Deflections and Construction Tolerances: The Good, The Bad, & The Ugly

ACI Spring Convention – Denver, CO
ACI Committees 117 & 435

Planning for the Control of Construction Tolerances and Deflections

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Introduction

- Contractors want to build fast, safe and efficiently with the least amount of remedial work as possible.
- Disconnect between division 3 and divisions 8 & 9 of project specifications
- Engineers designing buildings that are more efficient, slender, thinner, lightly reinforced, more highly stressed and more susceptible to deflection and creep
- Higher expectation of design team and owners for dimensional tolerance.

Pre-Construction

- Definition of project tolerances, ACI 117
- Building variation
  - SLAB DEFLECTION
  - SLAB SHORTENING
  - COLUMN SHORTENING
- POTENTIAL CONFLICTS BETWEEN STRUCTURE AND CLADDING
  - Window wall system needs to accommodate the additional long term deflections.
  - FLOORING
- Review of project specifications
- Formed face finish requirements

Slab Performance Criteria
ACI 318 vs Division 9

Structural Engineers utilize ACI 318 Ch 9 T. 9.5(b)

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	$\ell/180$*
Floors not supporting or attached to nonstructural elements likely to be damaged by large deflections	Immediate deflection due to live load L	$\ell/360$
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)†	$\ell/480$‡
Roof or floor construction supporting or attached to nonstructural elements not likely to be damaged by large deflections		$\ell/240$§

*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.

Owners are expecting 1/8 inch in 10ft from level

3.5 INSTALLATION TOLERANCES

A. Variation from Plumb: For vertical joints, external corners, and other conspicuous lines, do not exceed 1/8 inch in 8 ft..

B. Variation in Level: For horizontal joints and other conspicuous lines, do not exceed 1/8 inch in 10 ft., or 1/2 inch.

C. Variation in Surface Plane of Flooring: Do not exceed 1/8 inch in 10 ft. from level or slope indicated when tested with a 10-ft. straightedge.

D. Variation in Plane between Adjacent Units (Lipping): Do not exceed the following differences between faces of adjacent units as measured from a straightedge parallel to stone tiled surface:

1. Units with Polished Faces: 1/64 inch.
2. Units with Honed Faces: 1/64 inch.
3. Units with Thermal-Finished Faces: Depth of thermal finish or 3/16 inch, whichever is less.

Slab Deflection Problems

Excessive deflections that exceed ACI318 Ch 9 and/or Division 9 specifications can result in costly remedial measures such as:

- Placing a latex modified concrete leveling topping.
- Modifications and/or repairs to exterior cladding.
- Repair of damage to interior partitions & finishes.
- Repair/replacement of poorly performing floor finishes such as hardwood flooring.
- WINDOWS
- ALIGNMENT OF DOORS IN HALLWAYS
- KITCHEN CABINETS & COUNTERTOPS
- BACK PITCHING OF BALCONIES
- ELEVATOR DOOR FRAMES
- Window head and sill trim highlight deflections

