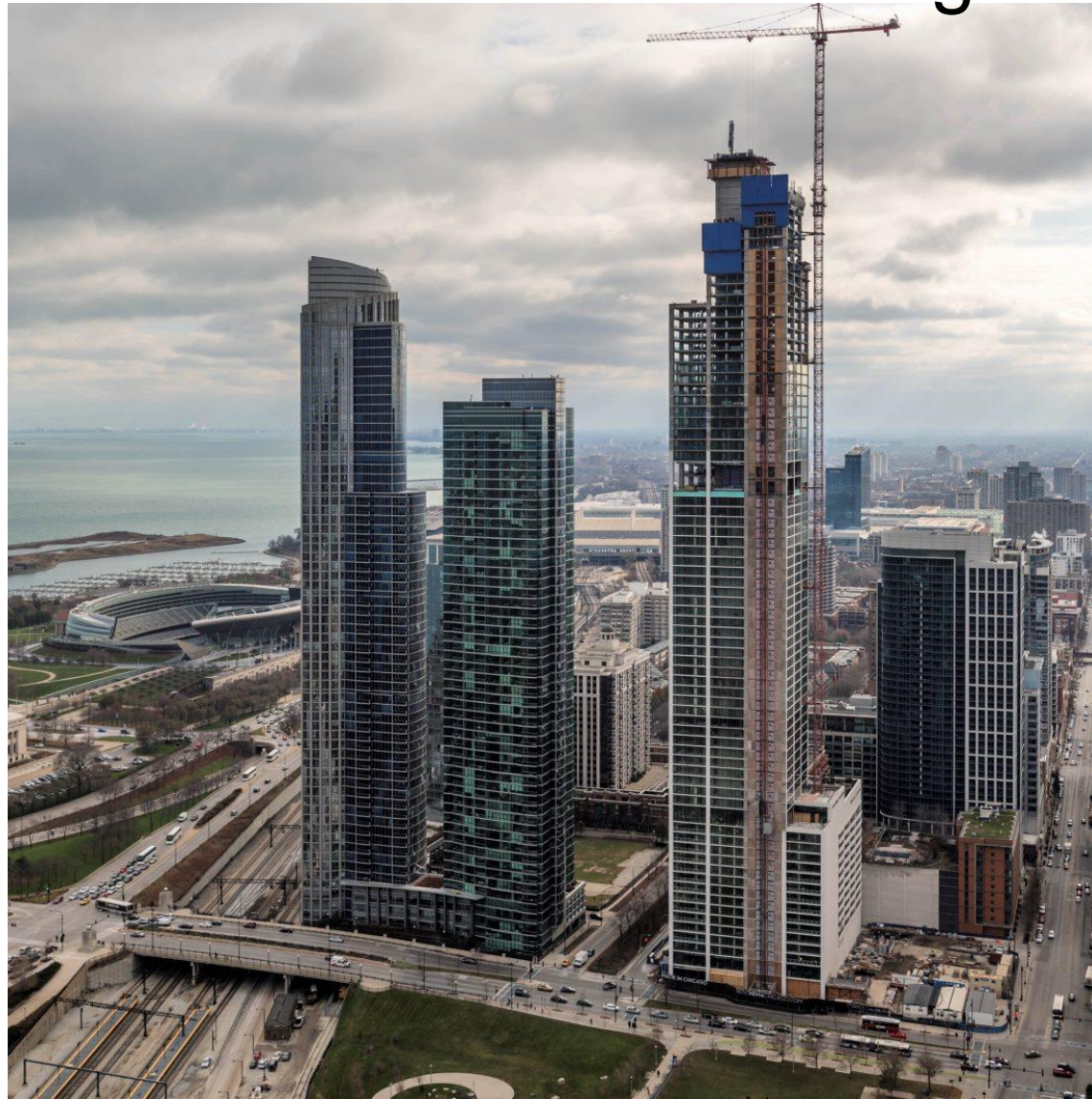


THE TROUBLE WITH TALL

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



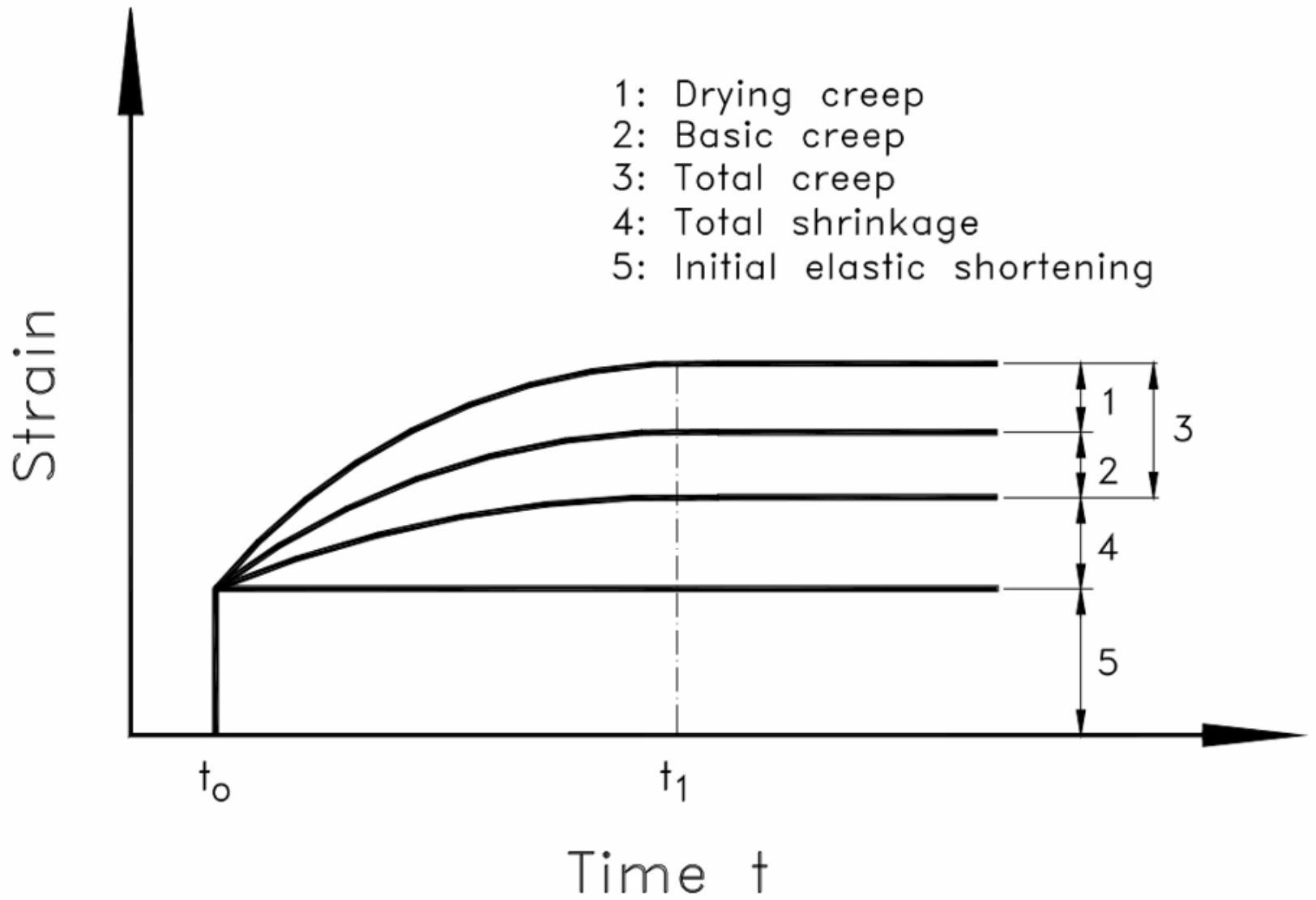
American Concrete Institute®

