350 MISSION

Fall 2015 | Denver
The Concrete Convention and Exposition

HIGH PERFORMANCE FLAT PLATE POST-TENSIONED DESIGN WITH INNOVATIVE MULTI-STORY CONSTRUCTION METHODOLOGIES

SOM David Shook

WEBCOR CONCRETE Eric Peterson


MISSION

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350 Mission St
San Francisco, California
Street View - Jul 2015
Market St
Mission St
350 Mission St
Stevenson St
Jessie St
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BUILDING OVERVIEW

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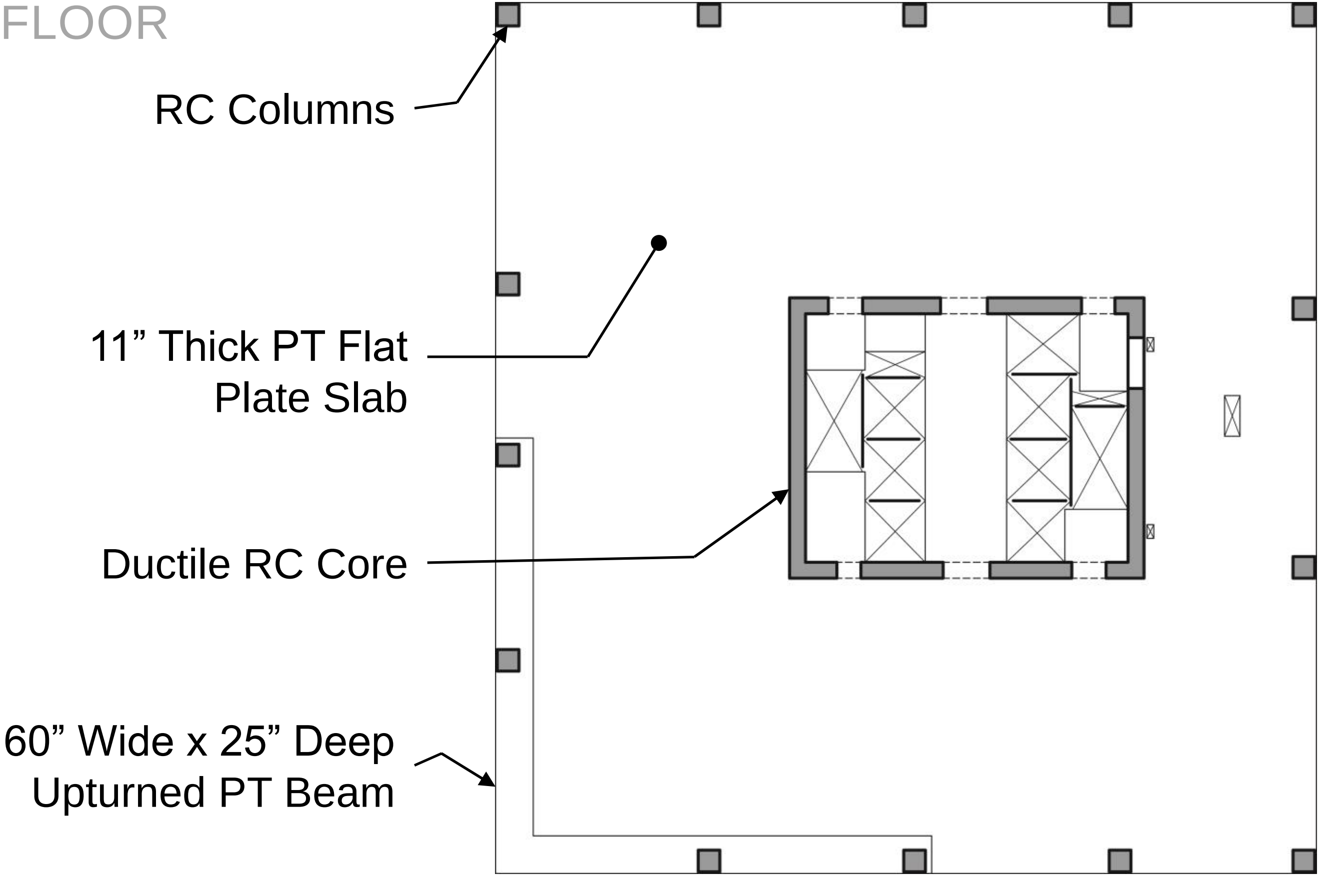
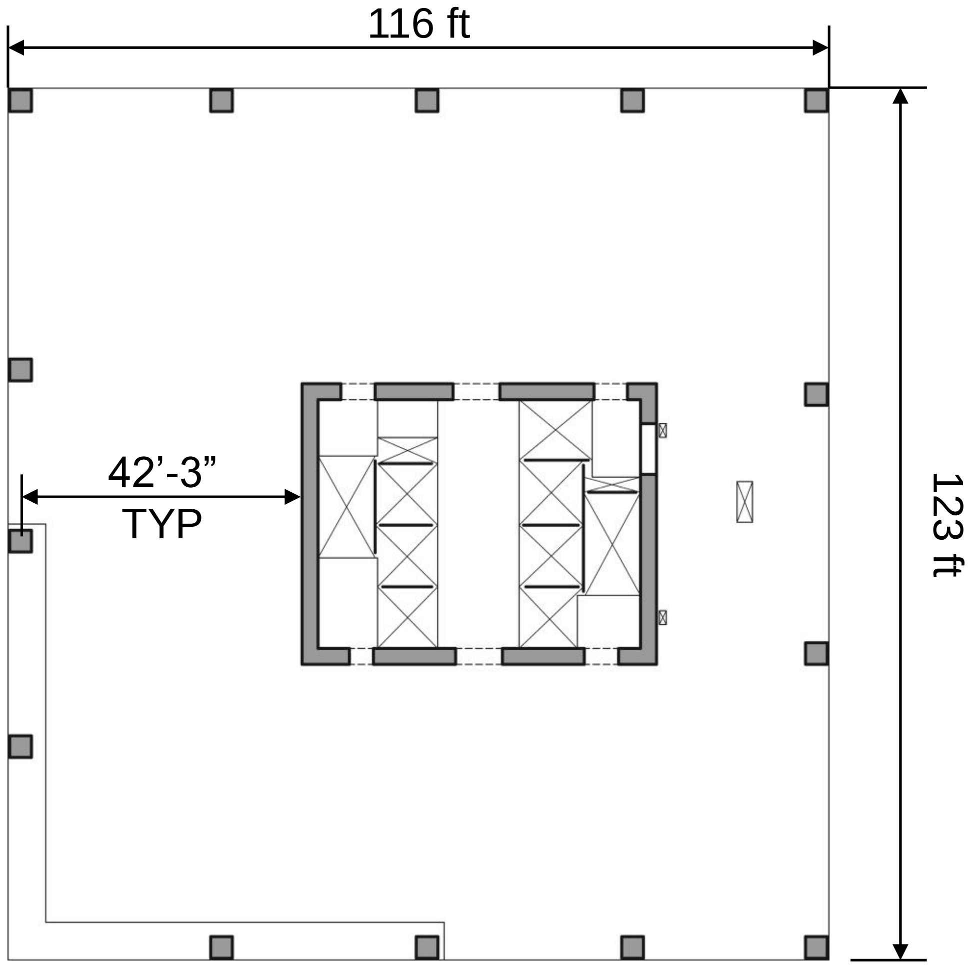
FRAMING PLAN
TYPICAL FLOOR