Slab Deflection Problems

Slab SHORTENING Problems

CLADDING

WINDOW WALL

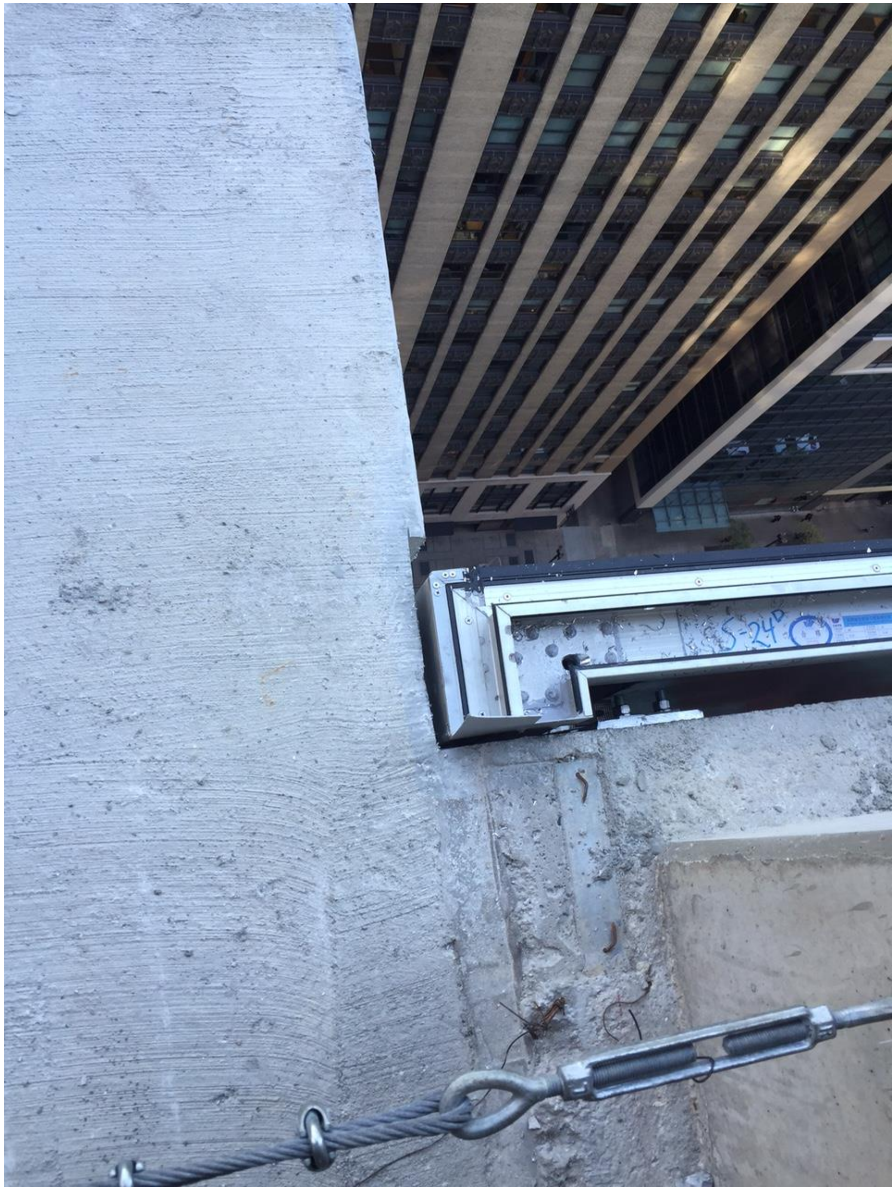
BRICK

ESTHETIC OF EXPOSED CONCRETE AT WALLS, COLUMNS, WHERE PLUMB WINDOWS MEET LEANING COLUMNS/WALLS

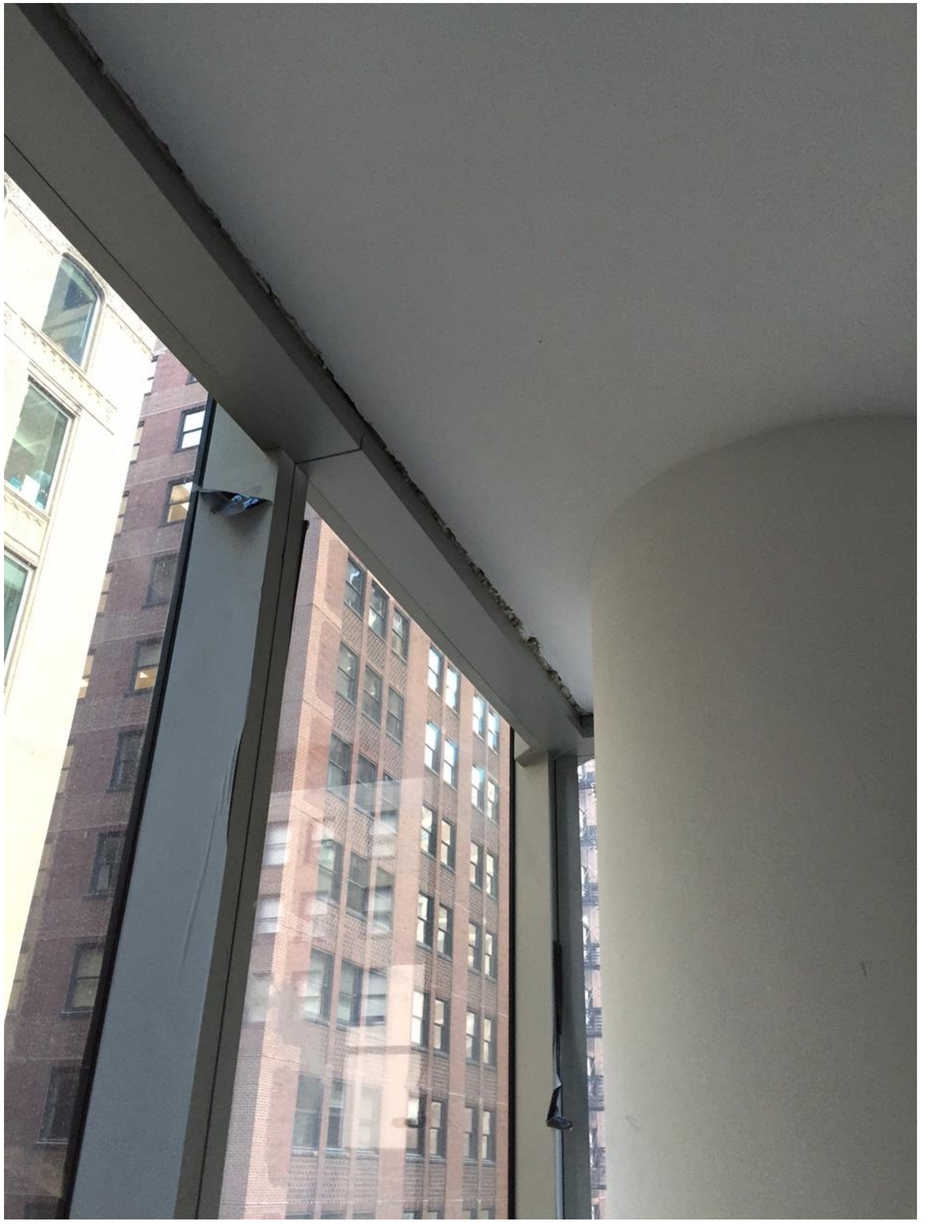
WINDOW FRAMES HIGHLIGHT SLAB SHORTENING ISSUES

Slab SHORTENING Problems

Slab SHORTENING Problems



Slab SHORTENING Problems



Column Shortening Problems

- WINDOWS
- ALIGNMENT OF DOORS IN HALLWAYS
- KITCHEN CABINETS & COUNTERTOPS
- ELEVATOR DOOR FRAMES
- DISTRESS AT CONNECTION BETWEEN COLUMN/WALL AND SPANDRELS

Column Shortening Problems

Contractor's Perspective

WHAT CONTRACTORS WANT…

- Contractors want to build FAST!
- Plan work to proceed safely on a fast efficient schedule.
- Delivers a structure to the client that meets all project specifications
    - Divisions 3, 8 & 9 of project specs
- And of course get paid!
    - No costly remedial work or disagreements of work non-compliance.
    - In the State of Illinois, the Statute of Repose is 10 years. That's a long time!

Contractor's Perspective

WHAT CONTRACTORS DO TO INFLUENCE/ IMPROVE SLAB DEFLECTION PERFORMANCE…

- Selection of formwork system.
- Construction equipment (such as tower crane, concrete pumps & placement booms).
- Mix design.
- Hot weather/cold weather construction methodologies
- Location of pour breaks/construction joints.
- Rate of construction.
- QA/QC program
- Curing conditions

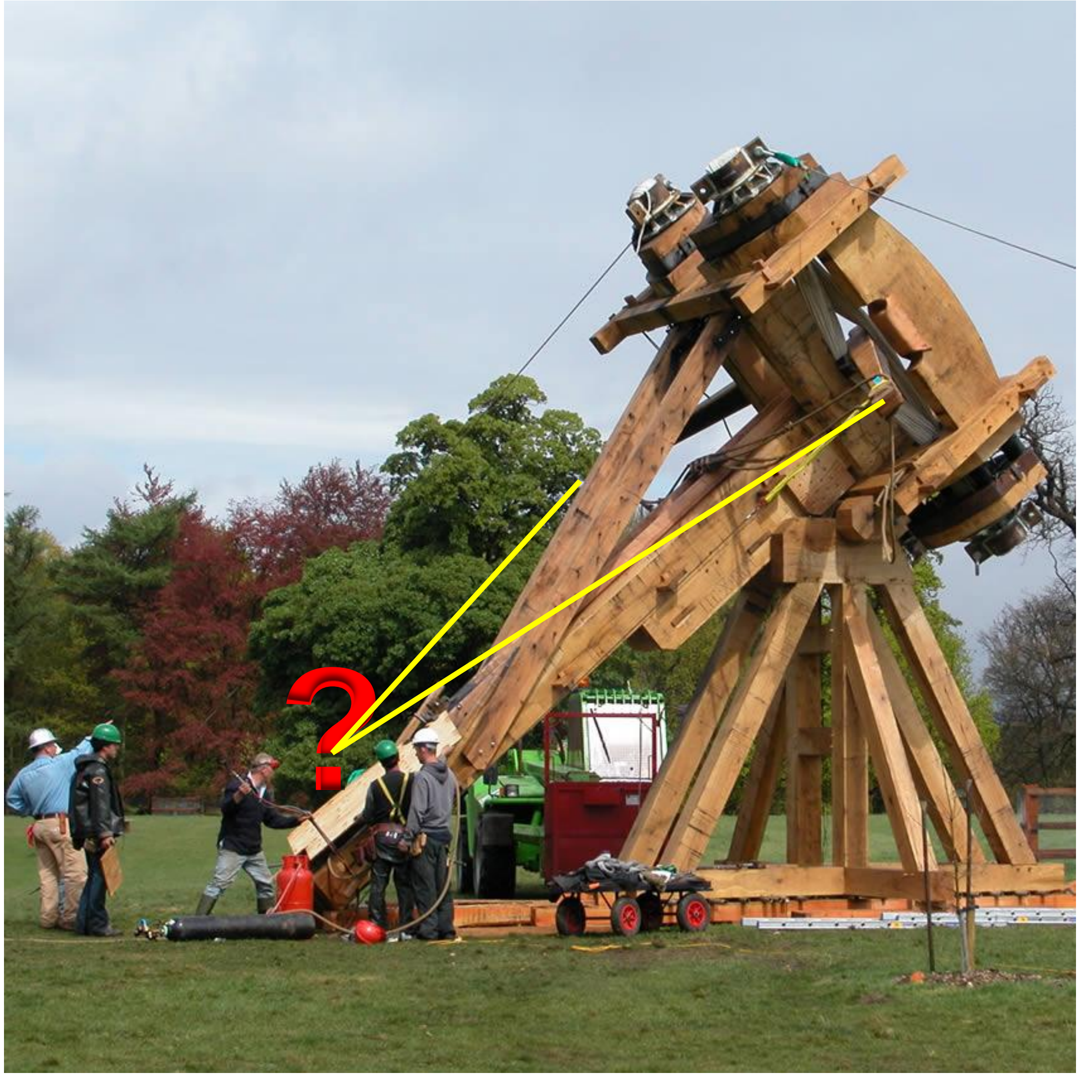
Pre-Construction

- Estimating team price in tolerance issues
- Contract clarifications identify tolerance conflicts and attempt to allocate responsibility appropriately
  - Managing client expectations

