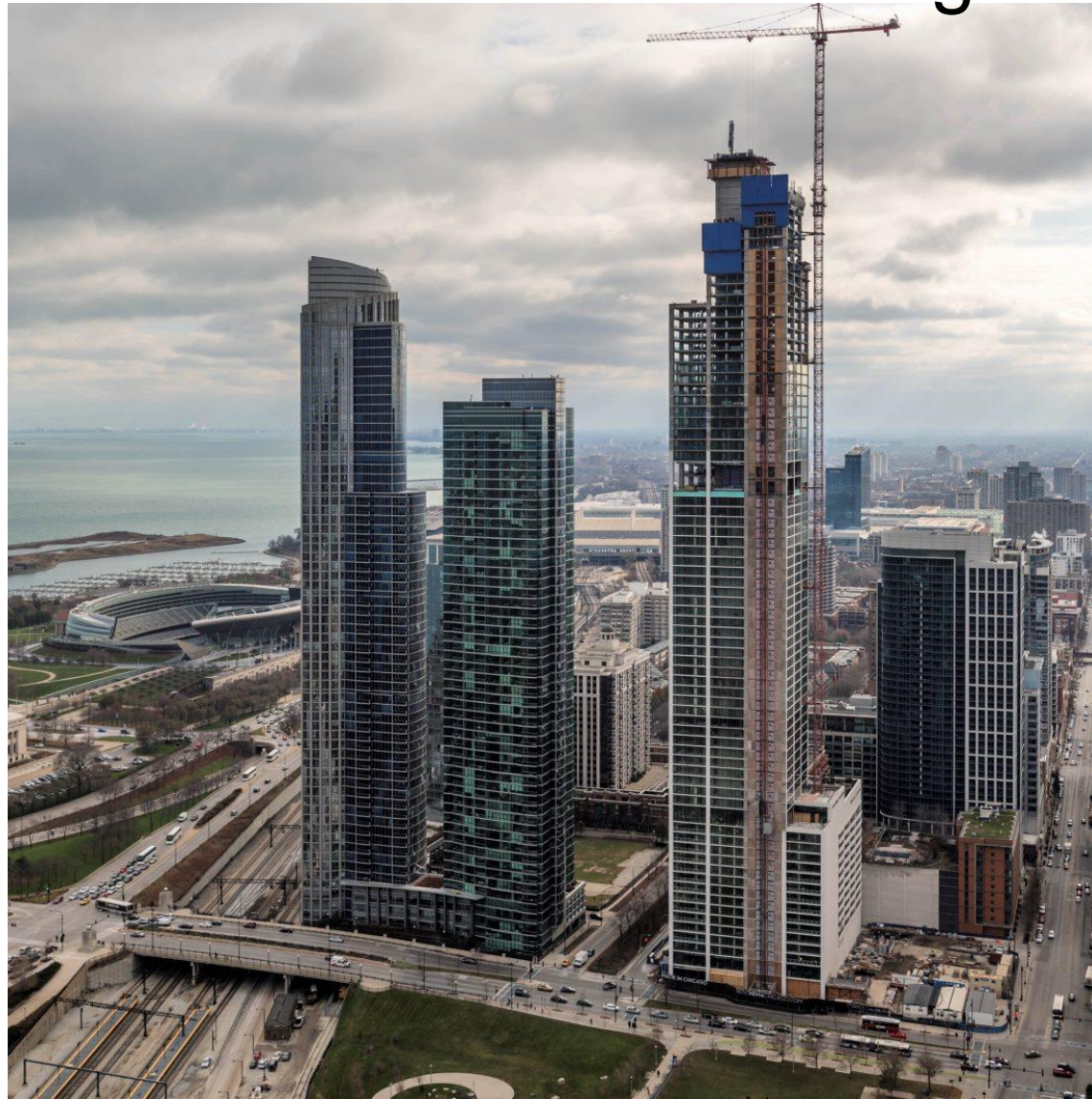# THE TROUBLE WITH TALL
Managing Creep and Shrinkage Issues in Tall Buildings

McHUGH

Introduction

- Shorter concrete buildings (<40 stories), the process of constructing the building to theoretical elevation for each successive floor corrects much of the shortening column effects (usually)

- Taller concrete buildings (>40 stories) experience creep & shrinkage effects that become problematic and need to be explicitly considered and addressed by SEOR & Contractor.

Definitions

- ## What is Creep?
  - A time dependent deformation of concrete under permanent loads, i.e. dead loads & PT forces.
- ## What is Shrinkage?
  - A time dependent volumetric change that concrete undergoes as it hydrates, and the free water evaporates. Not load dependent.
- Shrinkage & Creep deformations can be substantial, up to 2x instantaneous deformation!
- Can't be ignored!

Guide for Modeling and Calculating Shrinkage and Creep in Hardened Concrete
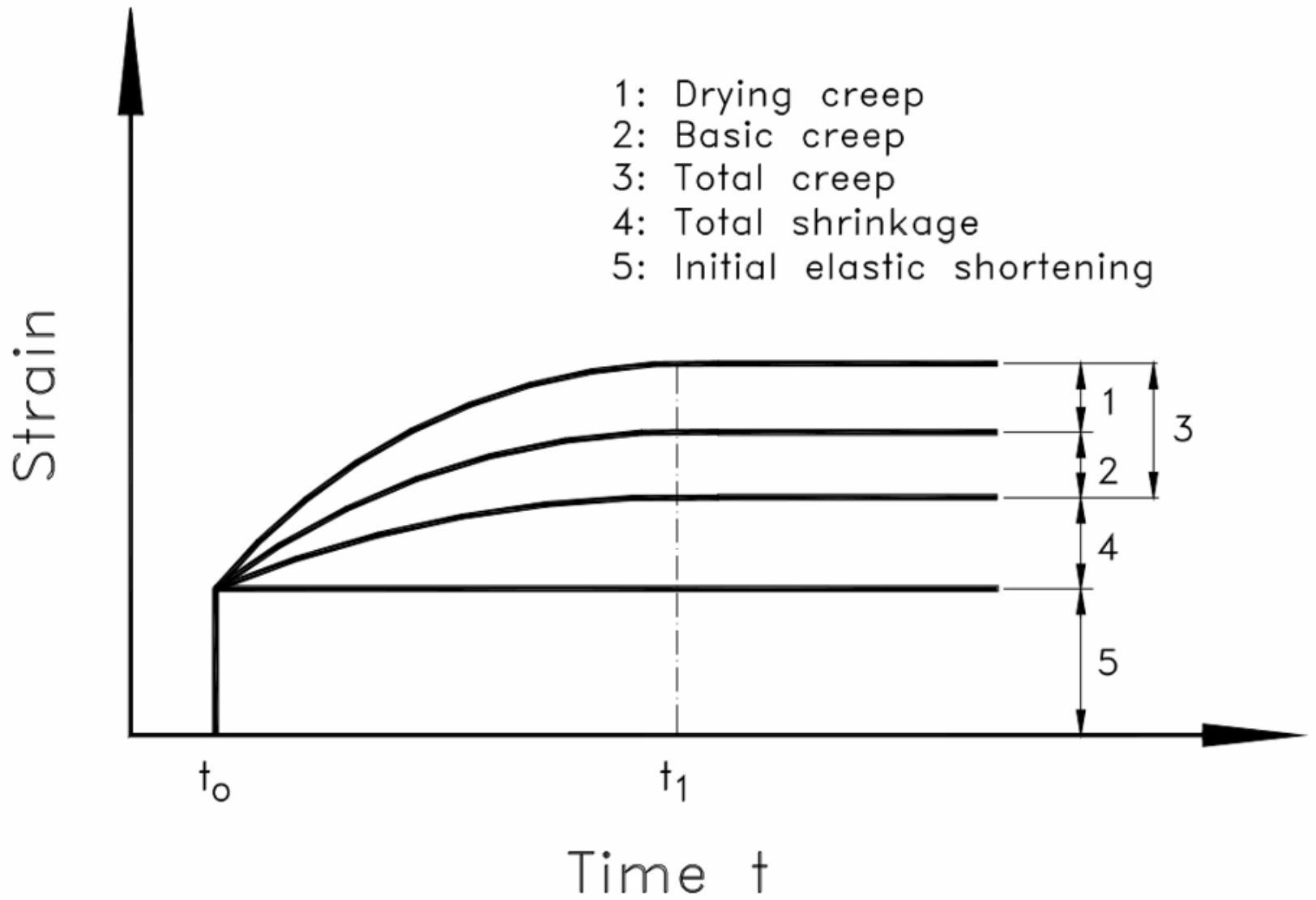
Reported by ACI Committee 209
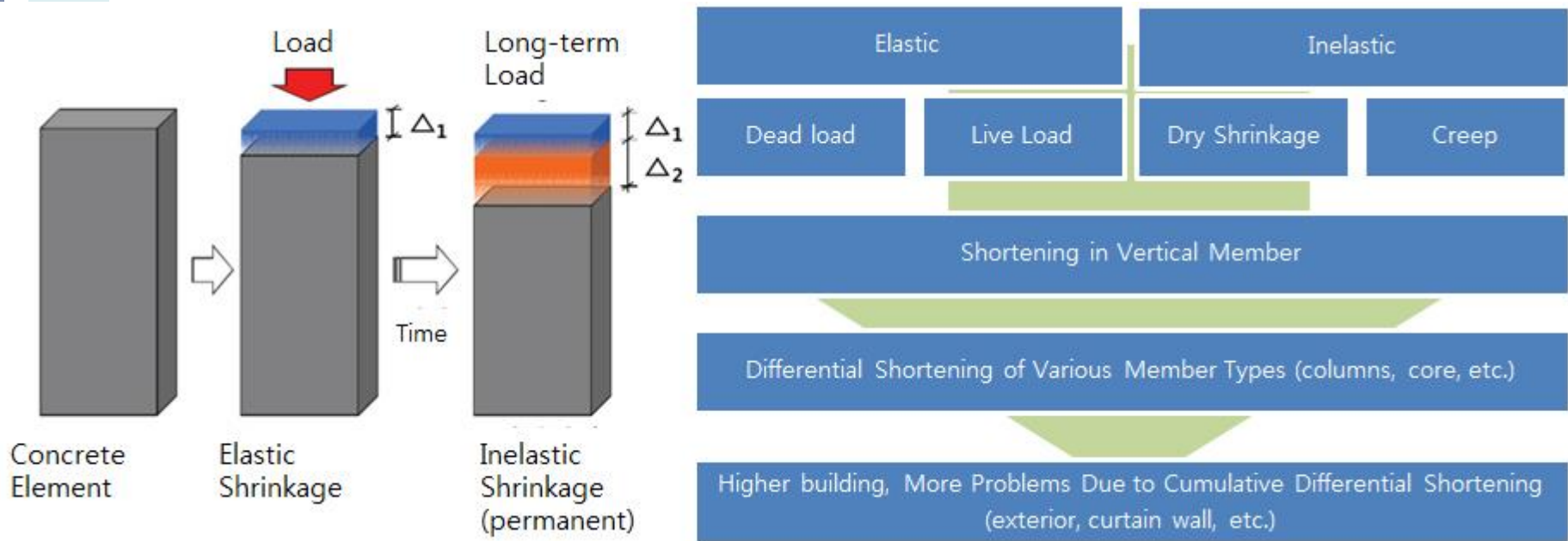
American Concrete Institute®