FRAMING PLAN
TYPICAL FLOOR



BUILDING SECTIONS
THROUGH CORE

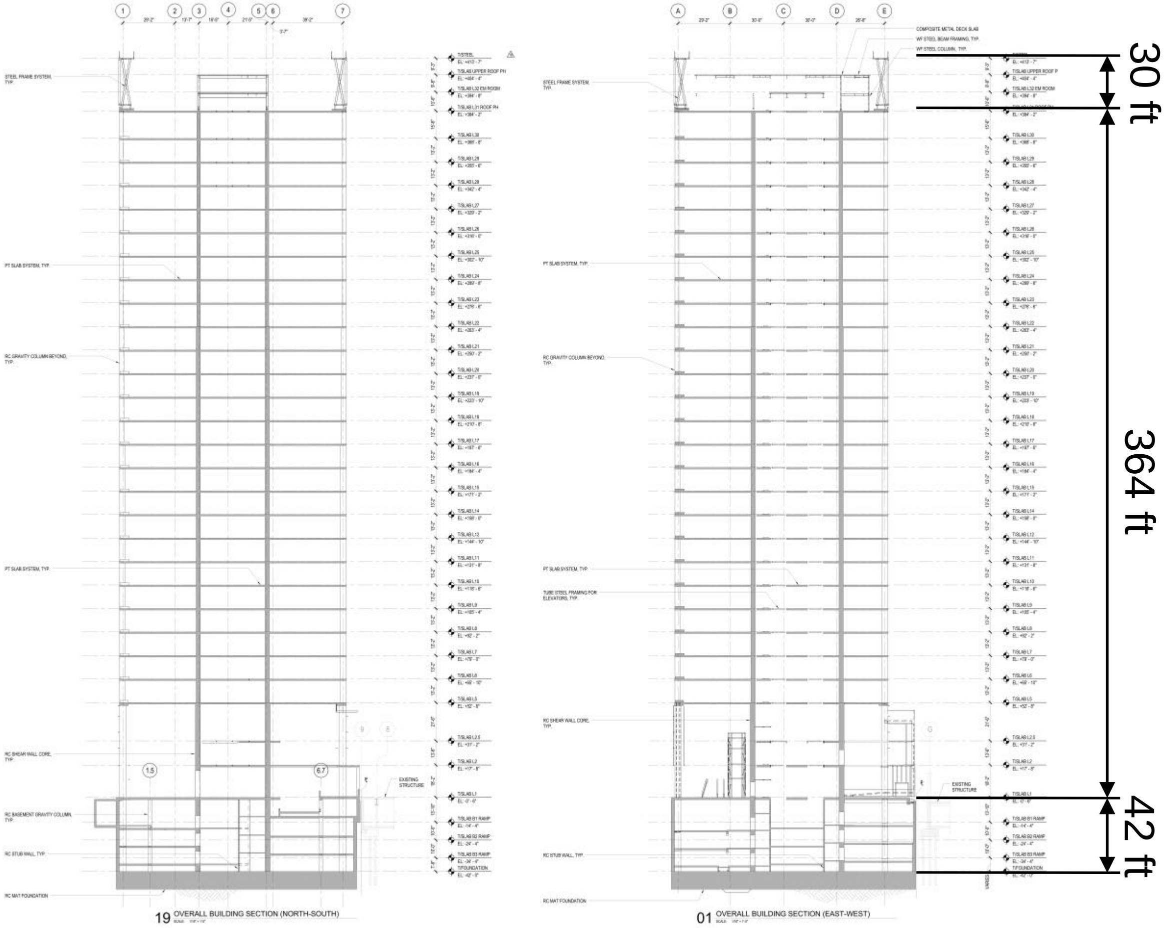
RC Columns
42x42 to 26x26

RC Walls
33 in to 24 in

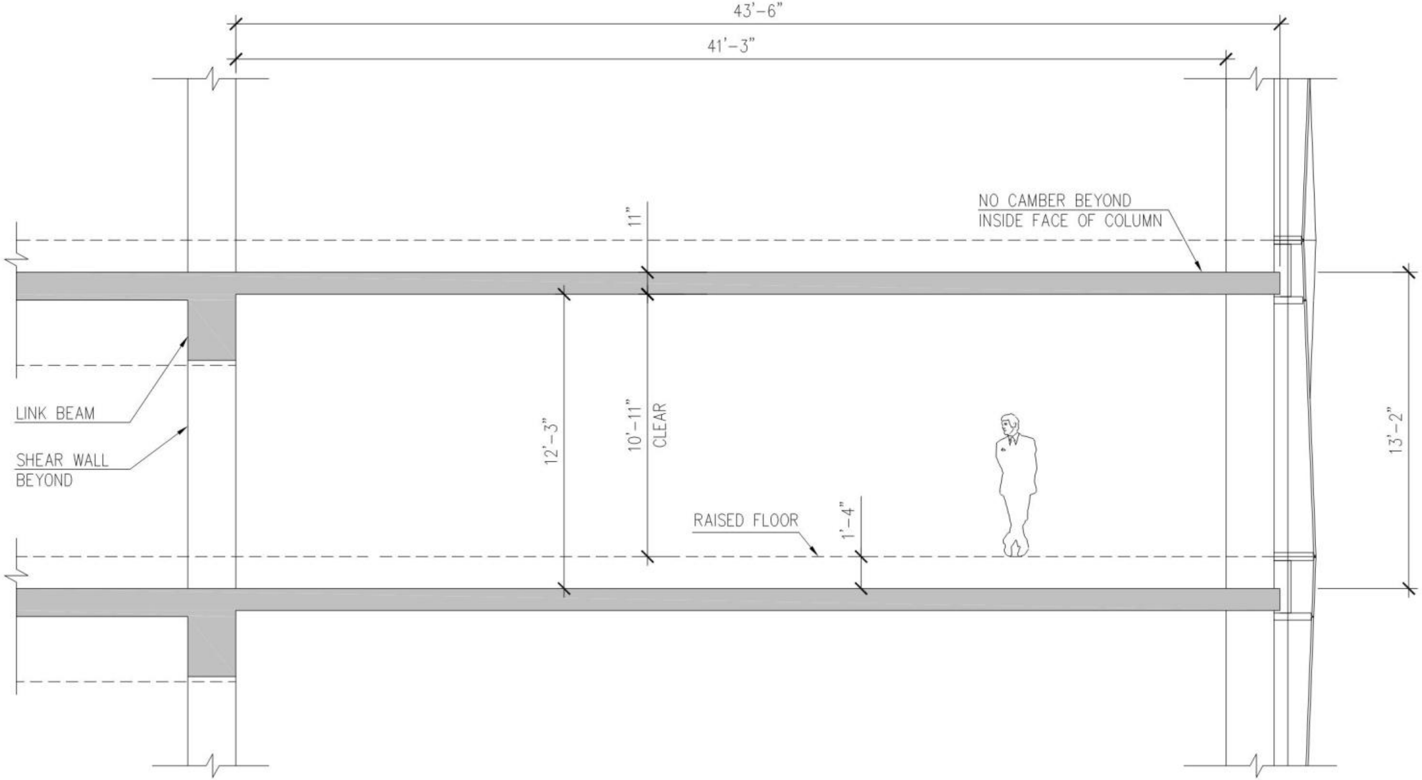
Slabs

PT Roof:	12 in
PT Typical:	11 in
Ground:	16 in
RC Bsmt:	10 in

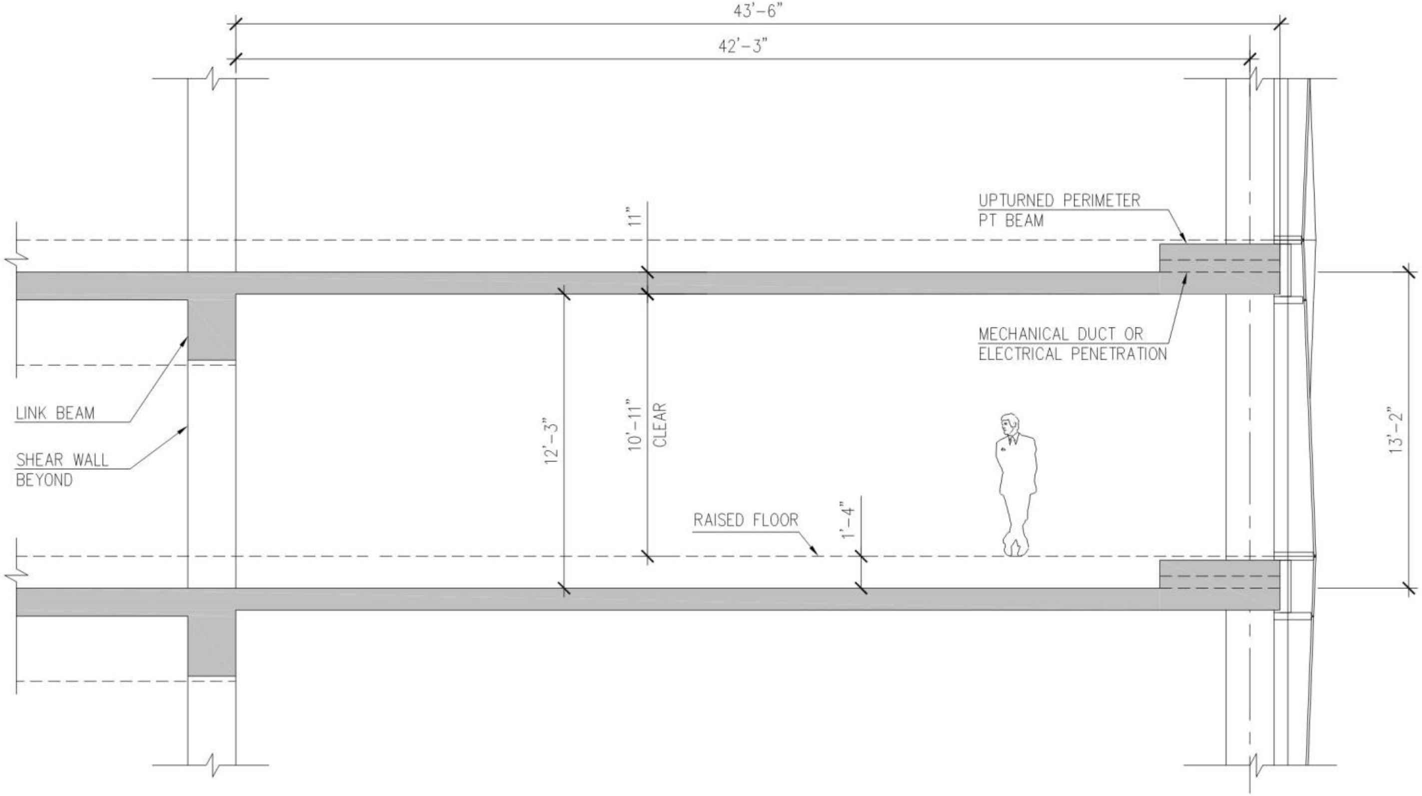
Mat 10 ft



FRAMING SECTION
TYPICAL FLOOR



FRAMING SECTION
TYPICAL FLOOR



LONG-SPAN FLAT PLATE SLAB DESIGN

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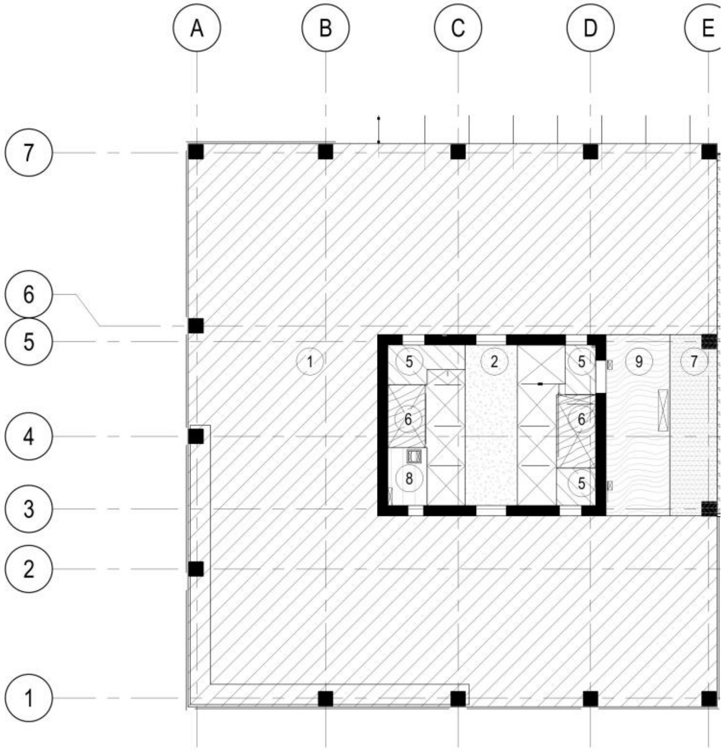
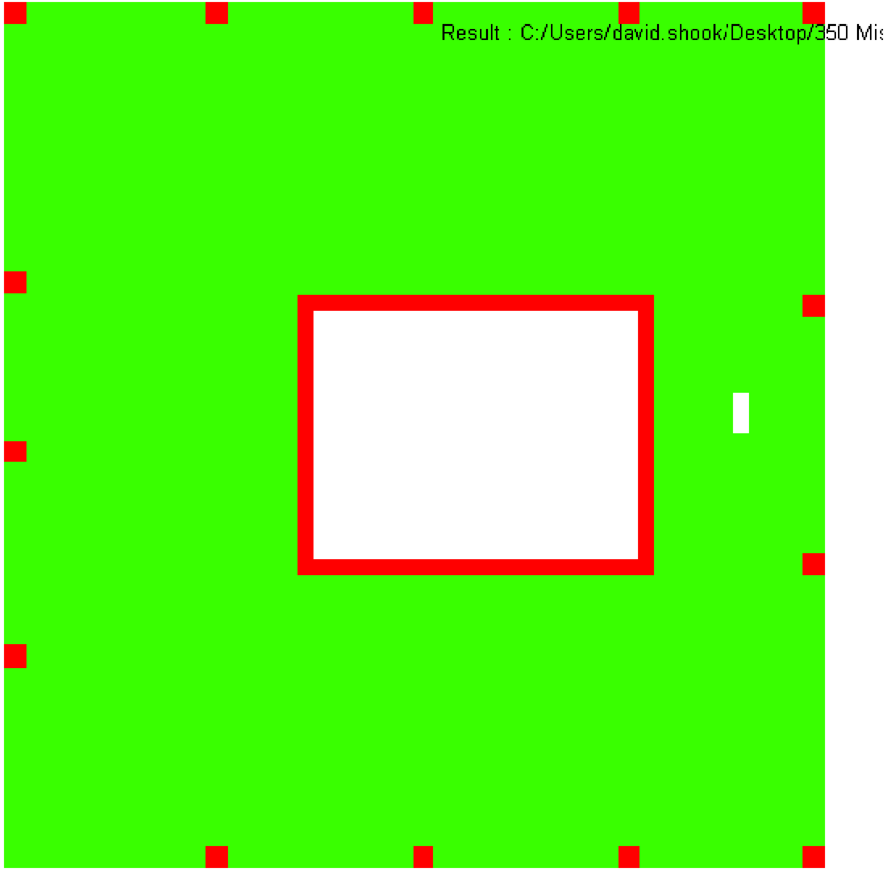
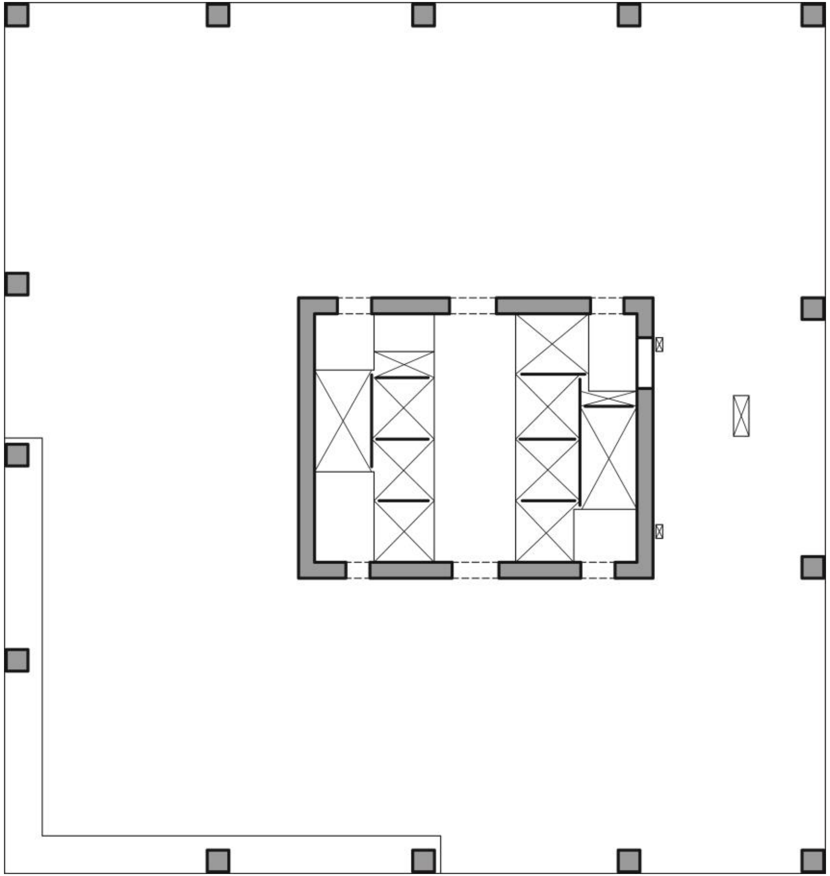
DESIGN CRITERIA
DESIGN LOADS

Dead Load (DL)	As Required
Post Tensioning (PT)	As Required
Superimposed Dead Load (SDL)	17 psf
Raised Floor, Ceiling, MEP	
Live Loads (LL)	
Occupancy	50 psf
Partitions	15 psf
Design Strength	5,000 psi
Rebar	
ASTM A615 Gr 60	Typical
ASTM A706 Gr 60	At walls & columns

