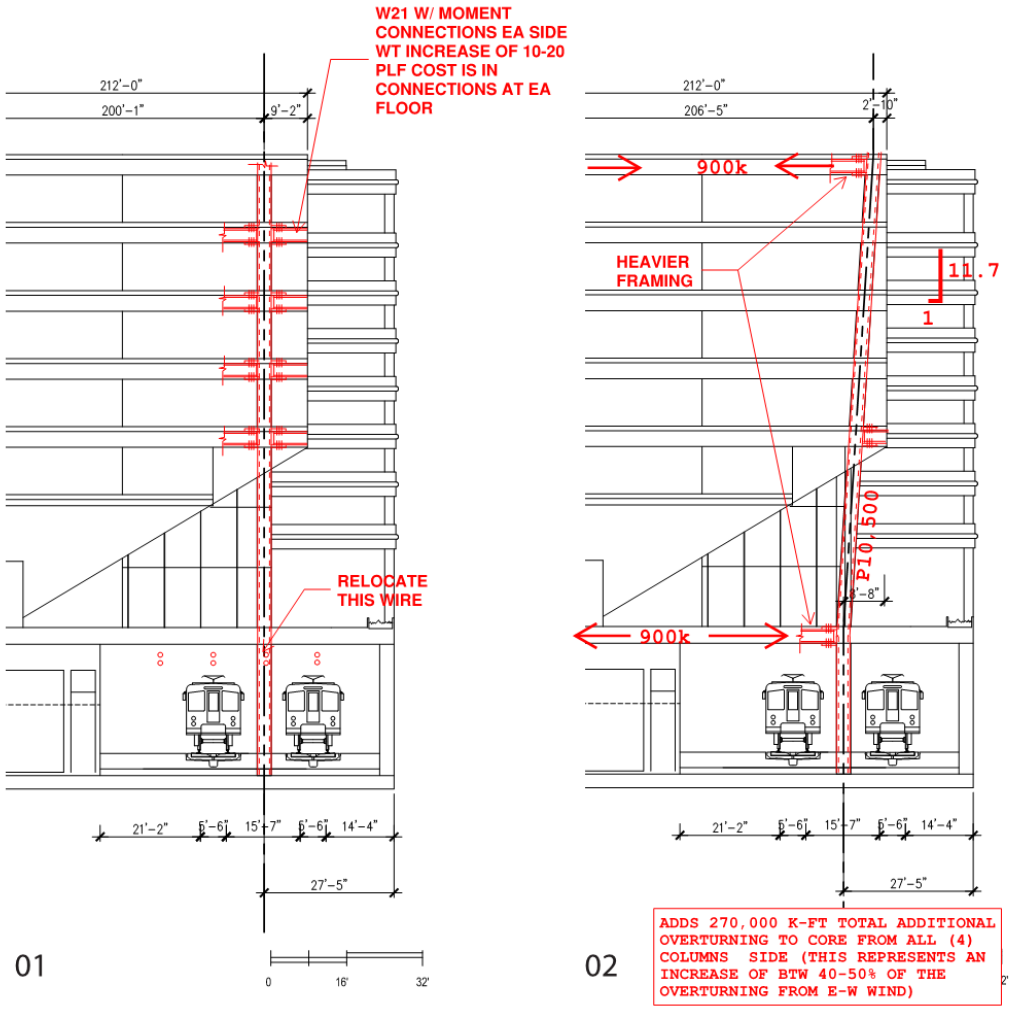
Dealing with Cocoon



CIRA SOUTH WALNUT TOWER

BUILDING SECTION: TRACK/COLUMN RELATIONSHIP

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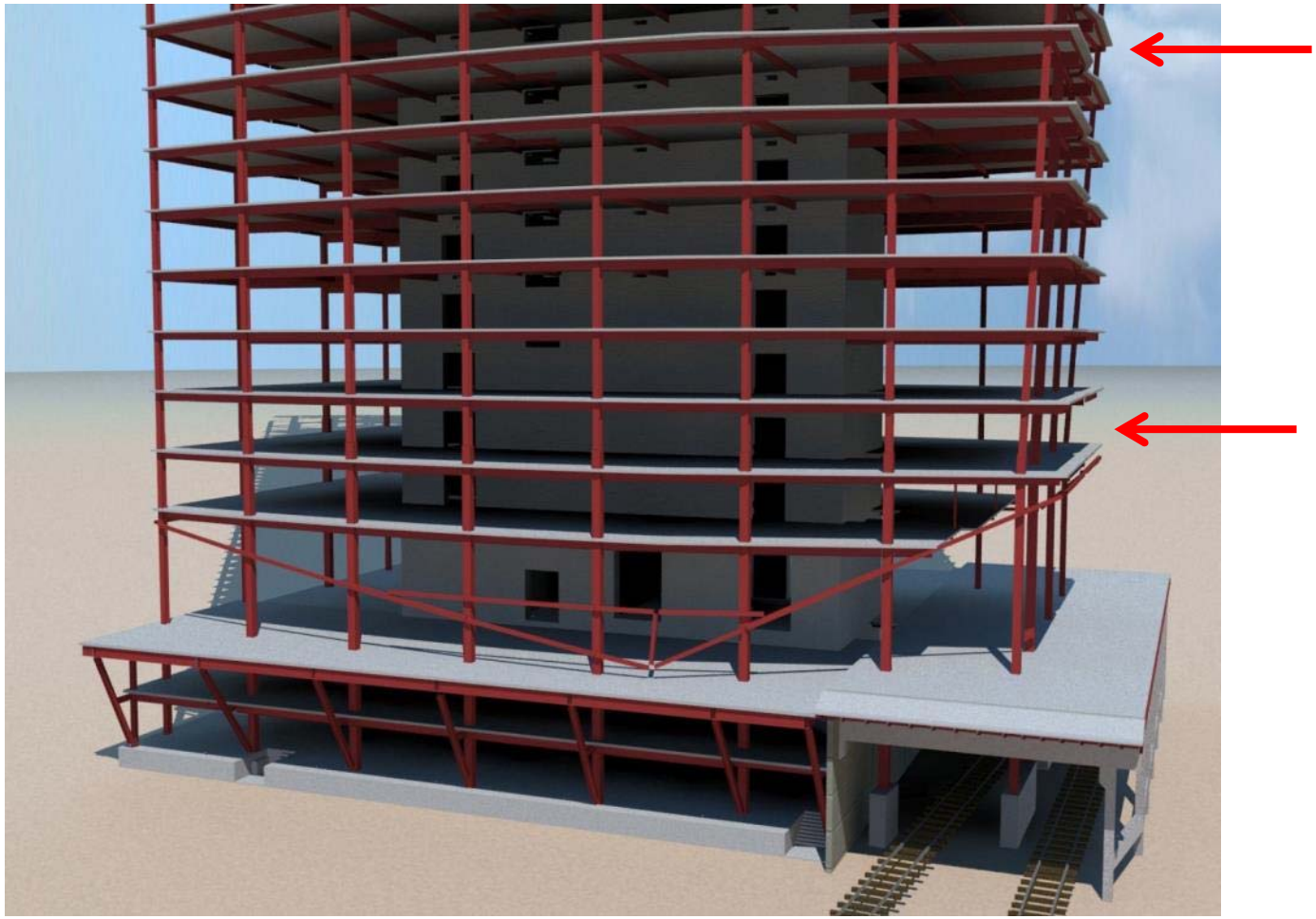
Column Slope



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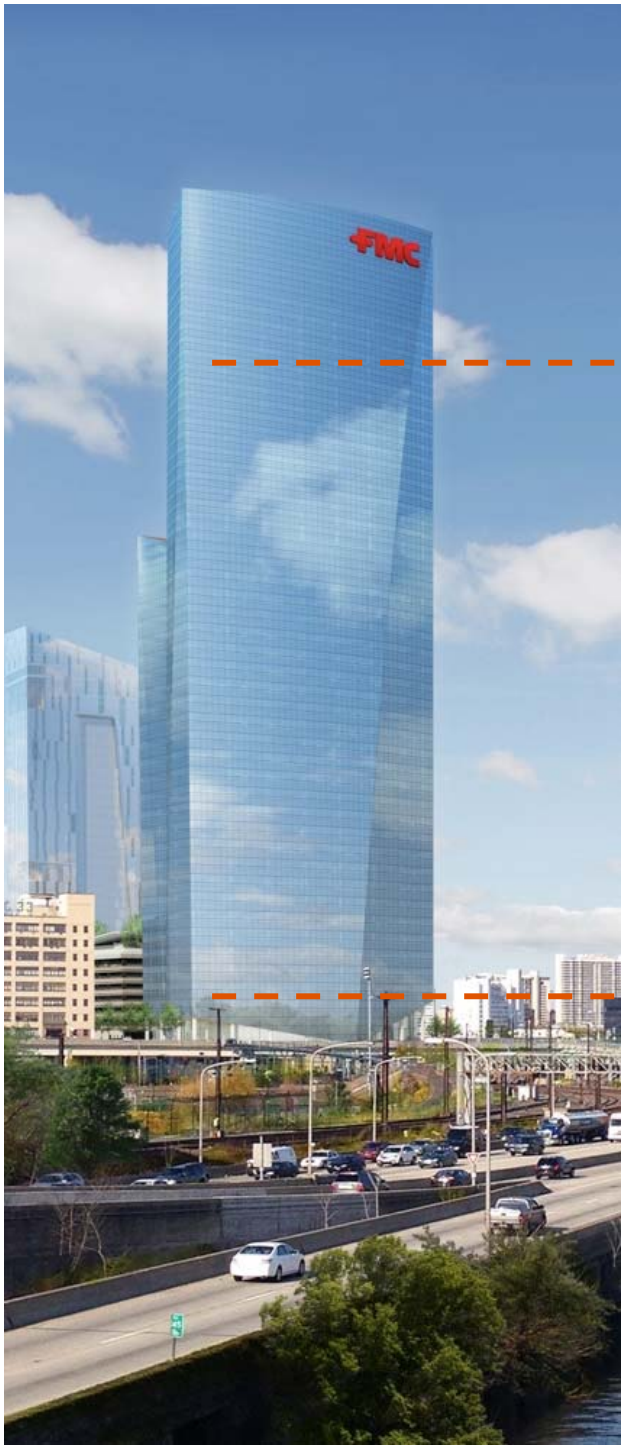
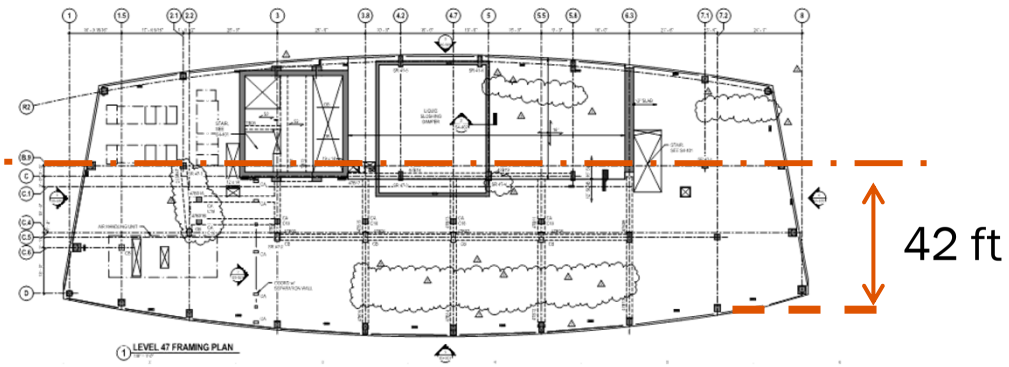
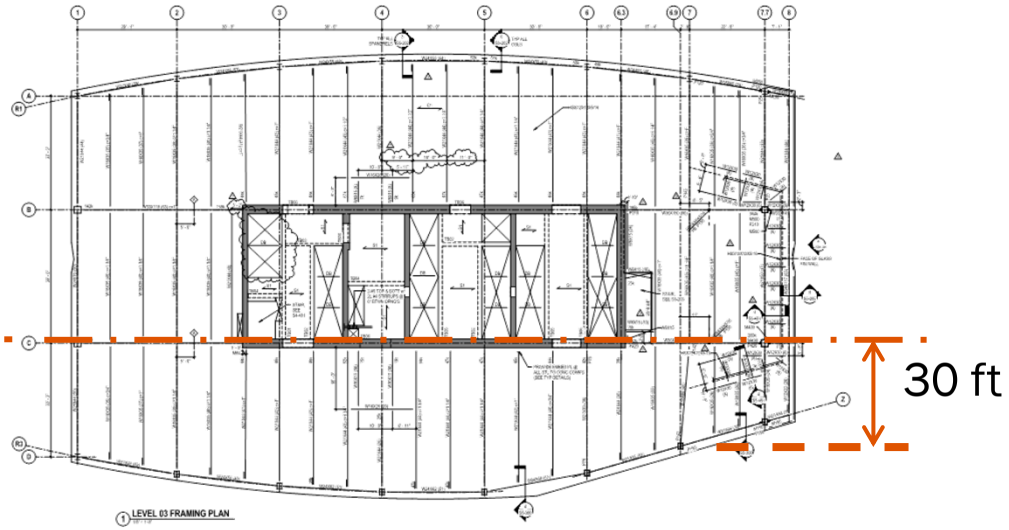


Column Slope





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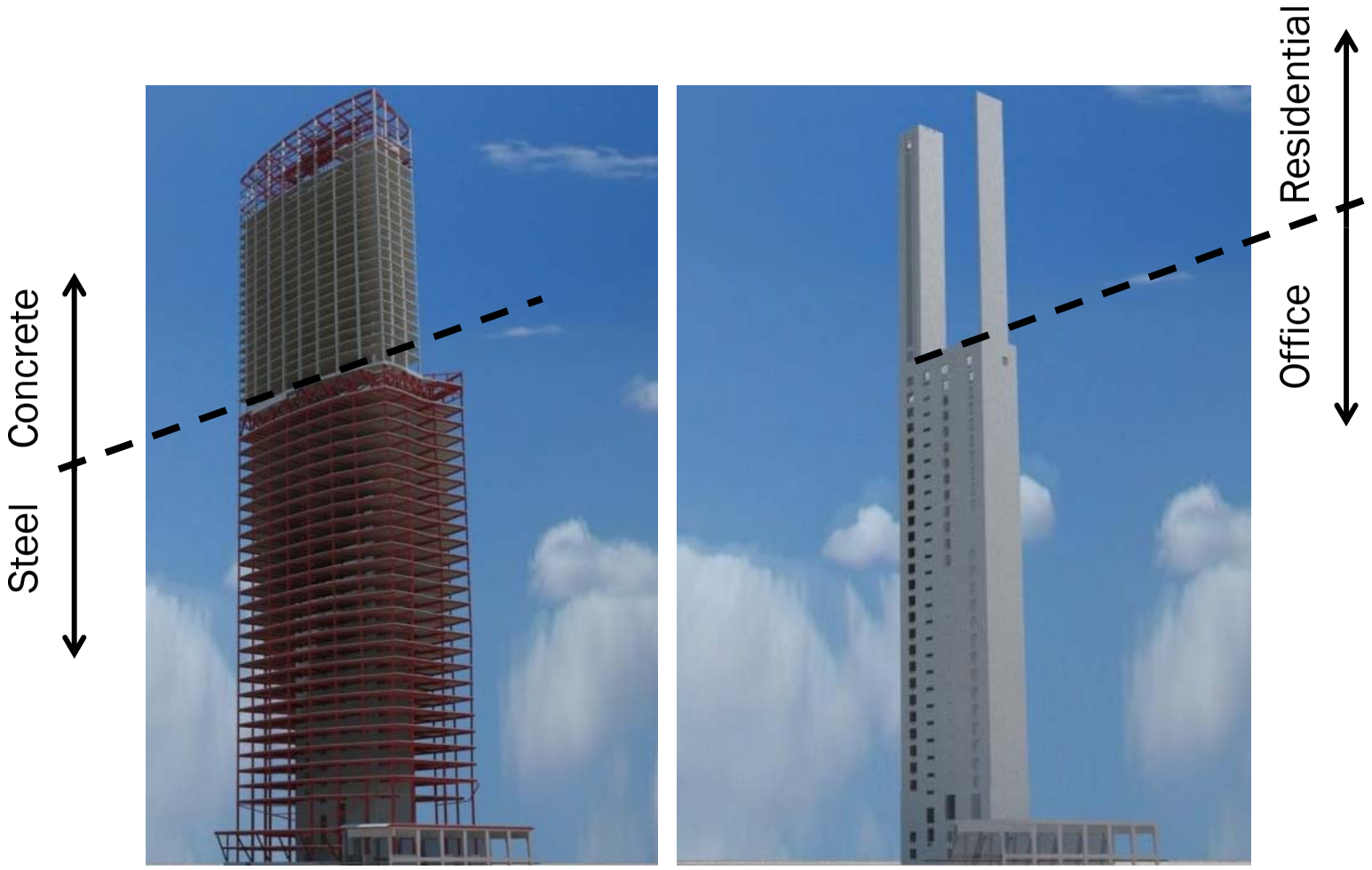
Concrete on Steel