Factors Effecting Creep

- Concrete mix proportions
  - Higher w/cm ratio, more creep
- Aggregate properties
  - Restrain creep, Higher E, reduced creep
- Age at loading
  - Early age loading increases creep
- Curing Conditions
  - Better curing, reduced creep
- Cement Properties
  - Higher f'c, reduced creep
- Temperature
  - Higher avg temperature, more creep
- **Stress level (most important factor)**
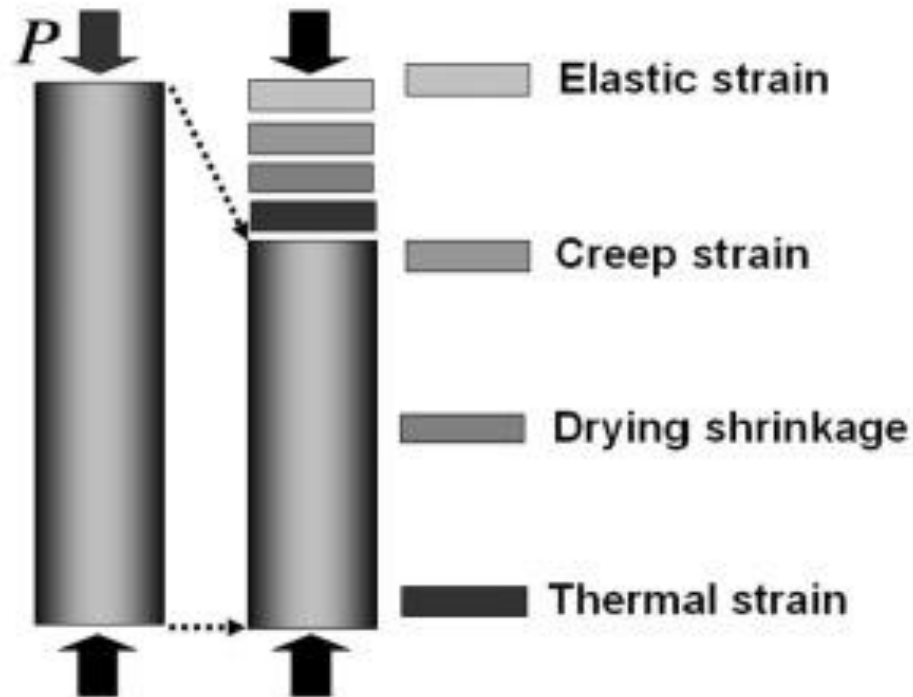 - **Higher stress, more creep!**

Factors Effecting Shrinkage

- Drying Conditions
  - Atmospheric Conditions, i.e. humidity
  - Lower humidity, increased shrinkage
- Time
  - Shrinkage rate decreases rapidly with time
  - 1/3 total in 28 days, 3/4 total in 1 year
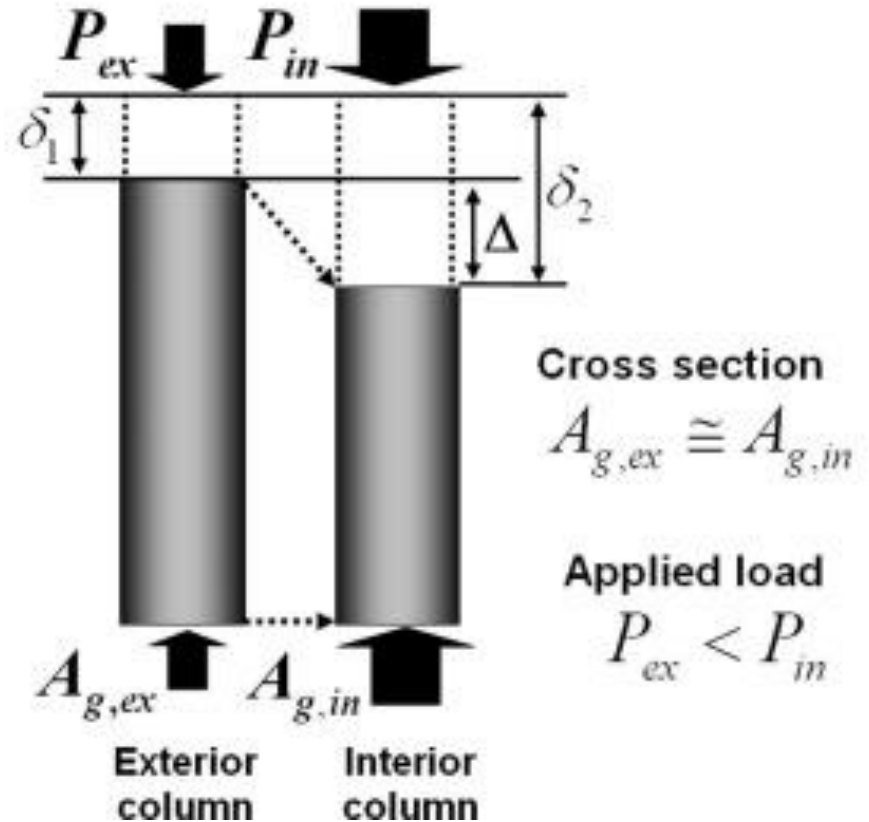- w/cm Ratio
  - Higher w/cm ratio, more shrinkage

Strain vs. Time t

1: Drying creep
2: Basic creep
3: Total creep
4: Total shrinkage
5: Initial elastic shortening

Load

Long-term Load

Δ_1

Δ_1
Δ_2

Time

Concrete Element

Elastic Shrinkage

Inelastic Shrinkage (permanent)

Elastic		Inelastic	
Dead load	Live Load	Dry Shrinkage	Creep

Shortening in Vertical Member

Differential Shortening of Various Member Types (columns, core, etc.)

Higher building, More Problems Due to Cumulative Differential Shortening (exterior, curtain wall, etc.)

Causes of total shortening

P

- Elastic strain
- Creep strain
- Drying shrinkage
- Thermal strain

Causes of differential shortening

P_{ex} P_{in}

δ_1 δ_2 Δ

Cross section
$$A_{g,ex} \cong A_{g,in}$$

Applied load
$$P_{ex} < P_{in}$$

$A_{g,ex}$ $A_{g,in}$

Exterior column   Interior column

- 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 taller, 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
  - COLUMN THERMAL MOVEMENT

- POTENTIAL CONFLICTS BETWEEN STRUCTURE AND CLADDING
  - Window wall system needs to accommodate both construction tolerance and short term and the additional long term deflections.

- Review of project specifications

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!
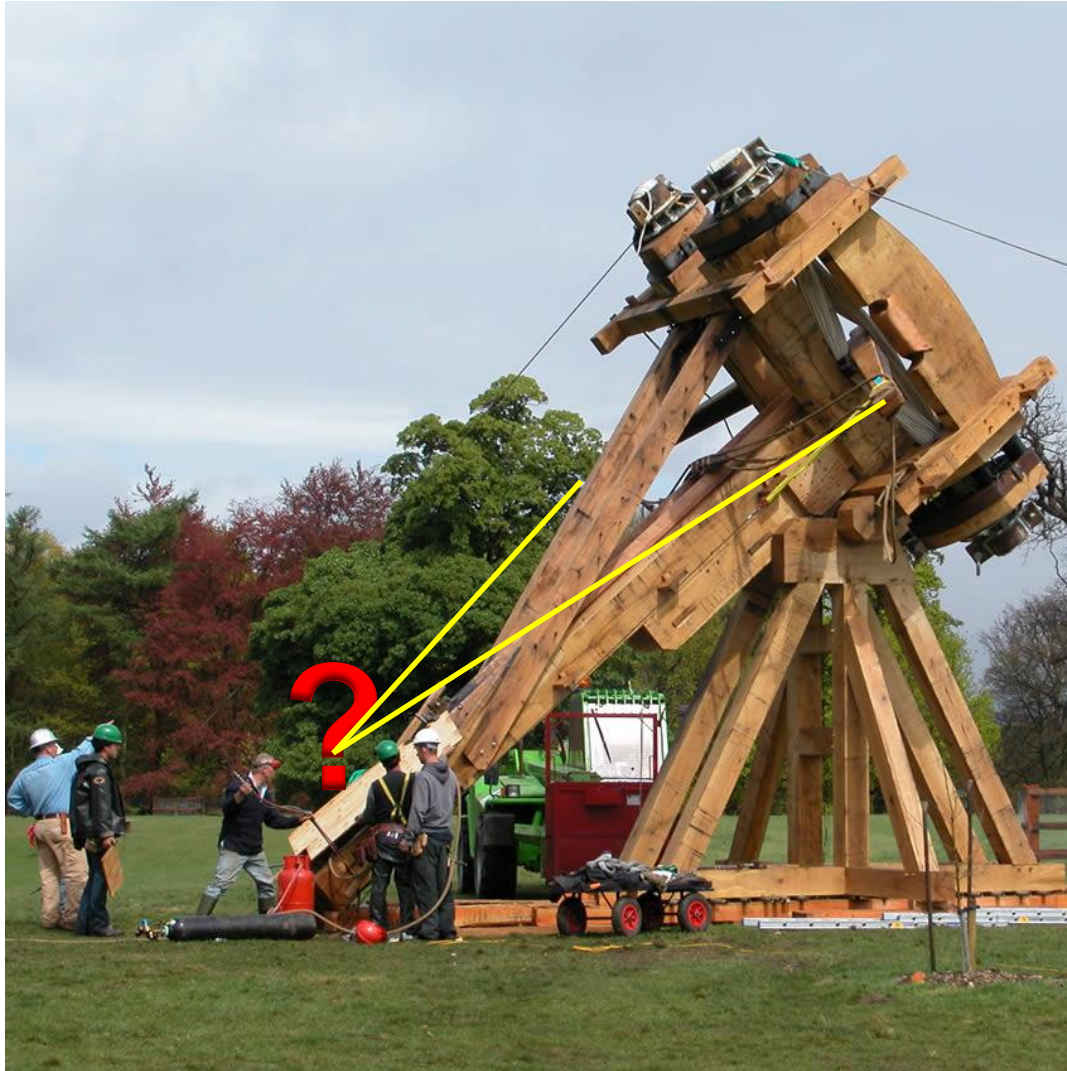
PATENTED MCHUGH RFI LAUNCHER!