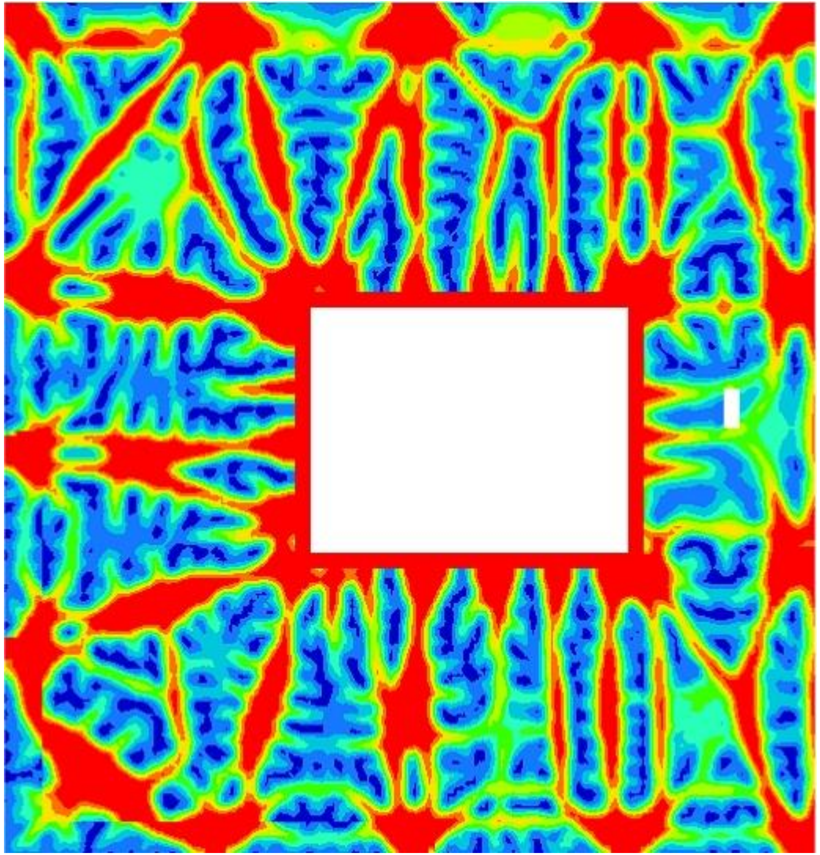


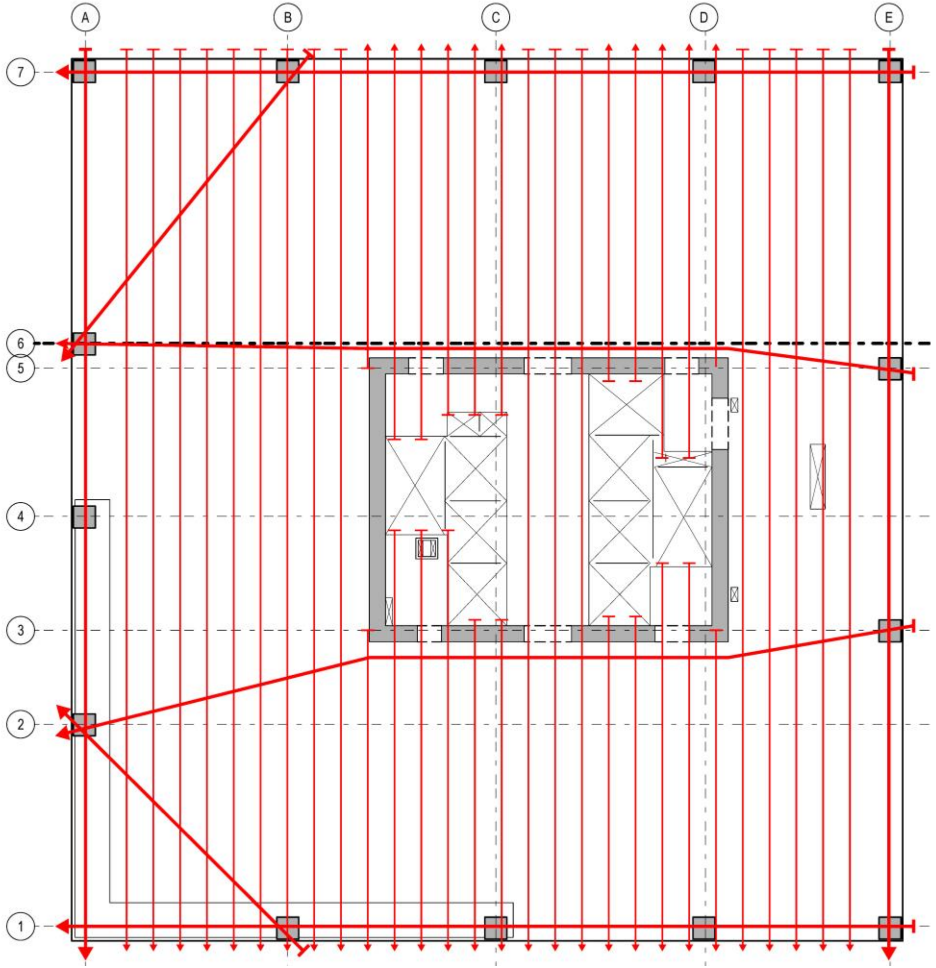
CONCEPTUAL DESIGN





CONCEPTUAL DESIGN





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DESIGN CRITERIA
DEFLECTION LIMITS

Deflection Span Ratios

L/240	(43.5' span)	2.2"
L/360	(43.5' span)	1.5"
L/480	(43.5' span)	1.0"

Partitions Deflection Accommodation	0.75"
Curtain Wall Deflection Accommodation	0.75"
Level 5 Curtain Wall Deflection Accommodation	0.375"

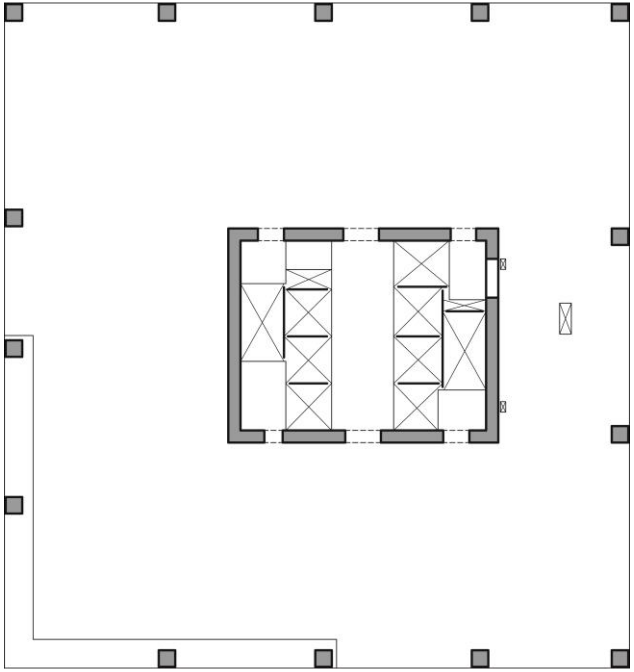


TABLE 9.5(b) — MAXIMUM PERMISSIBLE COMPUTED DEFLECTIONS

Type of member	Deflection to be considered	Deflection limitation
Flat roofs not supporting or attached to nonstructural elements likely to be damaged by large deflections	Immediate deflection due to live load ***L***	**ℓ/180***
Floors not supporting or attached to nonstructural elements likely to be damaged by large deflections	Immediate deflection due to live load ***L***	**ℓ/360**
Roof or floor construction supporting or attached to nonstructural elements likely to be damaged by large deflections	That part of the total deflection occurring after attachment of nonstructural elements (sum of the long-term deflection due to all sustained loads and the immediate deflection due to any additional live load)†	**ℓ/480‡**
Roof or floor construction supporting or attached to nonstructural elements not likely to be damaged by large deflections		**ℓ/240§**

*Limit not intended to safeguard against ponding. Ponding should be checked by suitable calculations of deflection, including added deflections due to ponded water, and considering long-term effects of all sustained loads, camber, construction tolerances, and reliability of provisions for drainage.

†Long-term deflection shall be determined in accordance with 9.5.2.5 or 9.5.4.3, but may be reduced by amount of deflection calculated to occur before attachment of nonstructural elements. This amount shall be determined on basis of accepted engineering data relating to time-deflection characteristics of members similar to those being considered.

‡Limit may be exceeded if adequate measures are taken to prevent damage to supported or attached elements.

§Limit shall not be greater than tolerance provided for nonstructural elements. Limit may be exceeded if camber is provided so that total deflection minus camber does not exceed limit.

DESIGN CRITERIA
ANALYSIS

Sustained Loads		1.0 DL+1.0 PT+1.0 SDL+0.2 LL	
Rupture Strength of Concrete (f_r)		$4\sqrt{f'_c}$	ACI 435 Table 4.1
f'c (design, for strength)		5,000 psi	
f'c (based on testing, for deflection)		7,000 psi	
Walls & columns above/below modeled			
Rigid zones over supports			
Method 1:	Cracked section analysis with long term multiplier		
	Long Term Creep Multiplier (λ_t)	3.5	ACI 435 Table 4.1
Method 2:	Cracked section analysis with creep and shrinkage effects using variable Ec		
	Creep Coefficient(C_u)	2.35	ACI 209R-92
	Shrinkage Coefficient (ε_{sh})	780×10^{-6}	ACI 209R-92
Design Software – SAFE:		Method 1 & 2	(CSI)
Verification Software – ADAPT Floor:		Method 1	(ADAPT)

DESIGN CRITERIA
ANALYSIS

Table 4.1—Multipliers recommended by different authors

Source	Modulus of rupture, psi	Immediate	Creep λ_c	Shrinkage λ_{sh}	Total λ_r
Sbarounis (1984)	$7.5\sqrt{f_c'}$	1.0	2.8	1.2	5.0
Branson (1977)	$7.5\sqrt{f_c'}$	1.0	2.0	1.0	4.0
Graham and Scanlon (1986b)	$7.5\sqrt{f_c'}$ $4\sqrt{f_c'}$	1.0 1.0	2.0 1.5	2.0 1.0	5.0 3.5
ACI Code	$7.5\sqrt{f_c'}$	1.0	2.0		3.0

Shrinkage warping deflections can also be determined using the equivalent tension force method outlined in ACI 209R.

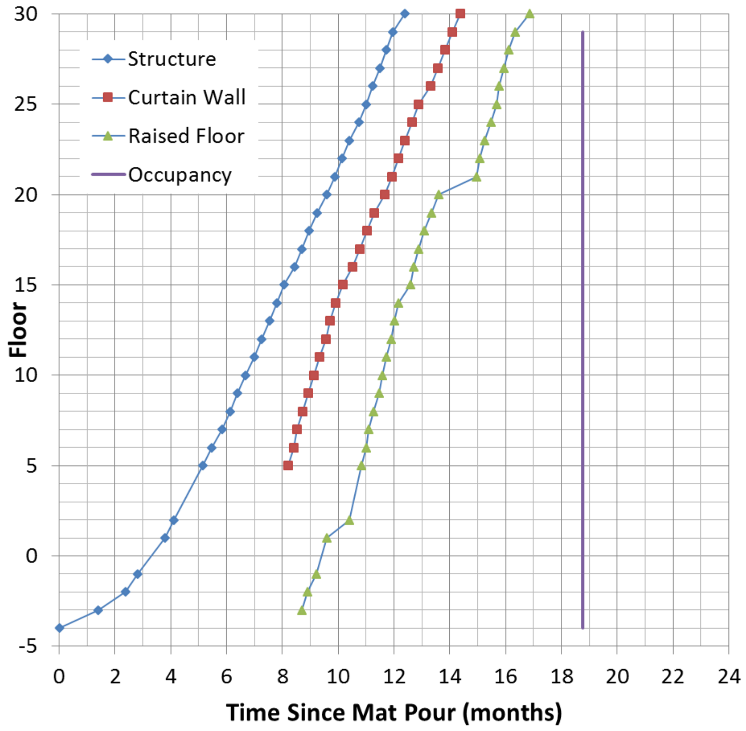
The total deflection at any time is obtained by adding immediate deflection due to sustained load, creep deflection due to sustained load, shrinkage warping deflection, and deflection due to the part of the live load that is transient.

Sophisticated finite element models have been developed (ASCE 1982) to account for time-dependent deformations of two-way slabs caused by creep and shrinkage. These models are generally used for research purposes and are considered to be too complex for normal design applications, particularly when the high variability of creep and shrinkage properties is considered.

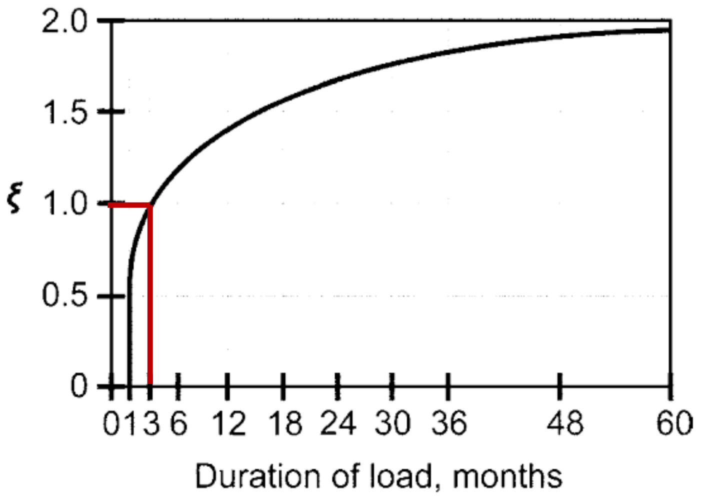
where restraint stresses are likely to have a significant effect on cracking, for example, large slab areas and stiff lateral restraint elements such as structure walls and columns, it is recommended that a reduced modulus of rupture given by $f_r = 4\sqrt{f_c'}$ psi ($0.33\sqrt{f_c}$ MPa) be used along with a long-term sustained-load multiplier of 2.5.

Values recommended in ACI 209R for ultimate creep and shrinkage coefficients are $C_u = 2.35$, and $\epsilon_{sh\infty} = 780 \times 10^{-6}$, respectively at standard conditions as discussed in Chapters 2 and 3. Sbarounis (1984) has suggested that at standard conditions the long-term multipliers be modified if the concrete properties are known, and better estimates of ultimate creep, $\overline{C}_u$, and shrinkage, $\overline{\epsilon}_{sh\infty}$, are available. Thus,

MATERIAL PERFORMANCE
CREEP AND SHRINKAGE



Construction Schedule



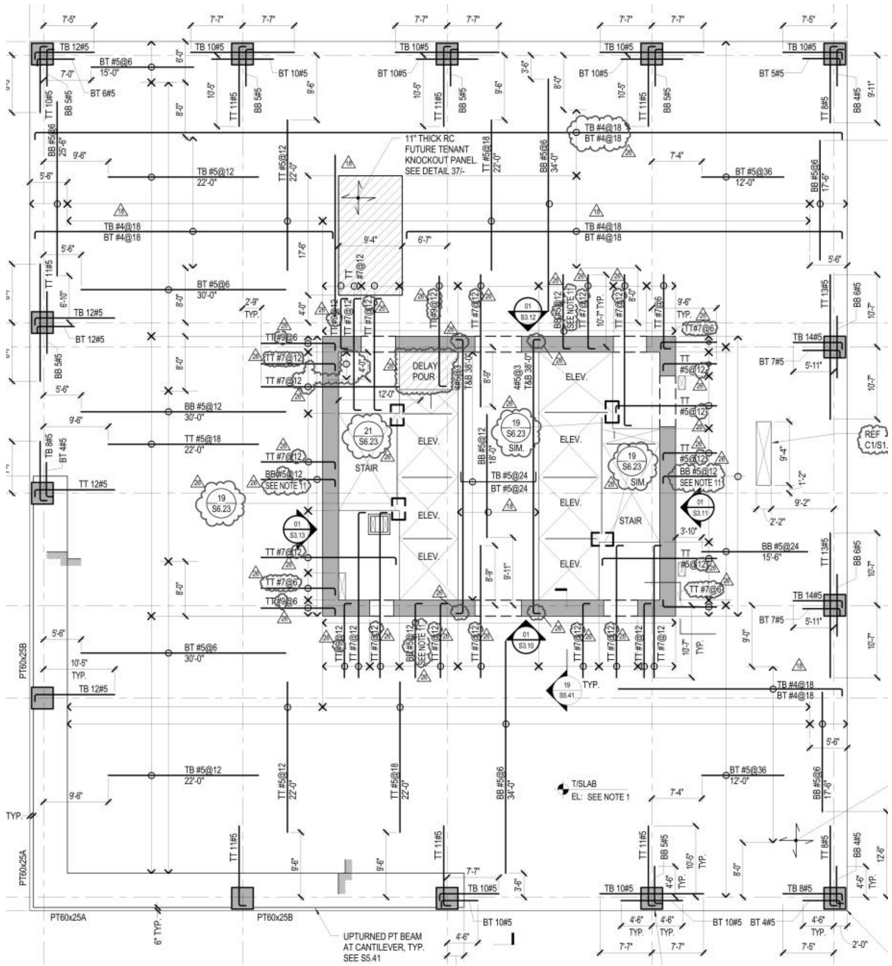
Raised floor and curtain wall installed approximately **90 days** after casting concrete.