Coordination of tolerances with other trades

Discussion of anticipated slab deflection, slab edge shortening, column shortening, lateral building deflection & story drift with SEOR

Review of construction means and methods, schedule and budget with regards to project tolerances and deflection



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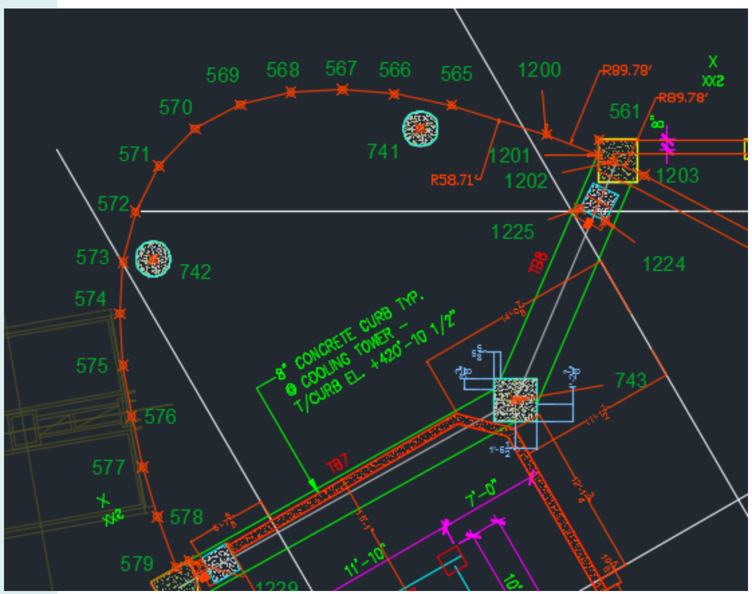
LAUNCHER!