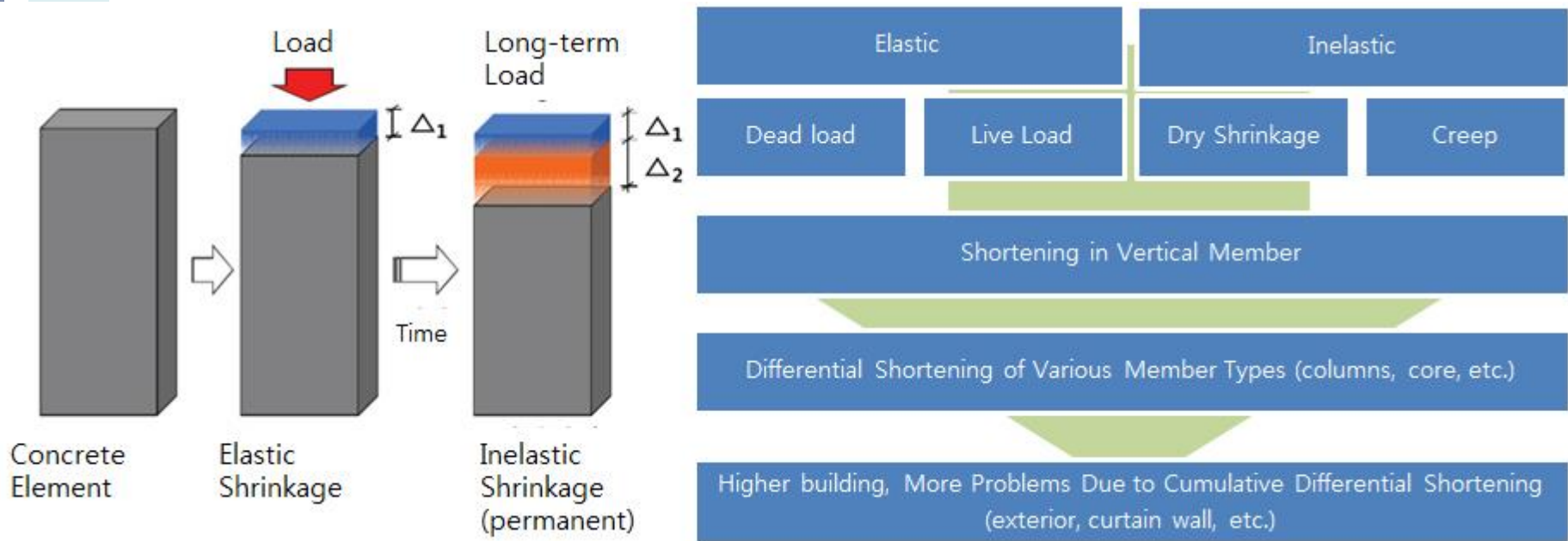
Factors Effecting Creep

- 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!**

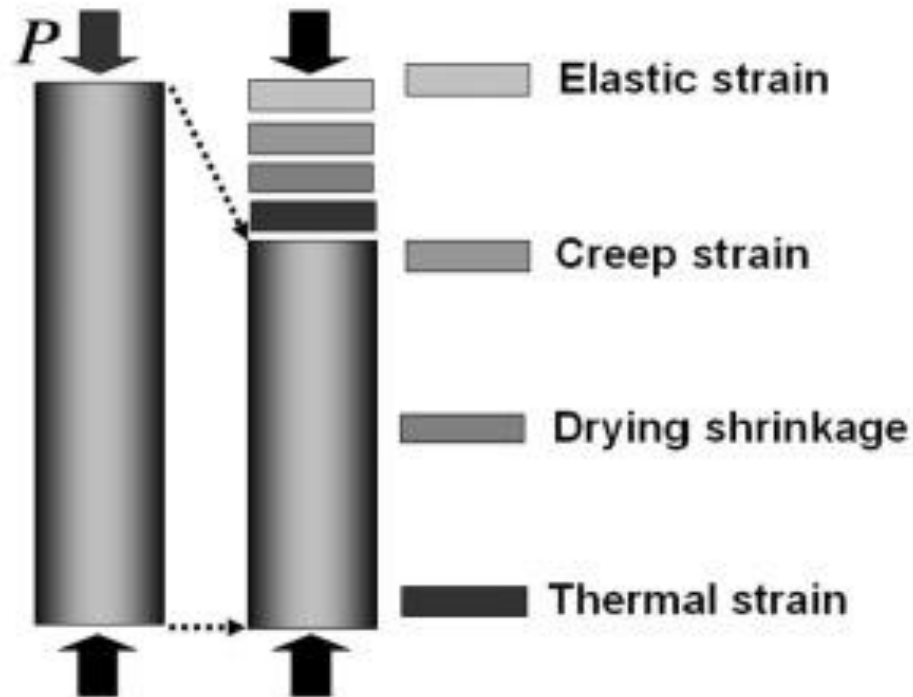
Factors Effecting Shrinkage