Superstructure

Concrete Core

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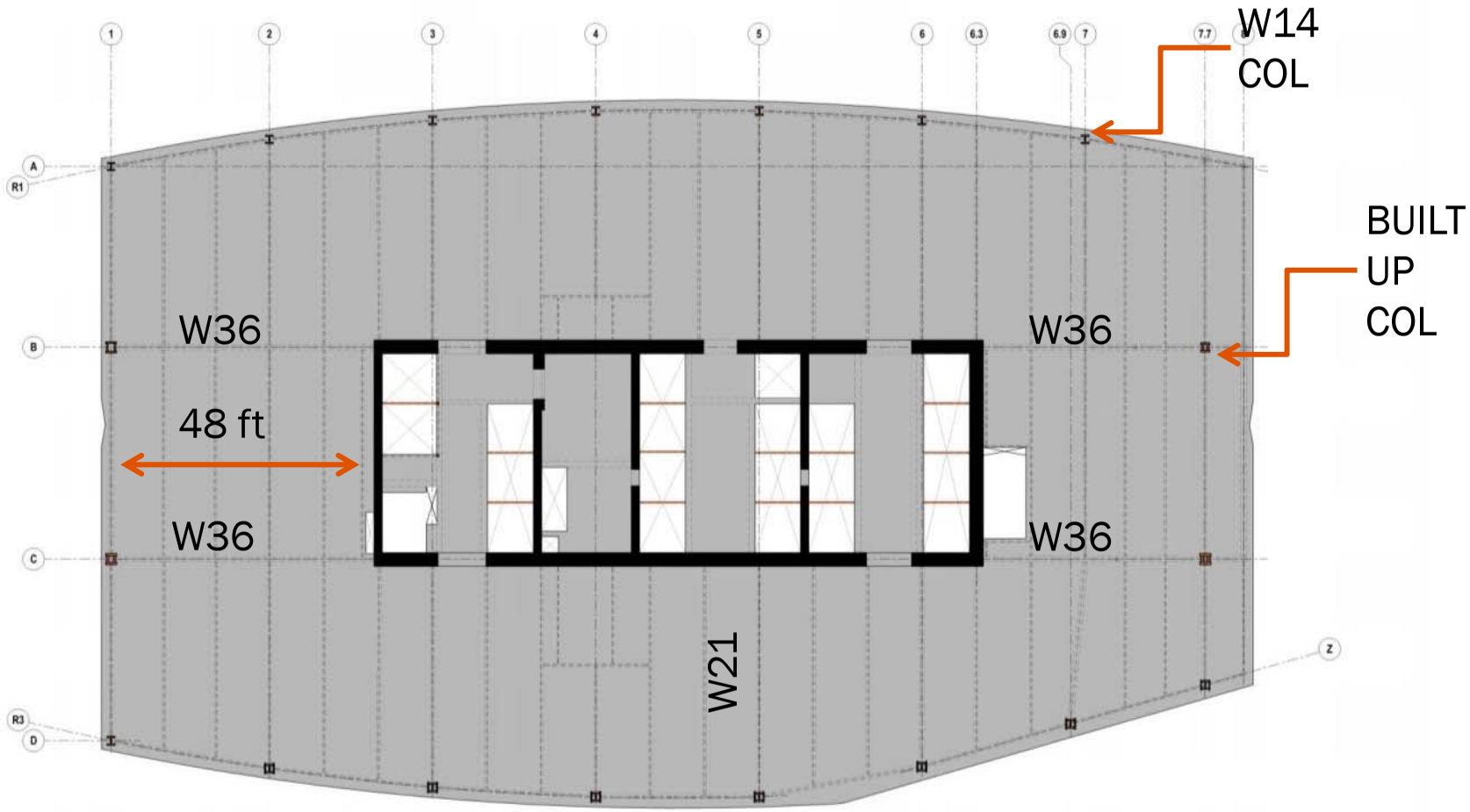
Typical Office Floor Plate



25000 ft^2 , 30 ft grid, spans up to 48 ft

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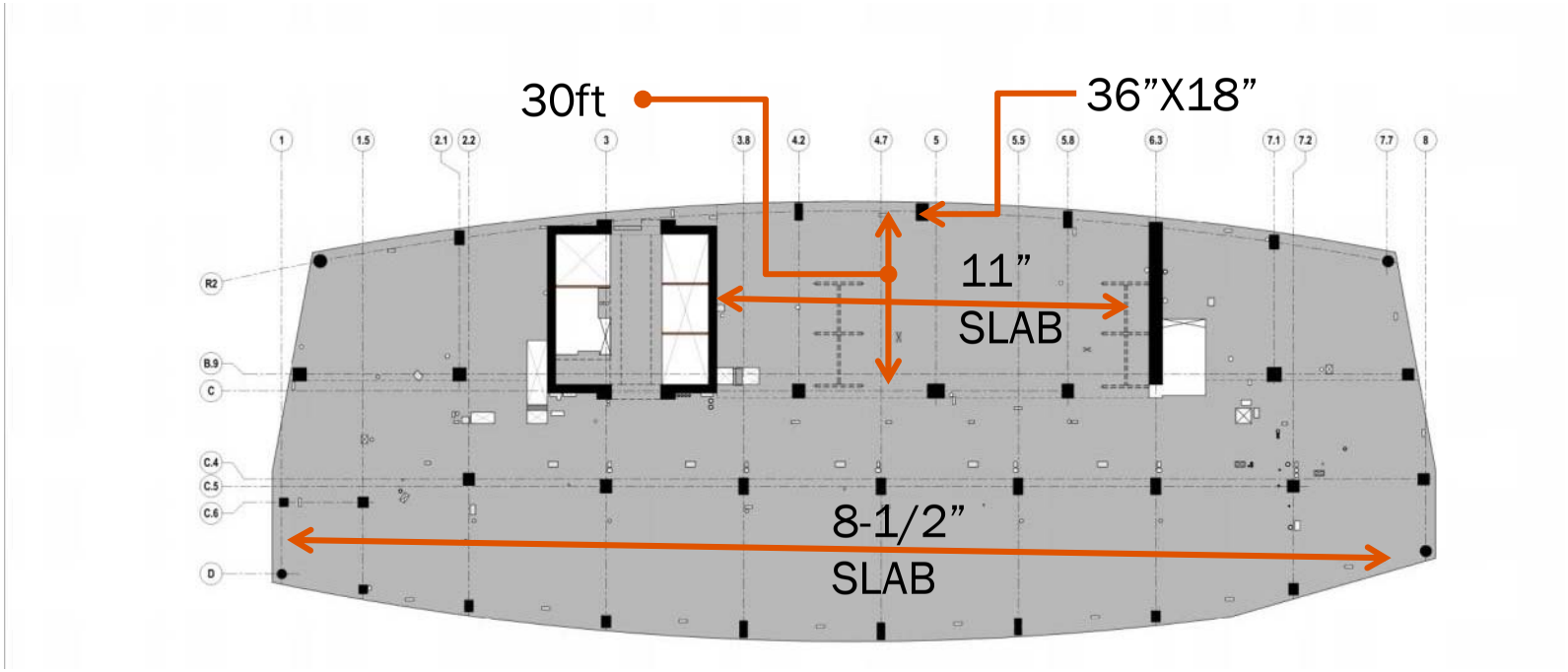
Typical Residential Floor Plate



15000 ft^2 , 25 ft grid, spans up to 30 ft

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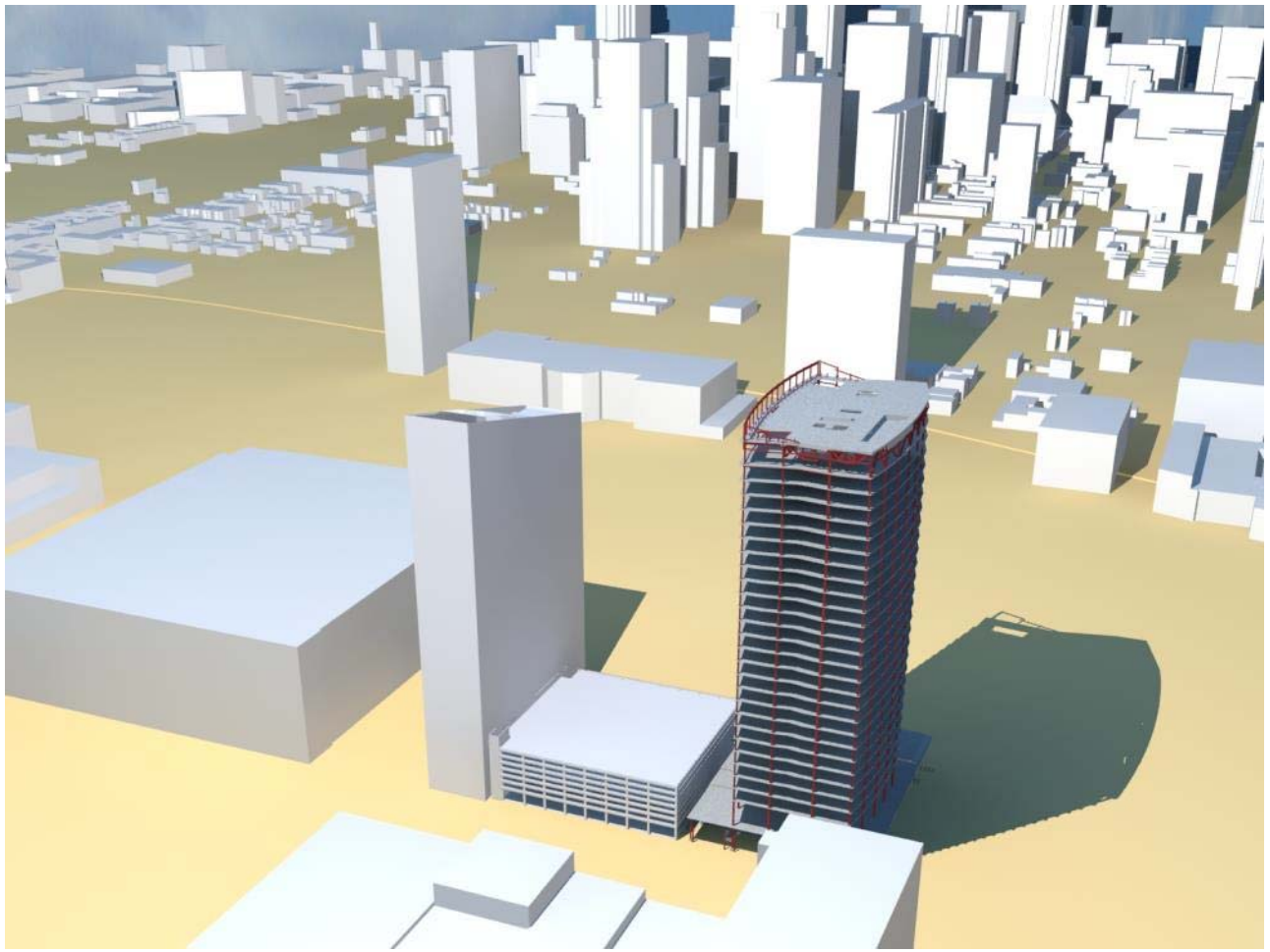
Steel Framed Office



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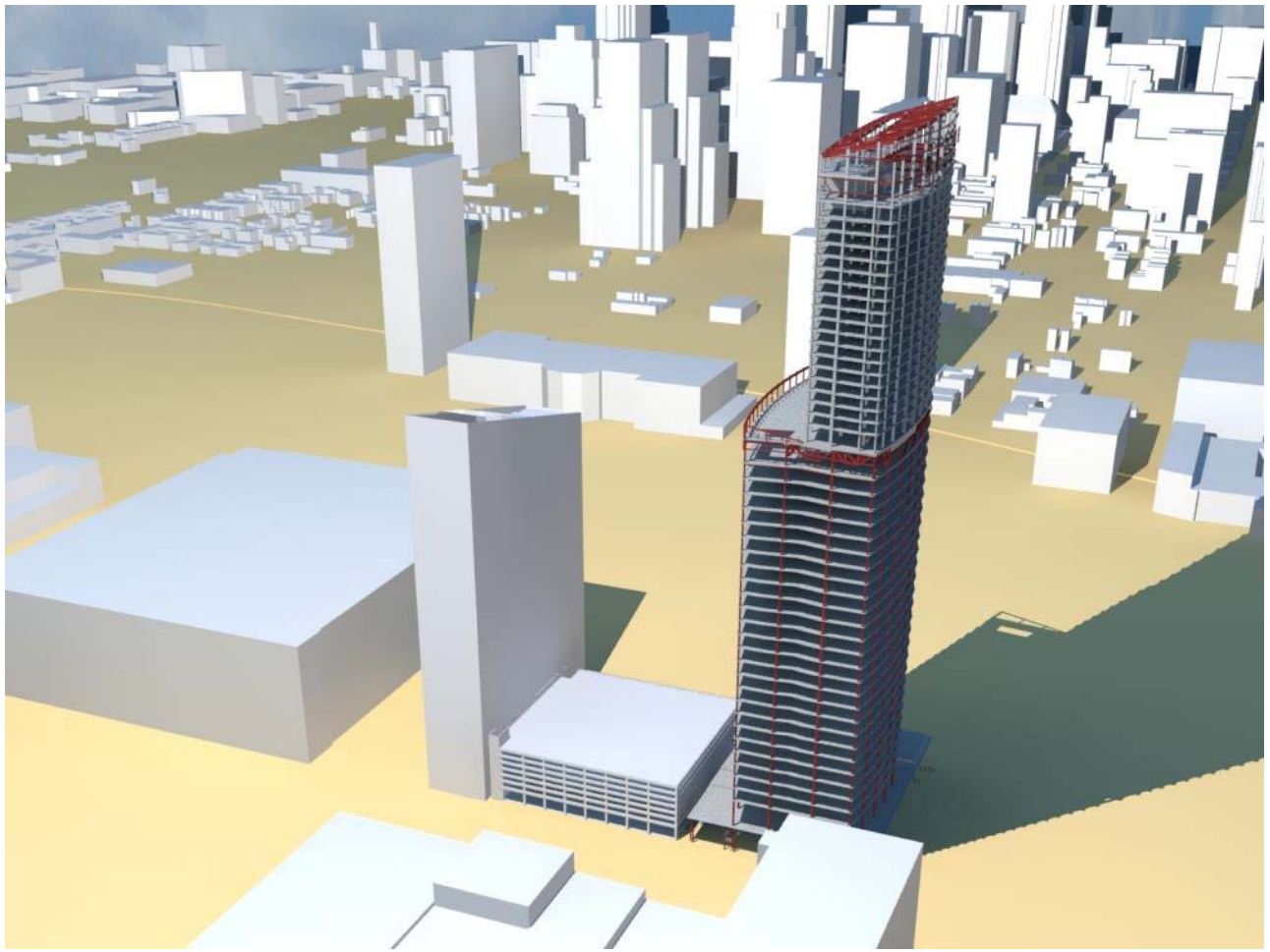
Concrete Framed Residential



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Three Options

1. Steel Office and Steel Residential
2. Concrete Office and Concrete Residential
3. Steel Office and Concrete Residential

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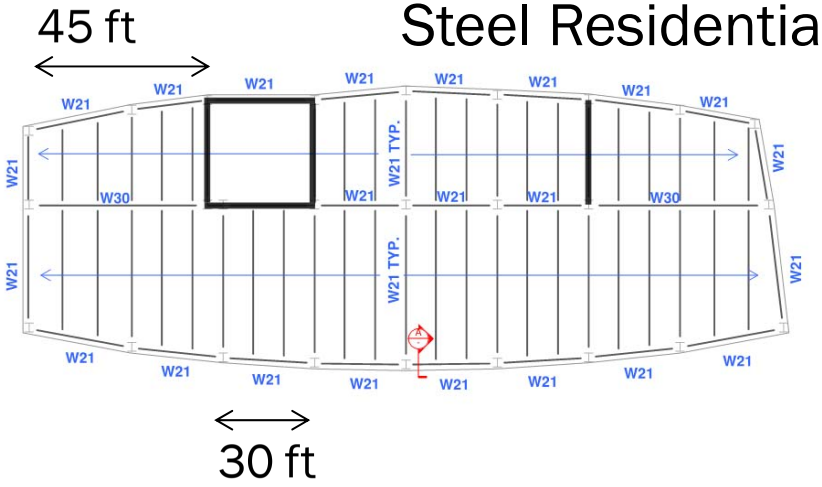
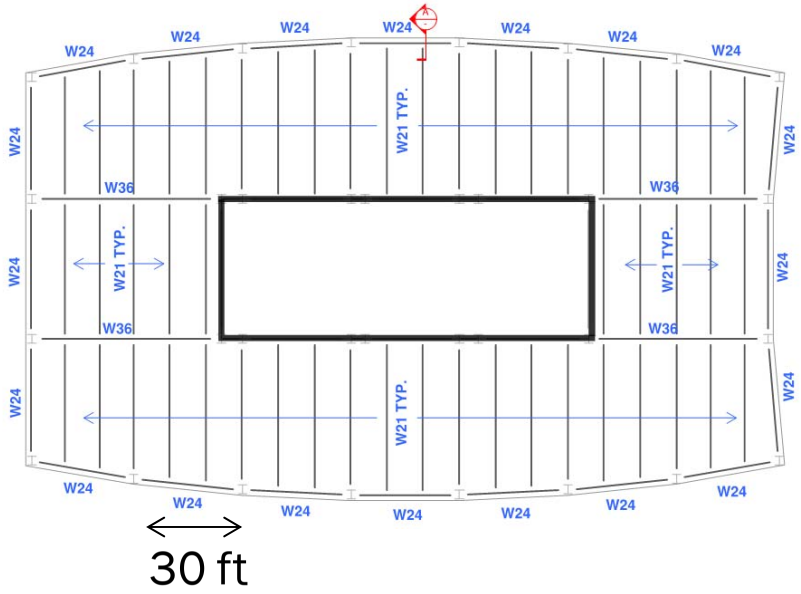
Steel Residential over Steel Office



PROS

- Quickest construction duration at 21.5 months to 1st occupancy
- No transfer floor required
- Lightest building, least expensive foundations



CONS

- Structural Envelope of 36", results in floor to floor of 12'-8" or additional building height of 36 ft relative to cast in place option (estimated at $1.5 million for curtainwall only) – doesn't capture lateral design costs
- Additional cost of hard ceiling and other finishes in residential (estimated at $1.5 million)
- 45 ft span at sides of core inefficient for residential (but not office)
- 30 ft grid not efficient for residential module
- Most expensive at $234/GSF

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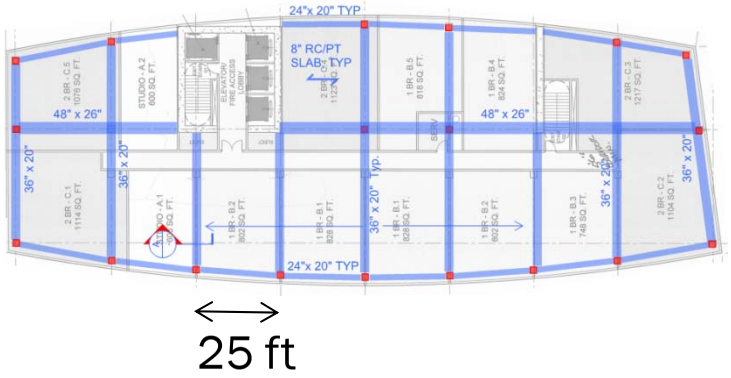
Concrete Residential over Concrete Office