Therefore 50% of long-term creep and shrinkage has occurred when curtain wall installed.

SLAB DESIGN
MILD REINFORCEMENT

At Walls	Typical	Rho (%)
Bottom Reinf:	#5@12	(0.23%)
Top Reinf :	#7@12	(0.49%)
At Wall Corners		
Bottom Reinf :	#5@12	(0.23%)
Top Reinf :	#9@6	(1.51%)
At Mid-Span		
Bottom Reinf :	#5@6	(0.47%)
Top Reinf :	#5@18	(0.15%)
At Columns		
Bottom Reinf :	#5@6	(0.47%)
Top Reinf :	#5@6	(0.47%)

NO UNIFORM REINFORCEMEMT
Mild Quantities: 3.7 psf



SLAB DESIGN
POST-TENSIONING

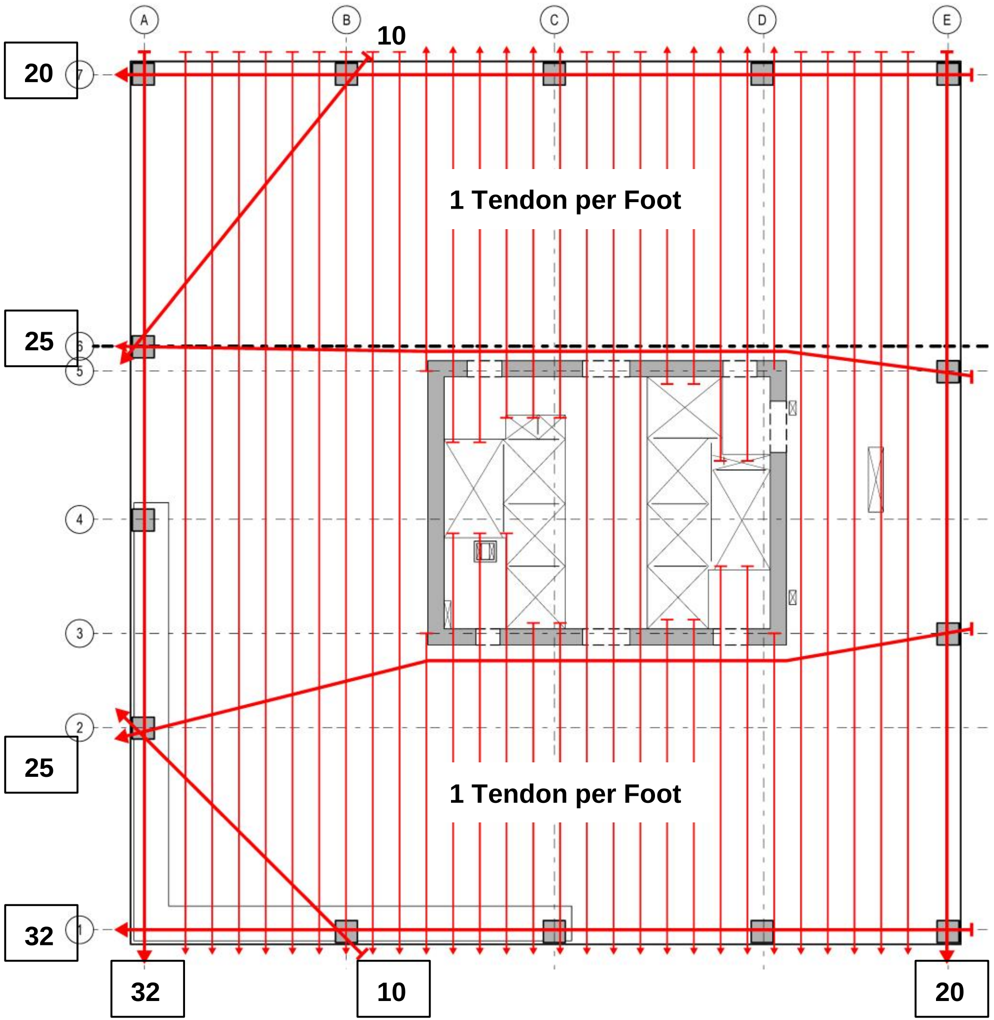
½” Diameter tendons

Unbonded tendons

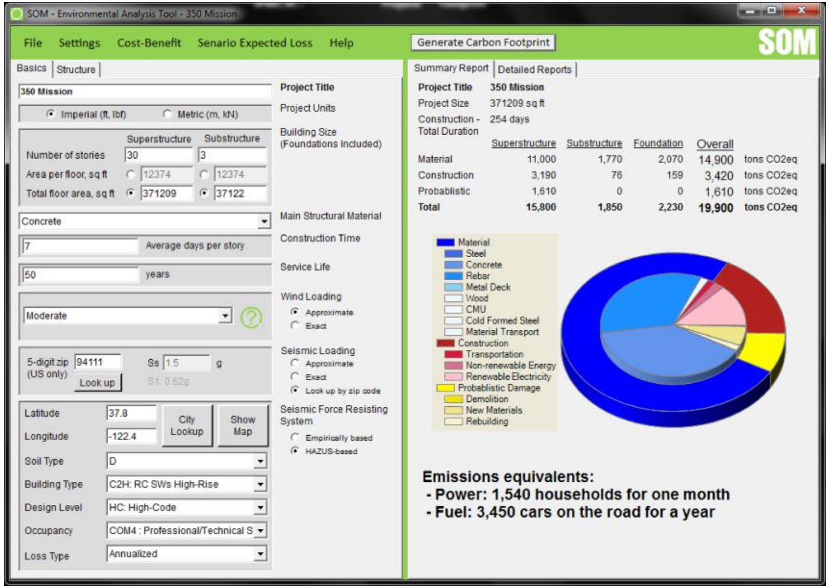
Fully encapsulated

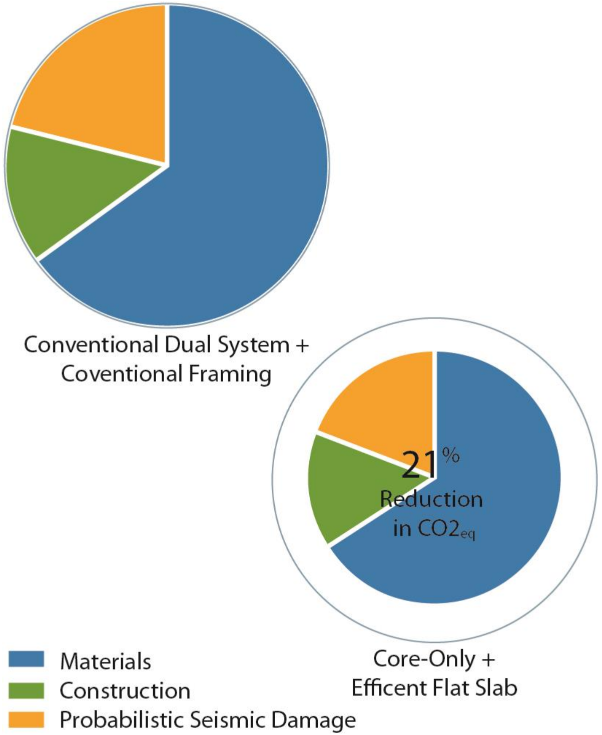
Tendons go through
concrete walls and columns

PT Quantities: 1.3 psf



EMBODIED CARBON
QUANTIFIED





600 truck loads of concrete eliminated

5,400 cubic yards of concrete

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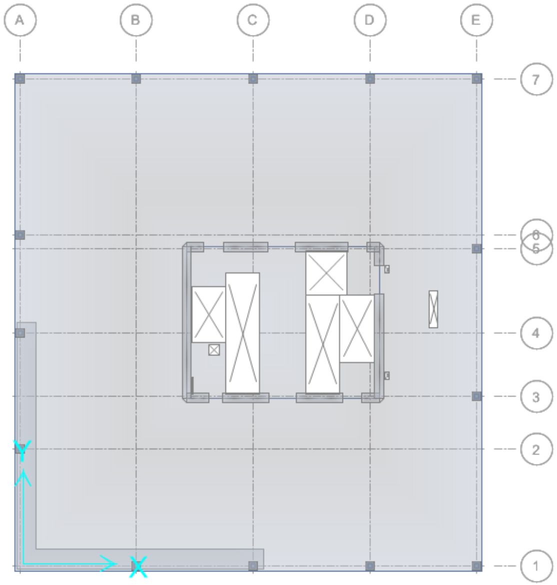
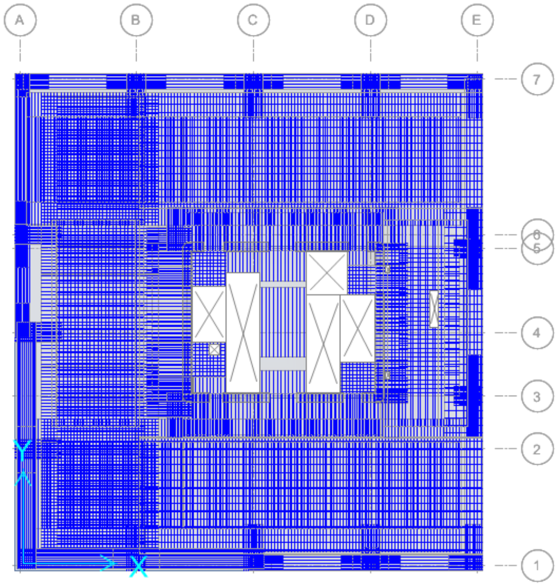
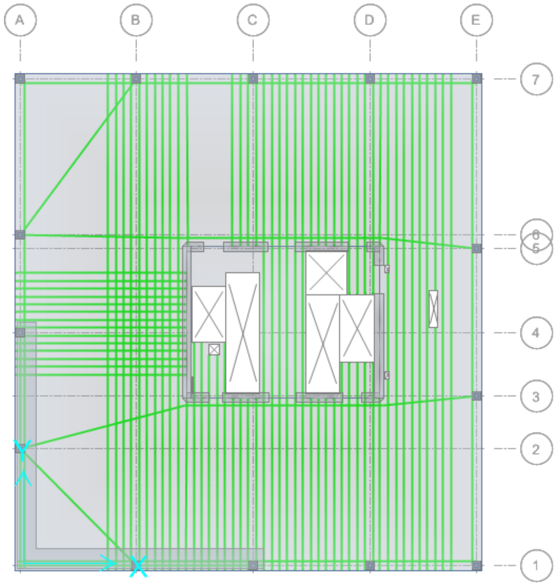
SLAB DESIGN
ANALYSIS