Slab Deflection & Column Shortening
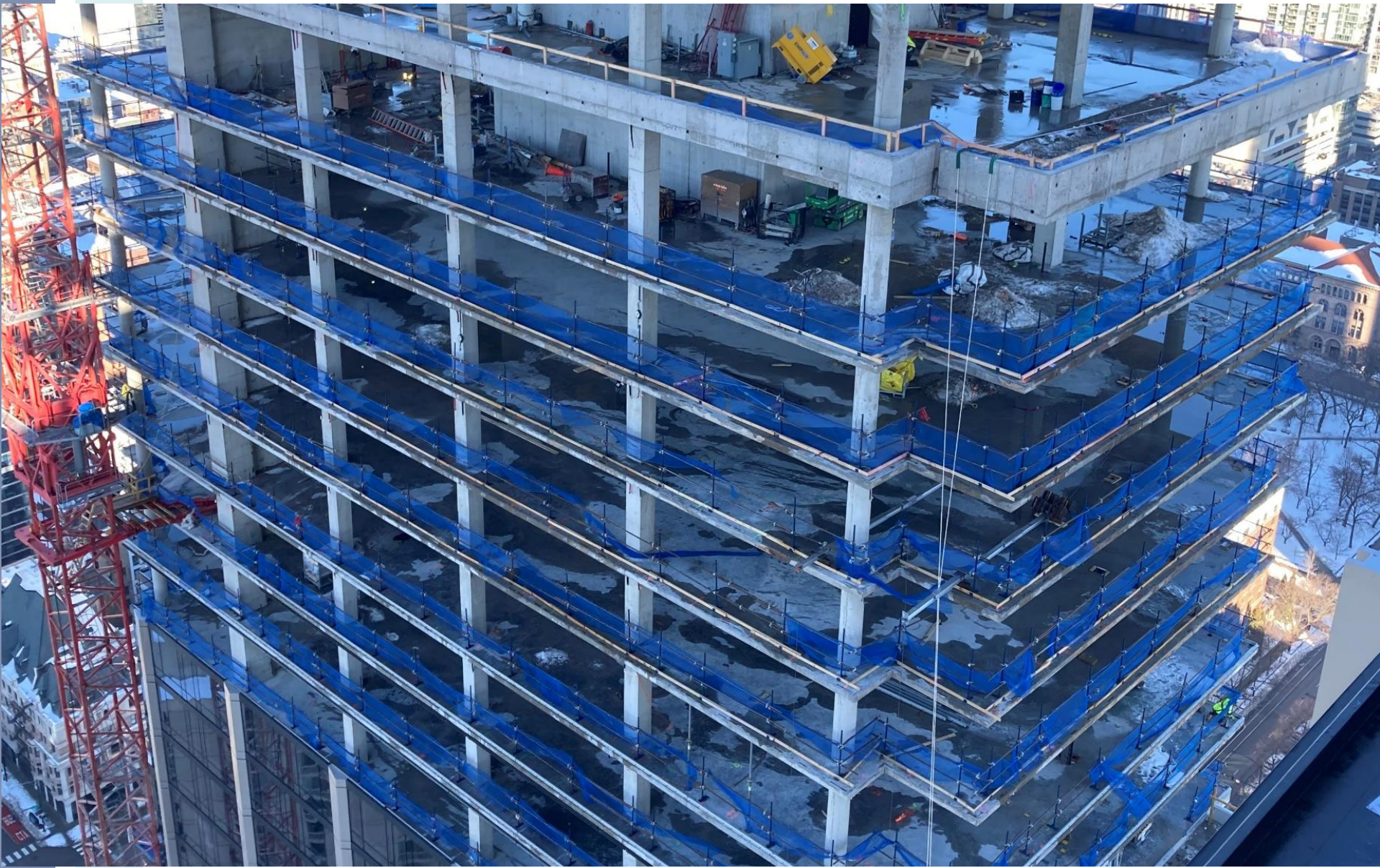
Longterm Movement-Sway under Gravity Load

2.5" total h/3500
1.3 " before the end of construction
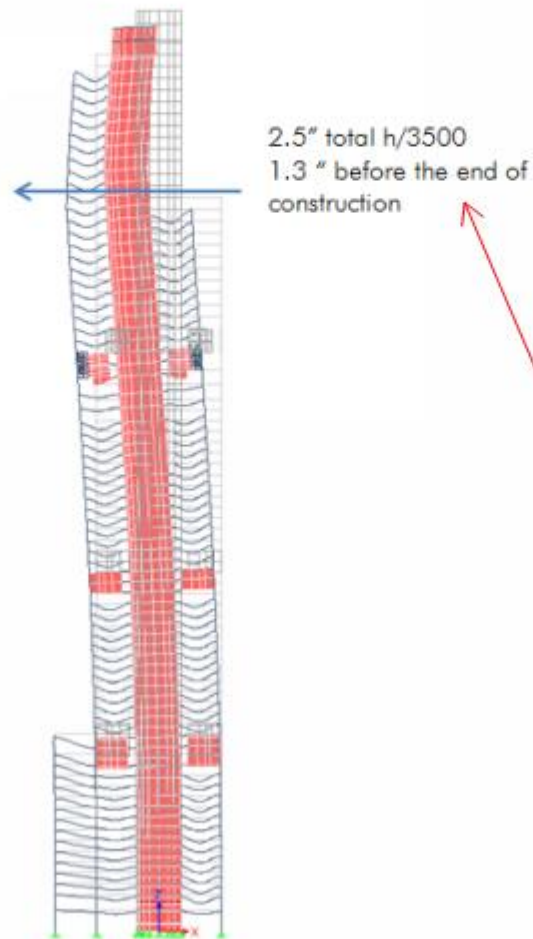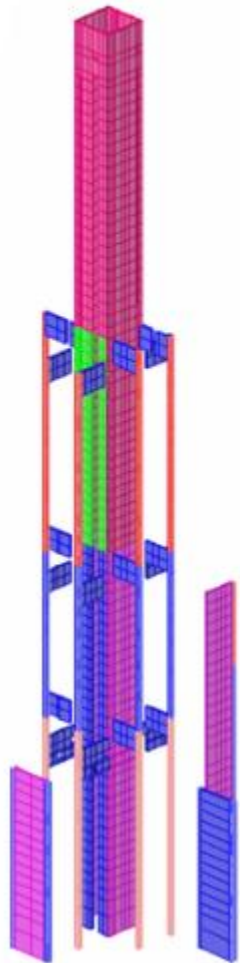
Building sway toward SE direction due to unbalanced mass on two sides of the core.

1.5" DIFFERENTIAL COLUMN SHORTENING IN ONE BAY AT ONE FLOOR!

— Column on Grid D2-Vertical deformation (Inch) subsequent to casting -5 years after top off

— Corner of the core on Grid E2-Vertical deformation (Inch) subsequent to casting -5 years after top off

— Column on Grid D2-Vertical deformation (Inch) subsequent to casting -5 years after top off

— Corner of the core on Grid C2-Vertical deformation (Inch) subsequent to casting -5 years after top off
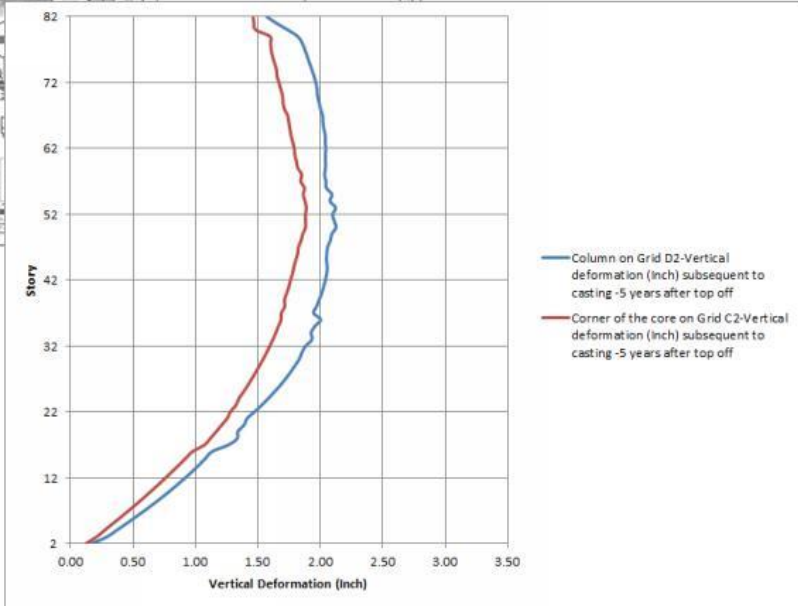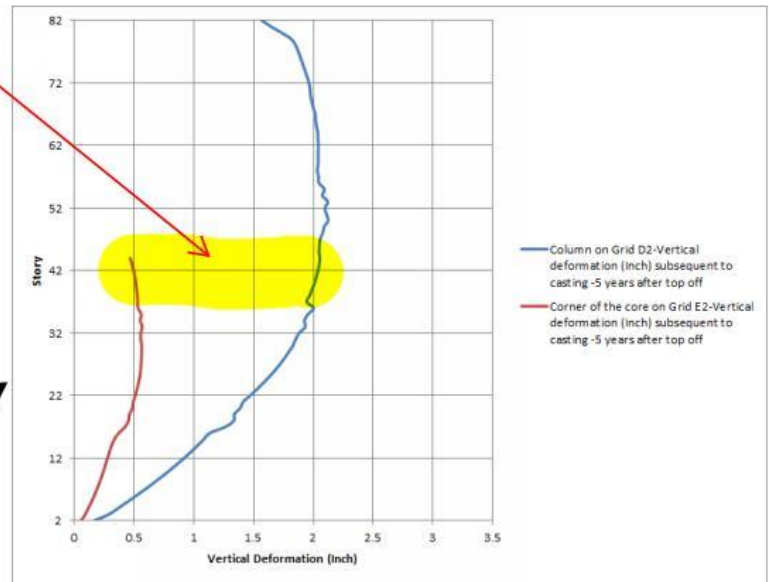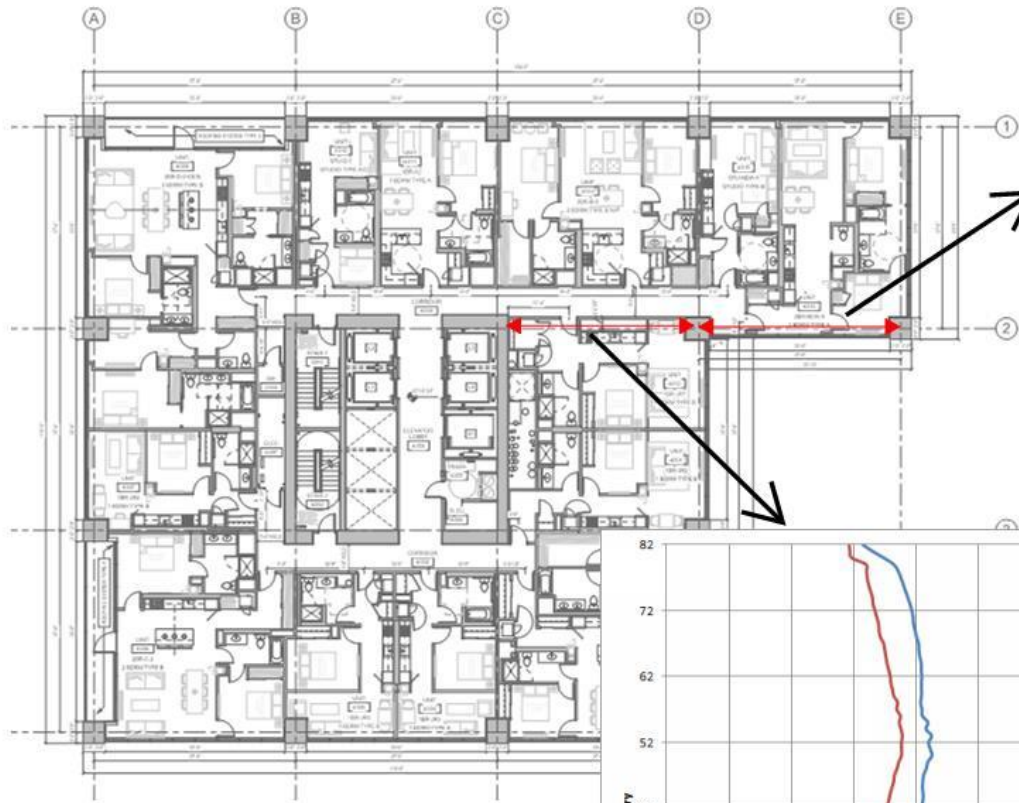
Longterm Staged Construction Analysis Results