PROS

- Least expensive at $224 / GSF
- Transfer floor can be done with cast in place
- Possibility of using post-tensioned concrete to reduce column sizes at base of building
- Flexibility in column locations

CONS

- Longest schedule at 26 months
- Spans not conducive to flat slab system (i.e. bays are rectangular)
- 45 ft span at sides of core inefficient for cast in place/ post-tensioned options in both office and residential floors
- Largest columns sizes (4-1/2 ft Ø) and foundations

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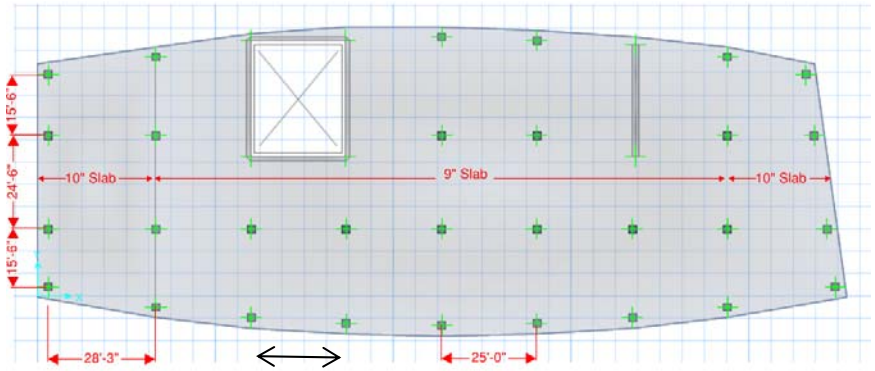
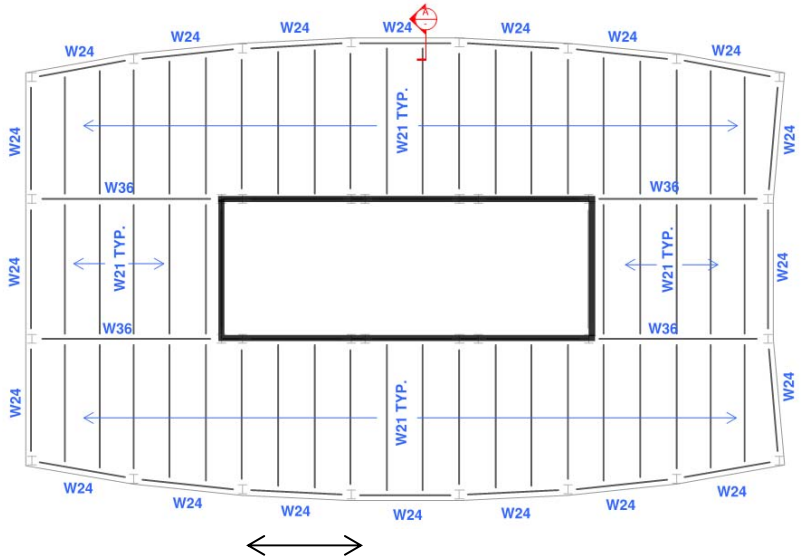
Concrete Residential over Steel Office



25 ft

PROS

- Schedule of 22 months meets tenant requirements
- Flexibility in column locations
- Structural envelope under 12”, results in shortest building
- No ceiling treatment required at residential floors
- Most efficient system for each occupancy



30 ft

CONS

- Cost at $230/ GSF is 3% more than lowest cost option
- Complex transfer required (concrete or steel or both?
- Complex behavior caused by elastic shortening of steel columns under DL of concrete above
- Uncertainty in cost related to simplicity of transfer design
- Heavy built up shapes at base of building

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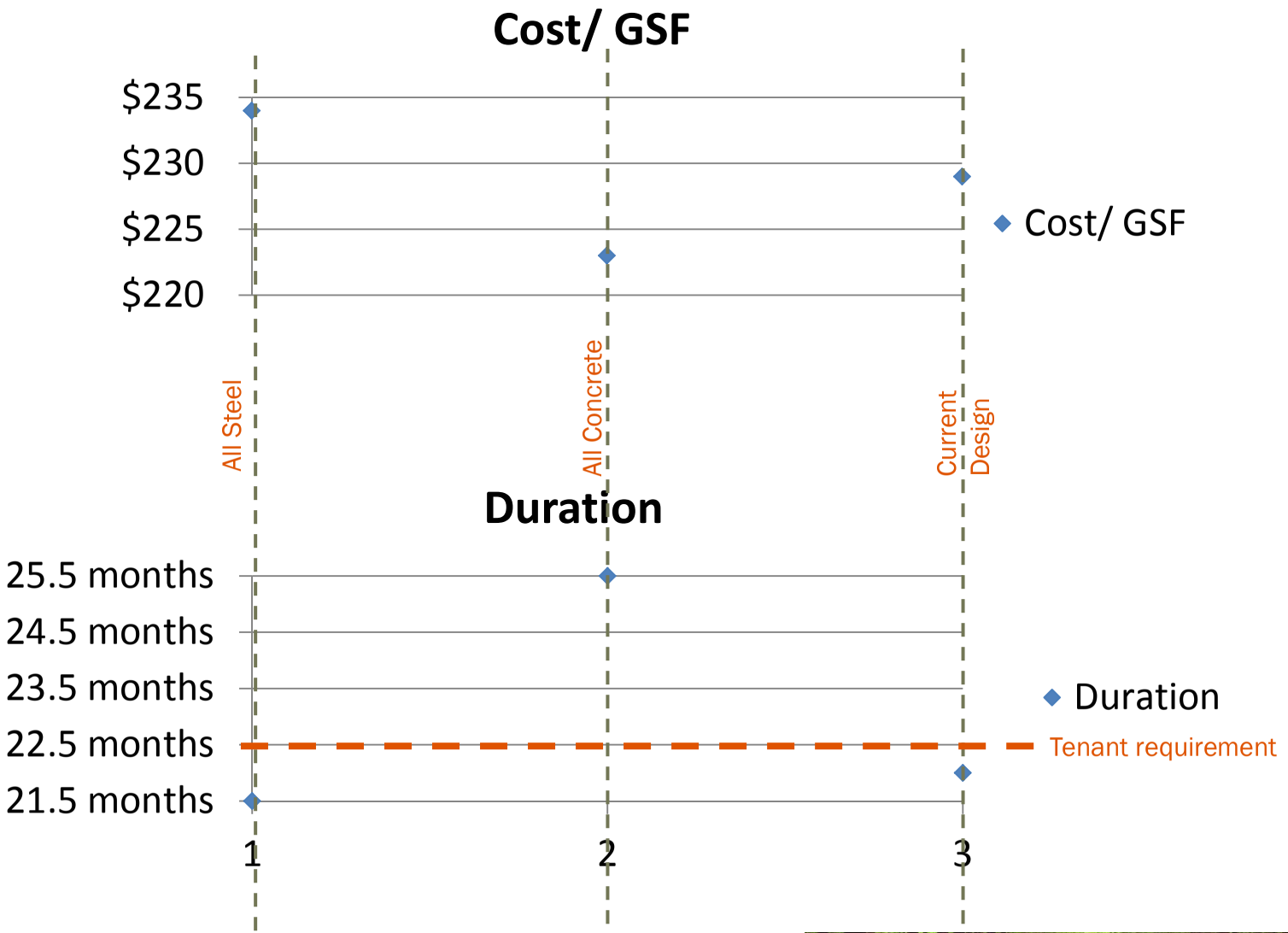
Selection of System



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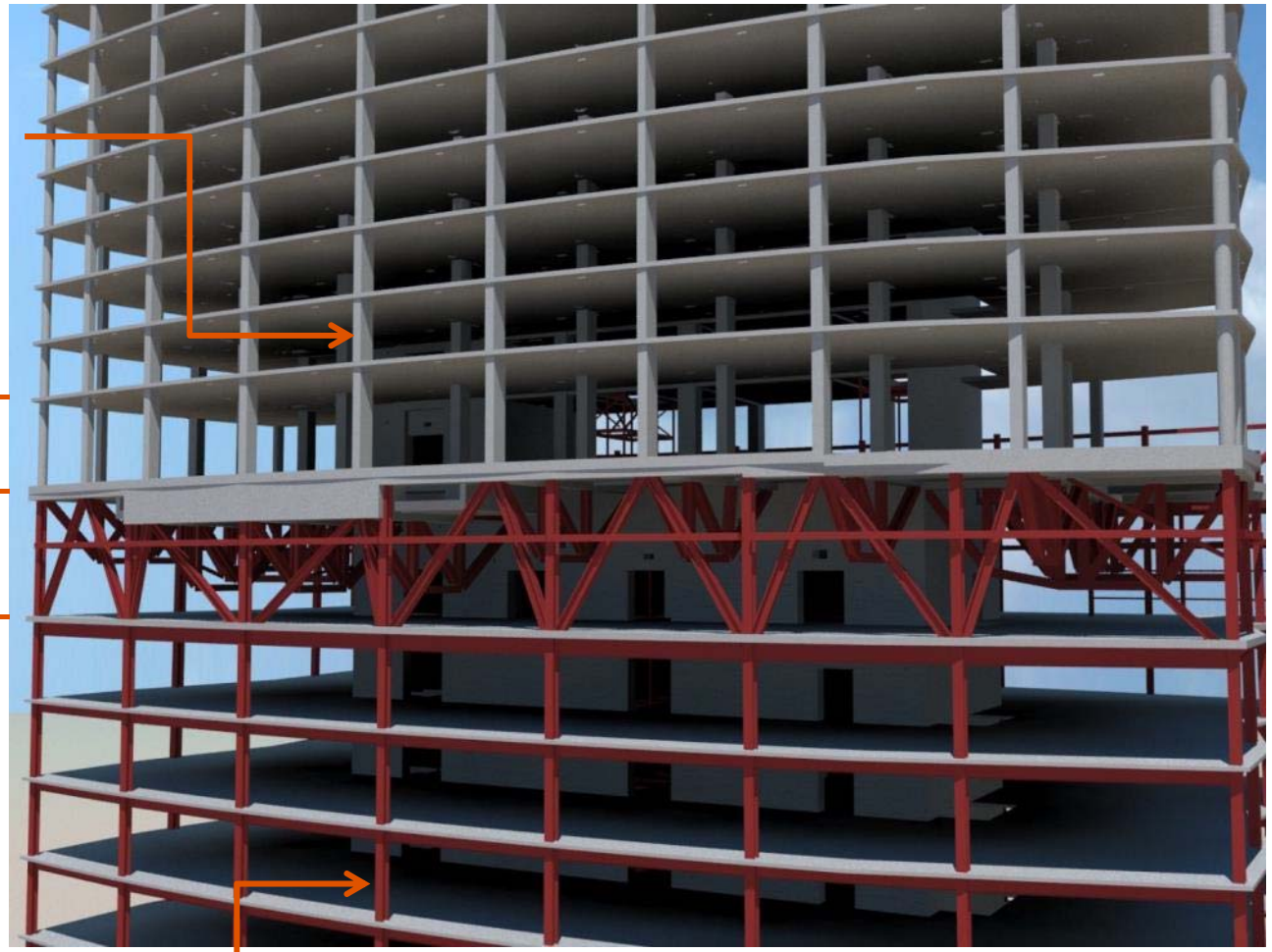
Transfer Level



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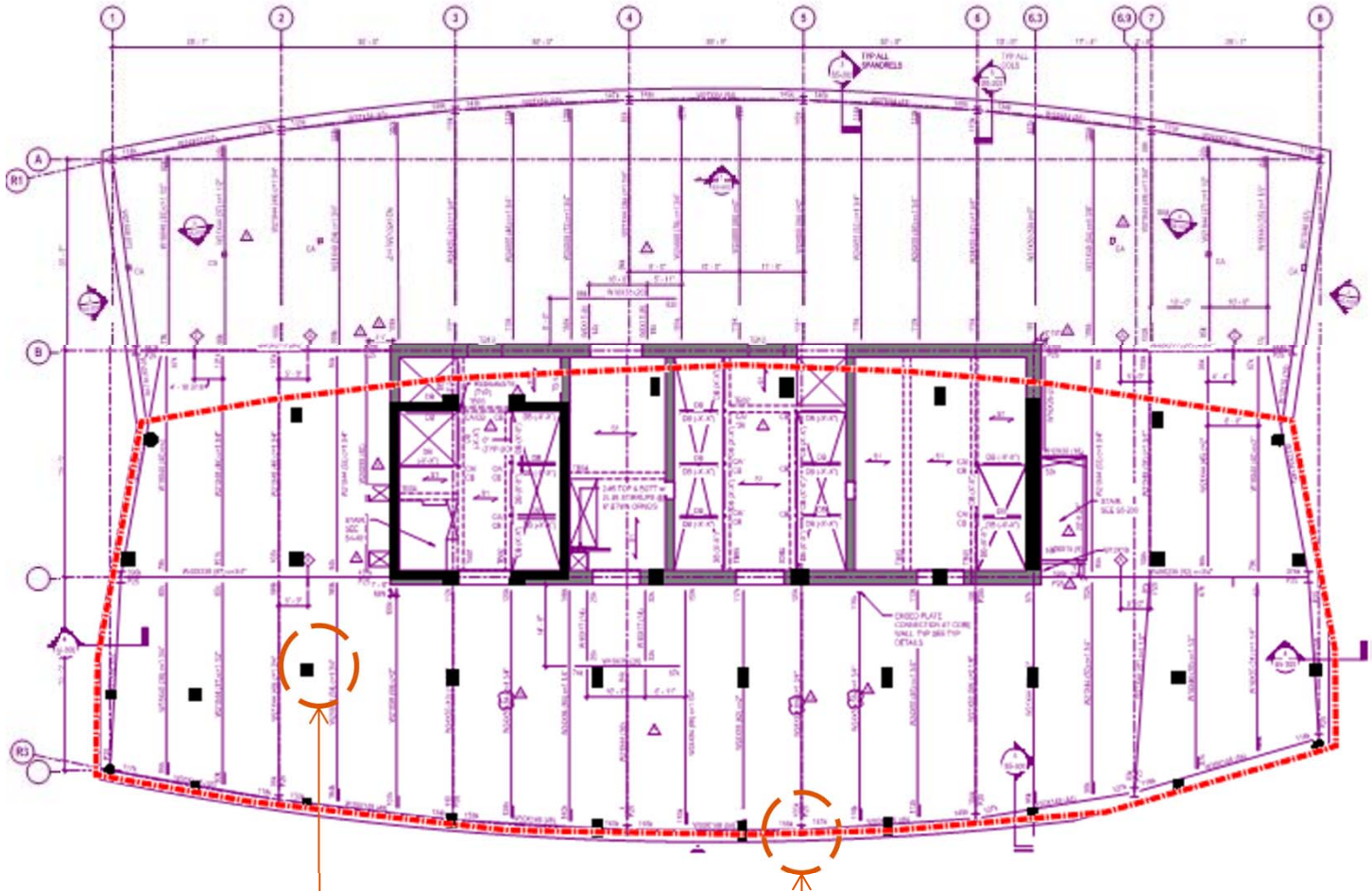
Concrete Columns on Typical Steel Floor



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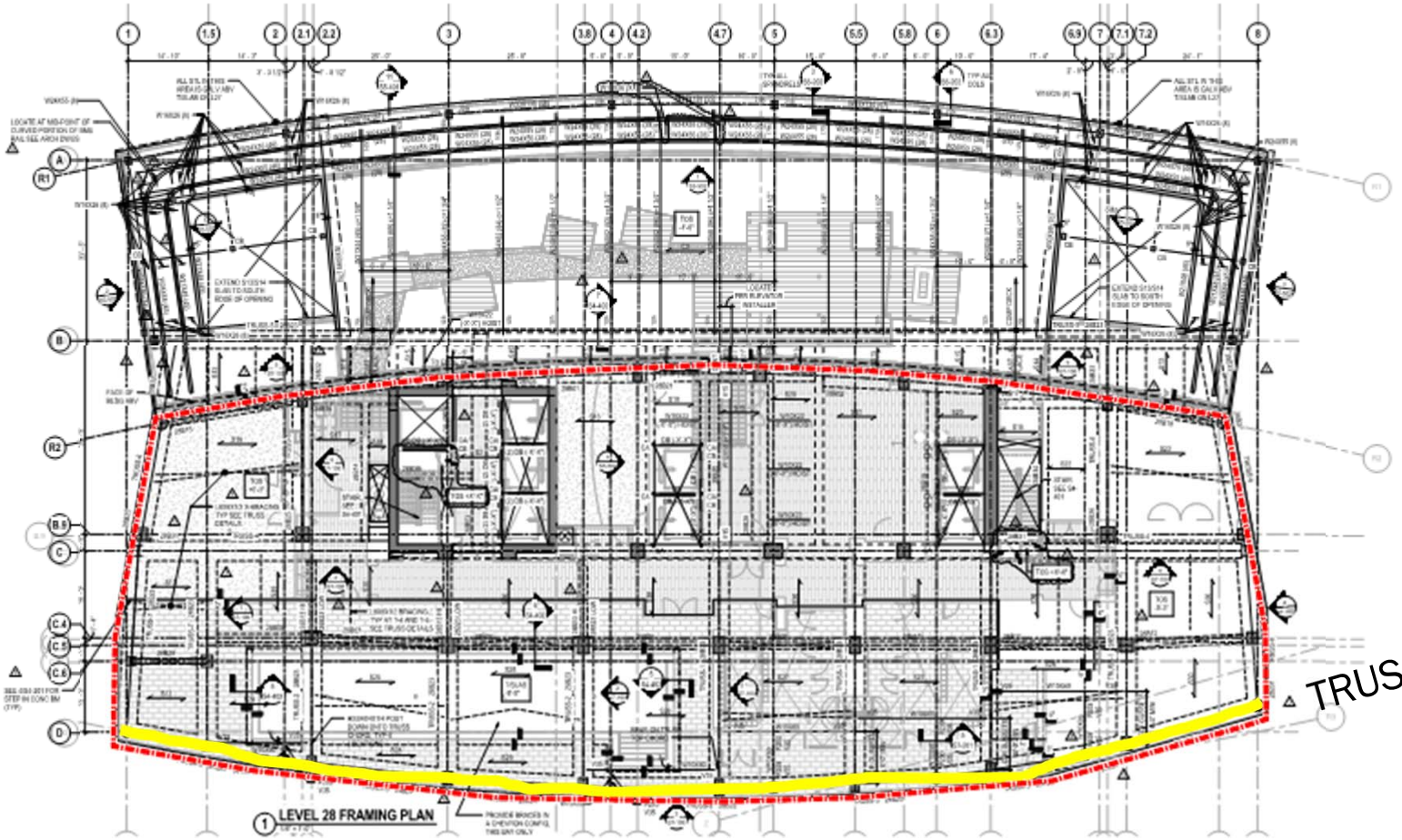
Transfer Level