FRAMING PLAN

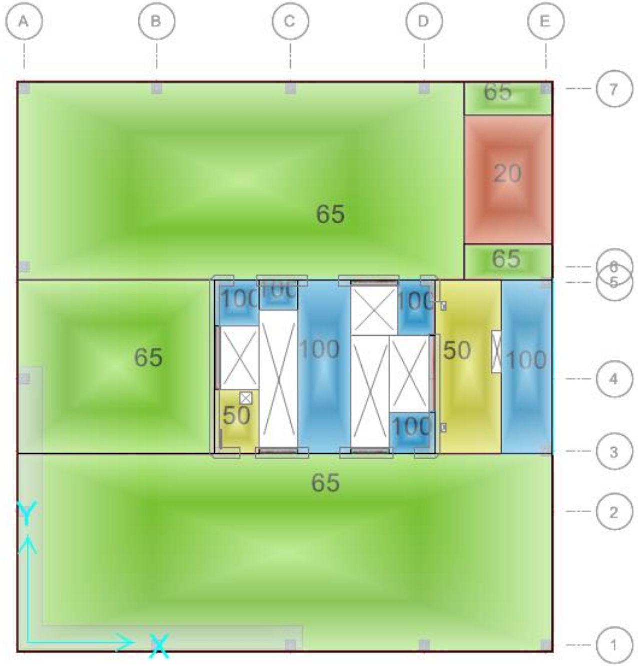


REBAR PLAN

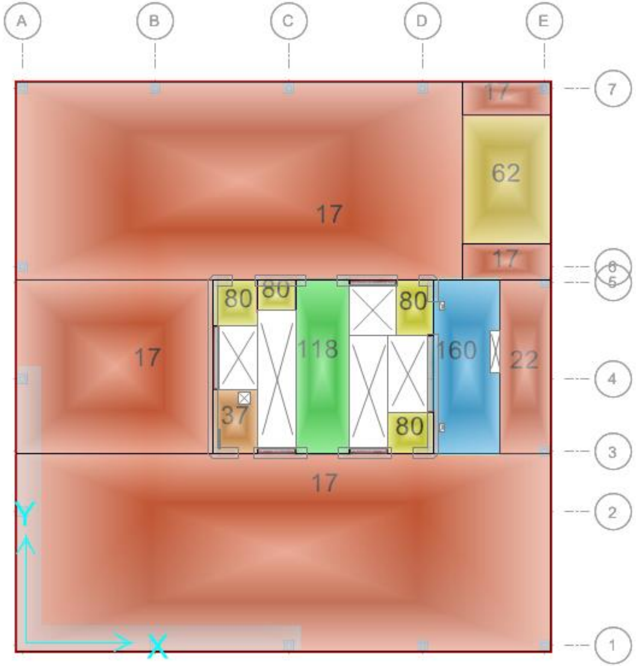


PT PLAN

SLAB DESIGN
LOADING

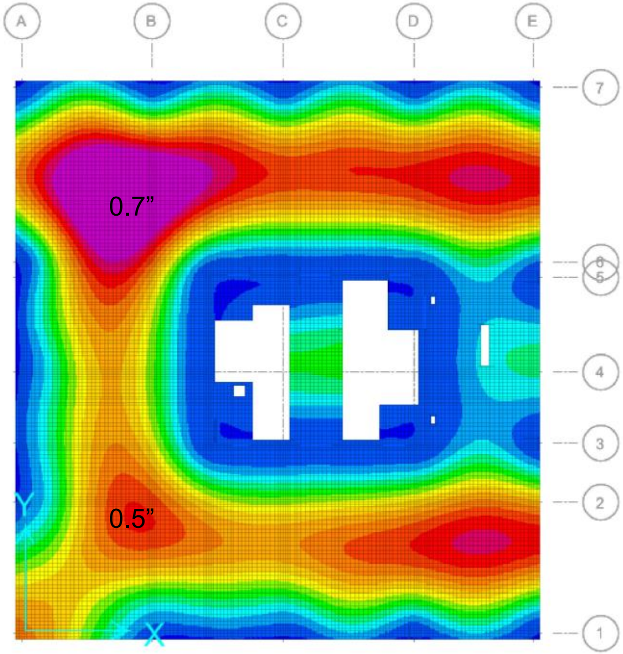


LIVE LOAD PLAN

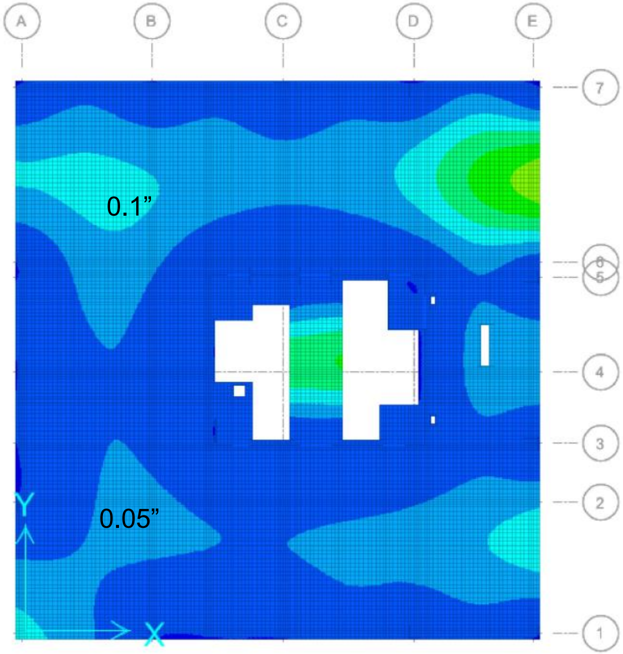


SUPERIMPOSED DEAD PLAN

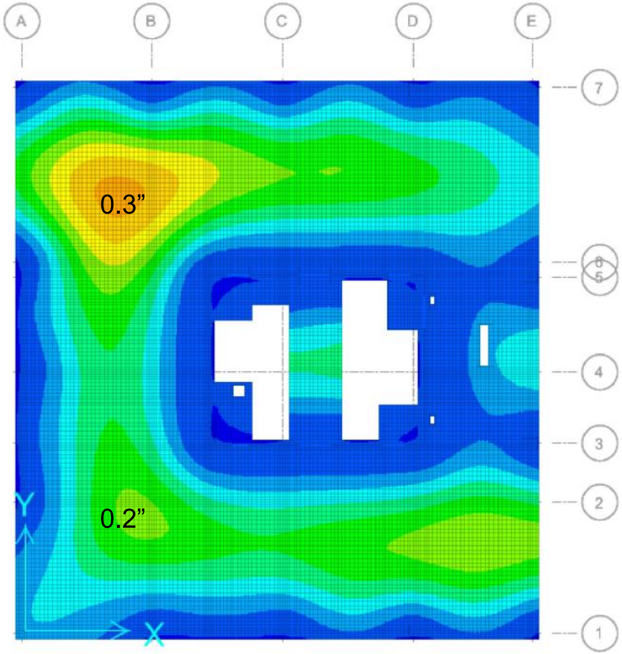
SLAB DESIGN
DEFLECTION



SELF WEIGHT

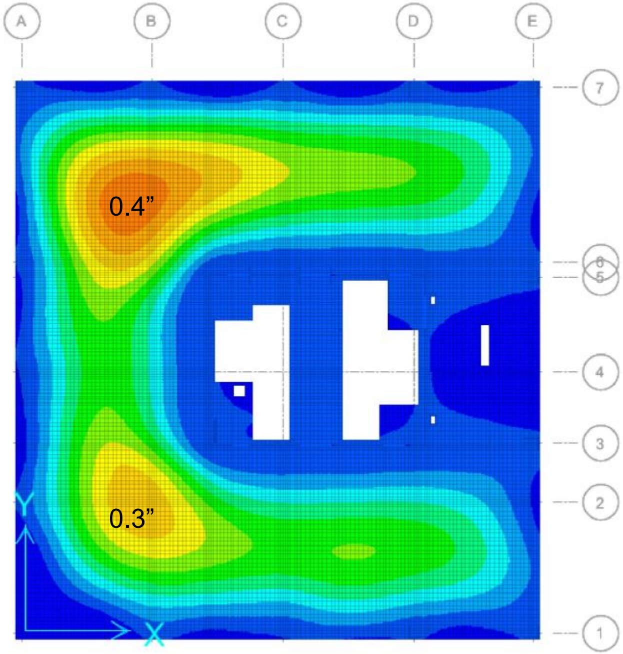


SUPERIMPOSED DEAD

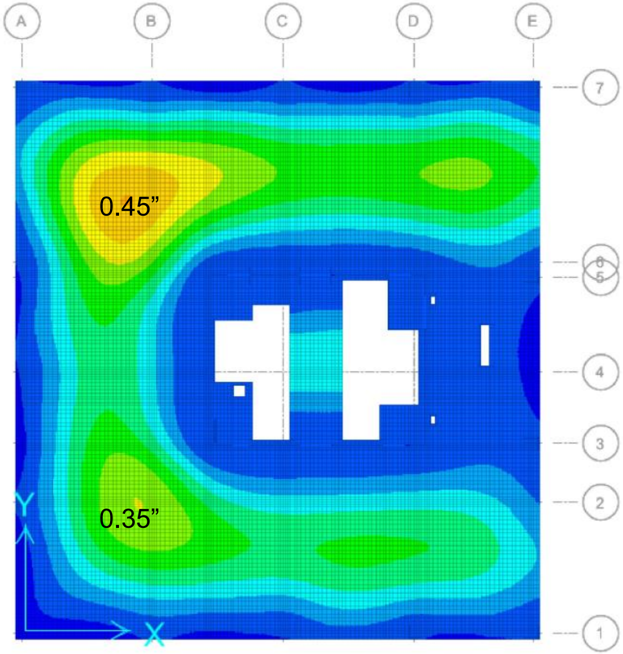


LIVE LOAD

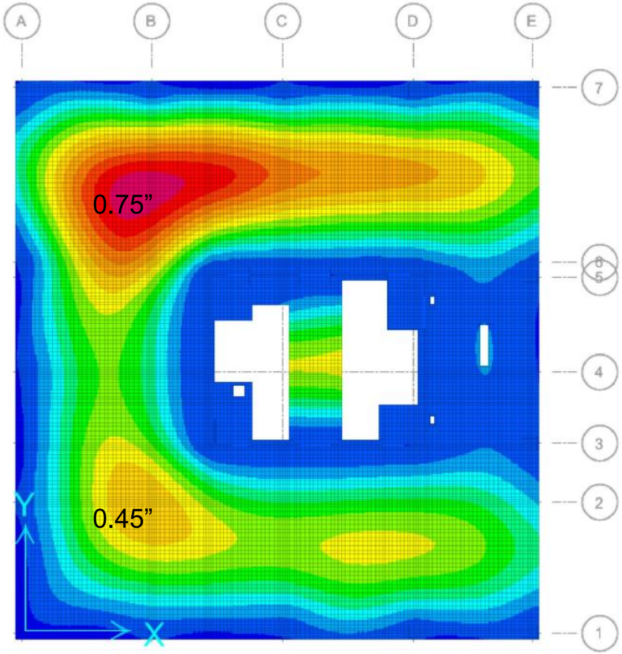
SLAB DESIGN
DEFLECTION



SELF WEIGHT + PT

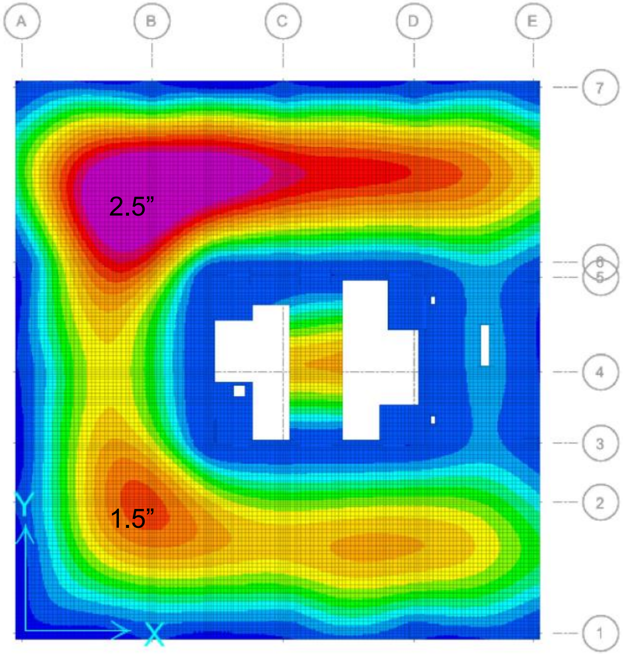


SERVICE LOADS (ELASTIC)



SERVICE (CRACKED)

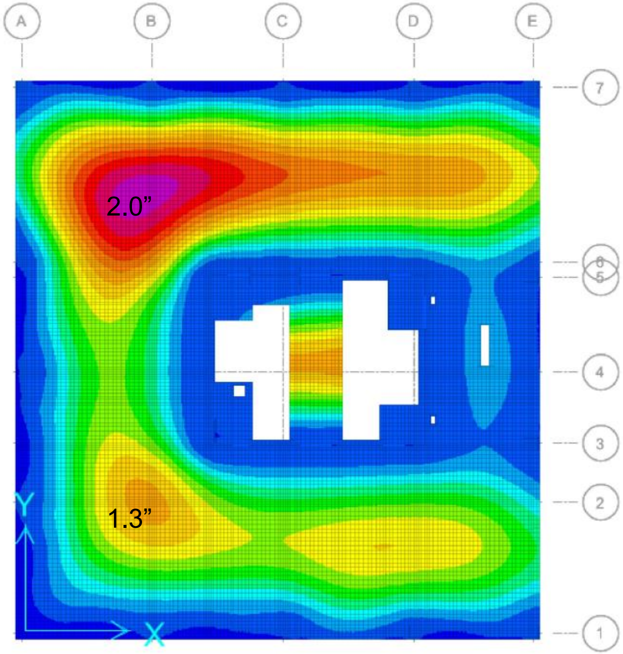
SLAB DESIGN
DEFLECTION



TOTAL LONG TERM SERVICE – METHOD 1

λ_t = 3.5 (2.5+1)

$f_r = \sqrt{4f'c}$

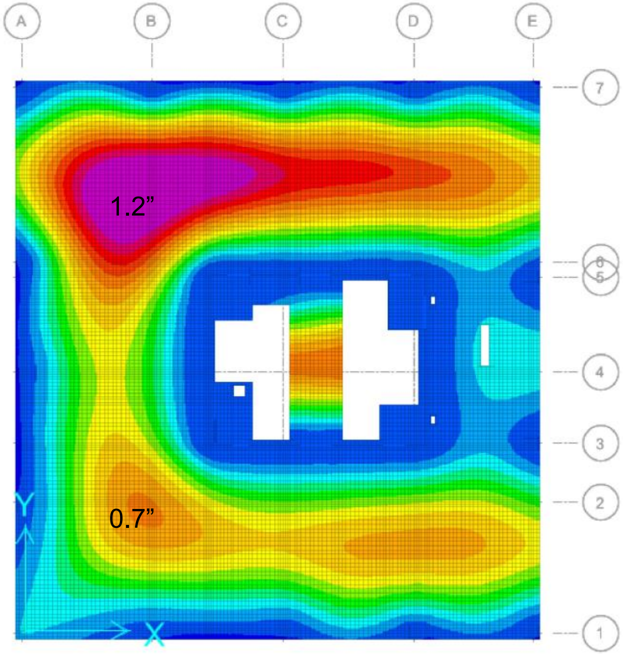


TOTAL LONG TERM SERVICE – METHOD 2

C_u = 2.35 & ε_{sh} = 780x10^{-6}

$f_r = \sqrt{4f'c}$

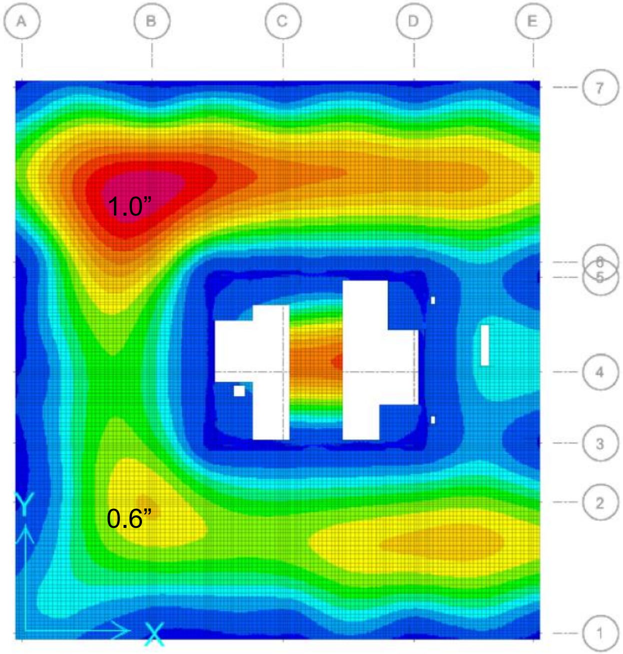
SLAB DESIGN
DEFLECTION



AFTER NSC WITH LIVE – METHOD 1

λ_t = 3.5 (2.5+1)