graphs show shortening five years after the completion of construction

0.75" FINAL DIFFERENTIAL AFTER COLUMN CAMBER, BUT WINDOWS ARE INSTALLED BEFORE COLUMN CAMBER HAS COME OUT. WINDOWS WILL SEE ALMOST 1.5"
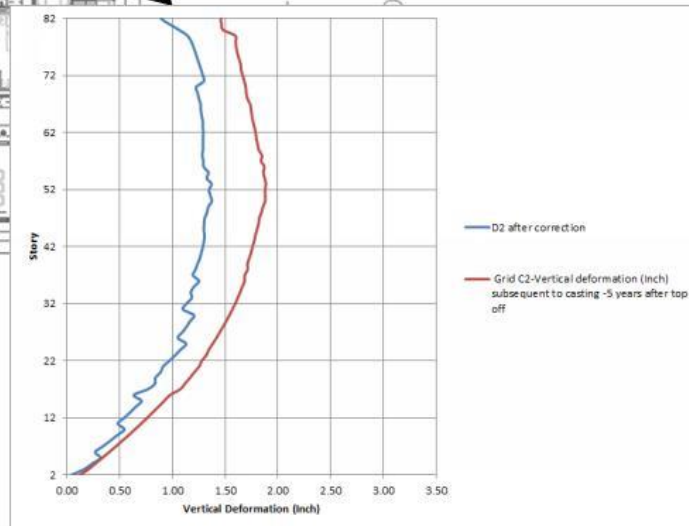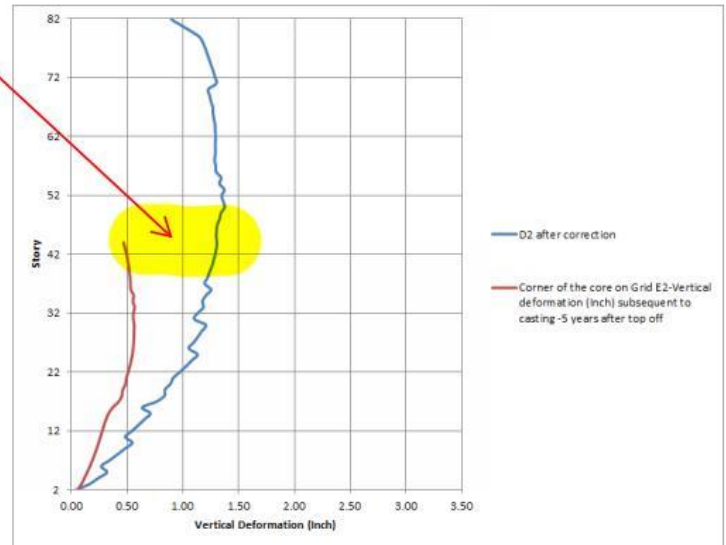
Longterm Staged Construction Analysis Results

After applying 3/4" camber to column D4 graphs show shortening five years after the completion of construction

Proposed Cambering-To be verified with survey data during construction

Level 35

-1.40in
-1.45in
-1.54in
-1.58in
-0.45in
-1.08in
-1.50in
-1.52in
-1.66in
-1.95in
-0.56in
-1.20in
N
-1.67in
-1.68in
-1.81in
-2.02in
-1.27in
-1.82in
-1.92in
-1.97in
-1.67in
-1.32in
-1.30in
-1.35in
-1.17in

XXin Represents deformation after camber.

Note: L/X values determined using corrected deformation after camber

<u>Long Term Deformation</u>
<u>Subsequent to Casting</u>
Level 35

Differential column shortening
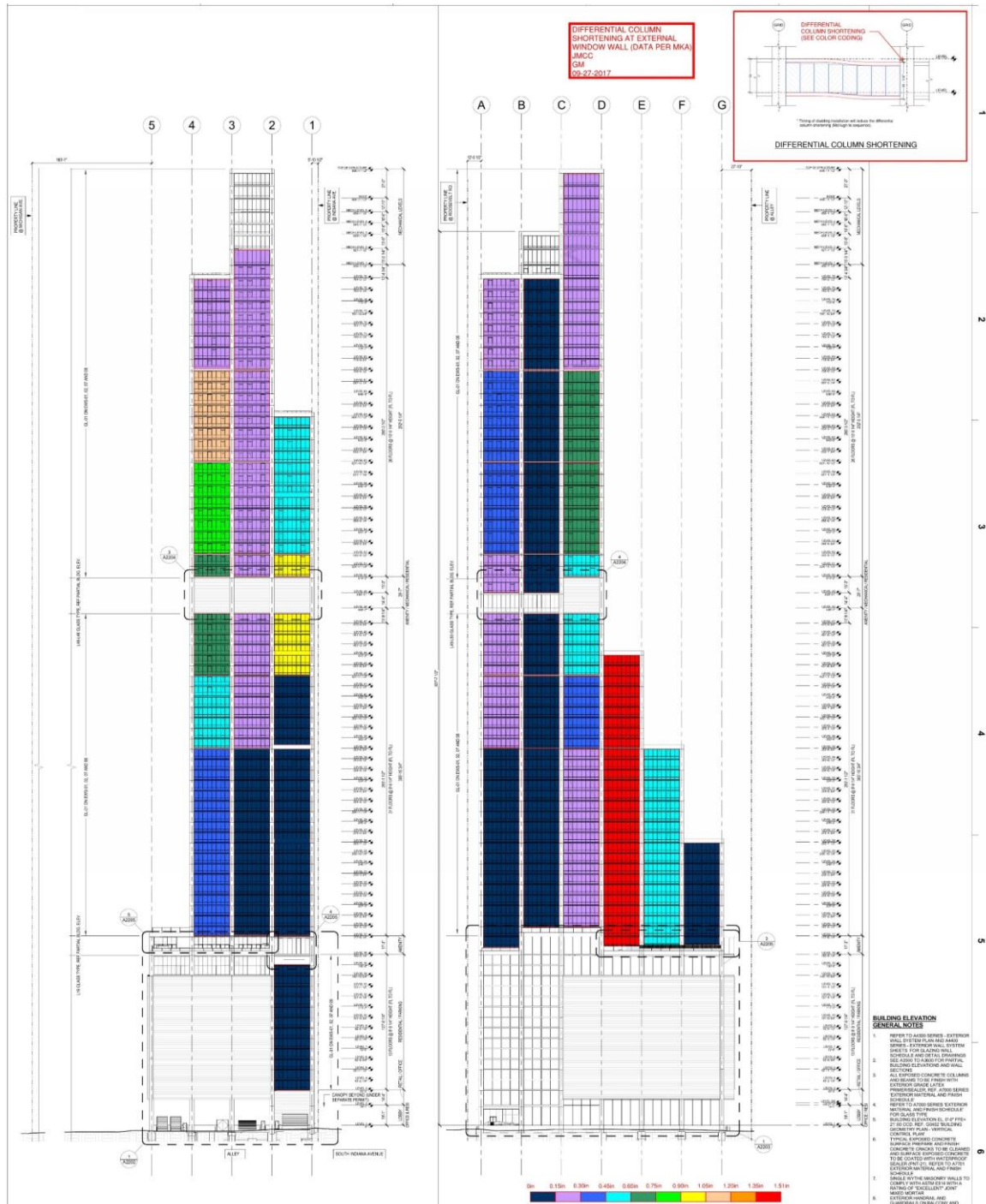
LONGTERM MOVEMENT-CLADDING EXTRA CARE
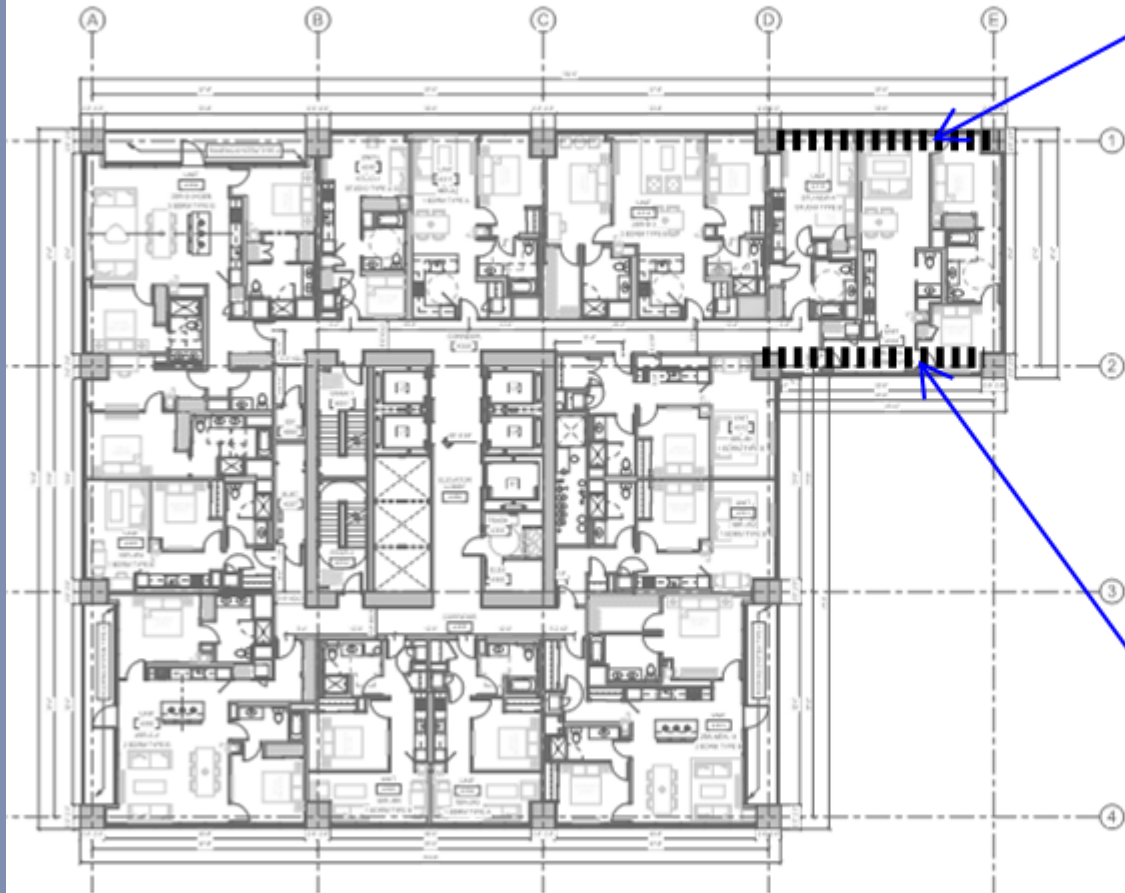
Allow 1-1/2" movement over 37'-6" span