Construction

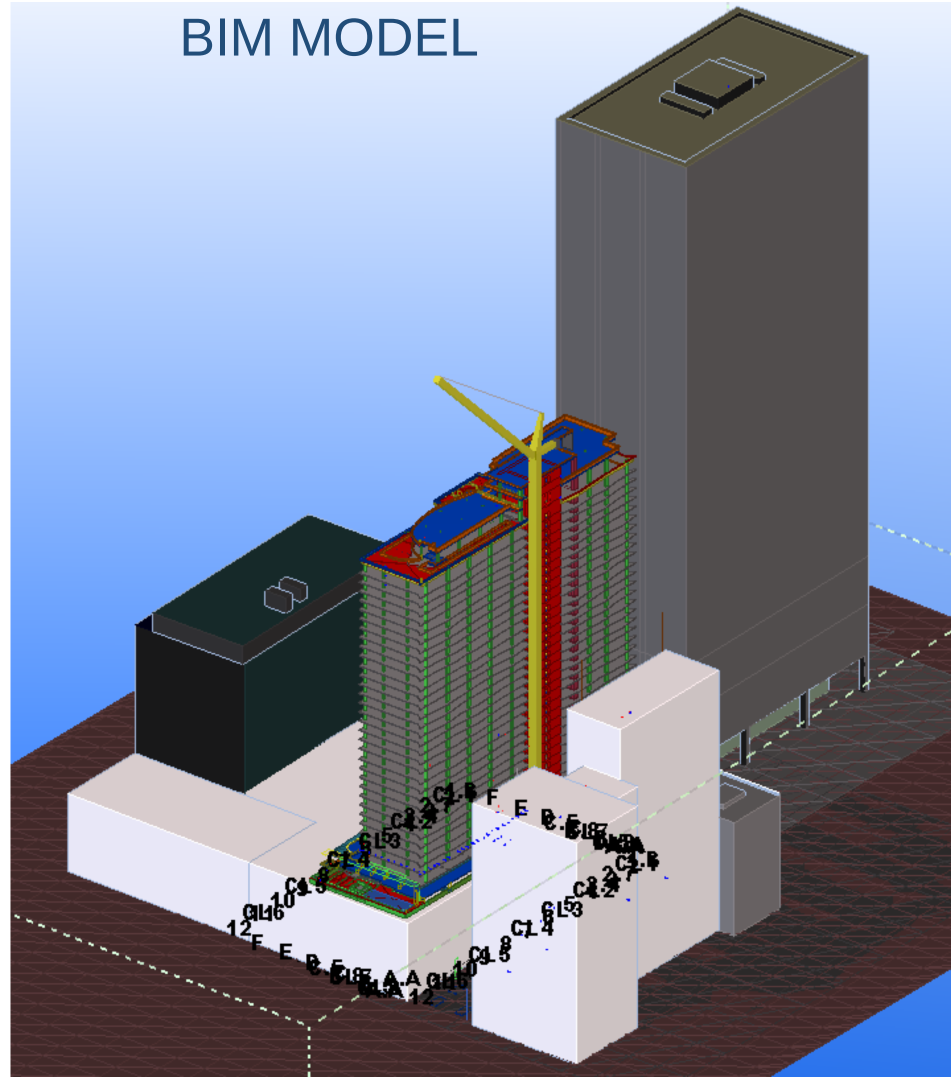
Field layout

- 2D ACAD VS BIM MODEL

2D ACAD



BIM MODEL



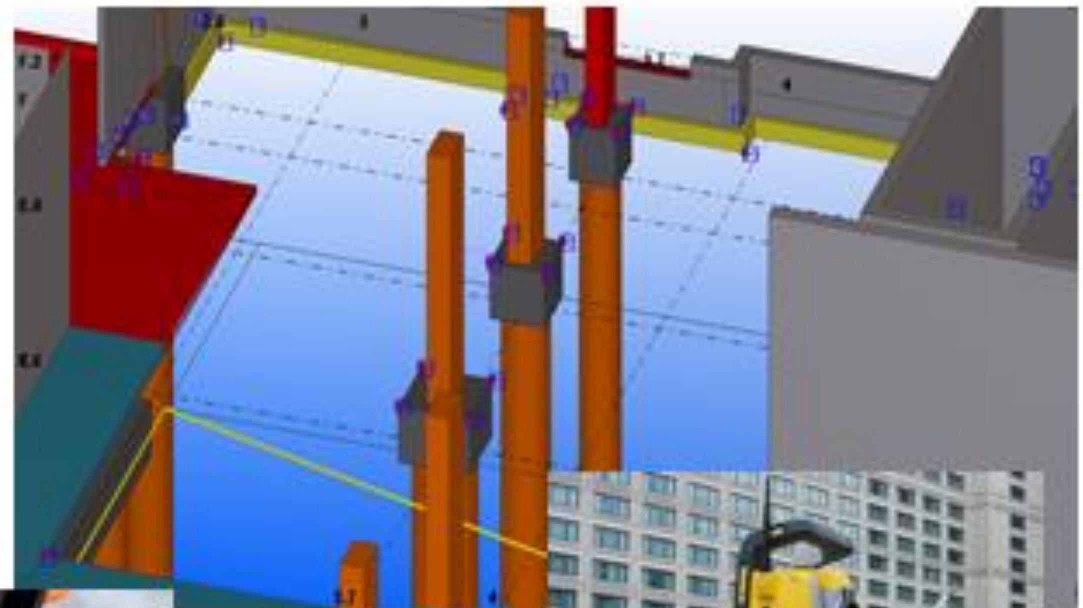
Construction

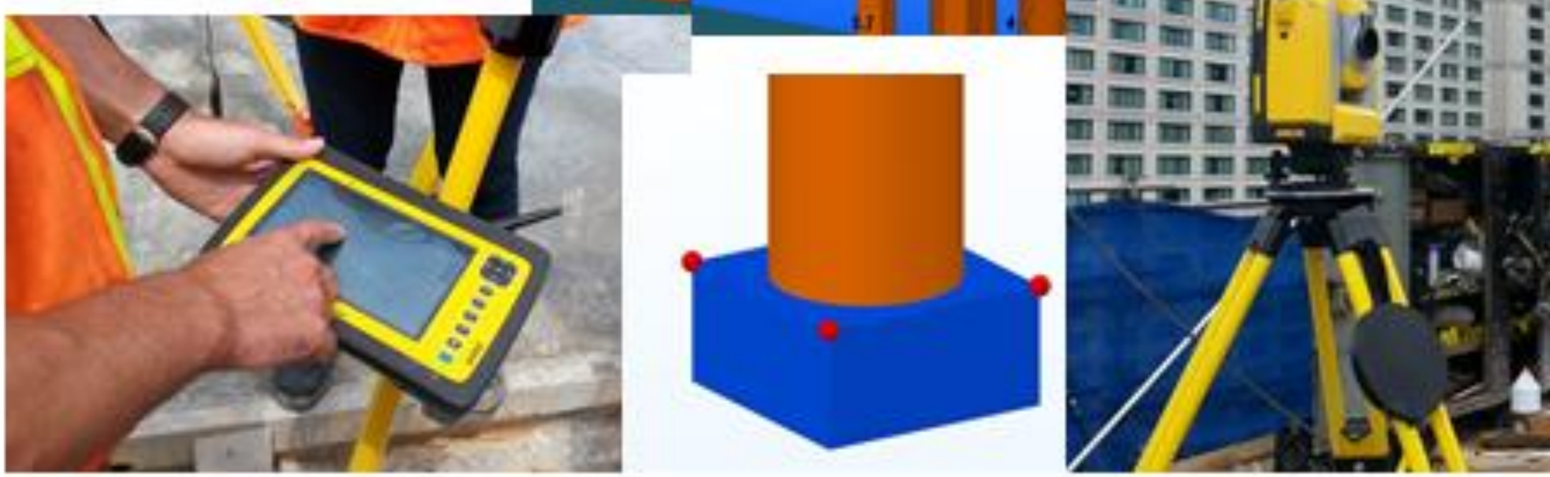
BIM MODEL USED DIRECTLY FOR FIELD LAYOUT

Emerson Project
Field Layout

Model used to lay out and manage points

- Improved accuracy
- Increased efficiency





Construction

FIELD LAYOUT

- BENCHMARK OUTSIDE BUILDING

- CONTROL LINES
  - < 20 STORIES, ESTABLISH CONTROL LINES BY PUTTING STICKER TARGETS ON SURROUNDING BUILDINGS AND COORDINATING THEM.
  - >20 STORIES, BUILDING SWAY BECOMES TOO GREAT. USE “BOMB SITE” TO BRING THE CONTROL POINTS UP EVERY 7 FLOORS. BACK CHECKED TO OUTSIDE.
  - CONFLICTING CONTROL LINES BETWEEN CONCRETE AND OTHER TRADES
    - EVERYONE USES CONCRETE’S CONTROL LINES EXCEPT WINDOW CLADDING COMPANY

Construction

MONITORING PROGRAMS

Formed surface finish quality

Slab Deflection

Slab FF & FL

Column shortening

Slab monitoring program

Top of slab vs bottom of slab

Numbers of shots vs Location

When is data taken:

1. Top formwork prior to concrete placement
2. Top of slab immediately after concrete placement
3. After PT stressing and release of shores
4. After all shoring and reshoring removed
5. Perimeter bottom of slab to validate window wall RO
6. Edge of slab to identify potential curtainwall issues

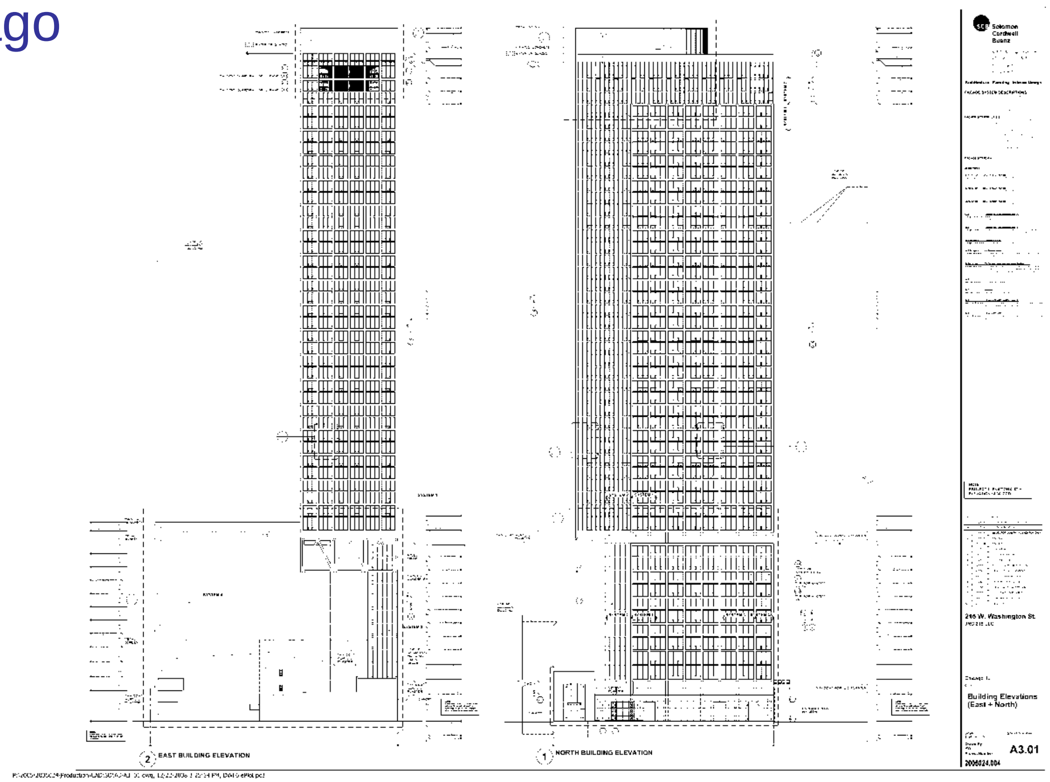
Construction

MONITORING PROGRAMS

- Accuracy of survey data, whose control lines??
- Tolerance of slab thickness
- Purpose
- Interpretation of Data
- Comparison of field data to SEOR predicted short term slab deflection to identify a problem that can be fixed on subsequent floors