- 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

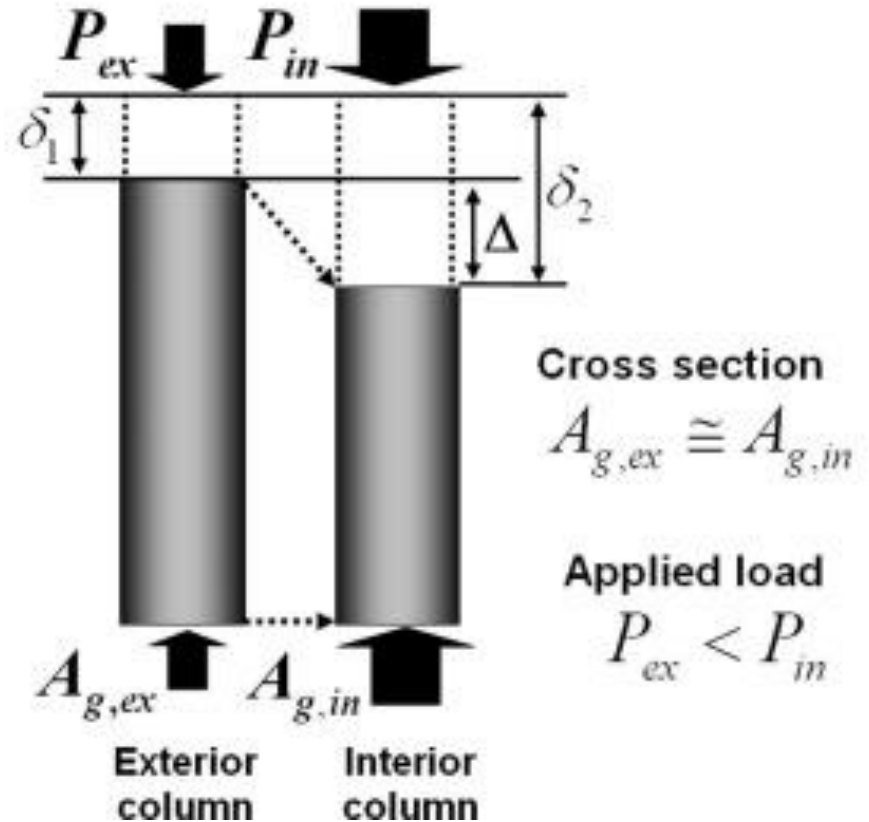




Causes of total shortening



Causes of differential shortening



- 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.