Allow 1" movement over 37'-6" span

SEOR PREDICTED THERMAL MOVEMENTS

THERMAL MOVEMENT-CLADDING EXTRA CARE

1200 SOUTH INDIANA
COLUMN SHORTENING DUE TO THERMAL
Δ TEMPERATURE = -62.5 DEG
(75 DEG INTERIOR, 12.5 DEG EXTERIOR)

Allow 1-1/4" movement over 37'-6" span

Allow 1" movement over 37'-6" span
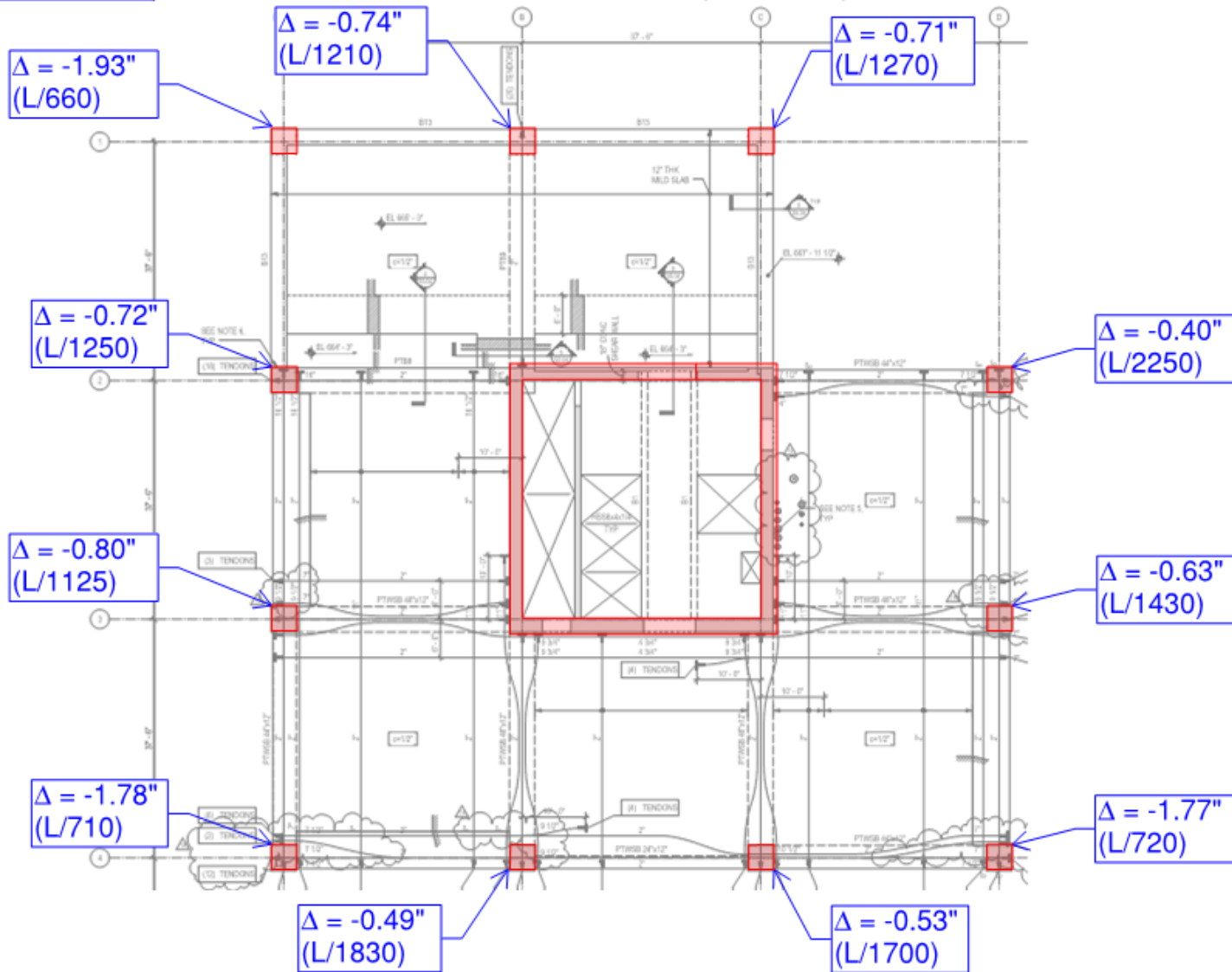
SEOR PREDICTED SLAB DEFLECTIONS

Levels58-63.cpt - 2/27/2017

Levels 58-63: Typical Tower Floor
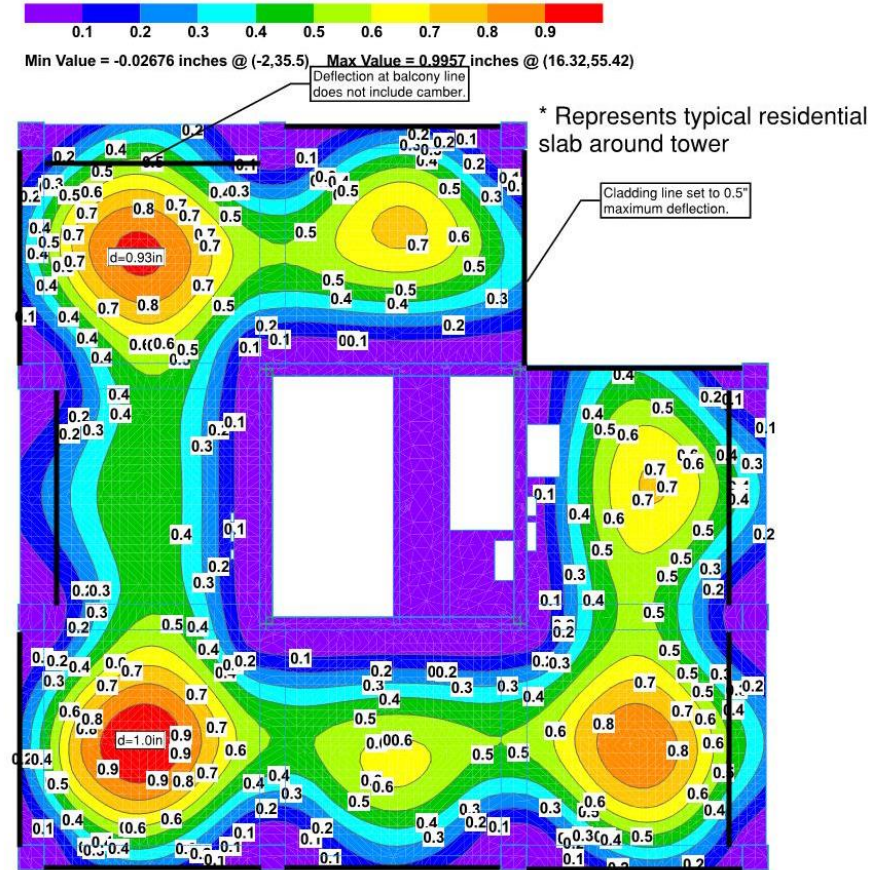
MAXIMUM LONG TERM DEFLECTION MINUS SELF WEIGHT

-Deflection plot highlights the total service dead and live load deflection subtracting the initial self weight. This is the long term deflection that occurs after the attachment of nonstructural items.

-Cladding lines (shown in black) are kept to 1/2" deflection.