CASE STUDY
Overall Project Description

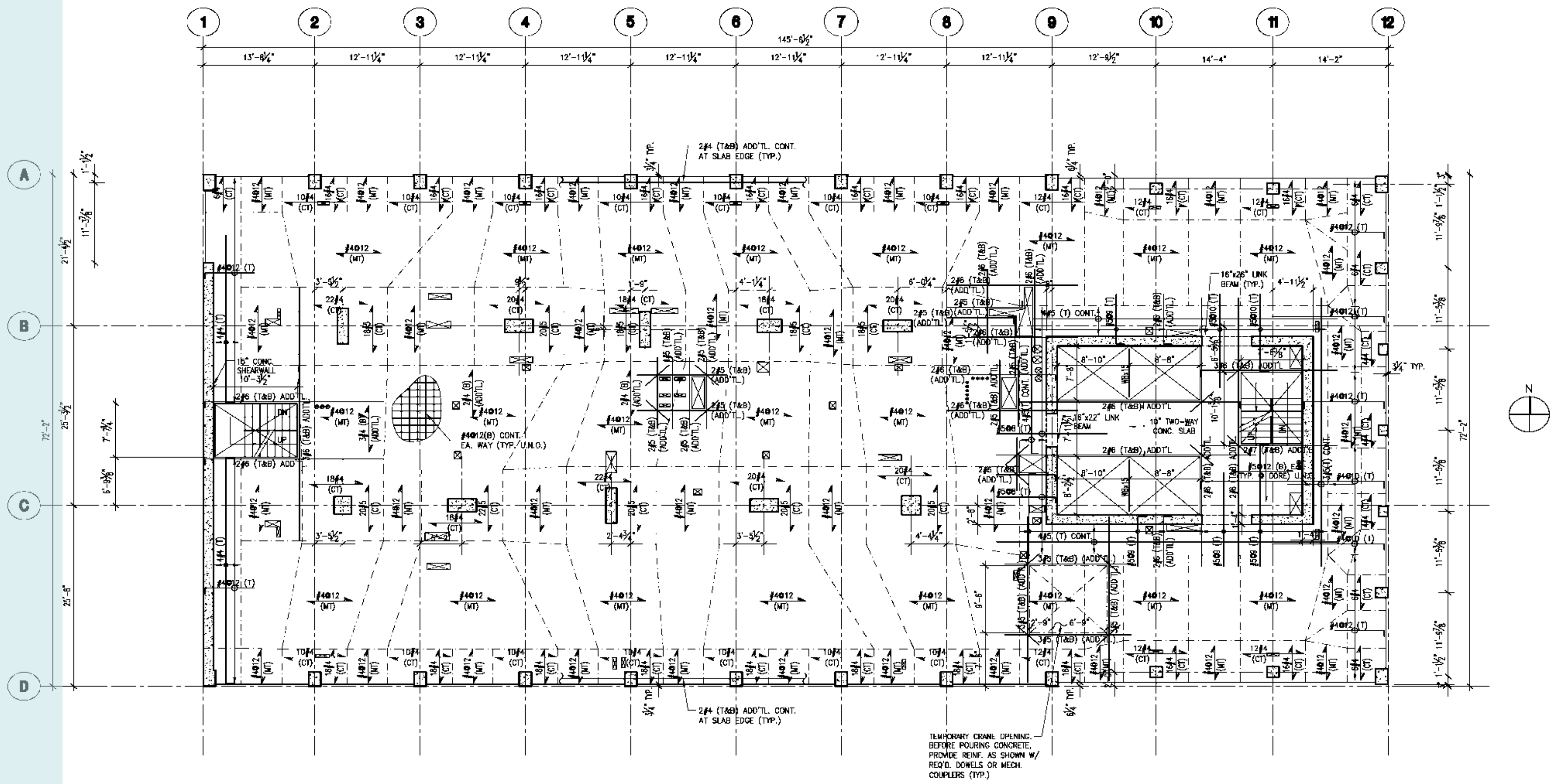
- Location: Downtown Chicago
- 50 Story R/C Residential Tower
- 505’ Height
- 674,750 sq ft
- Level 1 - 14: Retail, Lobby, Parking & Amenity level
- Level 15 - 50: Residential Levels
- 18 months construction period.



Typical Residential Floor (Levels 14-50)

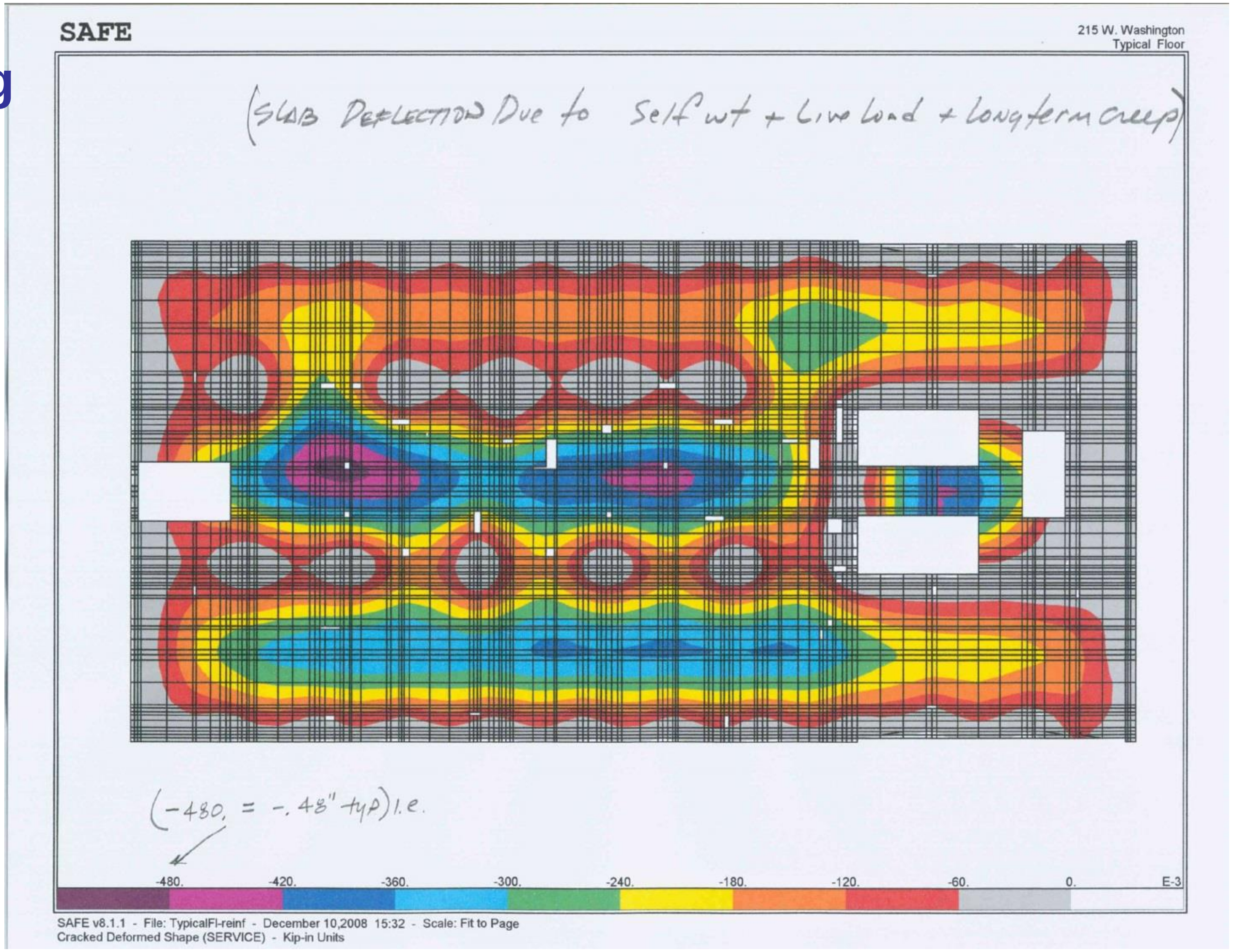
- 8” - 2-way RC flat plate
- 10,500 sq ft area
- Maximum clear span:
  - Exterior Panels: 22.58’ (ln/h=33.9)
  - Interior Panels:23.75’ (ln/h=35.6)
- f’c=5000psi
- Typ. #4 & #5 Gr.60 reinforcing bars
- Cover : 1” top and ¾” bottom
- Design Loads
  - Superimposed Dead Load: 25psf
  - Live Load: 40psf
- ACI318-05 T.9.5c Slab Rqd. Thickness: 9”