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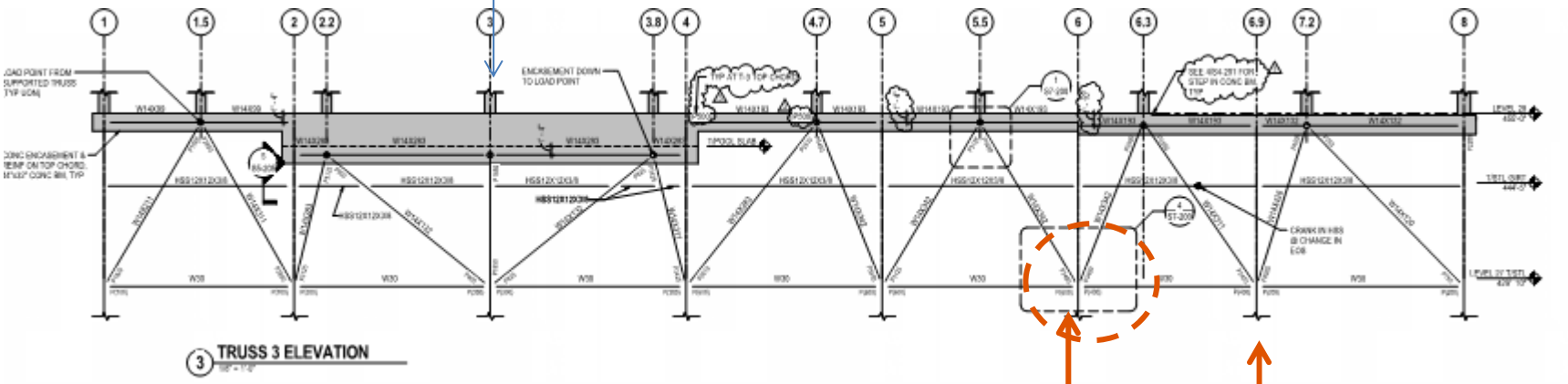
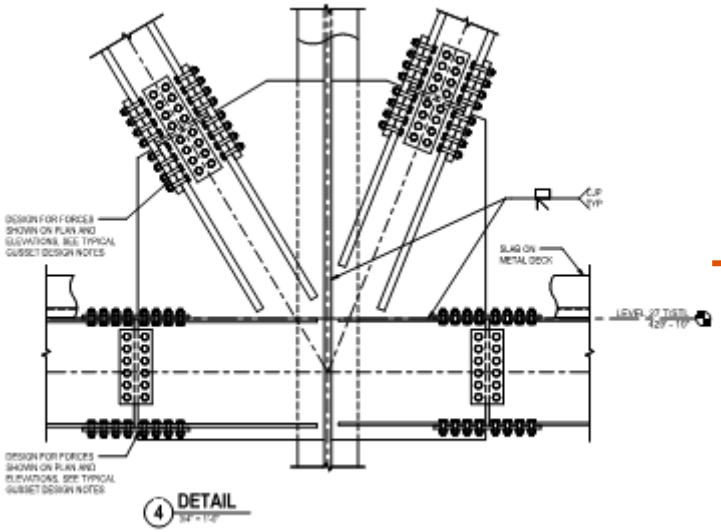
Transfer Level

CONC COL'S



STEEL WIDE FLANGE COLS



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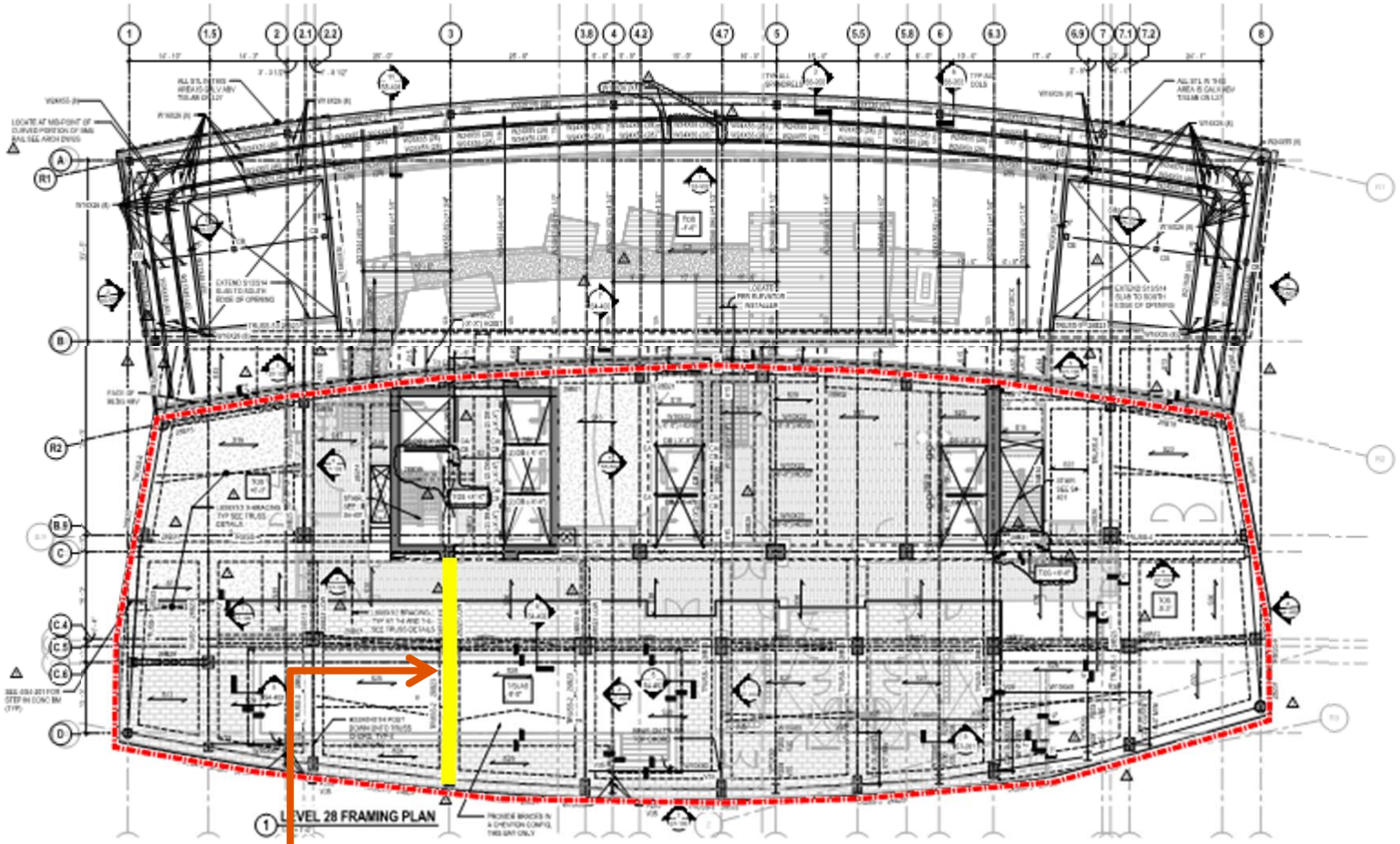
Transfer Level



TRUSS - 1

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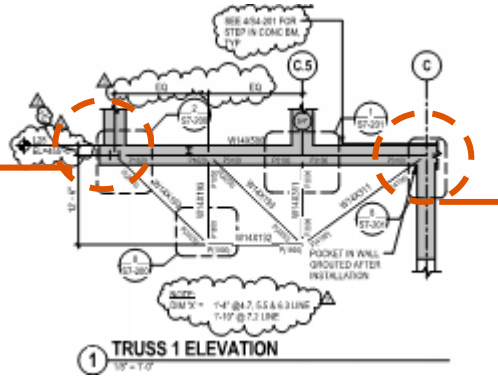
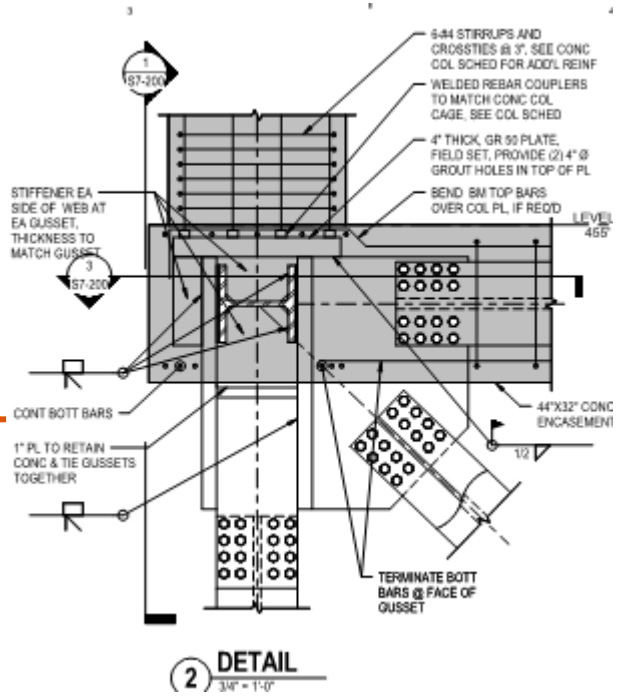
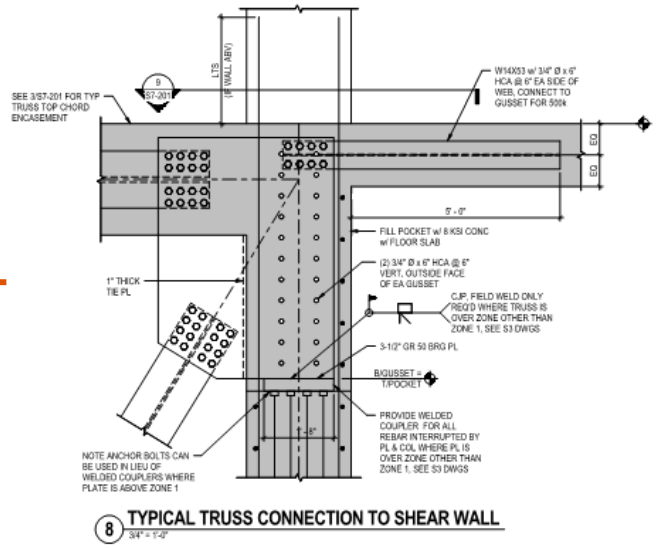
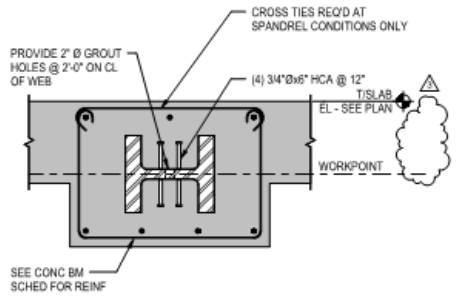
Transfer Level









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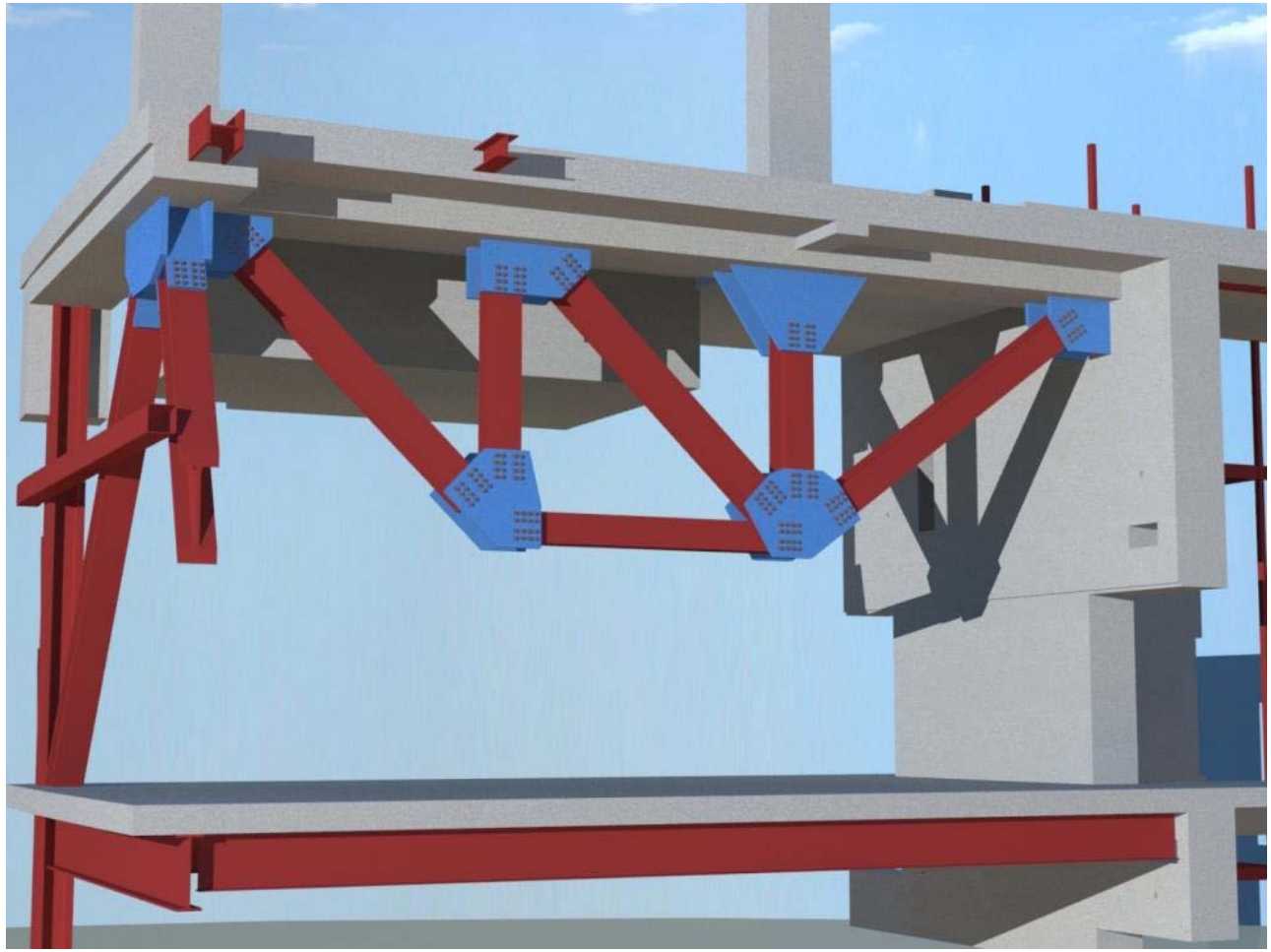
Transfer Level



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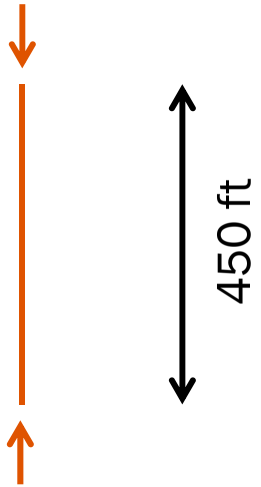
Steel Column Elastic Shortening

- Kl/r ~ 50
- Ultimate stress~40 ksi
- **STEEL** building, estimate DL = LL
  - Service DL is therefore 1.0/(1.2+1.6) = 35% of total ultimate axial force in column
  - Considering 25 psf SDL is estimate and design efficiency of 90%, use 75% of this value
  - Service axial stress from DL is 75%x35%x40 ksi ~ 10 ksi
  - Corresponds to 340 micro strain or **1.8** inches of AXIAL COMPRESSION at L28
  - That's about 1/16" per floor

$$\varepsilon = \sigma/\mathrm{E}$$

$$\delta = \varepsilon * L$$

$$\delta = 1.8"$$



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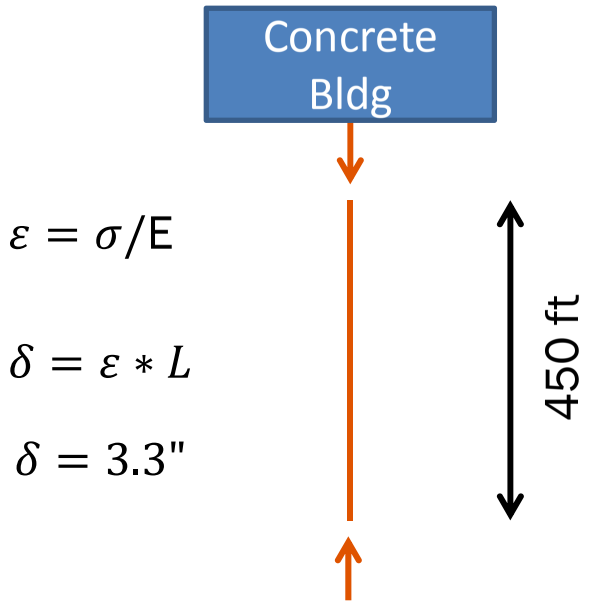
Steel Column Elastic Shortening

- Kl/r ~ 50
- Ultimate stress ~40 ksi
- **CONCRETE** building, estimate DL = 3*LL
  - Service DL is therefore 3.0/(3x1.2+1.6) = 60% of total ultimate axial force in column
  - Considering 25 psf SDL is estimate and design efficiency of 90%, use 75% of this value
  - Service axial stress from DL is 75%x60%x40 ksi ~ 18ksi
  - Corresponds to 620 micro strain or **3.3** inches of deflection at L28
  - Almost ¼" per floor….