Building Deformation Problems

$\Delta_{\text{Live Load}} = 1/2"$

LEVEL

LEVEL

LIVE LOAD DEFLECTION - TYPE 1

Differential column shortening
(1 1/2 worst case) *

LEVEL

$H - 1/4"$

LEVEL
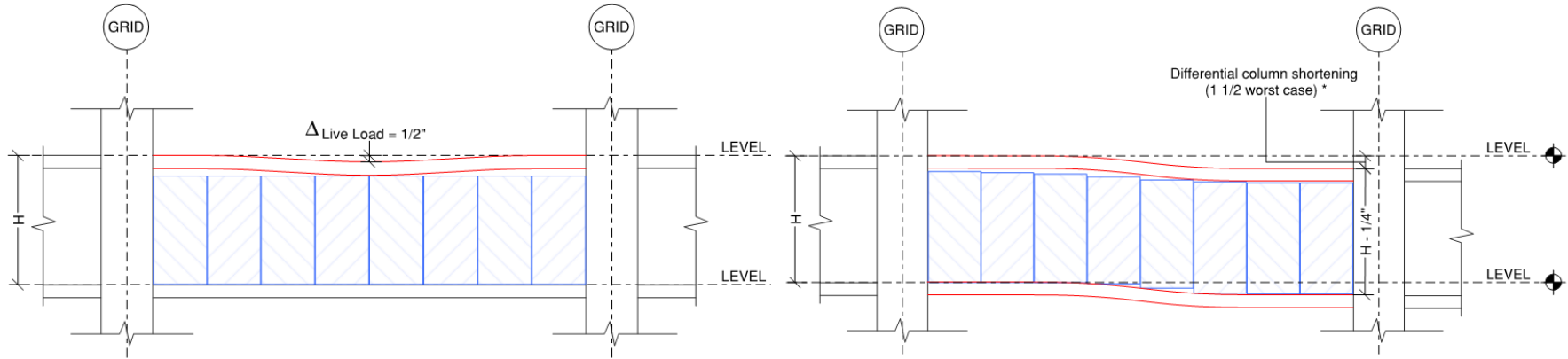
* Timing of cladding installation will reduce the differential
column shortening (McHugh to sequence).

DIFFERENTIAL COLUMN SHORTENING

LEVEL

LEVEL

$\Delta_{\text{Live Load}} = 1/2"$

LIVE LOAD DEFLECTION - TYPE 2

$\Delta_{\text{Wind}} =$
Max of 1/2" or H/400 (Service Wind)
Max of 1"or H/200 (Design Wind)
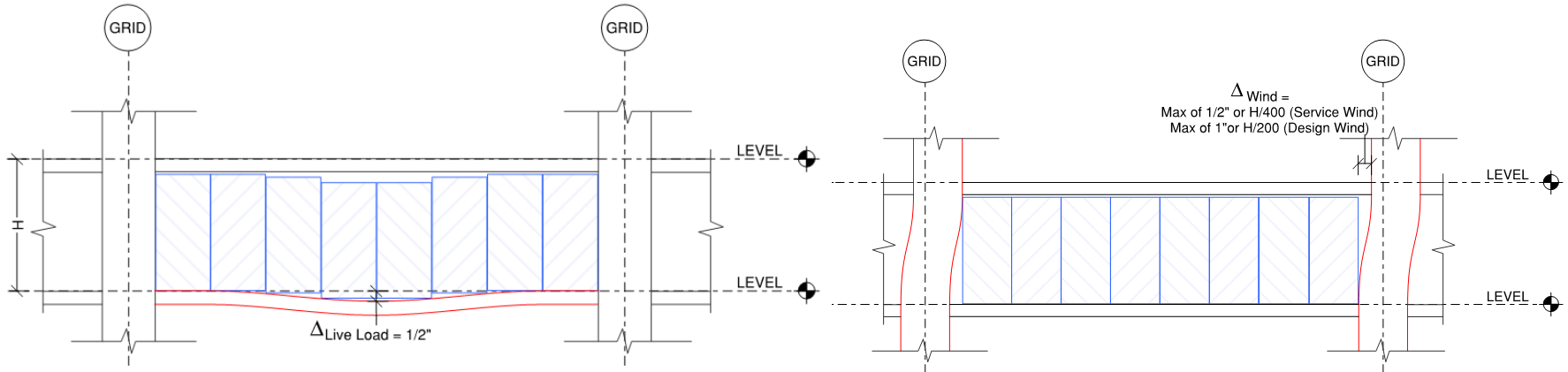
LEVEL

LEVEL

INTERSTORY WIND DRIFT

Building Deformation Problems
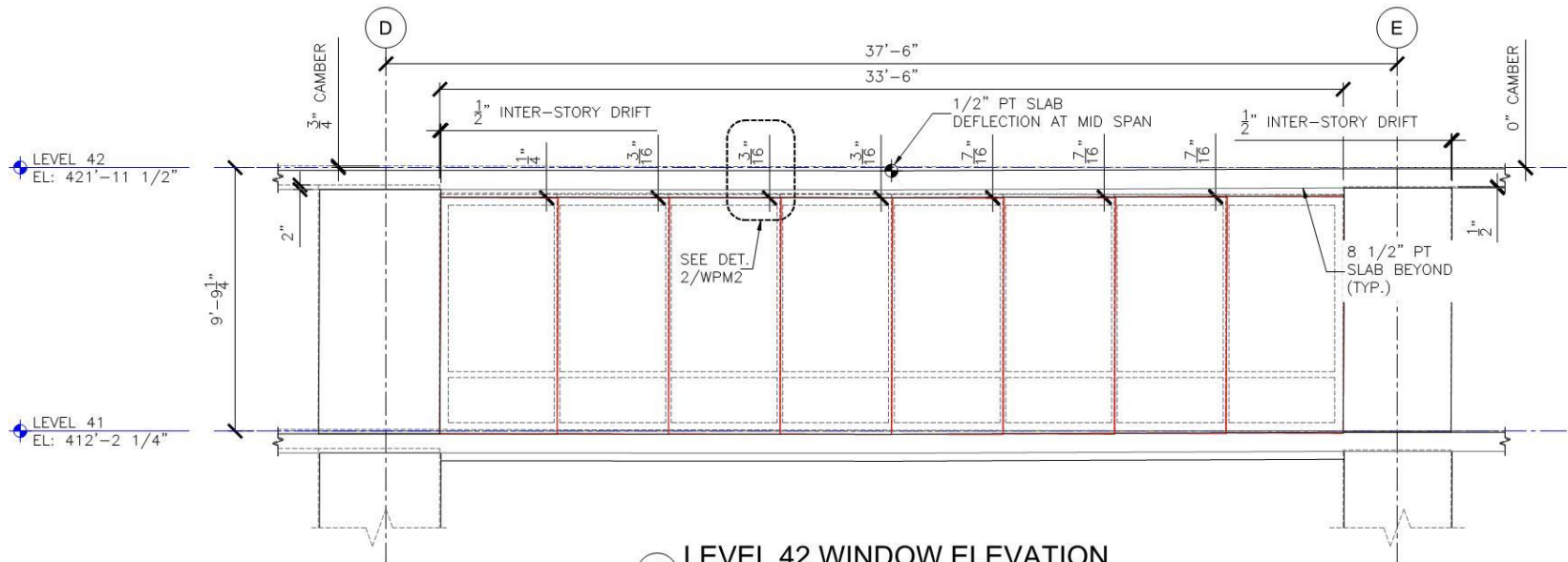
LEVEL 42 WINDOW ELEVATION
1 · SCALE: 1" = 4'-0"
REF. ENTEKK GROUP LTD. DET. EWS-1.03 SHEET NO. 1E02, DATED 05/05/17
& MKA SHEET S2.39, DATED 03/31/17
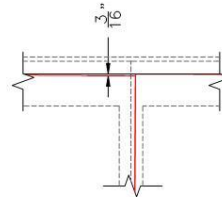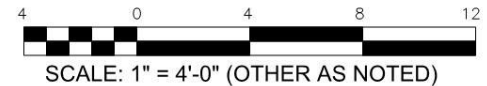
GENERAL NOTES:

1. DEFLECTED SHAPE OF LEVEL 42 WINDOW WALL ON GRID LINE 2
   AND BETWEEN D & E CONSIDERS:
   a. COLUMN DEFLECTION AT LEVEL 42 AS PER MKA
   b. COLUMN SHORTENING PER STORY
   c. MAX. SLAB DEFLECTION OF 0.5" AT CLADDING LINE, PER MKA
   d. MAX. LATERAL INTER—STORY DRIFT OF 0.5" PER MKA
2. AS BUILT CONDITION ASSUMES BUILDING IS CONSTRUCTED AT
   THEORETICAL ELEVATIONS WITH COLUMN CAMBER AS SPECIFIED
   PER MKA.

LEGEND	
--------	AS BUILT (THEORETICAL + COL. CAMBER)
————	DEFLECTED SLAB BEYOND
————	DEFLECTED SHAPE
————	T/SLAB ELEVATION WITHOUT CAMBER
————	WINDOW PANEL MOVEMENT

DETAIL
2 · SCALE: 1" = 1'-0"

SCALE: 1" = 4'-0" (OTHER AS NOTED)

WINDOW PANEL MOVEMENT

1200 S. INDIANA AVE. CHICAGO, ILLINOIS

McHUGH

WPM-2
DRAWN BY: GM
DATE: 09/27/2017
SCALE: AS NOTED

Building Deformation Problems

- WINDOWS SYSTEM NEEDS TO ACCOMMODATE CONSTRUCTION TOLERANCE AND ALL ANTICIPATED MOVEMENTS OF STRUCTURE BOTH LONG TERM AND SHORT TERM

CONSTRUCTION TOLERANCE OF +/-1"