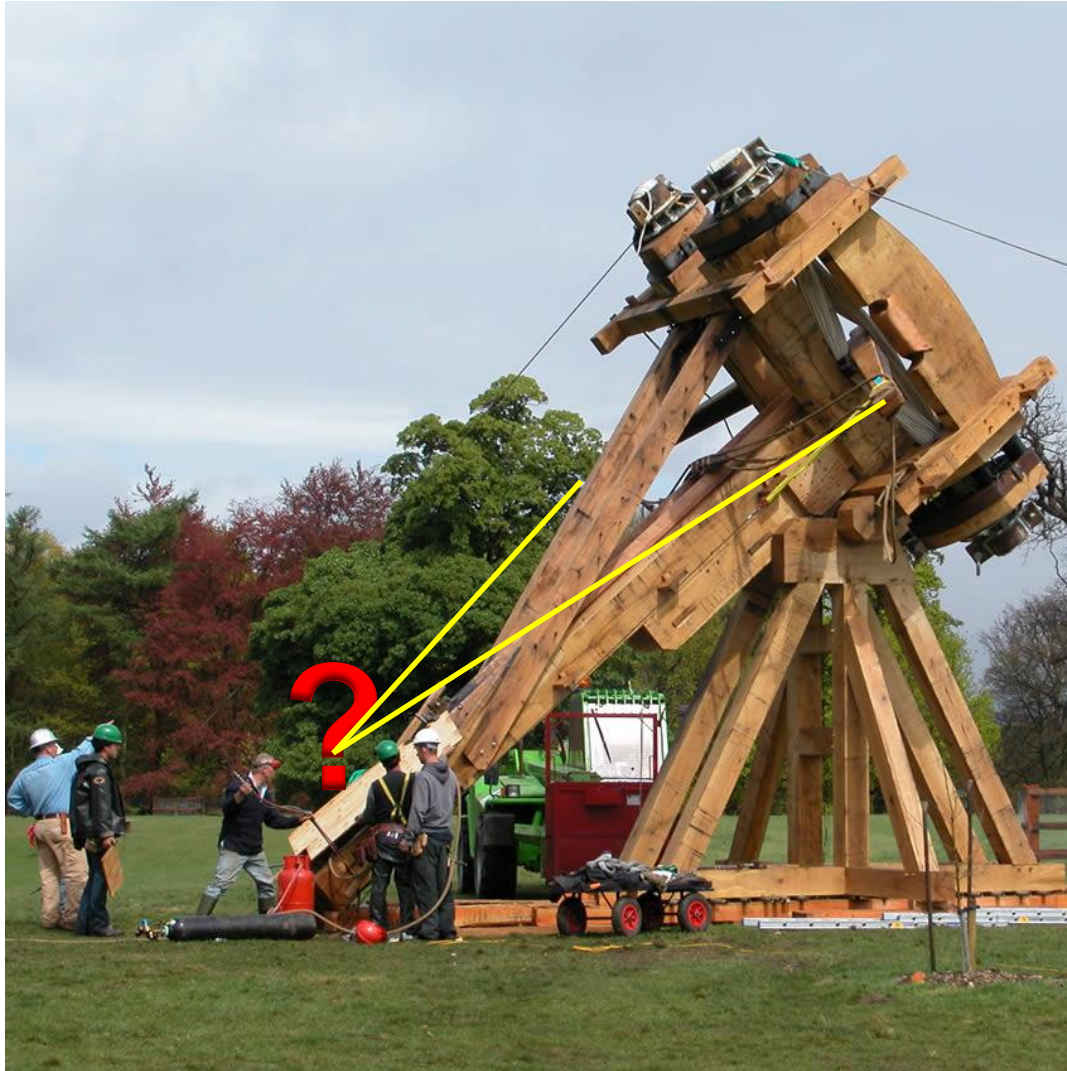
Pre-Construction

- 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

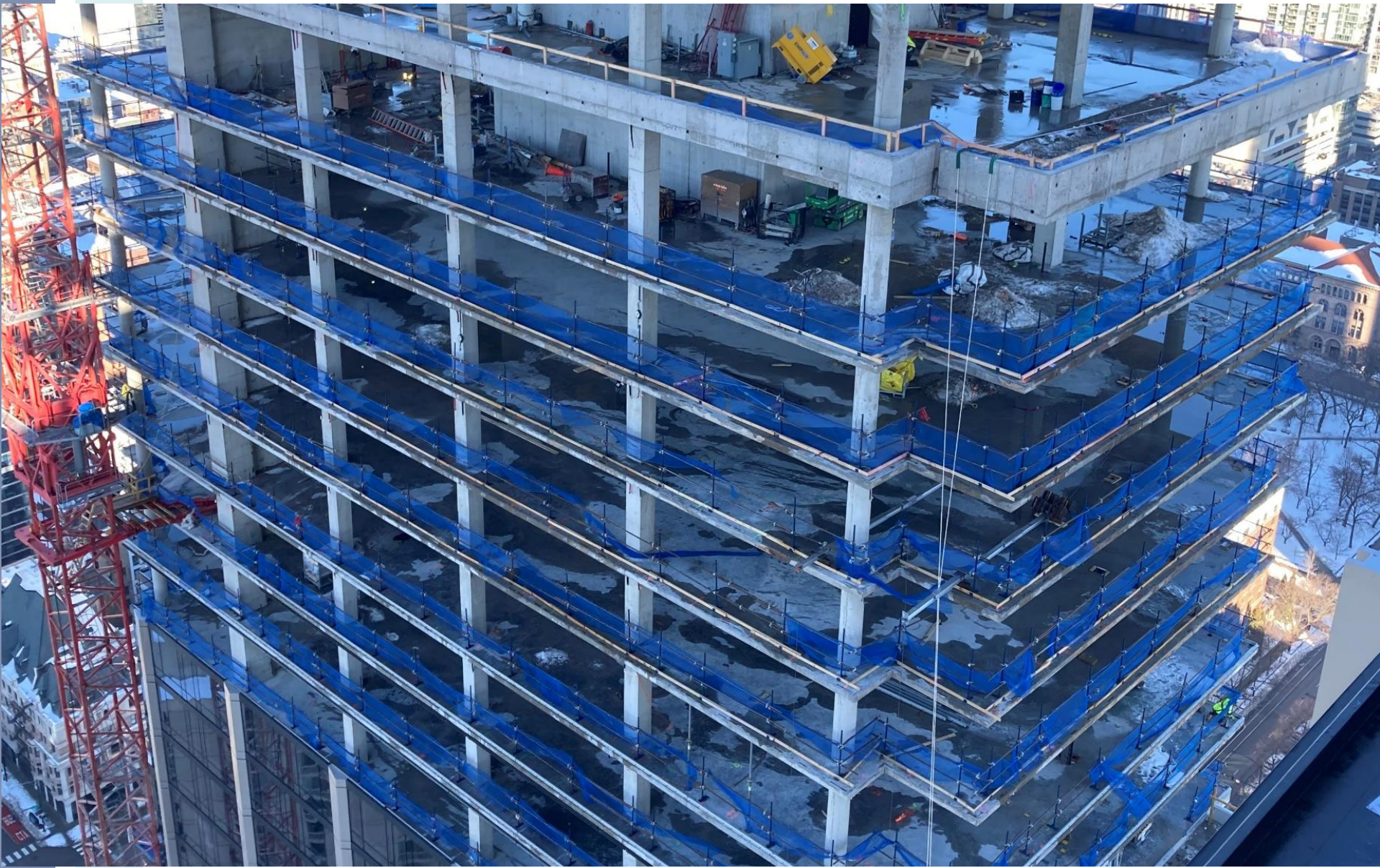
WHAT CONTRACTORS WANT...