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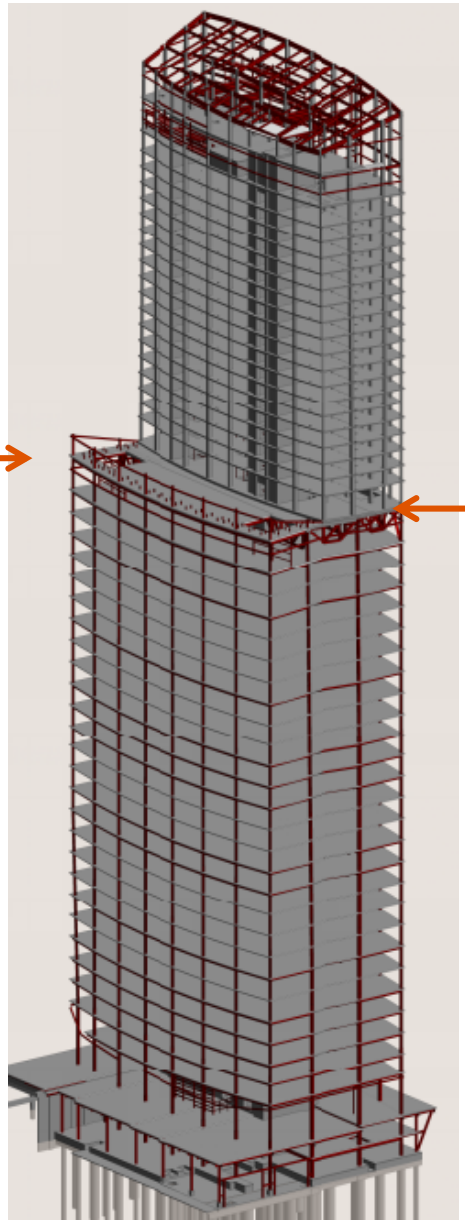
Steel Column Elastic Shortening

1.8 inches axial compression @ L28 construction



3.3 inches axial compression @ top out of whole building

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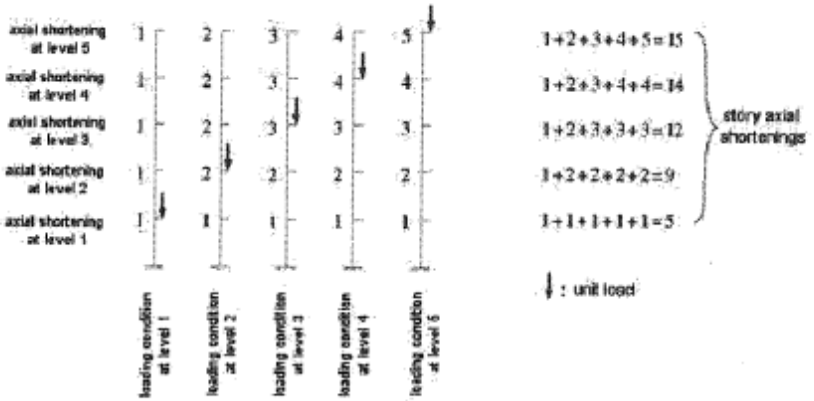
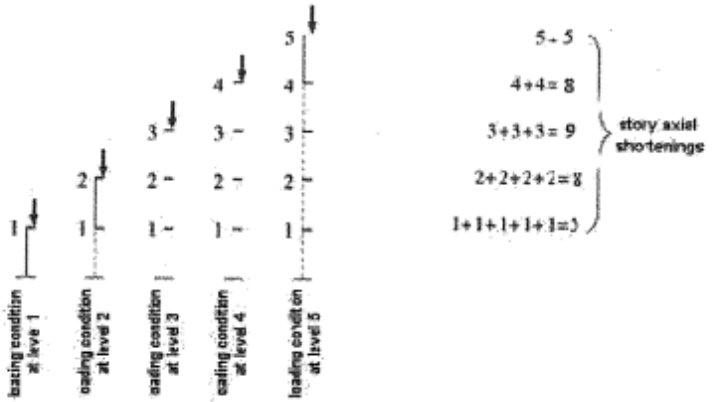
Core Elastic Shortening

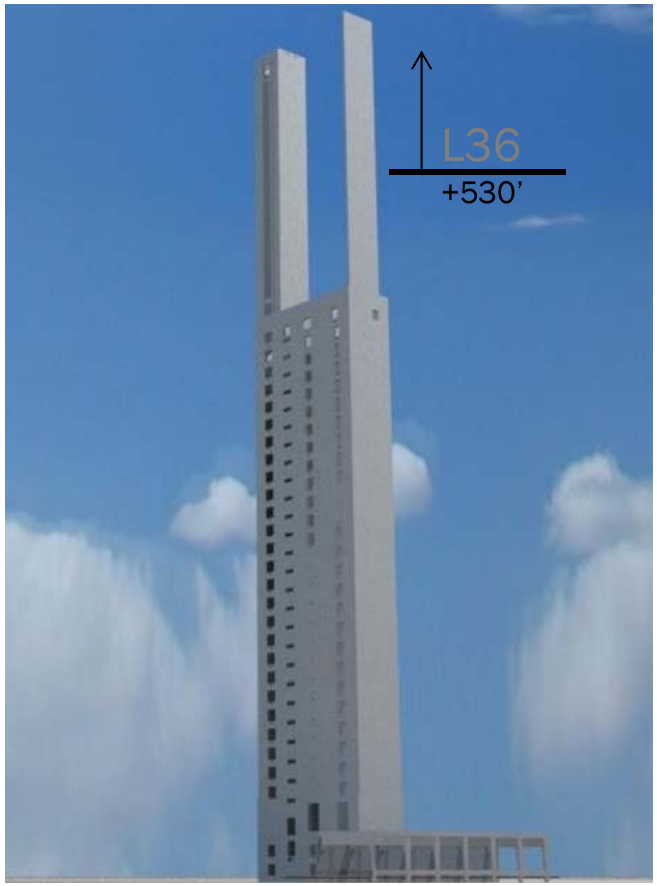
- Concrete, unlike steel, is built to the theoretical floor elevation at each level irrespective of shortening
- Limits the amount of elastic shortening since it is ‘built out’
-
-



(a) Conventional analysis results



(b) Erection sequence analysis results



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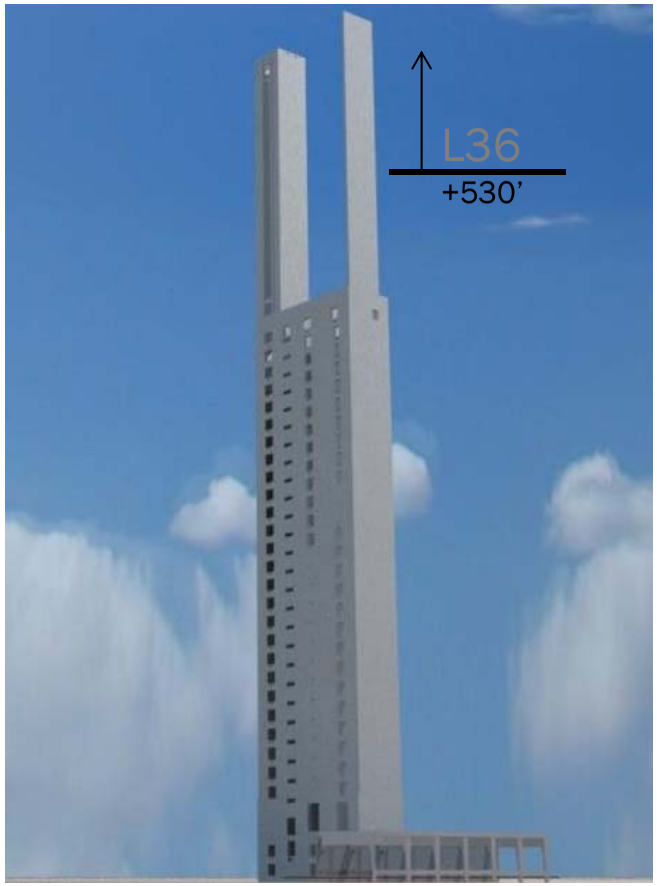
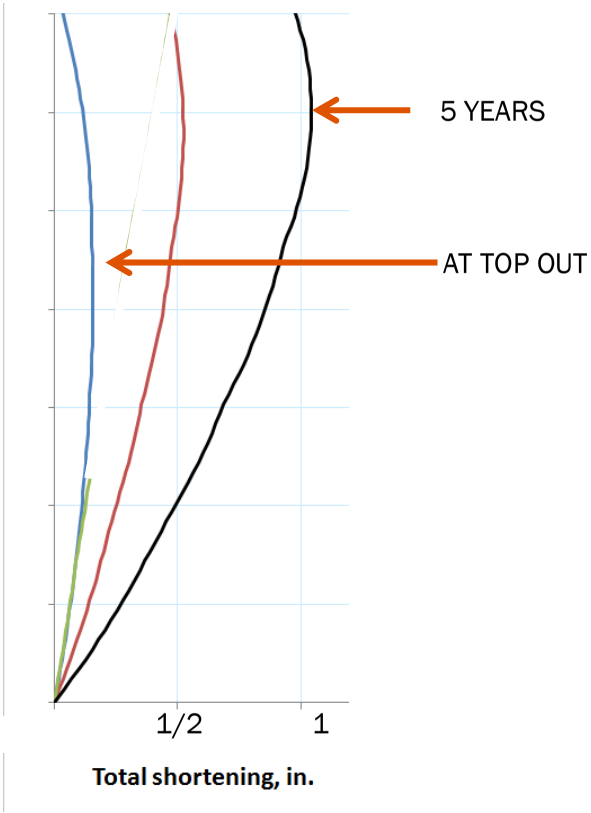
Core Elastic Shortening

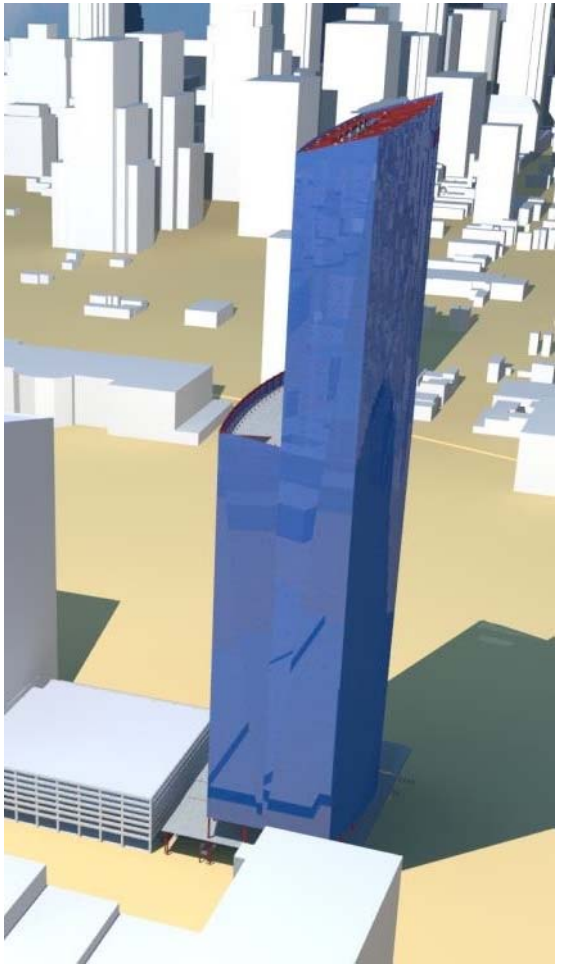
- Concrete, unlike steel, is built to the theoretical floor elevation at each level irrespective of shortening
- Limits the amount of elastic shortening since it is 'built out'
- Worst location is about 2/3 up building
- @L36, h = 530 ft
  - additional 11 floors still to be built
  - add another 200 psi stress to core
  - corresponds to 40 micro strain or **¼ in deflection** from elastic shortening



Core Creep and Shrinkage

- Core is lightly stressed under DL (sized for stiffness in wind) < 1000 psi stress





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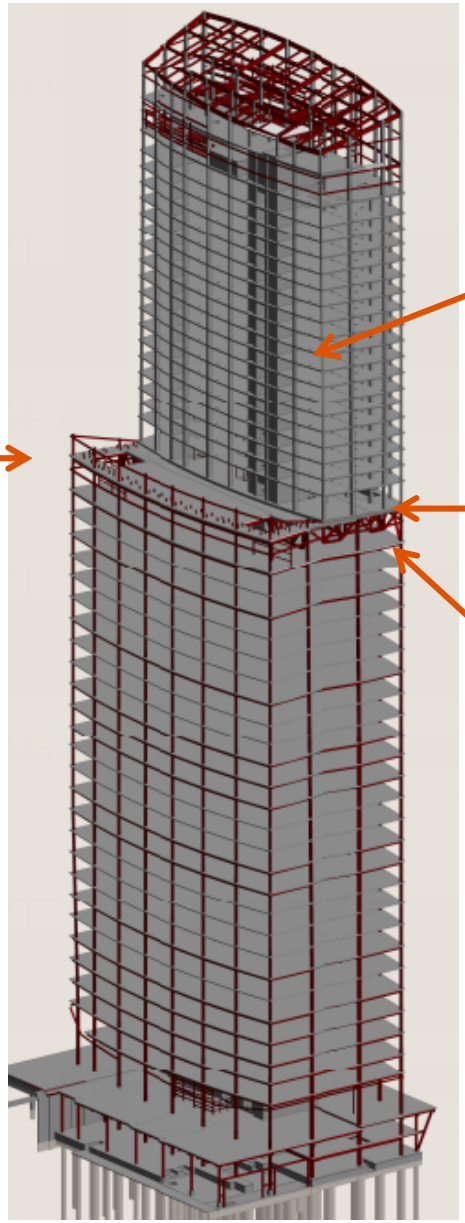
Combined Shortening



Steel Column 1.8 inches axial compression @ L28 construction

Core 1/4” deflection at top out

Steel column 3.3 inches axial compression @ top out of whole building

Also have flexibility of trusses to consider

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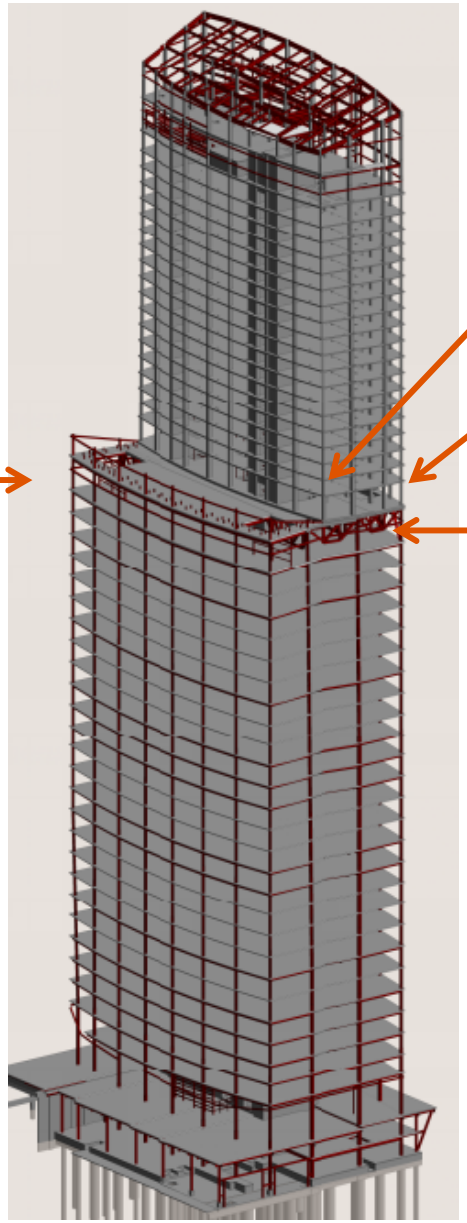
Vertical Mitigation



Overbuild core ½” @ L28

Overbuild conc columns above steel columns and trusses

Overbuild north columns 1/16” per floor = 1.75” @ L28

Overbuild south columns by 3/32” per floor = total 2.6” @ L28

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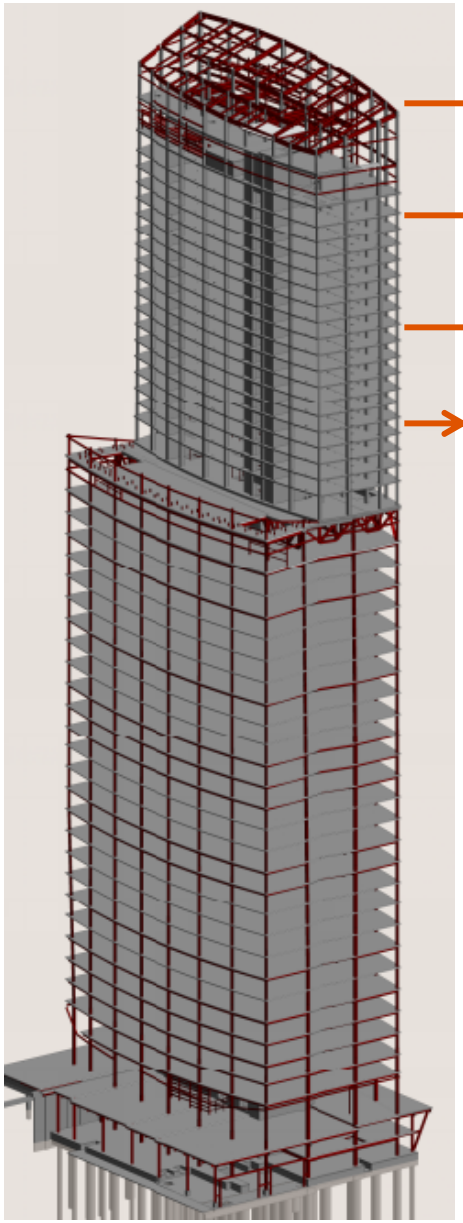
Horizontal Movement



Core will bend in this direction during construction of Residential Floors

Self climbing form will be pulled to plumb at each floor, so worst case is near the top, (but not at the top)

2.5 inches lateral deflection at top out @ L36, about 10% of expected wind load deflection at 10 year wind