Typical Residential Floor (Levels 14-50)



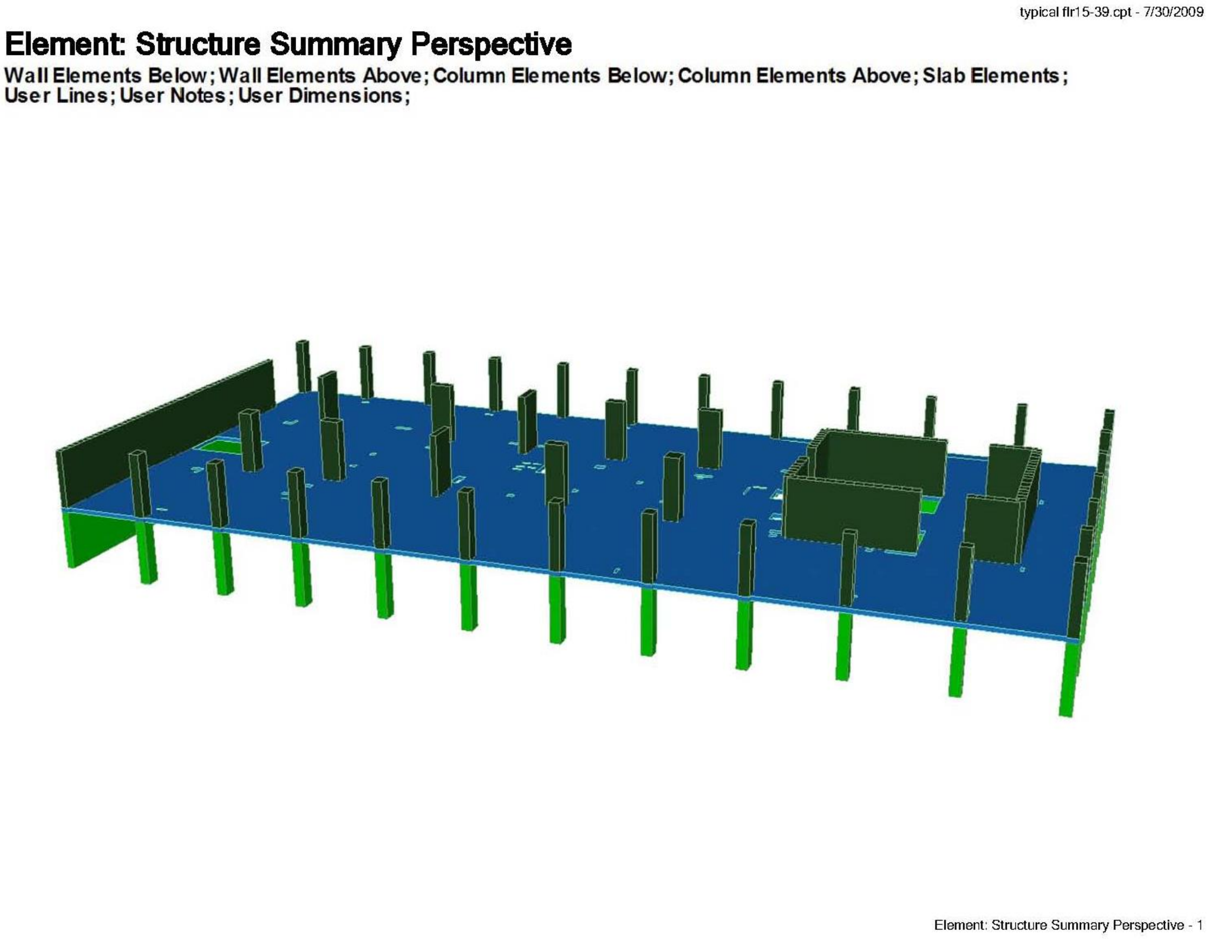
SEOR Predicted Deflections

- SEOR issued long term deflection contour diagram
- Prediction: maximum long term deflection value – approx.
- 0.5" (Int. Bay)
- 0.42" (S. Bay)