VERTICAL LIVE LOAD DEFLECTION

ENTEKK WINDOW WALL SYSTEM
VERTICAL LIVE LOAD DEFLECTION TOLERANCE

+3/4" DEFLECTION

0" DEFLECTION

-3/4" DEFLECTION
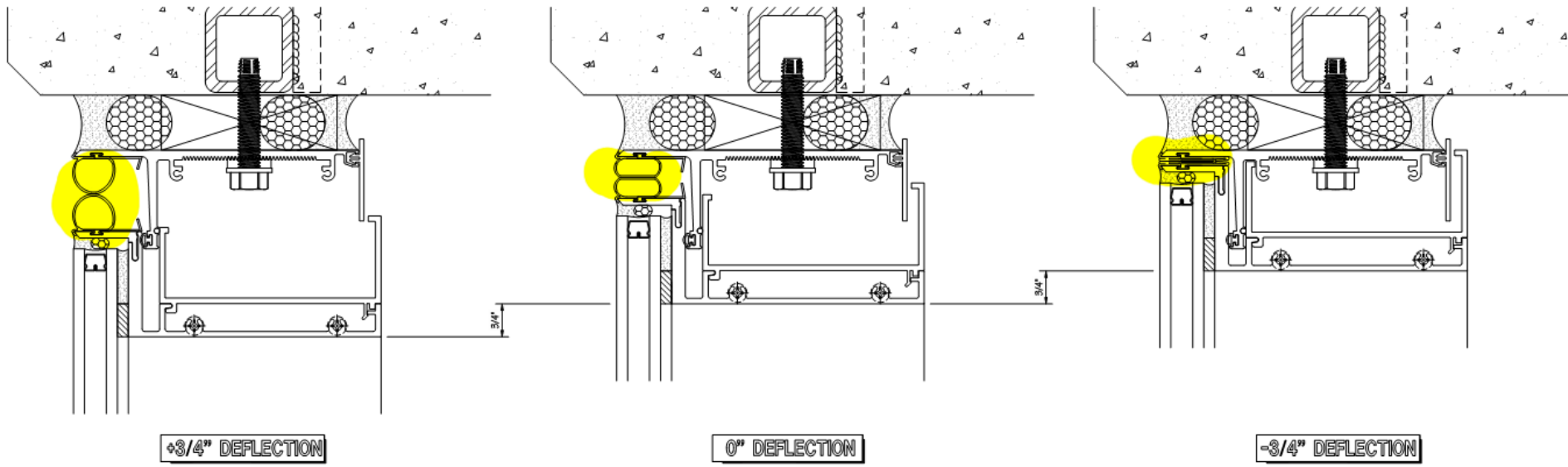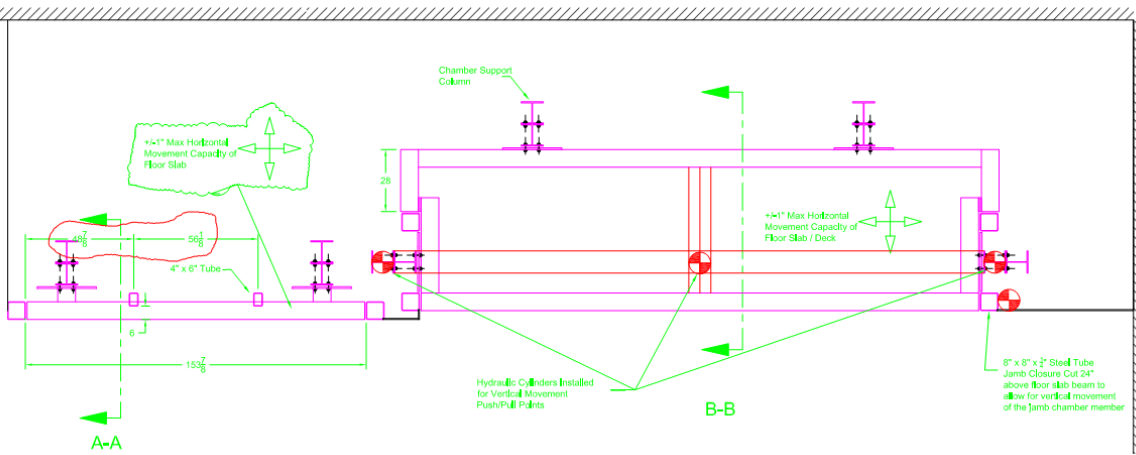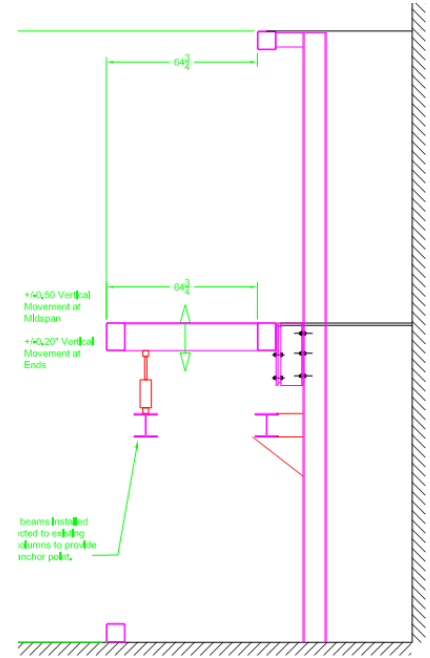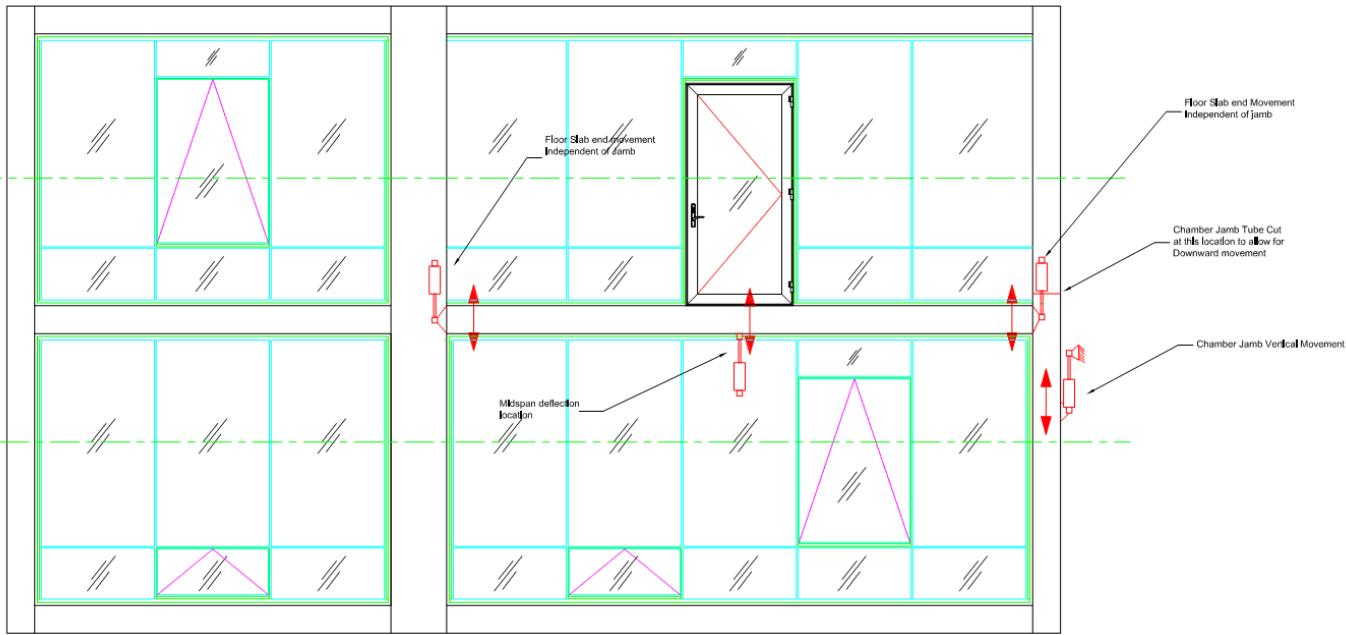
WINDOW TESTING

Mid Level Plan

WINDOW TESTING

RAFAEL VINOLY ARCHITECTS
1200 S INDIANA
SEPTEMBER 29, 2017
CUMULATIVE MOVEMENTS OF A STRUCTURAL BAY
REVIEWED AND APPROVED BY MKA

$(21.09375ft \times 0.625in)/(33.5ft) = 0.4in$

Total length of 5 test panels

Actual length of 8 panels between columns

Clear Between Columns
33'-6"

Vertical Movements

One time movement after cladding is installed

COL.   COL.

A movement of 0.25" downward, uniformly across the column bay representing maximum column creep within the floor to floor

Position 1

An additive movement of 0.625" downward at one column representing differential column creep (McHugh to control cladding installation schedule to meet this criteria) .625" x 60% = .375"

Position 2

0.625" x 64% = 0.4" (FOR 5 PANELS)

Variable movements after cladding is installed

An additive movement of 0.625" downward at the same column as above representing thermal expansion. .625" x 60% = .375"

Position 2

0.625" x 64% = 0.4" (FOR 5 PANELS)

An additive movement of 0.5" applied downward at the mid-span, returned back to relative neutral, applied upward at the mid-span, returned back to relative neutral to represent the variable live loading.

Position 3 & 4

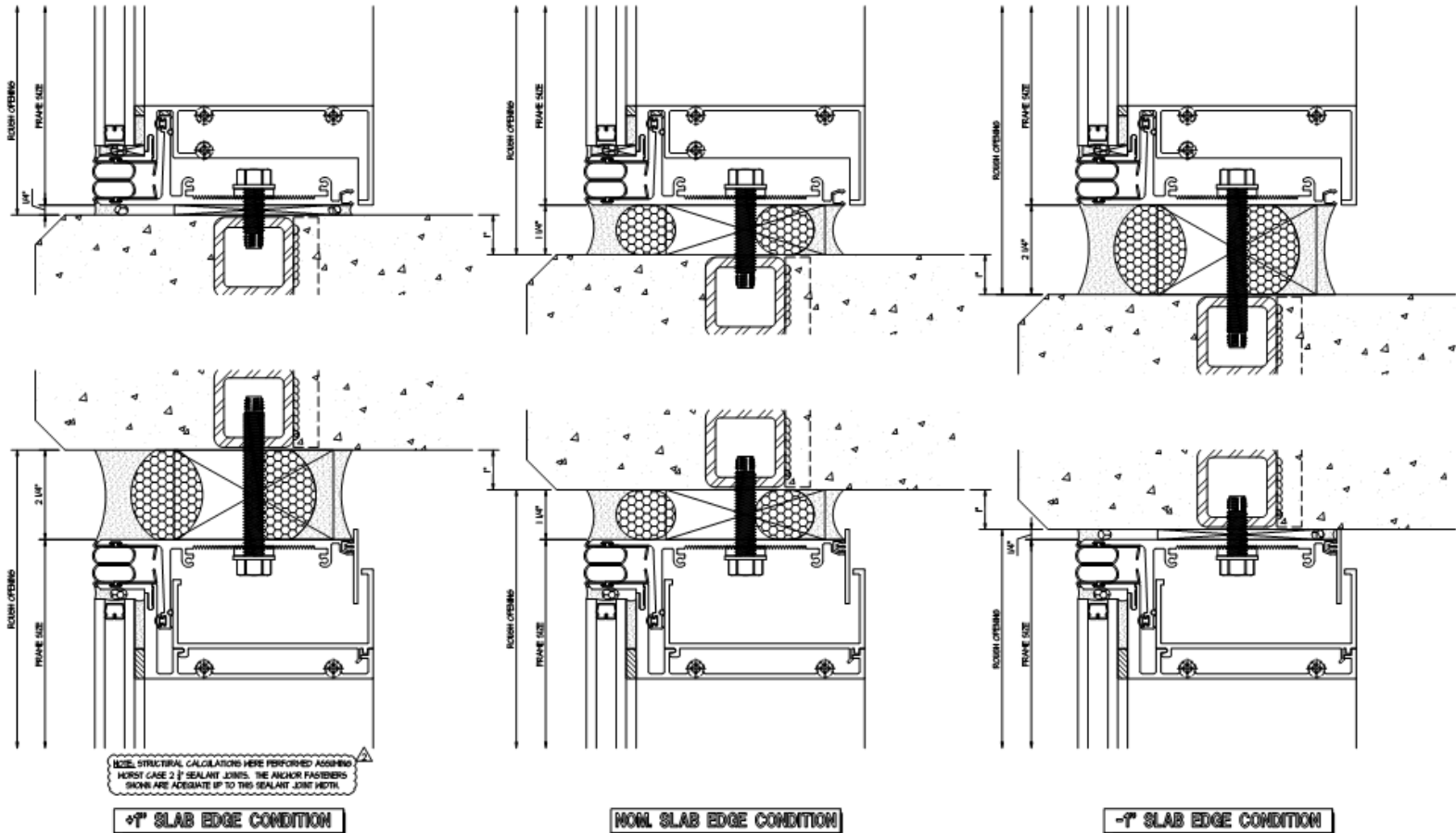A movement of 0.625" upward at the same column as above representing a return to the new neutral position without thermal expansion.
.625" x 60% = .375"   0.625" x 64% = 0.4" (FOR 5 PANELS)