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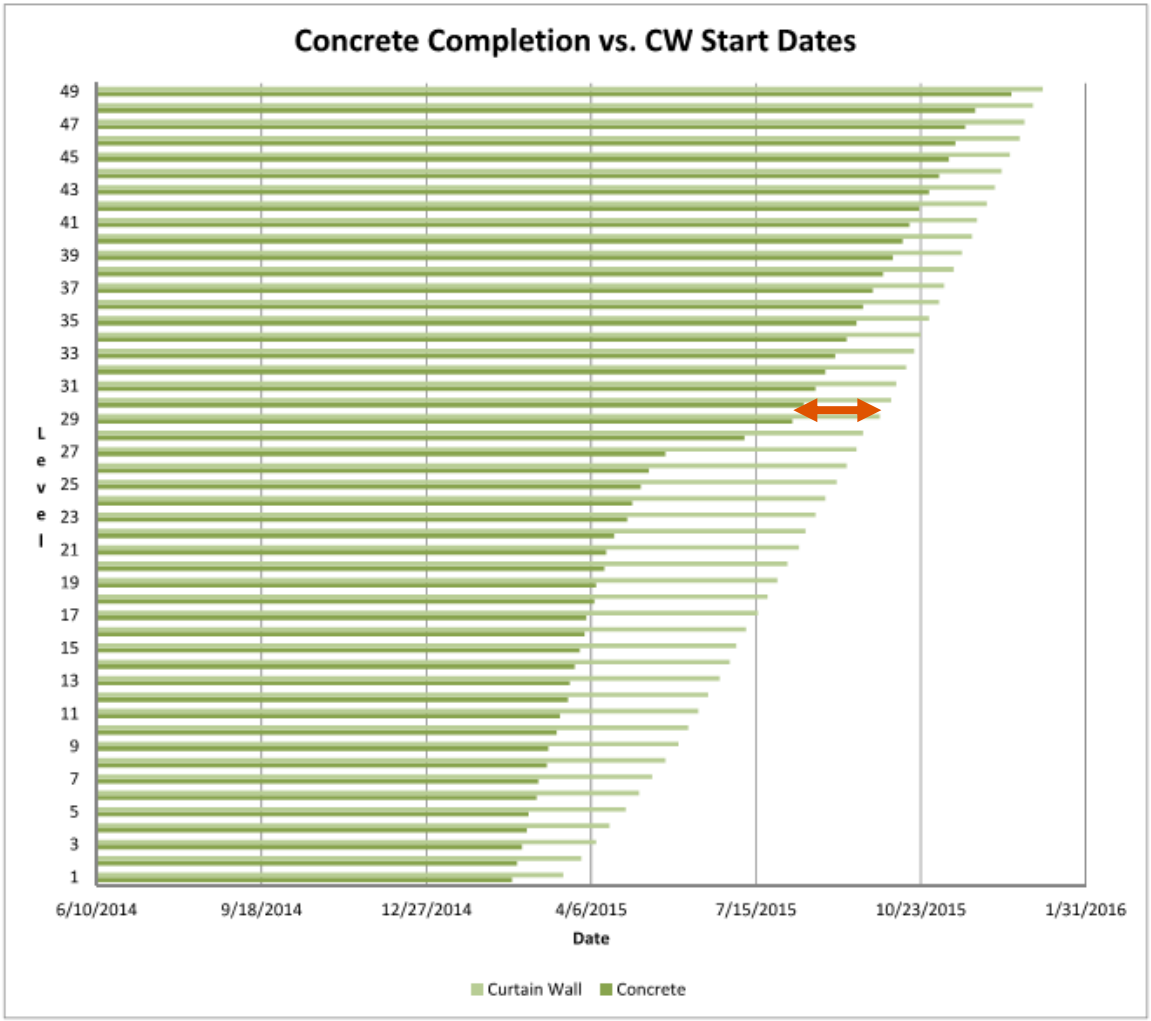
Horizontal Movement



1.5 months lag, will curtainwall installer even notice lateral movement?

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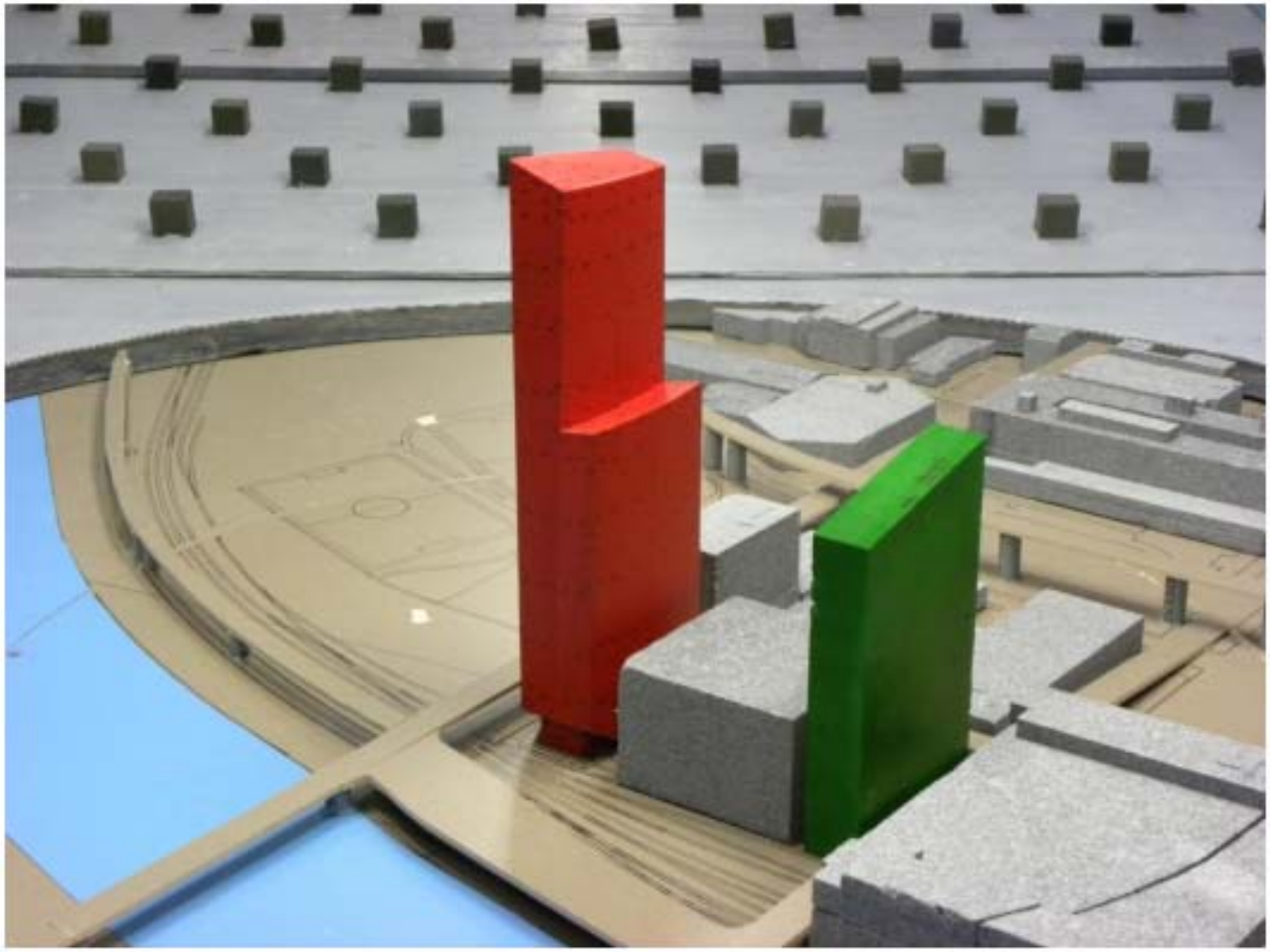
Wind Tunnel Model



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Occupant Comfort: Wind Tunnel

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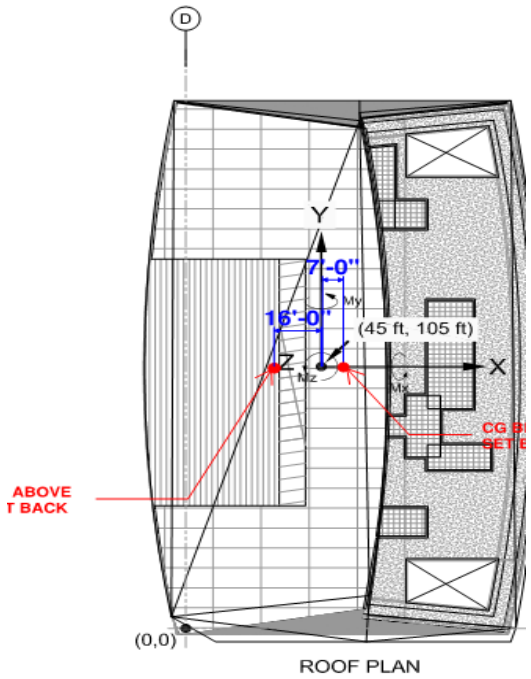
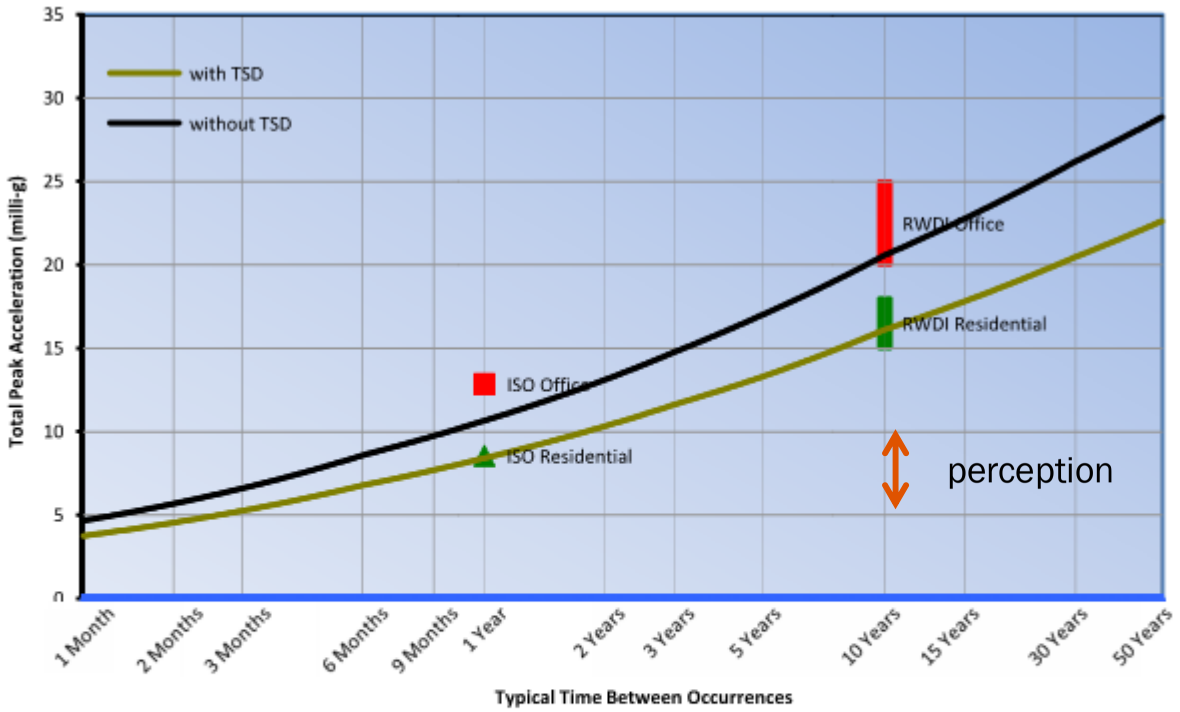
Peak Accelerations



ROOF PLAN



Return Period (Years)	Peak Accelerations[2] (milli-g) Total - [X, Y and torsional components]		Peak Torsional Velocities (milli-rads/sec)		
	without TSD	with TSD	without TSD	with TSD	CTBUH[5] Criteria
1	11 - [10, 4.0, 4.7]	8.4 - [7.9, 4.0, 4.7]	1.2	1.2	1.5
5	17 - [17, 5.8, 7.3]	13 - [13, 5.8, 7.3]	1.8	1.8	-
10	21 - [20, 6.6, 8.3]	16 - [15, 6.6, 8.3]	2.1	2.1	3

1.5% Inherent Damping

5% Damping with TSD

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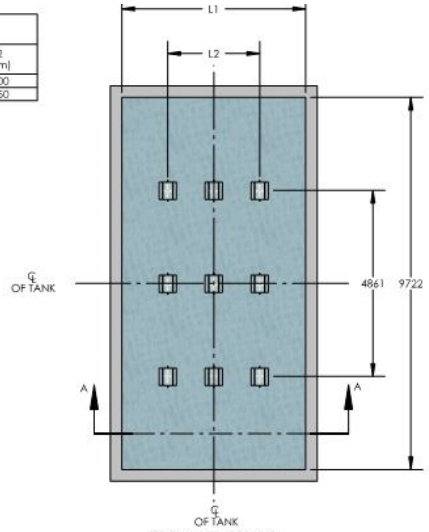
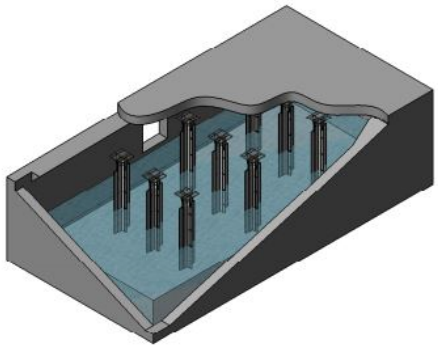
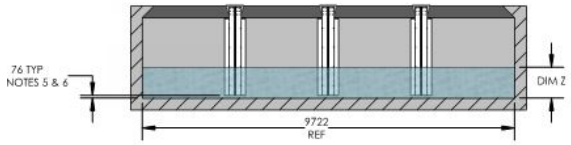
TANK DIMENSIONS		
TANK	L1 (mm)	L2 (mm)
A,B	4800	2400
C	4500	2250

TANK WATER DEPTHS AND VOLUMES			
AS-BUILT FREQUENCY	TANK ID	DIM 'Z' STATIC WATER DEPTH (m)	WATER VOLUME (m^3)
-5%	A	0.99	46.0
	B	1.10	51.3
	C	1.24	54.4
NOMINAL	A	1.10	51.1
	B	1.23	57.2
	C	1.40	61.3
+15%	A	1.46	68.3
	B	1.68	78.3
	C	1.99	86.9

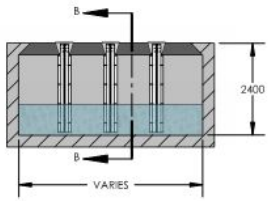


TSD PLAN VIEW TOP AND CHAMFER REMOVED FOR CLARITY


ISOMETRIC CUT-AWAY VIEW OF TYPICAL TSD

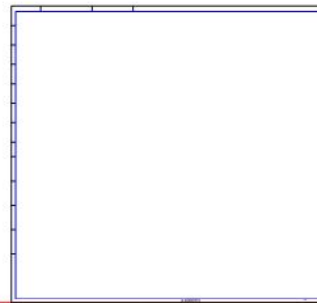


SECTION B-B



SECTION A-A

SEE DRAWING D00 FOR GENERAL NOTES.
WATERPROOFING MEMBRANE AND FLASHING TO BE KEMPEROL 2K-PUR SYSTEM OR EQUIVALENT.
PROVIDE XYPEX OR EQUIVALENT CONCRETE WATERPROOFING ADMIXTURE FOR ALL CONCRETE MIX.
NOTES 2 AND 3 ARE GUIDELINES ONLY. ARCHITECT TO DETERMINE WATERPROOFING DETAILS.
THE STRUCTURAL ENGINEER MAY ELECT TO USE THE PADDLE(S) AS A COLUMN TO SUPPORT THE TSD COVER. CONSULT WITH RWDI REGARDING COLUMN DESIGN TO DETERMINE IF THERE IS ANY IMPACT ON TSD PERFORMANCE.
AN ACCESS HATCH WILL BE REQUIRED FOR INSPECTION AND MAINTENANCE. THE ACCESS HATCH MUST BE A WATERPROOF, MARINE-GRADE HATCH THAT CAN WITHSTAND THE TOTAL PRESSURES PROVIDED ON DRAWING D02. THE FINAL POSITION OF THIS HATCH IS TO BE COORDINATED BY ARCHITECT.