$f_r = \sqrt{4f'c}$



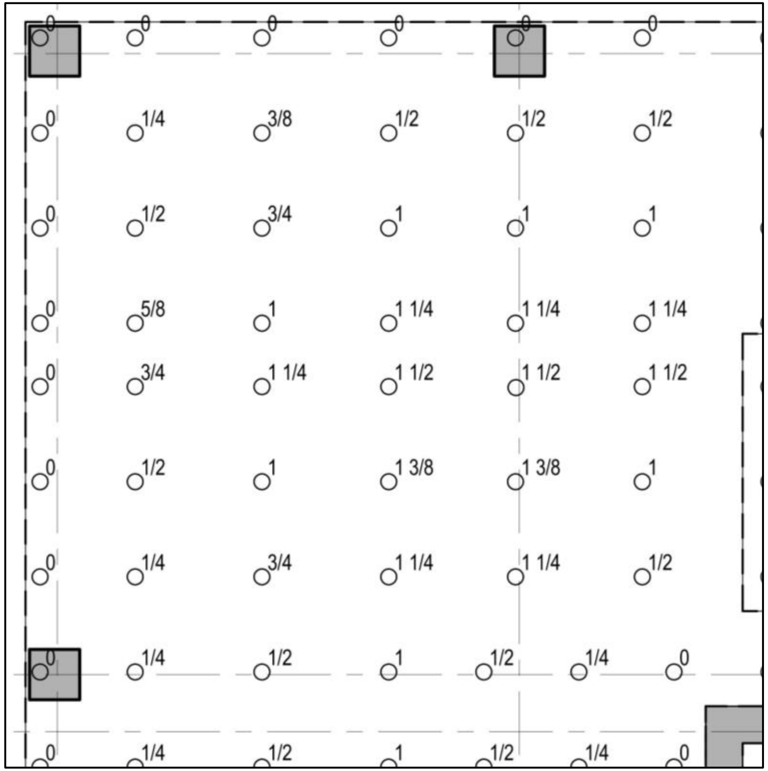
AFTER NSC WITH LIVE – METHOD 2

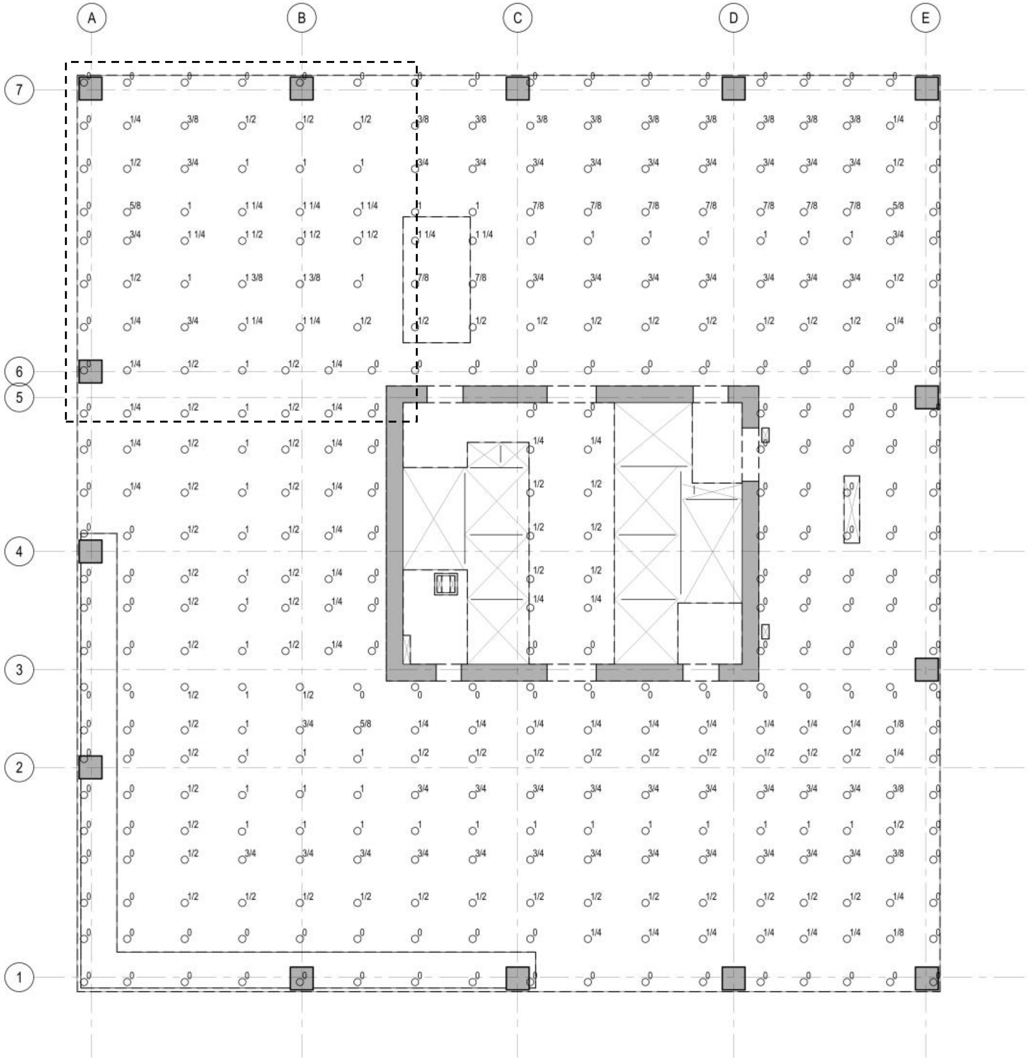
C_u = 2.35 & ε_{sh} = 780x10^{-6}

$f_r = \sqrt{4f'c}$

CAMBER DESIGN

SHORING CONSIDERATIONS





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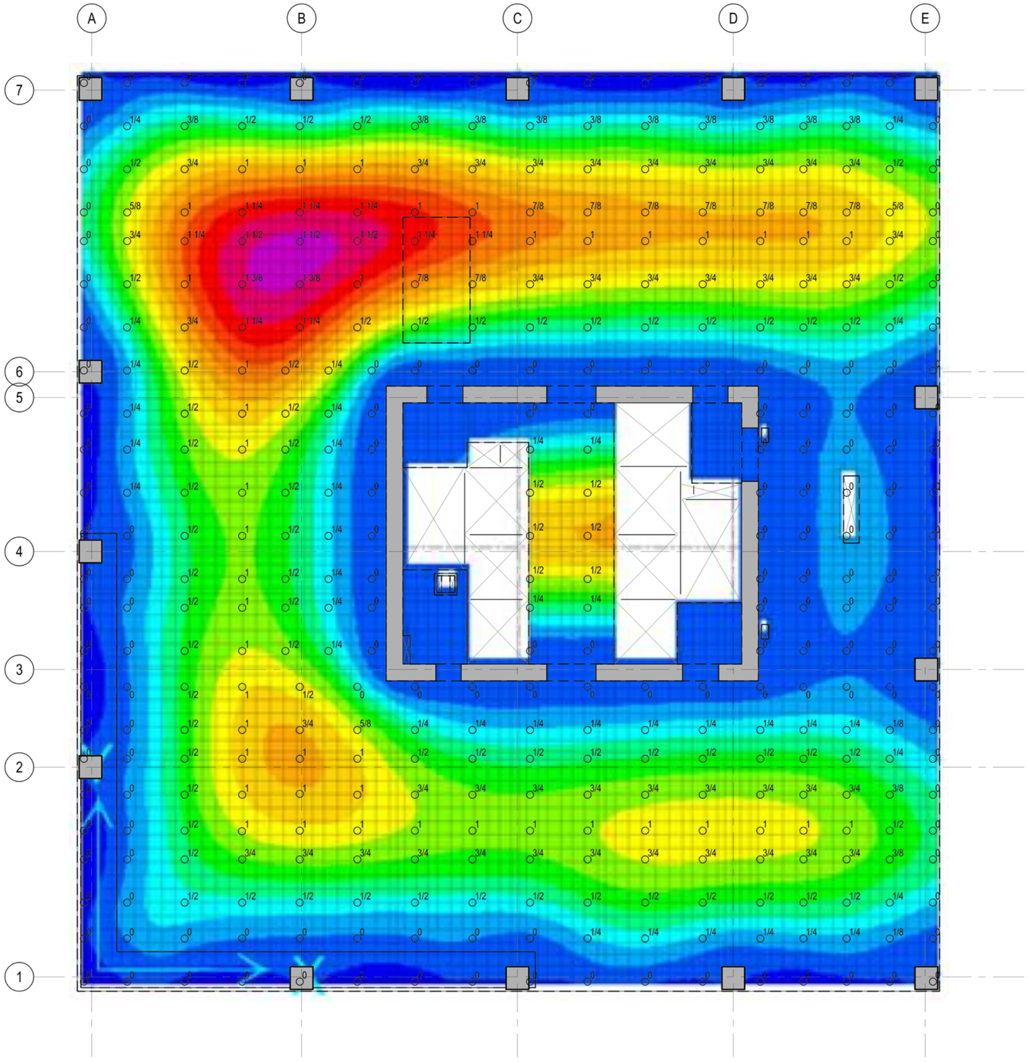
CAMBER DESIGN

SHORING CONSIDERATIONS



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CONSTRUCTION METHODS

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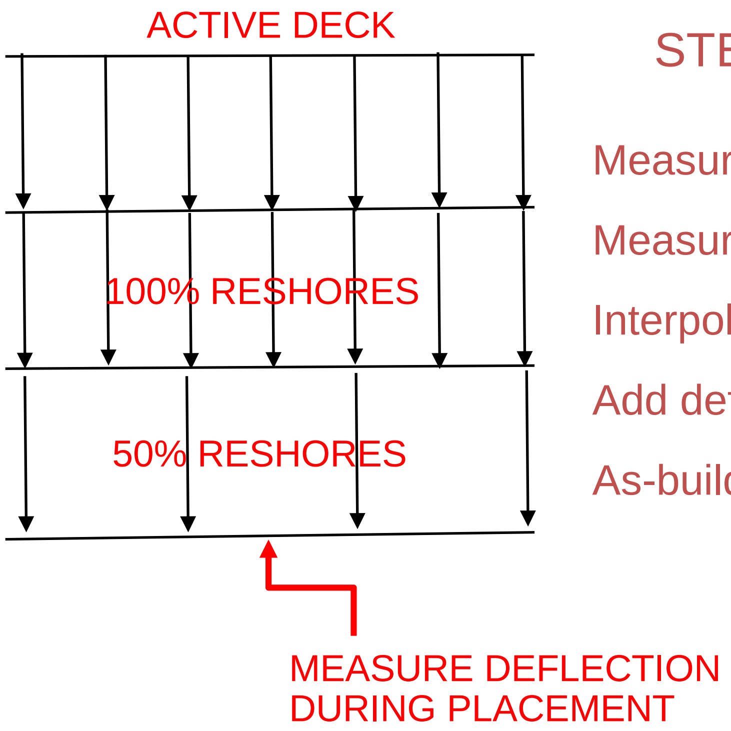
SHORING SYSTEM
METHOD OF GRADING



STEPS REQUIRED TO OBTAIN SOFFIT PROFILE

Measure deflection of lowest reshored level during placement

Measure shortening of formwork system during placement

Interpolate values based upon shore location relative to supports

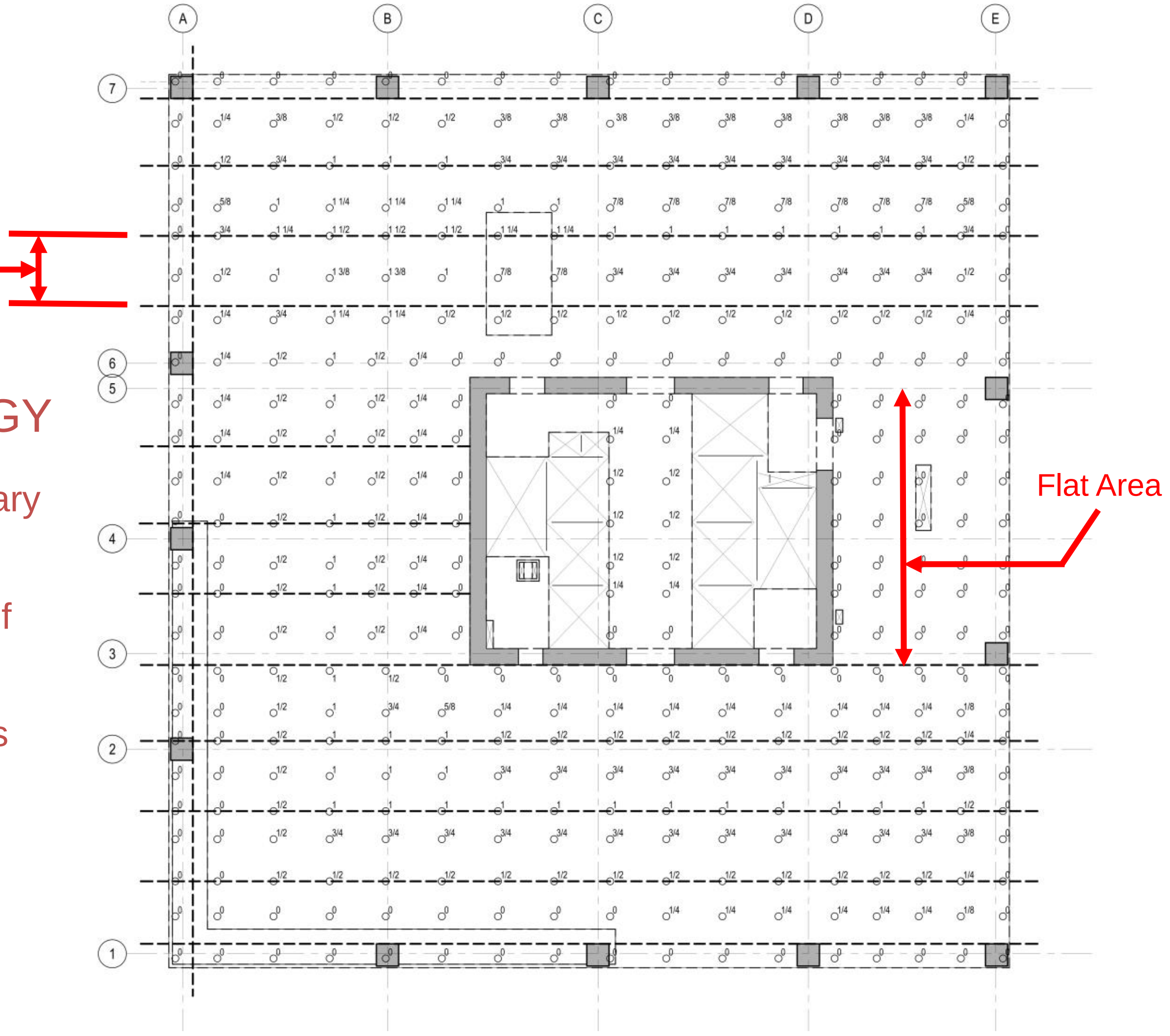
Add deflection + formwork shortening to specified camber values