- 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!



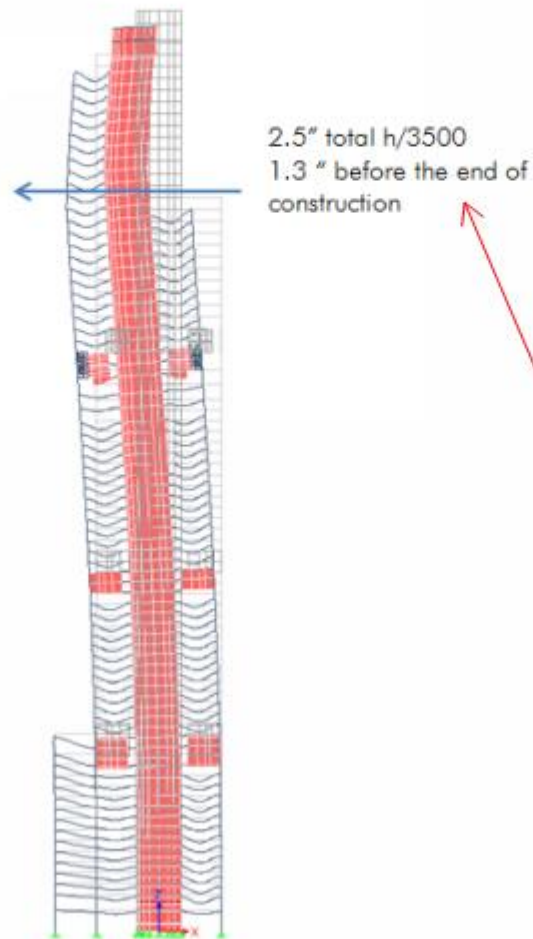
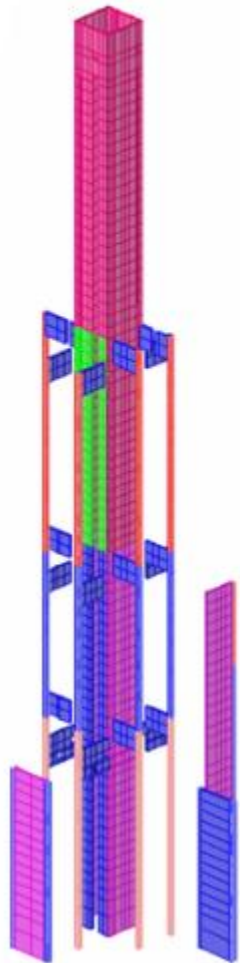
PATENTED
MCHUGH RFI
LAUNCHER!