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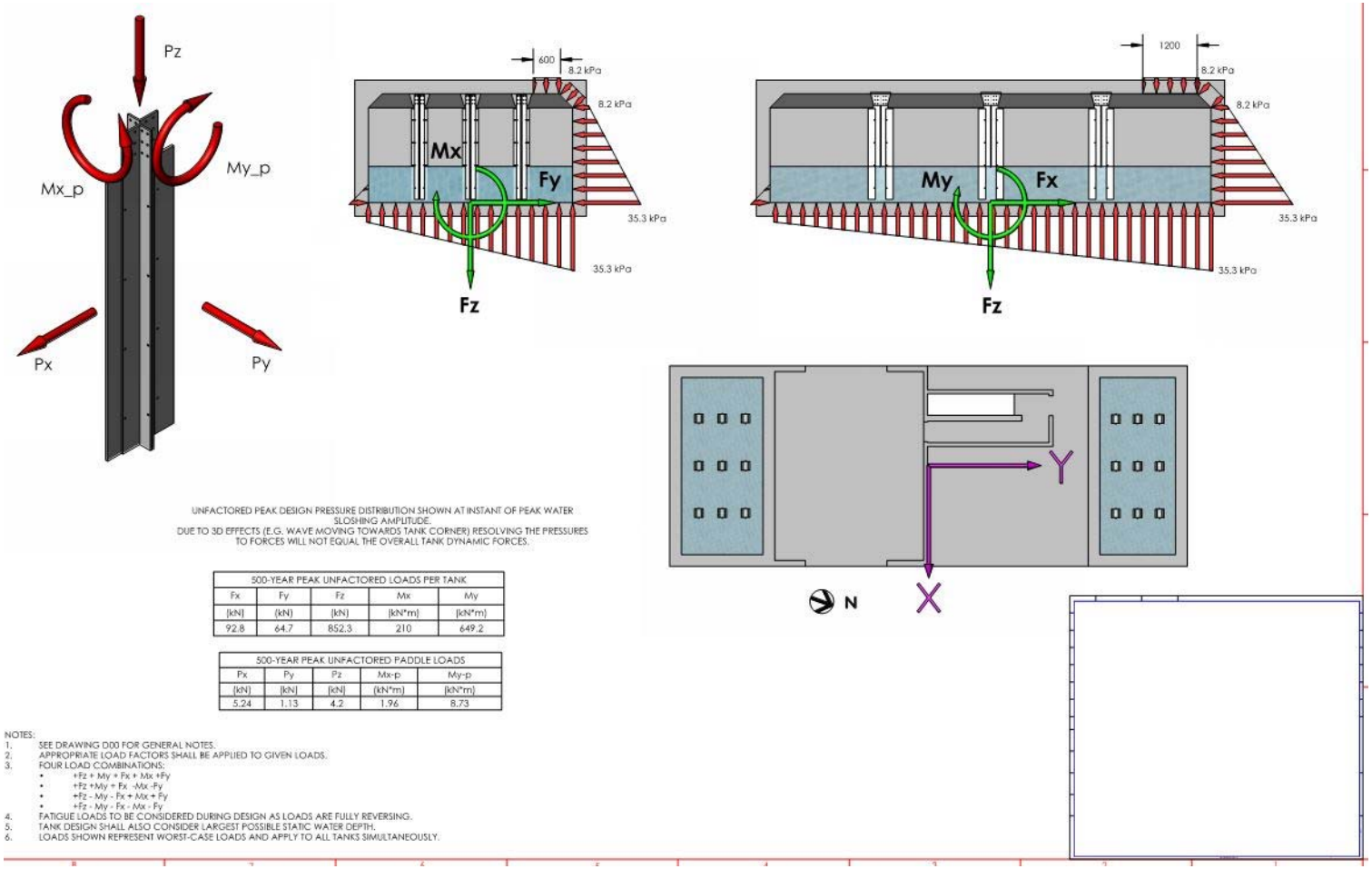

UNFACTORED PEAK DESIGN PRESSURE DISTRIBUTION SHOWN AT INSTANT OF PEAK WATER SLOSHING AMPLITUDE.
DUE TO 3D EFFECTS (E.G. WAVE MOVING TOWARDS TANK CORNER) RESOLVING THE PRESSURES TO FORCES WILL NOT EQUAL THE OVERALL TANK DYNAMIC FORCES.

500-YEAR PEAK UNFACTORED LOADS PER TANK				
Fx	Fy	Fz	Mx	My
(kN)	(kN)	(kN)	(kN*m)	(kN*m)
92.8	64.7	852.3	210	649.2

500-YEAR PEAK UNFACTORED PADDLE LOADS				
Px	Py	Pz	Mx-p	My-p
(kN)	(kN)	(kN)	(kN*m)	(kN*m)
5.24	1.13	4.2	1.96	8.73

NOTES:
1. SEE DRAWING D00 FOR GENERAL NOTES.
2. APPROPRIATE LOAD FACTORS SHALL BE APPLIED TO GIVEN LOADS.
3. FOUR LOAD COMBINATIONS:
   - +Fz + My + Fx + Mx +Fy
   - +Fz +My + Fx -Mx -Fy
   - +Fz - My - Fx + Mx + Fy
   - +Fz - My - Fx - Mx - Fy
4. FATIGUE LOADS TO BE CONSIDERED DURING DESIGN AS LOADS ARE FULLY REVERSING.
5. TANK DESIGN SHALL ALSO CONSIDER LARGEST POSSIBLE STATIC WATER DEPTH.
6. LOADS SHOWN REPRESENT WORST-CASE LOADS AND APPLY TO ALL TANKS SIMULTANEOUSLY.

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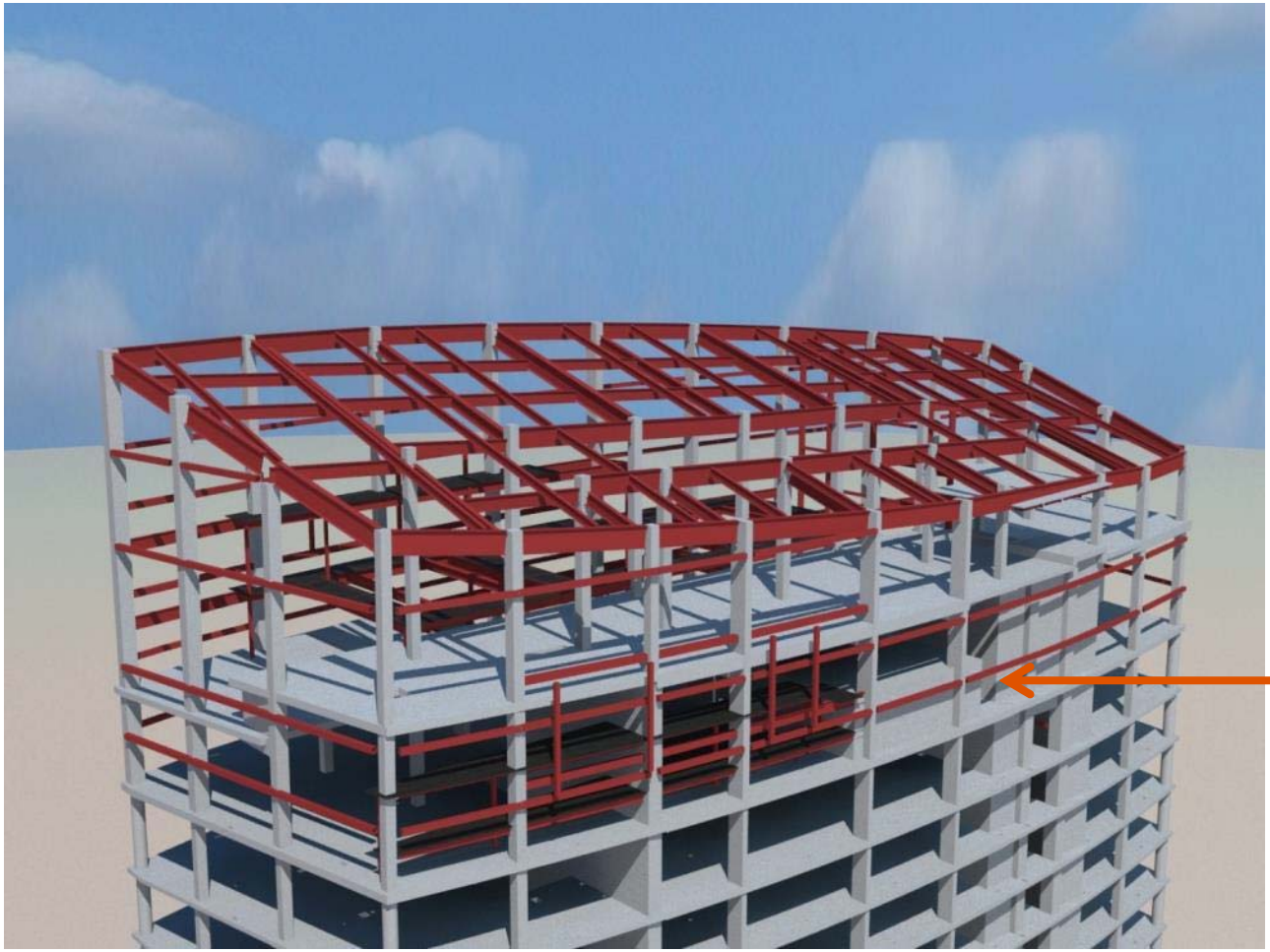

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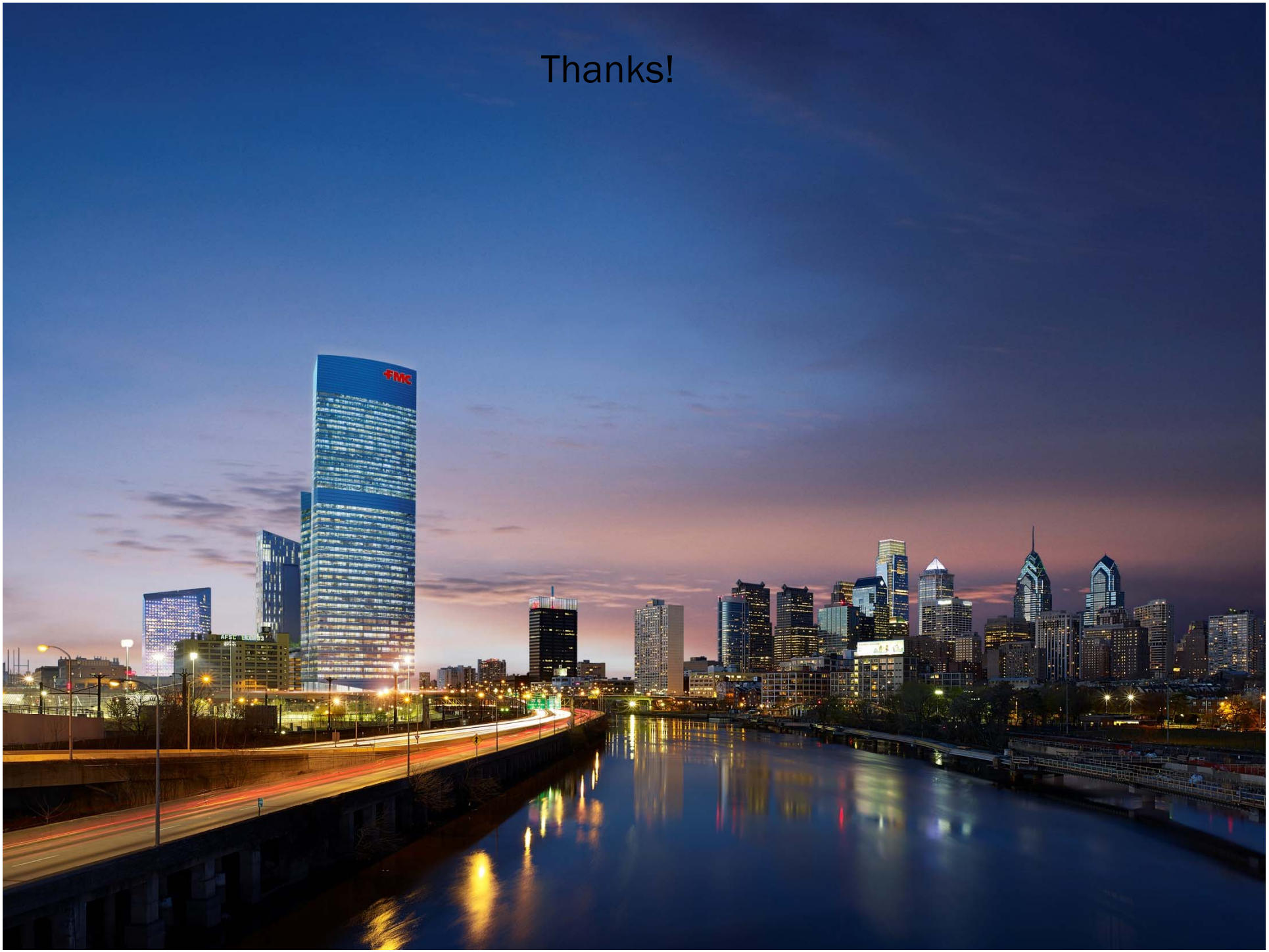
Thanks!



Self Rising Form System

http://www.formingconcepts.com/selfrising.htm

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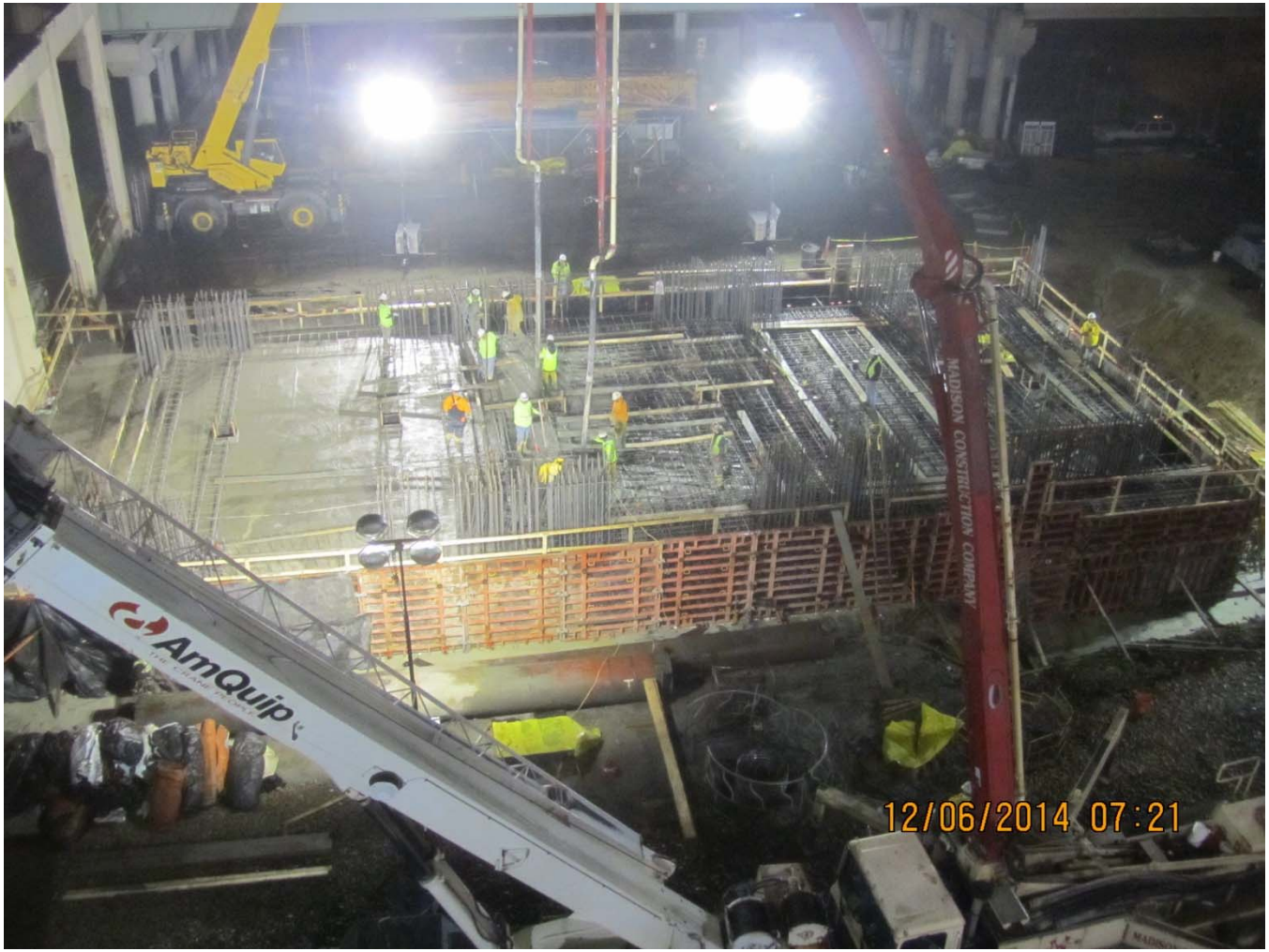

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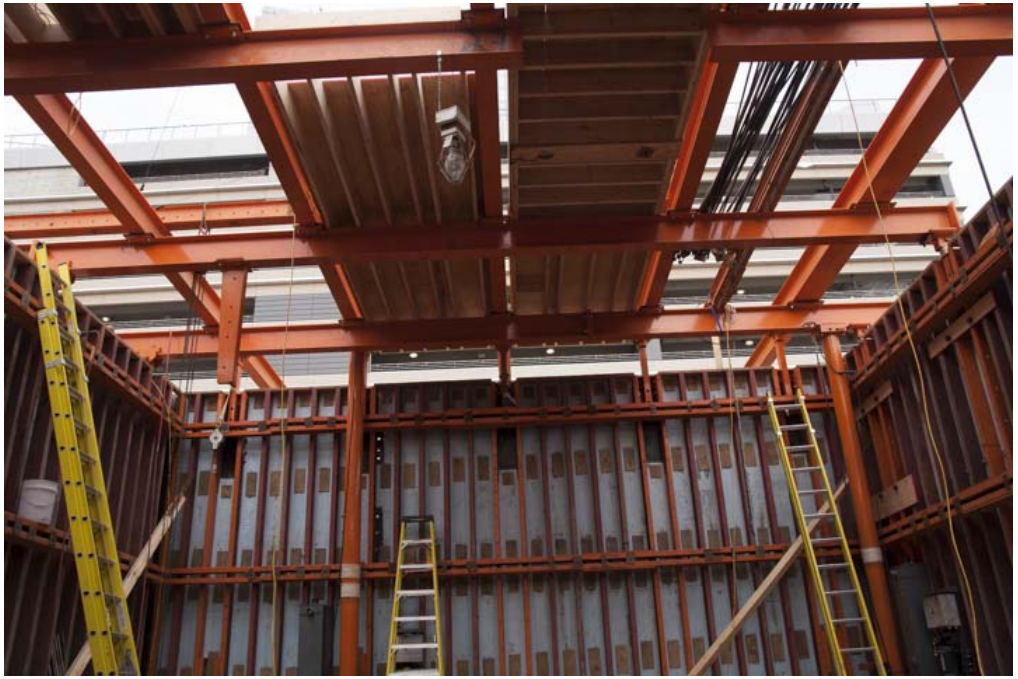