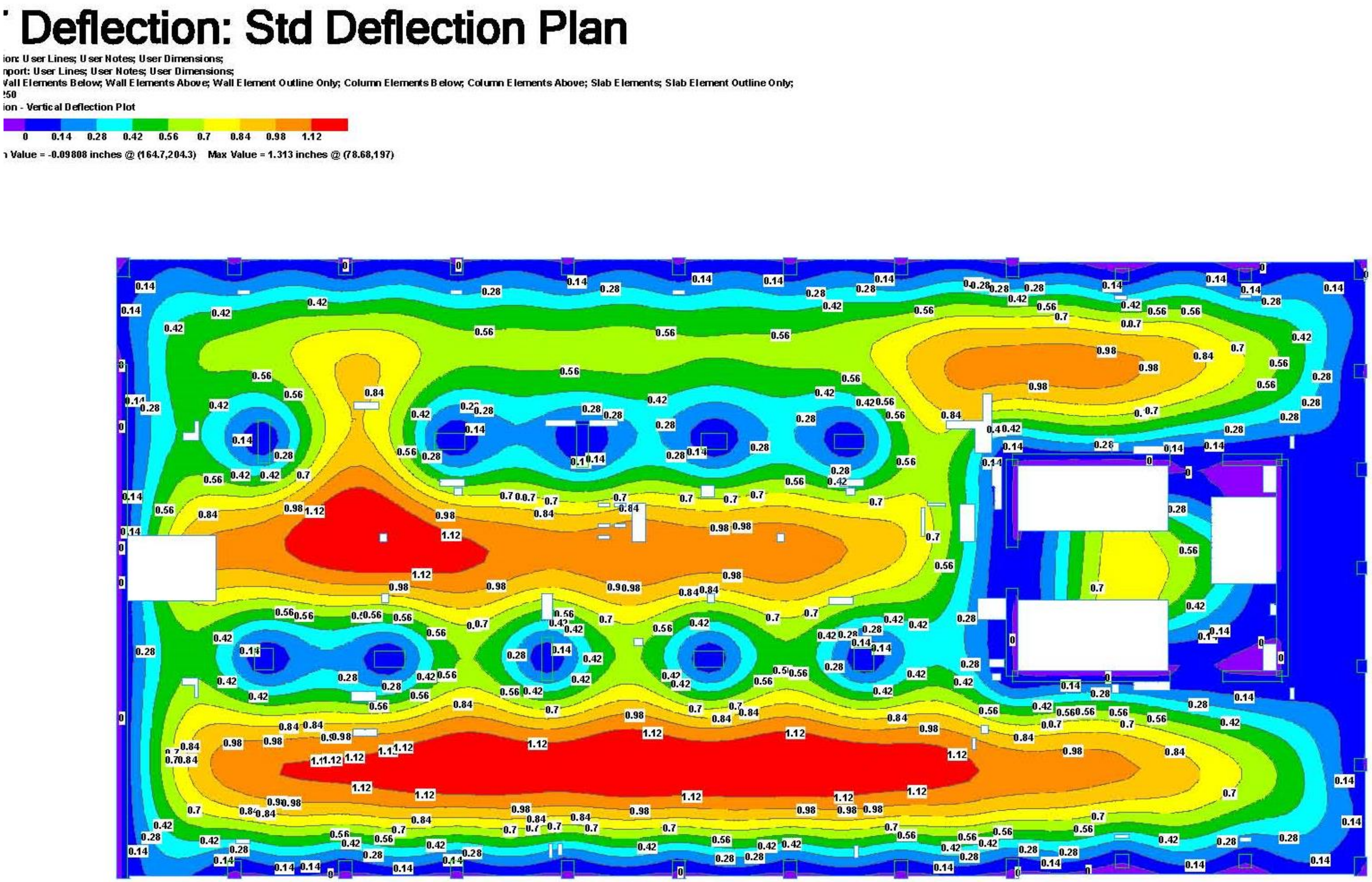


McHugh Slab Deflection Study

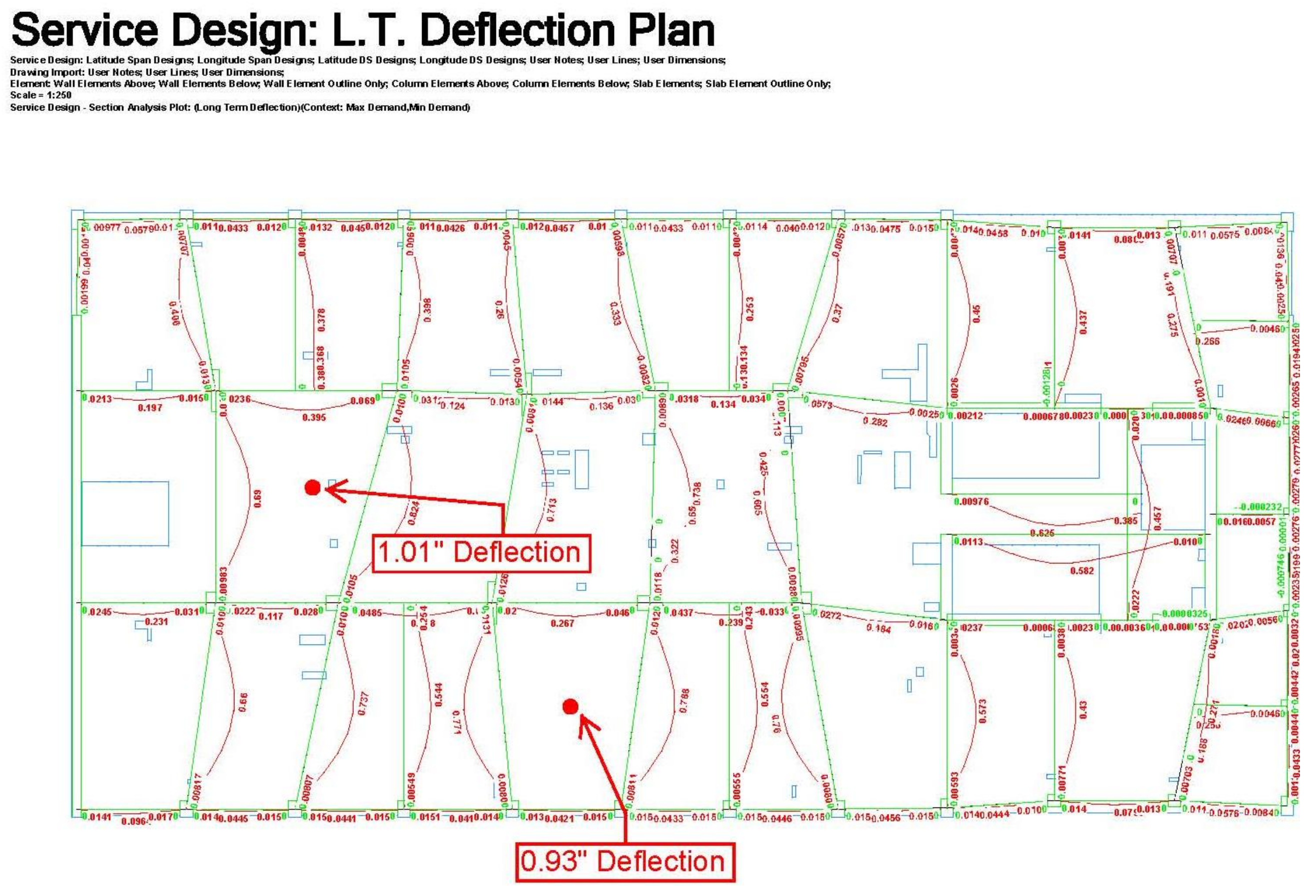
- **Independent Deflection Study**



Independent Deflection Analysis



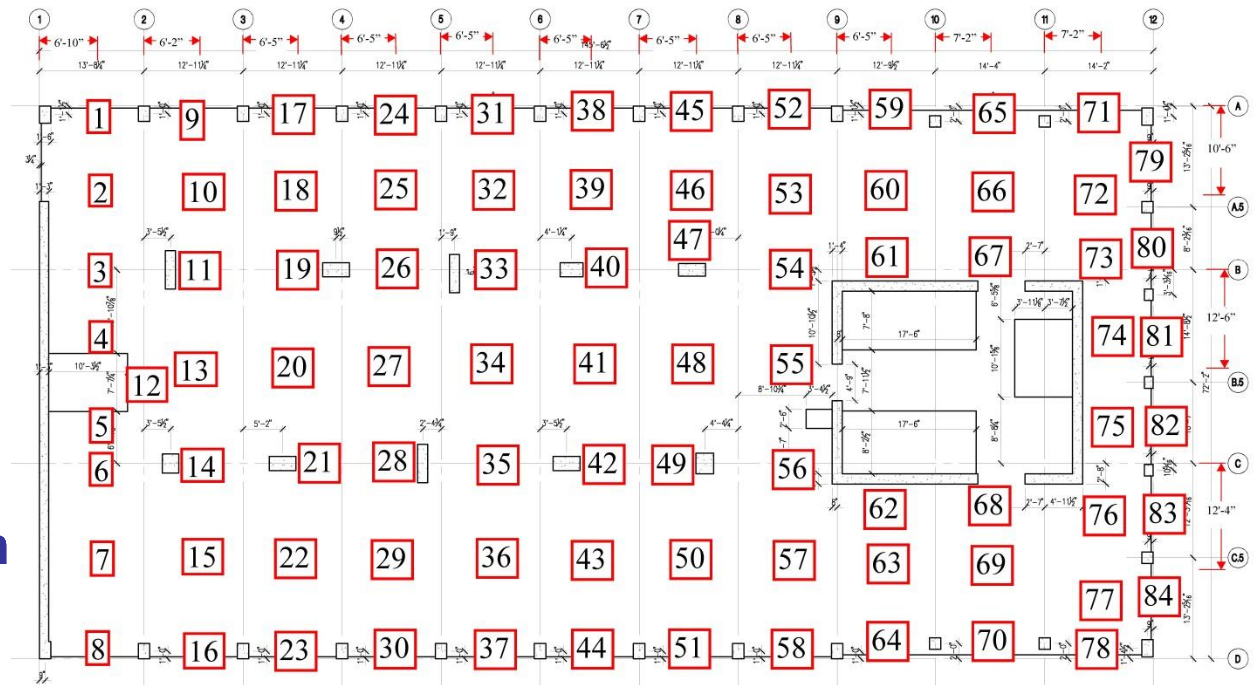
Independent Deflection Analysis



- Max estimated lon term deflection
- 1.0” (Int. Bay)
- 0.9” (S. Bay)