Position 5

An additive movement of 0.625" upward at the same column as above representing thermal expansion in the opposite direction.
.625" x 60% = .375"   0.625" x 64% = 0.4" (FOR 5 PANELS)

Position 5

An additive movement of 0.5" applied downward at the mid-span, returned back to relative neutral, applied upward at the mid-span, returned back to relative neutral to represent the variable live loading.

Position 6 & 7

Lateral movements:

Service level lateral inner-story wind drift: maximum of ½" either direction (remains water tight and without damage)

JMCC MARK-UP
10-05-2017

Design level lateral inner-story drift: maximum of 1" either direction (no life-safety damage)

Window Wall Caulk Joint

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

SEOR Predicted Slab edge movement!

Time After Slab Casting	Grid 11 Westward Movement
1 Week	3/8"
28 Days	9/16"
1 Year	7/8"
5 Years	1-1/8"

Slab SHORTENING Problems

Displaced & Leaning Columns

PT slab - unstressed

Step 1

PT slab - stressed

Step 2

PT slab - unstressed

PT slab - stressed

Step 3

PT slab - stressed

PT slab - stressed

Step 4
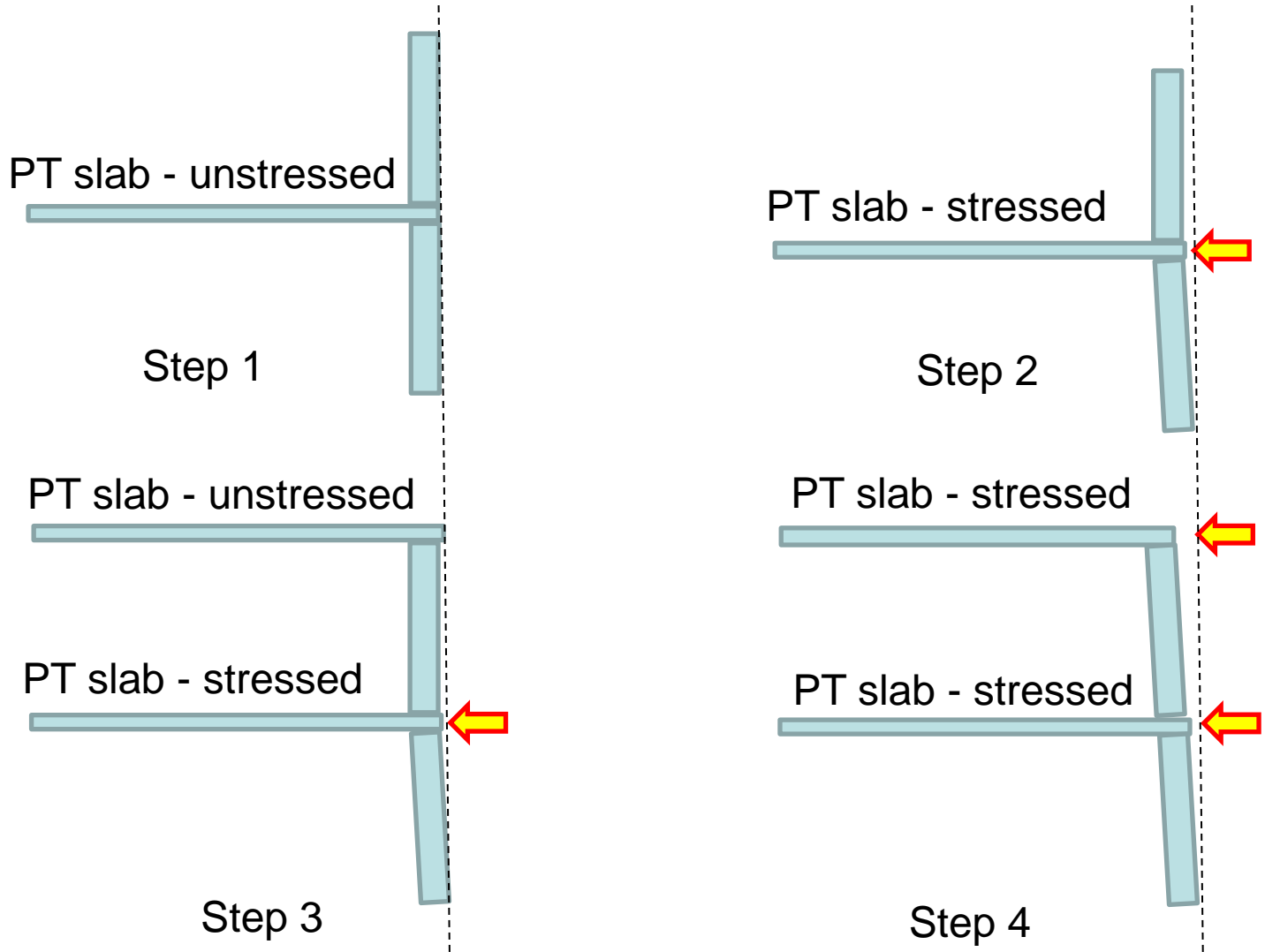
Slab SHORTENING Problems

Slab SHORTENING Problems

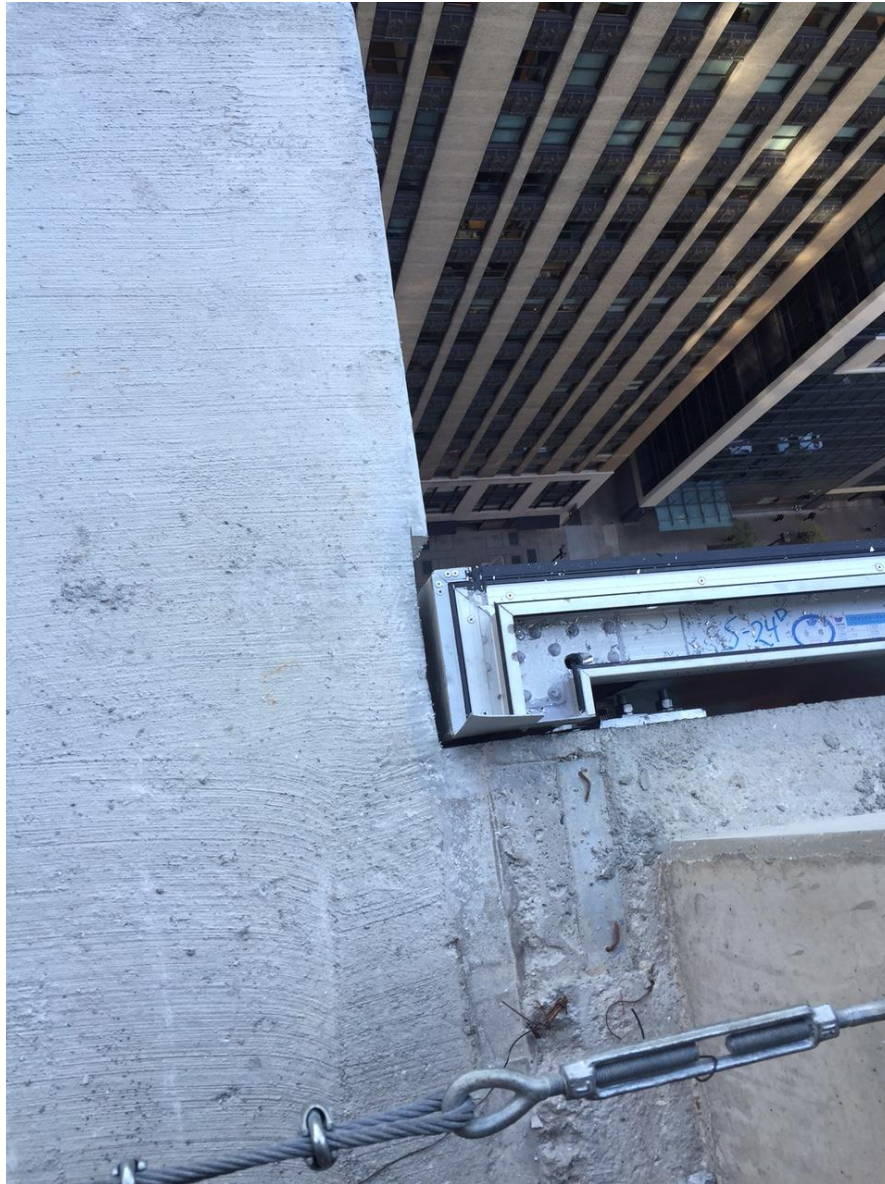# Slab SHORTENING Problems

Specifications, Guides & Checklists!

ACI 117-10

Specification for Tolerances for Concrete Construction and Materials (ACI 117-10) and Commentary

An ACI Standard

Reported by ACI Committee 117

American Concrete Institute®

ACI 117.1R-14

Guide for Tolerance Compatibility in Concrete Construction

Reported by ACI Committee 117

American Concrete Institute
Always advancing

Conclusions

- **RFI SEOR FOR ANTICIPATED BUILDING DEFORMATIONS!!**

- **Better planning for deflections, column shortening and tolerances = Less Remedial Work = Cost Savings = Happy Repeat Client!**

- **Buy the same tolerances from all trades!**

- **Communication is the key to success!**

McHUGH

QUESTIONS?

THANK YOU!!

McHUGH