Slab Deflection & Column Shortening



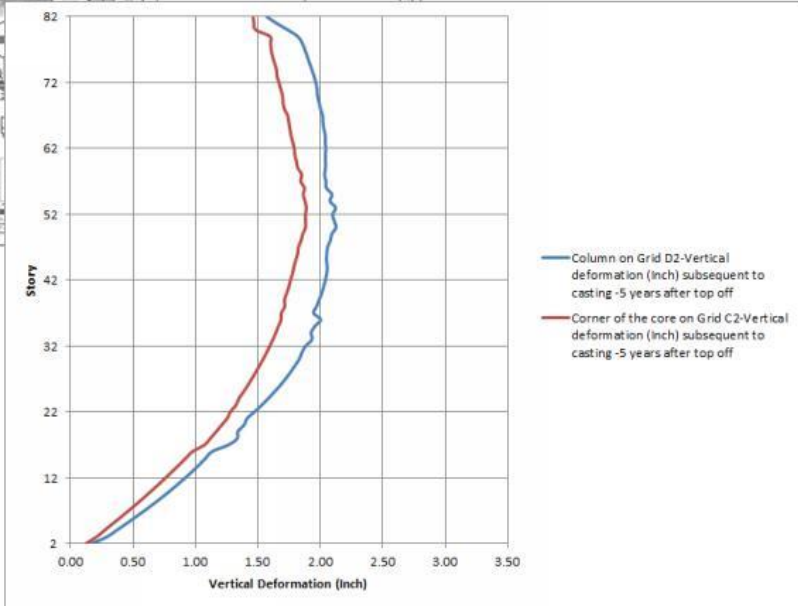
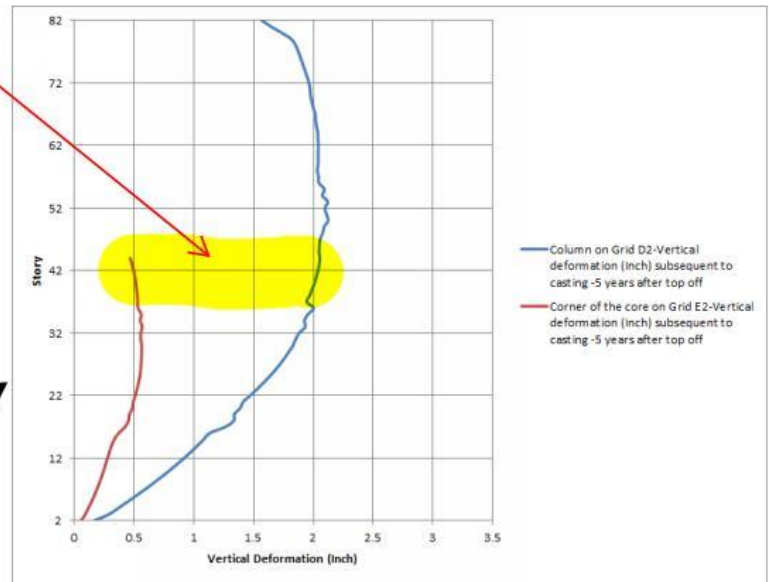
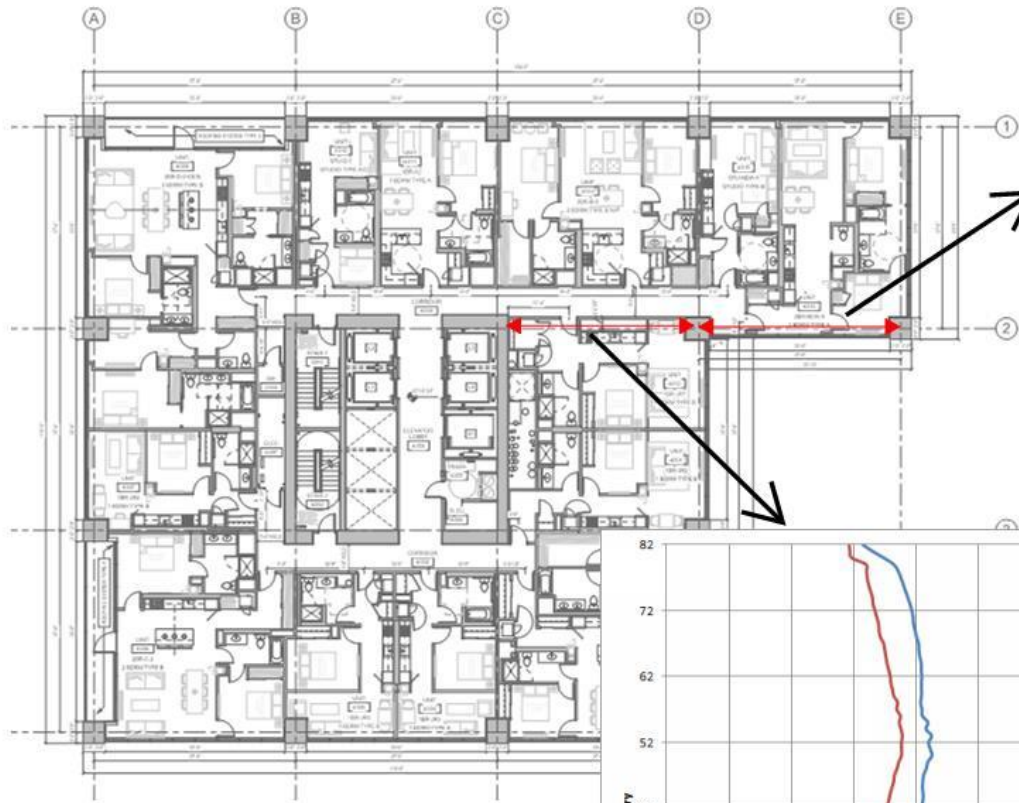
SEOR PREDICTED COLUMN SHORTENING