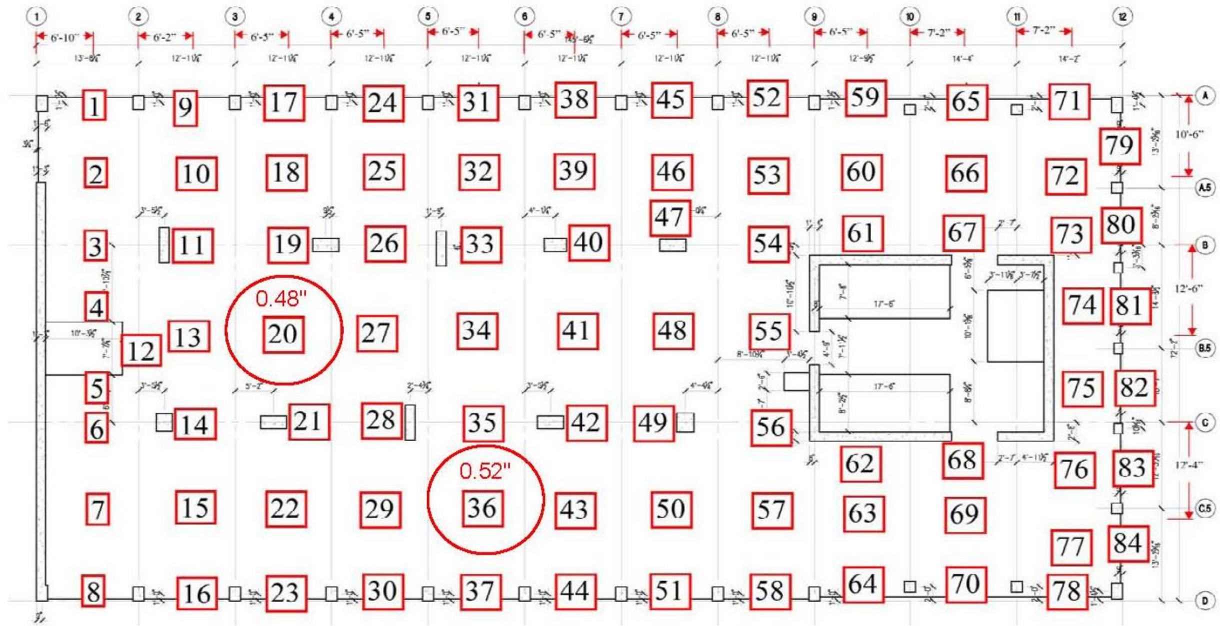
Field Measurement of Slab Deflections

- 2 top of slab elevs taken at 84 points on each typ. floor slab
- 1st meas. taken 1 day after placement with full shoring
- 2nd meas. taken approx. 1 month after placement with no shoring/reshoring
- 6048 Field Measurements



Maximum Measured Deflection

- **Max meas. Int. & Ext. bay deflection @ 1 month;**
  - **Point #20 - 0.48”**
  - **Point #36 - 0.52”**
- **Points match SEOR’s & McHugh’s predicted max deflection locations**
- **Est. Total LT Deflection - 2x this avg. meas. value per ACI318 9.5.2.5.**



Average Measured Slab Deflection of Points 20 & 36 of Level 15 thru 50 at 3.5 to 4 weeks of age.

Comparison of Predicted vs. Observed

	Numerical Prediction		Measured	Projected
Point #	SEOR Model LT D	Independent Analysis LT D	Field Meas D (@1month)	Projected Field LT D (2x Field Meas)
20	0.50”	1.01”	0.48”	0.96”
36	0.42”	0.93”	0.52”	1.04”

Based upon this independent analysis, McHugh suggested slab camber to be provided for slabs at locations of maximum deflection

Bathrooms and large format tile

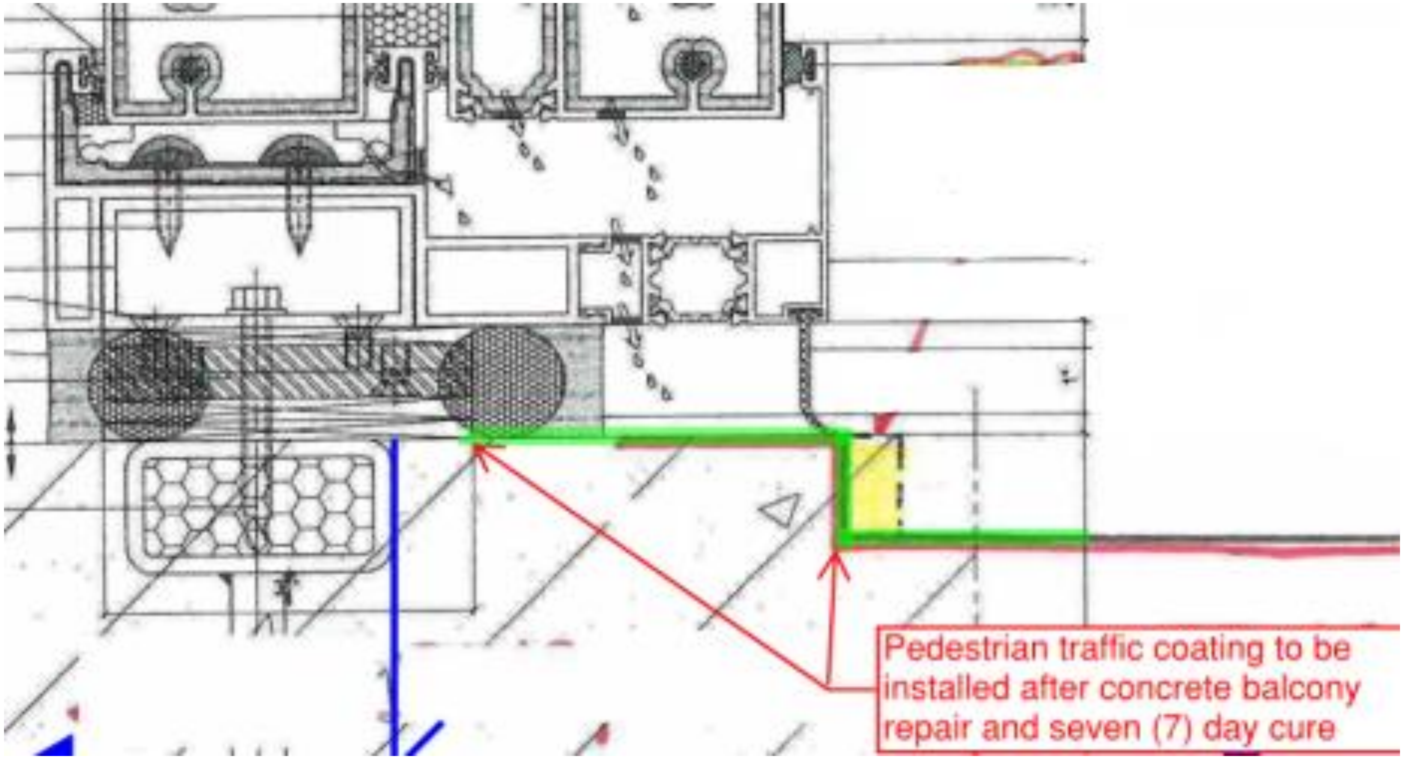
- The latest thing. Very unforgiving.
- One client requested separate FF numbers for bathrooms, even though the minimum sample size is 10'x10'
- Finishing @ toilet and tub penetrations
  - Estimators need to carry these $$

Details that potentially vanish within acceptable tolerances.

- Balcony depressions and window wall interface.
- Sloped PT balcony may back pitch over time.
- Façade features – long term risk if coverage not within tolerance.

Fine Architectural details challenging for a formwork carpenter on a 3 day pour cycle.

- Unreasonable client expectations



Even with a significant pre-construction effort, there may be surprises.

- i.e. Window system arrives on-site which don't match the shop dwgs!

Conclusions

- **Better planning for deflections and tolerances = Less Remedial Work = Cost Savings = Happy Repeat Client!**
- **Buy the same tolerances from all trades!**
- **Communication is the key to success!**

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QUESTIONS?

THANK YOU!!

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