As-build deck soffit formwork elevations prior to placement

CAMBER DESIGN

TOP SURFACE FINISHING

Target Screed Placement
10-FT On Center



PLACE AND FINISH STRATEGY

- Strike-off was perpendicular to primary camber direction on long runs
- 10-ft increments to minimize effect of corded profile
- Verify screed elevations after deck is loaded / before strike-off
- No pans used for finishing

TOLERANCES
TIGHT CONTROL

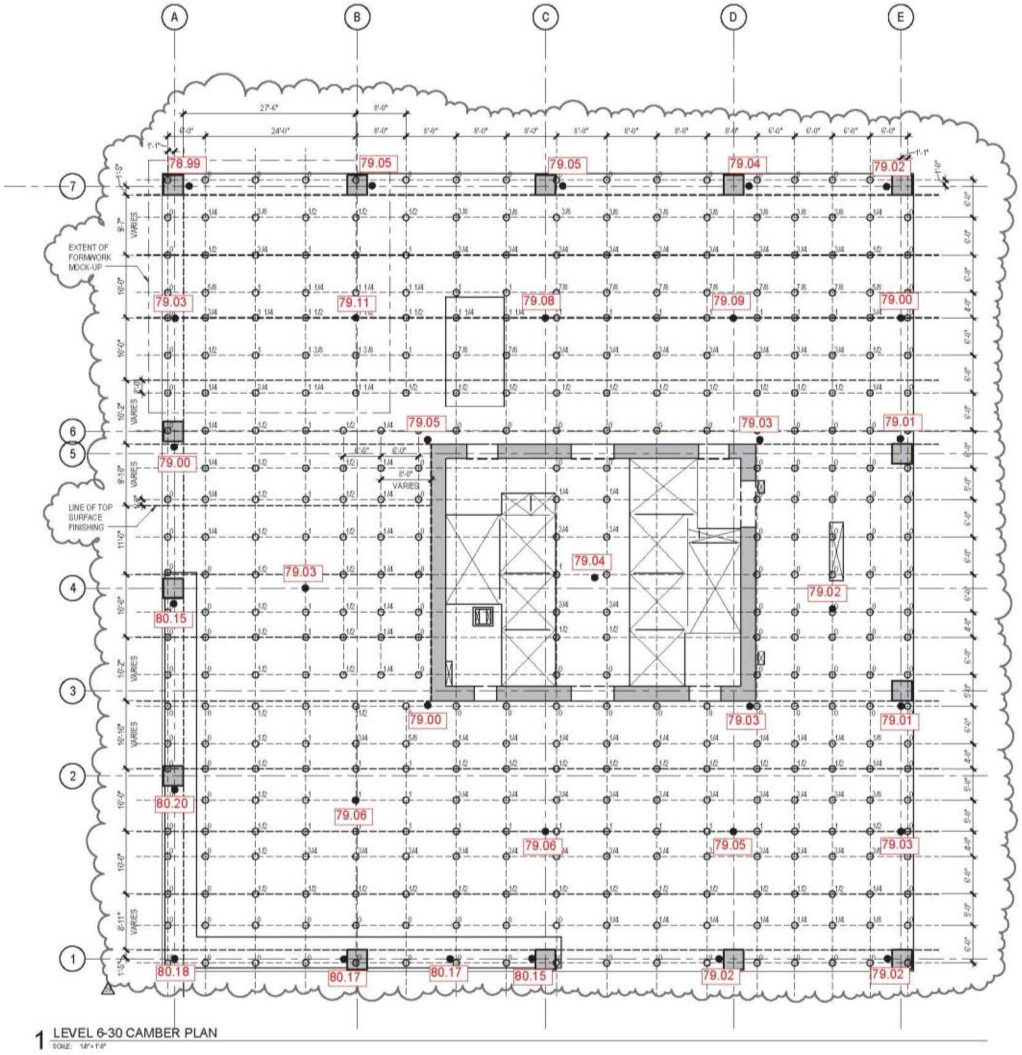
Tolerance Requirements:

Deviation from elevation

ACI 117-10	+/- 3/4"
350 Mission	+1/4”, -1/8”

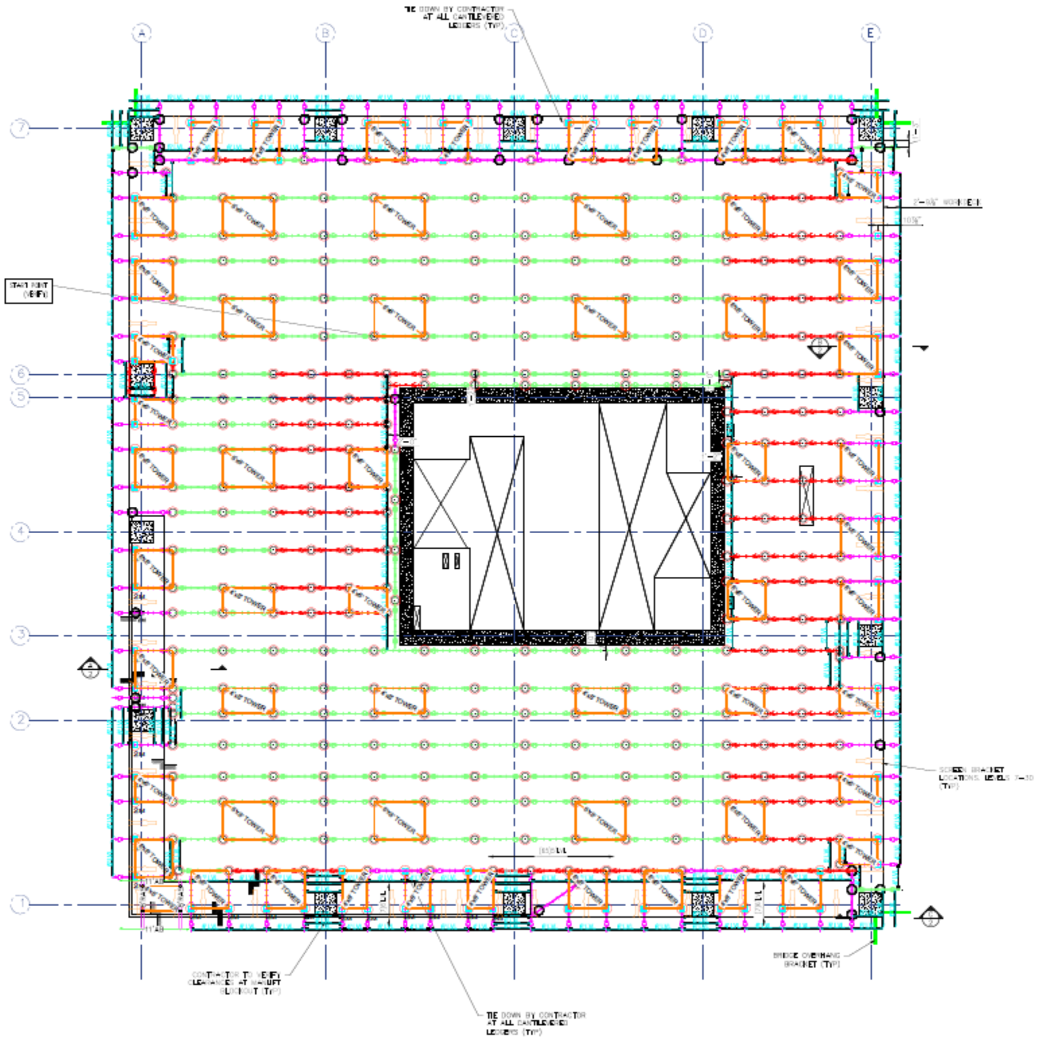
Deviation of Cross Thickness

ACI 117-10	- 1/4“, no + limit
350 Mission	-1/8 in., +1/2 in.



SHORING SYSTEM
HAND SET

Hand set Pro-Shore




WEBCOR
CONCRETE

Day 3 – Tendons stressed and shores installed for next floor

Day 30 – Reshores out, mechanical equipment staging

Day 60 – Curtain wall staging

Day 90 – Mostly free of staging

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PLACEMENT TOLERANCES AND DEFLECTION PERFORMANCE

AS-BUILT SURVEY

SURVEY PROGRAM

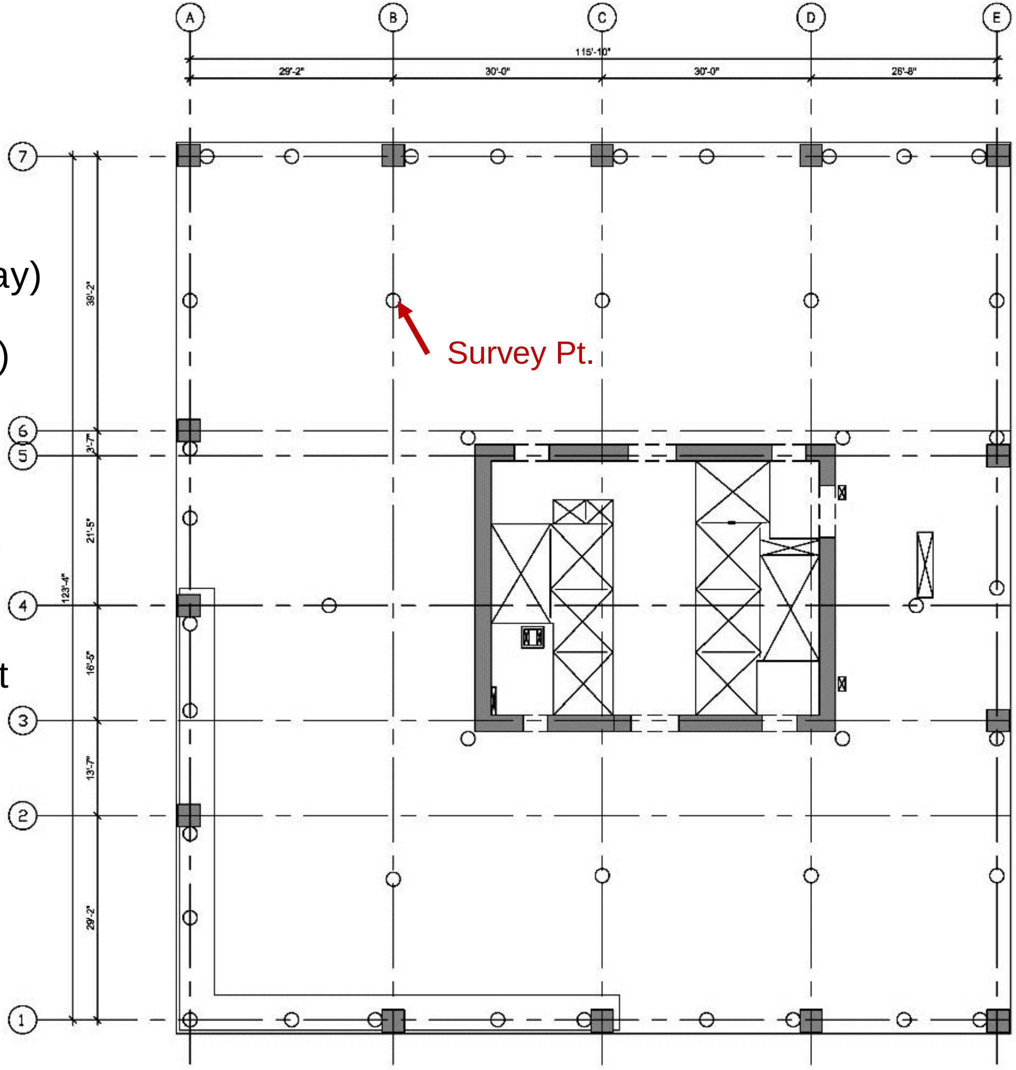
PLACEMENT & DEFLECTION

Survey Program

1. Formwork survey prior to pouring (-1 day)
2. Prior stressing of tendons (0-1 day)
3. After removal of all reshores (~28 days)
4. After 60 days (4 floors)
5. After 90 days (4 floors)

All floor surveyed at intervals 1, 2 & 3.
First 4 floors poured received 60 & 90 day surveys.

Purpose of survey was to verify placement and monitor slab deflections for potential impacts on finish installation.