Longterm Movement-Sway under Gravity Load



Building sway toward SE direction due to unbalanced mass on two sides of the core.

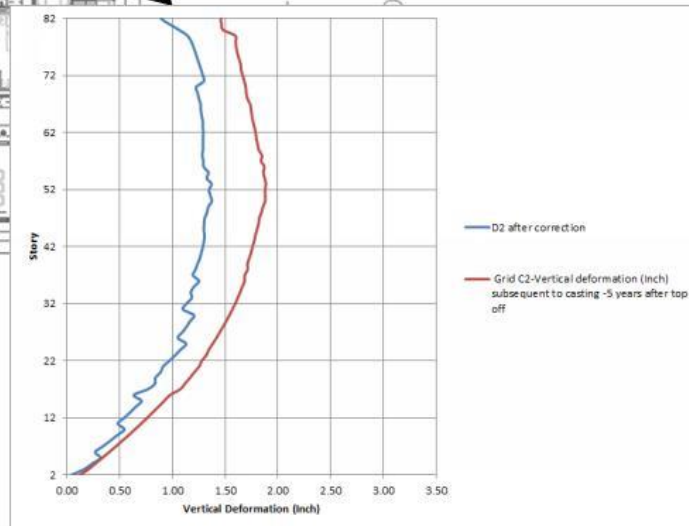
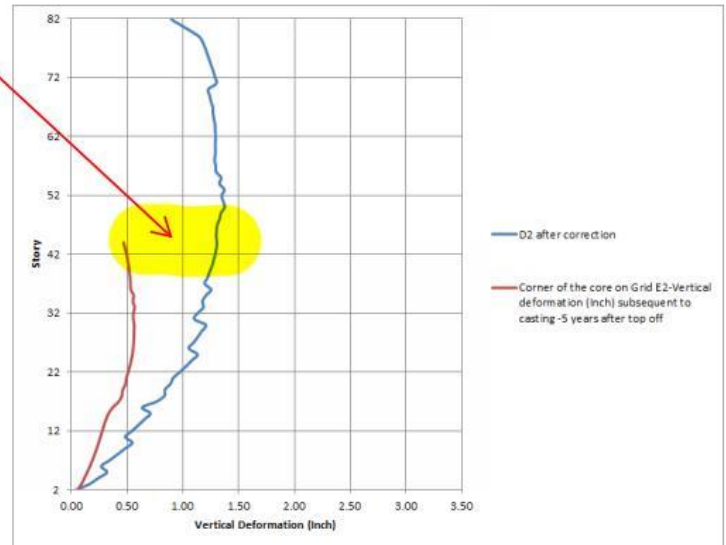
**1.5" DIFFERENTIAL
COLUMN SHORTENING IN
ONE BAY AT ONE FLOOR!**



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"