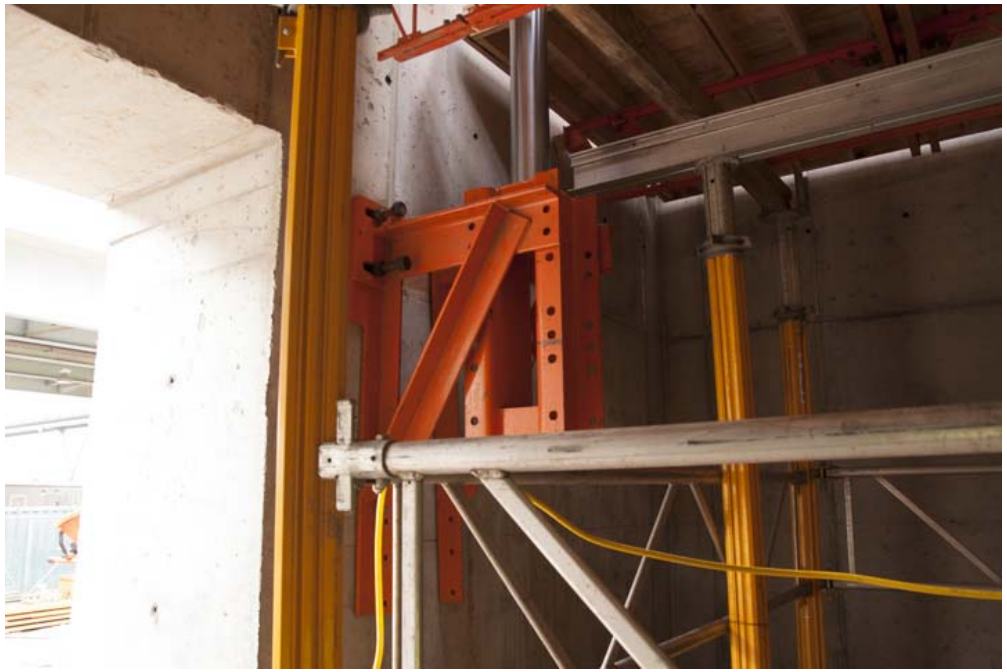

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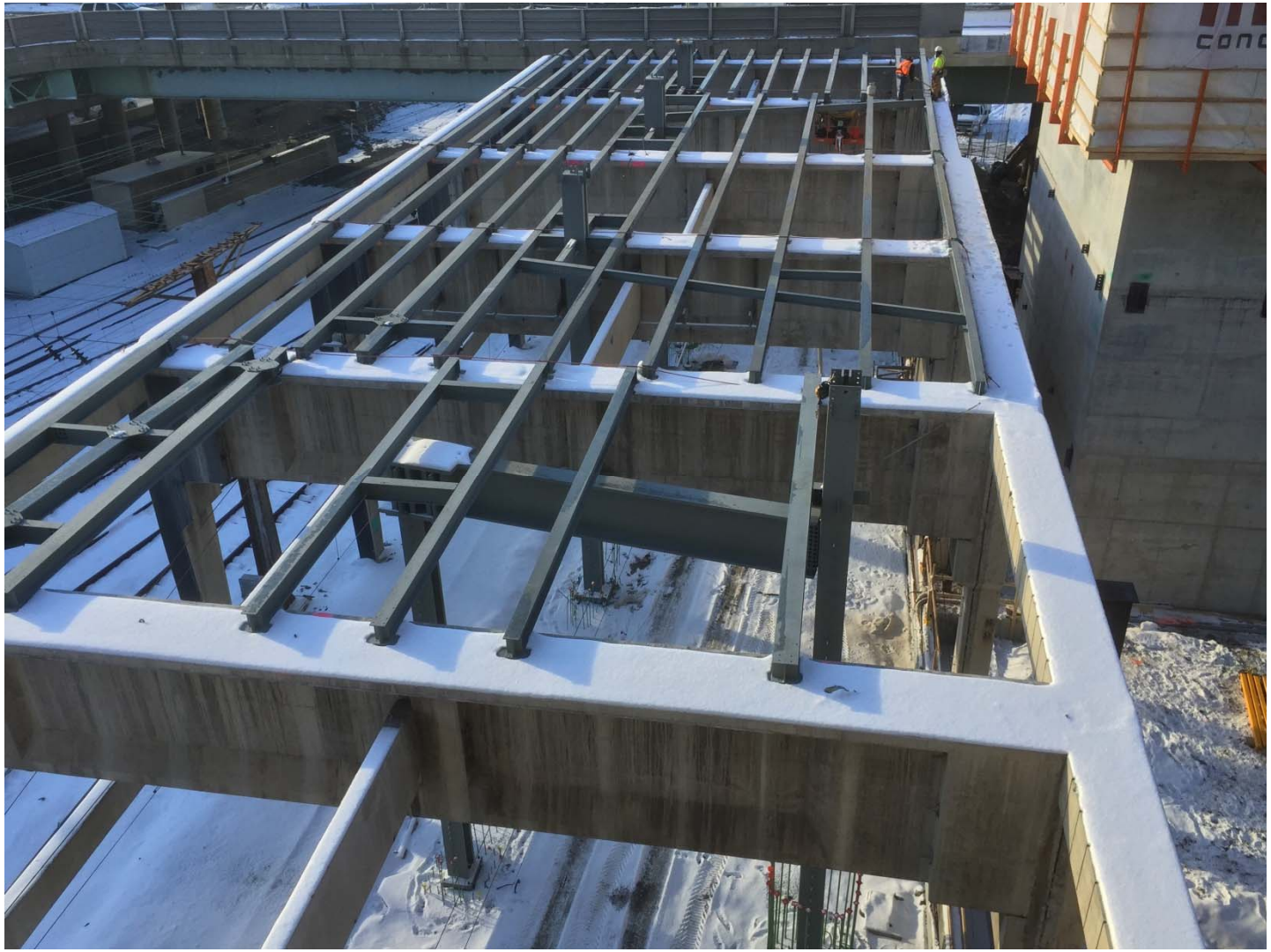

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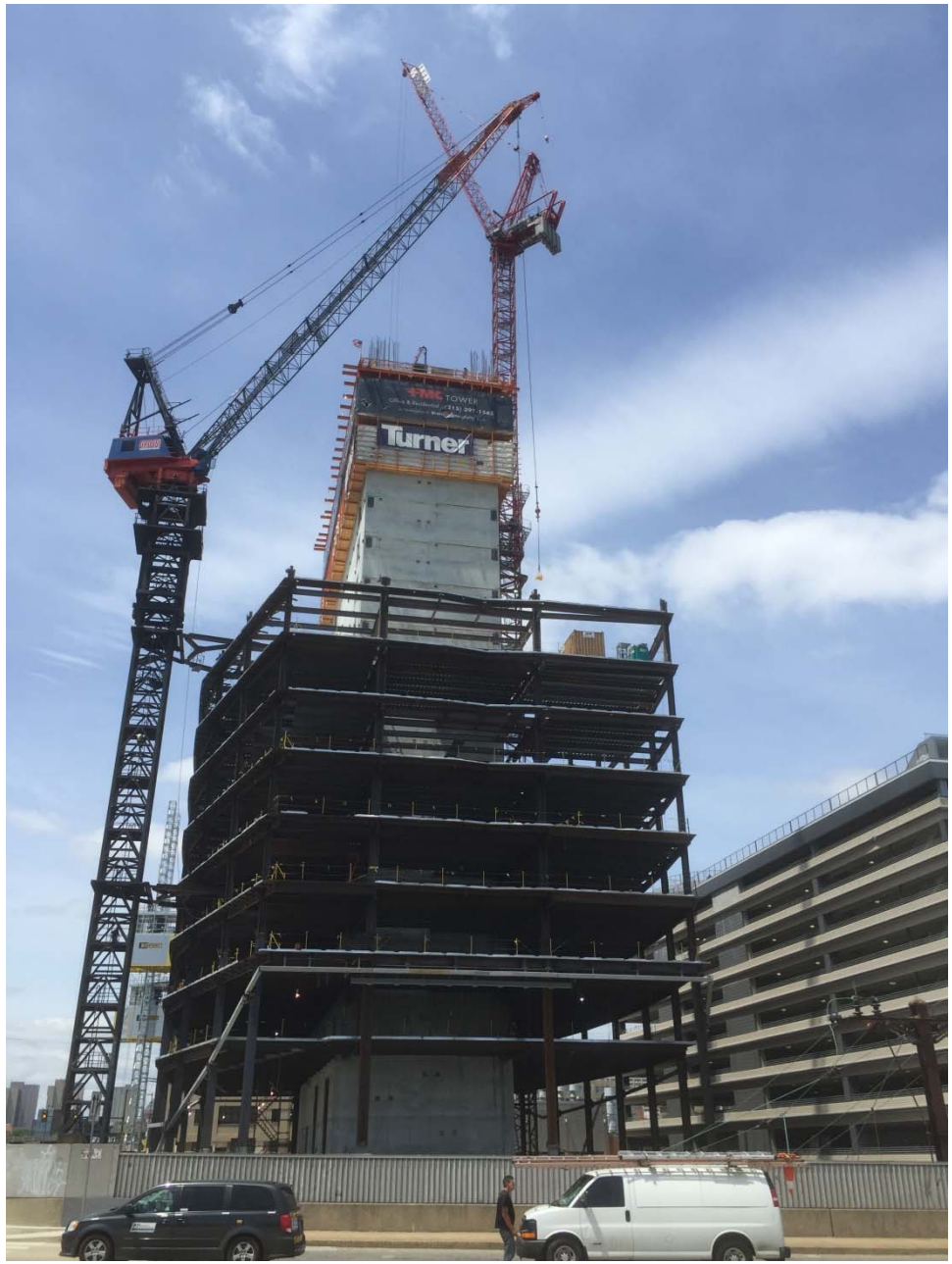

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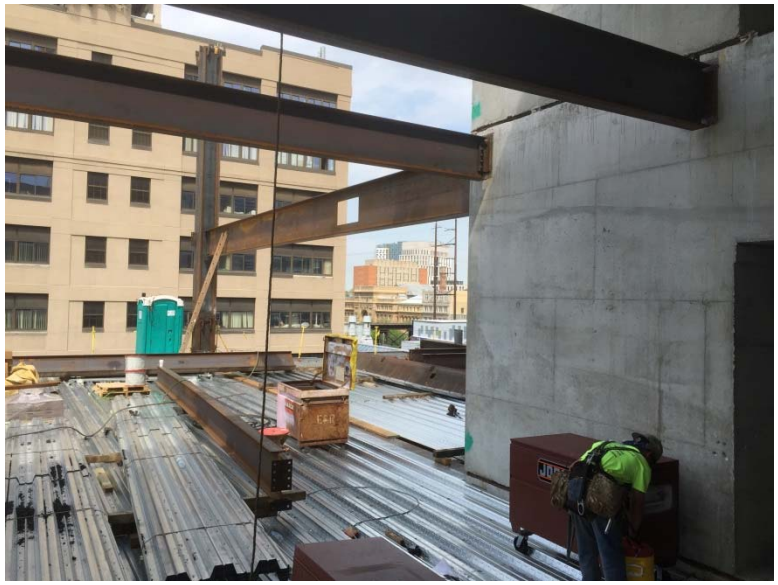

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View from Southeast

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View from Southeast

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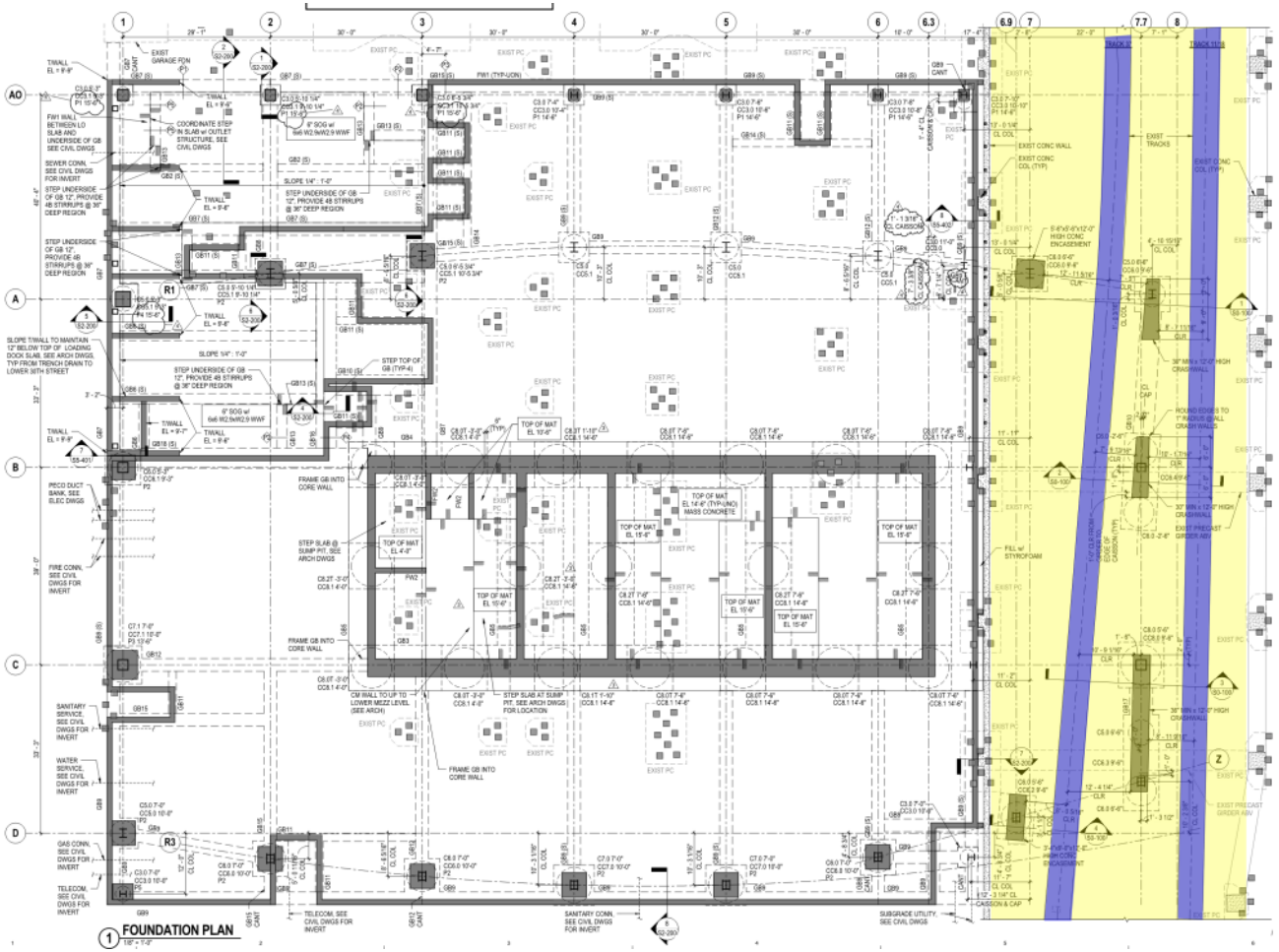

Amtrak Track Zone

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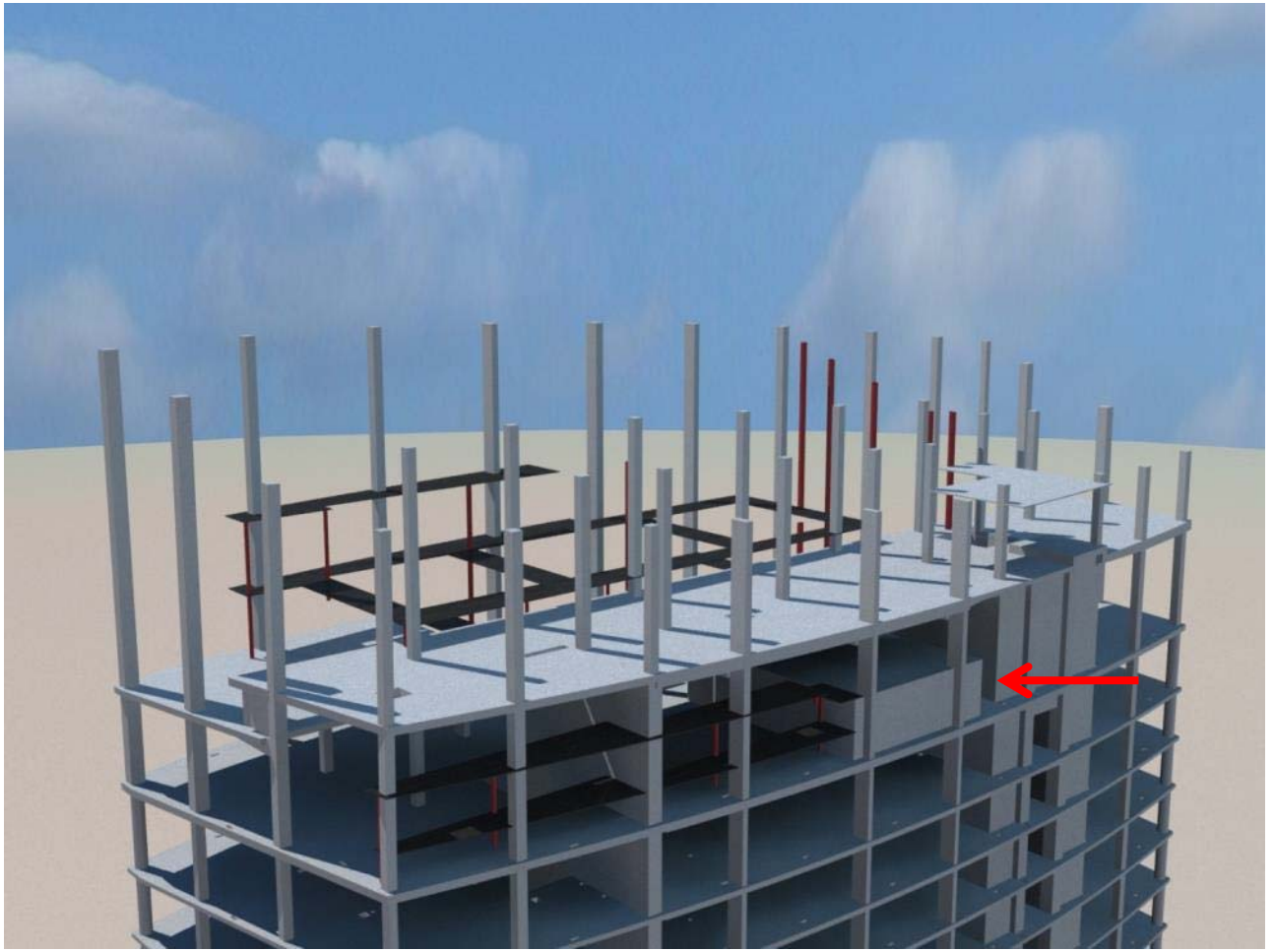

View from Northeast

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