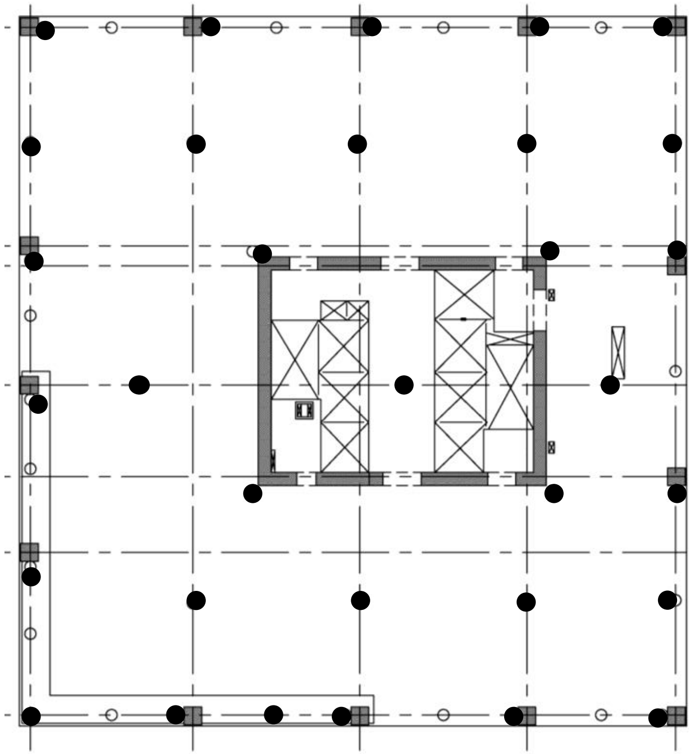


SURVEY PROGRAM
PLACEMENT ACCURACY

- **All Locations**

	If Placed High (in)	If Placed Low (in)	All Conditions (abs, in)
Avg	**0.25**	**-0.15**	**0.22**
Std Dev	0.16	0.15	0.17
Max	1.12	-0.96	1.12

+ up | - down



Survey immediately after casting

No. Cambered Pt Surveys:	8 pts x 22 floors	= 176
No. Non-Cambered Pt Surveys:	24 pts x 22 floors	= 528
Total		= 704

SURVEY PROGRAM
PLACEMENT ACCURACY

● Non-Cambered Locations

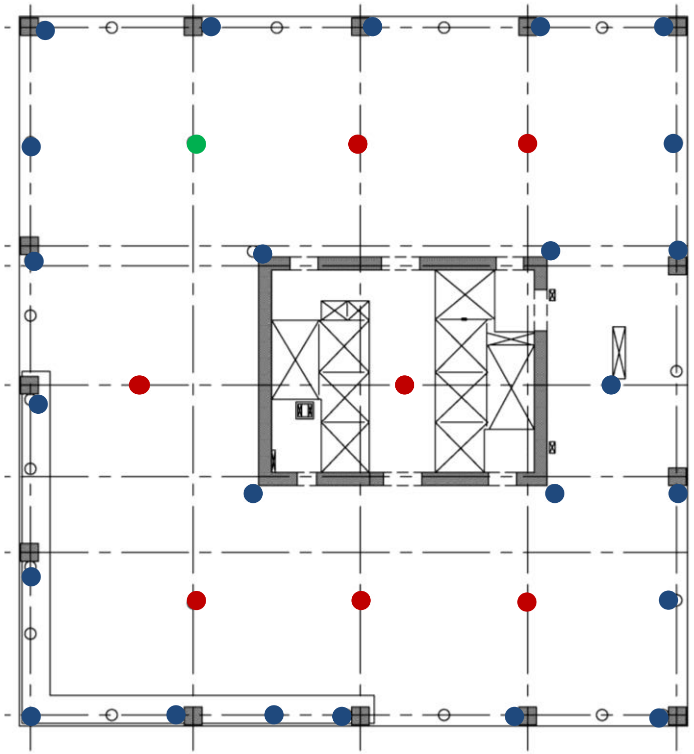
	If Placed High (in)	If Placed Low (in)	All Conditions (abs, in)
Avg	**0.27**	**-0.09**	**0.23**
Std Dev	0.15	0.12	0.16
Max	1.12	-0.96	1.12

●1” and ● 1.5” Cambered Locations

	If Placed High (in)	If Placed Low (in)	All Conditions (abs, in)
Avg	**0.22**	**-0.21**	**0.22**
Std Dev	0.18	0.17	0.18
Max	1.06	-0.80	1.06

Survey immediately after casting

+ up | - down



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No. Non-Cambered Pt Surveys:	24 pts x 22 floors	= 528
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SURVEY PROGRAM
DEFLECTION FROM PLACEMENT

● Non-Cambered Locations

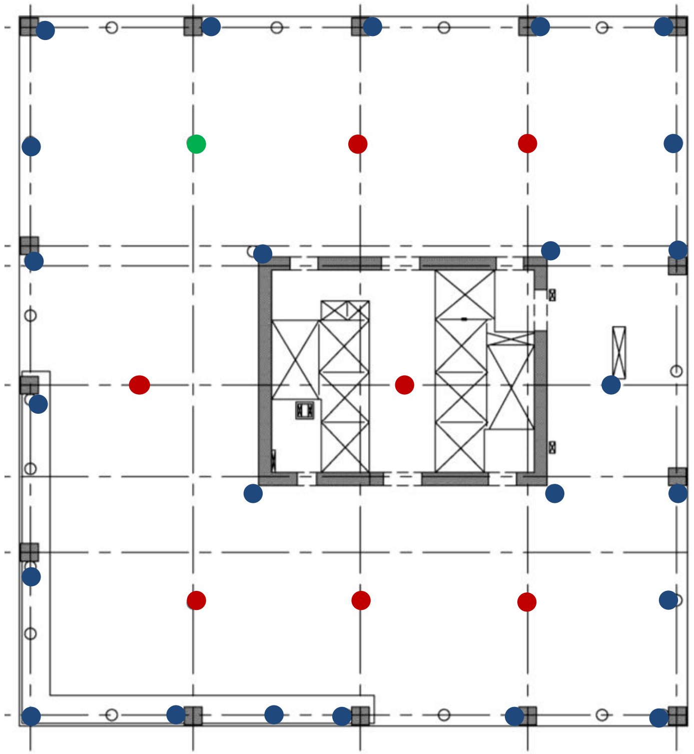
	28 Days (in)	60 Days (in)	90 Days (in)
Avg	**0.14**	**0.2**	**0.16**
Std Dev	0.14	0.13	0.09
Max	1.2	0.6	0.36

● 1” Cambered Locations

	28 Days (in)	60 Days (in)	90 Days (in)
Avg	**0.53**	**0.64**	**0.45**
Std Dev	0.27	0.33	0.15
Max	1.68	1.44	0.72

+ up | - down

Survey at 28, 60 & 90 days after casting
No. 28-day Pt Surveys: 24 pts x 22 floors = 528
No. 60-day Pt Surveys: 24 pts x 4 floors = 96
No. 90-day Pt Surveys: 24 pts x 4 floors = 96
Total = 720



SURVEY PROGRAM
DEFLECTION FROM PLACEMENT

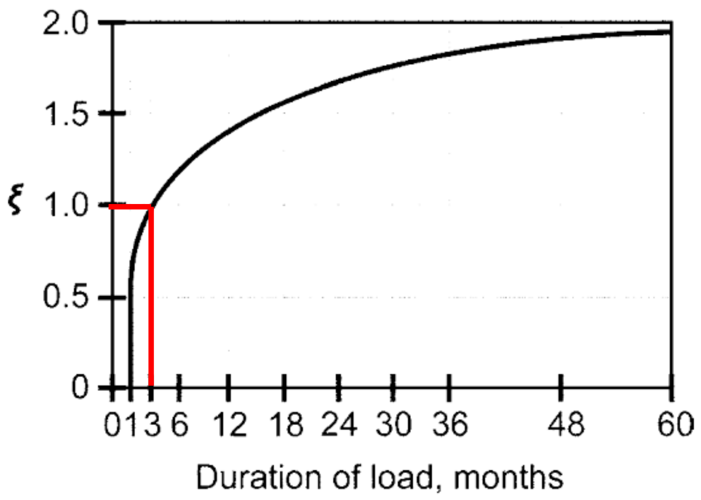
- **Non-Cambered Locations**

	28 Days (in)	60 Days (in)	90 Days (in)
Avg	**0.14**	**0.2**	**0.16**
Std Dev	0.14	0.13	0.09
Max	1.2	0.6	0.36

- **1" Cambered Locations**

	28 Days (in)	60 Days (in)	90 Days (in)
Avg	**0.53**	**0.64**	**0.45**
Std Dev	0.27	0.33	0.15
Max	1.68	1.44	0.72

+ up | - down



Survey at 28, 60 & 90 days after casting
No. 28-day Pt Surveys: 24 pts x 22 floors = 528
No. 60-day Pt Surveys: 24 pts x 4 floors = 96
No. 90-day Pt Surveys: 24 pts x 4 floors = 96
Total = 720

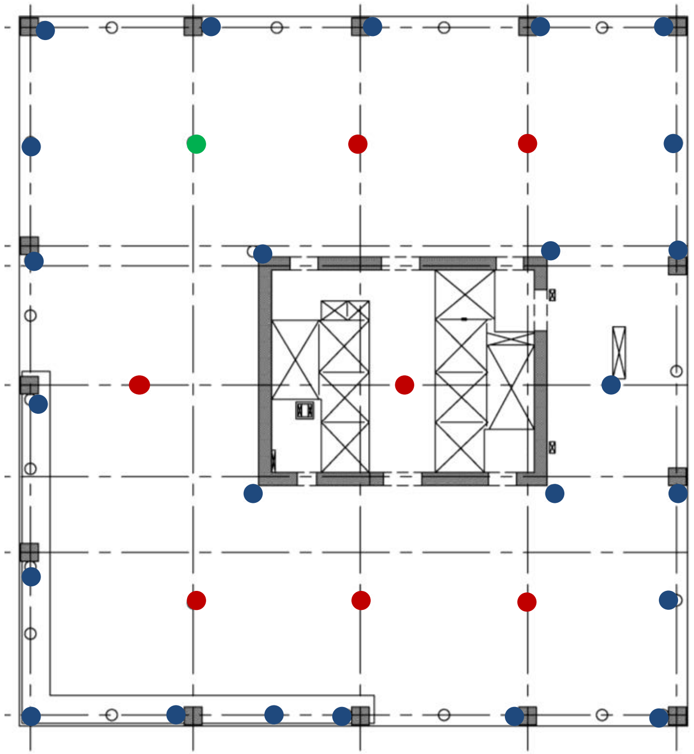
SURVEY PROGRAM

DEFLECTION FROM PLACEMENT

● **1.5” Cambered Locations**

	28 Days (in)	60 Days (in)	90 Days (in)
Avg	**1.05**	**1.08**	**0.87**
Std Dev	0.28	0.42	0.11
Max	1.56	1.80	0.84

+ up | - down



Survey at 28, 60 & 90 days after casting
No. 28-day Pt Surveys: 24 pts x 22 floors = 528
No. 60-day Pt Surveys: 24 pts x 4 floors = 96
No. 90-day Pt Surveys: 24 pts x 4 floors = 96
Total = 720

SURVEY PROGRAM
DIFFERENCE FROM TARGET

Non-Cambered Locations

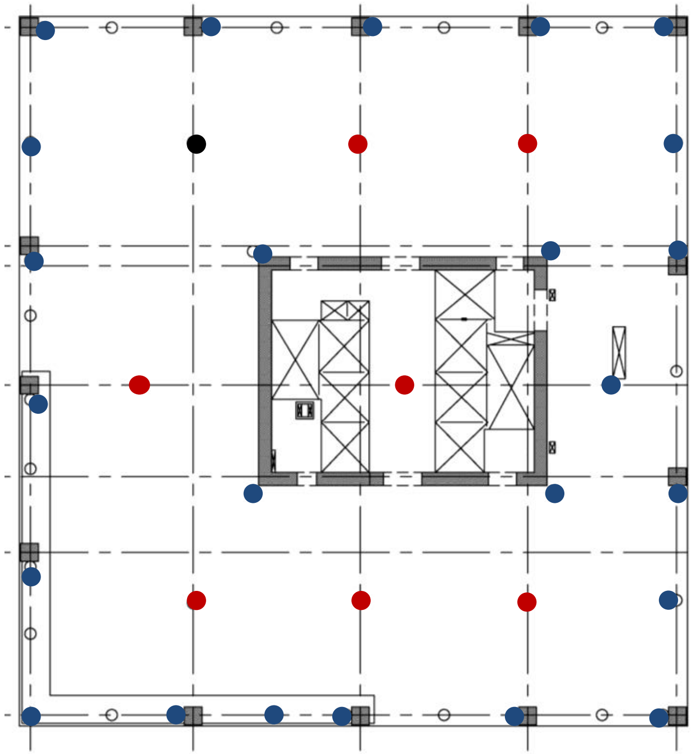
	As-Cast (in)	28 Days (in)	60 Days (in)	90 Days (in)
Avg	**0.23**	**0.25**	**0.28**	**0.34**
Std Dev	0.16	0.18	0.21	0.23
Max	1.12	1.04	1.2	0.96

1” Cambered Locations

	As-Cast (In)	28 Days (in)	60 Days (in)	90 Days (in)
Avg	**0.91**	**0.41**	**0.24**	**0.30**
Std Dev	0.28	0.29	0.19	0.20
Max	1.56	1.20	0.84	0.72

+ up | - down

Survey at 28, 60 & 90 days after casting
No. 28-day Pt Surveys: 24 pts x 22 floors = 528
No. 60-day Pt Surveys: 24 pts x 4 floors = 96
No. 90-day Pt Surveys: 24 pts x 4 floors = 96
Total = 720

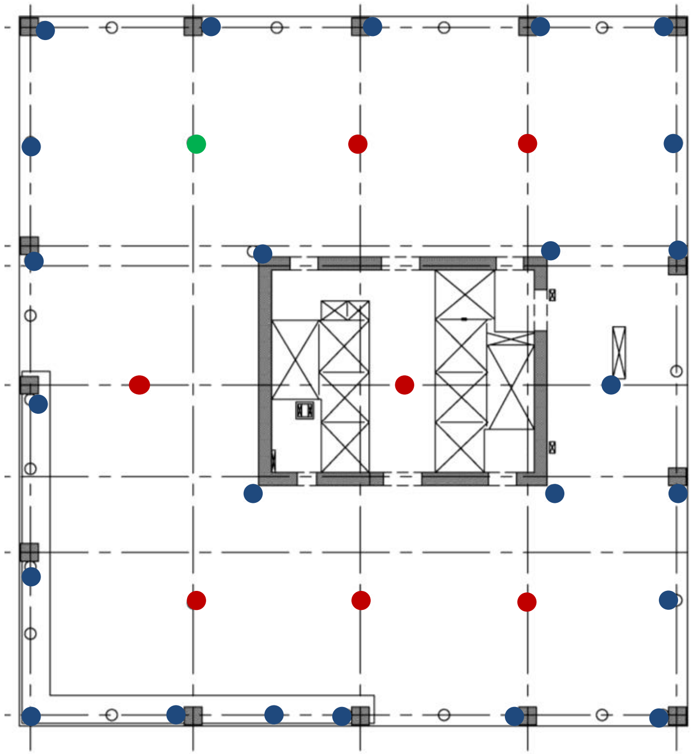


SURVEY PROGRAM
DIFFERENCE FROM TARGET

1.5” Cambered Locations

	As-Cast (in)	28 Days (in)	60 Days (in)	90 Days (in)
Avg	**1.44**	**0.39**	**0.48**	**0.49**
Std Dev	0.24	0.31	0.35	0.31
Max	1.80	0.88	0.80	0.84

+ up | - down



Survey at 28, 60 & 90 days after casting
No. 28-day Pt Surveys: 24 pts x 22 floors = 528
No. 60-day Pt Surveys: 24 pts x 4 floors = 96
No. 90-day Pt Surveys: 24 pts x 4 floors = 96
Total = 720


23


350 MISSION – SAN FRANCISCO

SKIDMORE, OWINGS & MERRILL LLP + WEBCOR CONCRETE


SOM David Shook
WEBCOR
CONCRETE Eric Peterson