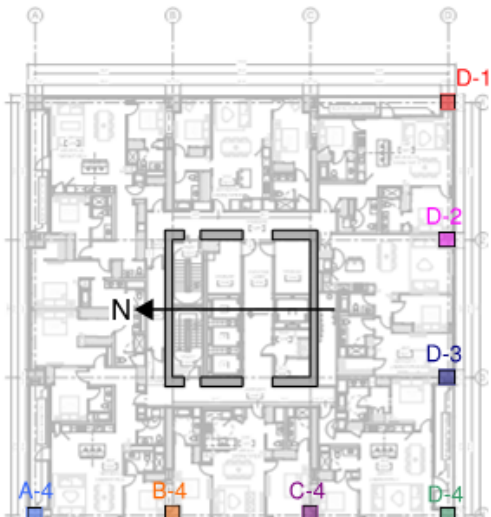


Longterm Staged Construction Analysis Results

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



COLUMN D-1

Column D1	Height (ft)	Area (sq ft)	Volume (cu ft)
157	587-6.314	2867-1	134
156	578-9.172	578-9.314	134
155	569-2.102	569-2.102	134
154	557-3	557-3.114	134
153	548-5.314	548-6	134
152	539-8.172	539-8.718	308
151	526-11.314	524-11.518	308
150	514-2	514-2.318	308
149	499-11	498-11.318	308
148	489-2	489-2.318	308
147	470-9.314	470-10.318	308
146	461-0.172	461-1	172
145	451-3.114	451-3.218	172
144	441-6	441-6.122	172
143	431-8.314	431-9.114	172
142	421-11	422-0	172
141	412-2.114	412-2.318	172
140	402-5	402-5.122	172
139	392-7.314	392-8.114	172
138	382-10.172	382-11	172
137	373-11.172	373-11.314	172
136	363-4	363-4.172	172
135	353-8.314	353-7.114	172
134	343-9.172	343-10	172
133	334-8.174	334-8.314	172
132	324-3	324-3.172	172
131	314-2.314	314-2.314	172
130	304-8.172	304-9	172
129	294-11.314	294-11.314	172
128	285-2	285-2.172	172
127	275-5.314	275-5.172	172
126	265-7.172	265-7.172	172
125	255-10.174	255-10.318	308
124	246-1	246-1.318	308
123	236-5.314	236-4.718	308
122	226-8.174	226-8.718	308
121	216-9.114	216-9.718	308
120	207-0	207-0.318	308
119	197-3.314	197-3.118	308
118	187-8.172	187-8.718	308
117	177-8.174	177-8.818	308
116	167-5.114	167-5.518	308
115	157-9	157-8.114	174
114	147-10.314	147-11	174
113	137-11.172	137-11.314	174
112	127-4.174	127-4.174	174
111	111-7	111-7.114	174
110	101-9.314	101-10	174
109	92-0.172	92-0.172	174
108	82-3.174	82-3.174	174
107	72-6	72-6.114	174
106	62-8.314	62-9	174
105	52-11.174	52-11.518	174
104	43-2.114	43-2.318	174
103	33-5	33-5.178	174
102	23-7.174	23-7.174	174
101	13-10.174	13-10.174	174
100	3-13.174	3-13.174	174

COLUMN D-2

Column D2	Height (ft)	Area (sq ft)	Volume (cu ft)
180	892-11	892-11.518	518
179	882-5	882-5.518	518
178	872-11.172	872-10	518
177	862-11.172	862-10	518
176	852-5.314	852-5.718	518
175	842-7.172	842-8	518
174	832-11.172	832-10	518
173	822-7.172	822-7.172	518
172	812-7.172	812-7.172	518
171	802-7.174	802-7.718	518
170	792-2.172	792-2.318	518
169	782-6.174	782-6.318	518
168	772-6.174	772-6.318	518
167	762-11.174	762-11.318	518
166	752-11.174	752-11.318	518
165	742-4.174	742-4.718	518
164	732-8	732-8.318	518
163	722-11.172	722-11.318	518
162	712-11.172	712-11.318	518
161	702-4.174	702-4.718	518
160	692-7.172	692-7.318	518
159	682-9.314	682-10.172	518
158	672-11.174	672-11.318	518
157	662-5.174	662-5.318	518
156	652-9.174	652-9.318	518
155	642-11.174	642-11.318	518
154	632-2.174	632-2.318	518
153	622-6.174	622-6.318	518
152	612-10.172	612-10.318	518
151	602-11.172	602-11.318	518
150	592-4.174	592-4.318	518
149	582-8.174	582-8.318	518
148	572-11.174	572-11.318	518
147	562-5.174	562-5.318	518
146	552-9.174	552-9.318	518
145	542-11.174	542-11.318	518
144	532-2.174	532-2.318	518
143	522-6.174	522-6.318	518
142	512-10.172	512-10.318	518
141	502-11.172	502-11.318	518
140	492-4.174	492-4.318	518
139	482-8.174	482-8.318	518
138	472-11.174	472-11.318	518
137	462-5.174	462-5.318	518
136	452-9.174	452-9.318	518
135	442-11.174	442-11.318	518
134	432-2.174	432-2.318	518
133	422-6.174	422-6.318	518
132	412-10.172	412-10.318	518
131	402-11.172	402-11.318	518
130	392-4.174	392-4.318	518
129	382-8.174	382-8.318	518
128	372-11.174	372-11.318	518
127	362-5.174	362-5.318	518
126	352-9.174	352-9.318	518
125	342-11.174	342-11.318	518
124	332-2.174	332-2.318	518
123	322-6.174	322-6.318	518
122	312-10.172	312-10.318	518
121	302-11.172	302-11.318	518
120	292-4.174	292-4.318	518
119	282-8.174	282-8.318	518
118	272-11.174	272-11.318	518
117	262-5.174	262-5.318	518
116	252-9.174	252-9.318	518
115	242-11.174	242-11.318	518
114	232-2.174	232-2.318	518
113	222-6.174	222-6.318	518
112	212-10.172	212-10.318	518
111	202-11.172	202-11.318	518
110	192-4.174	192-4.318	518
109	182-8.174	182-8.318	518
108	172-11.174	172-11.318	518
107	162-5.174	162-5.318	518
106	152-9.174	152-9.318	518
105	142-11.174	142-11.318	518
104	132-2.174	132-2.318	518
103	122-6.174	122-6.318	518
102	112-10.172	112-10.318	518
101	102-11.172	102-11.318	518
100	92-4.174	92-4.318	518

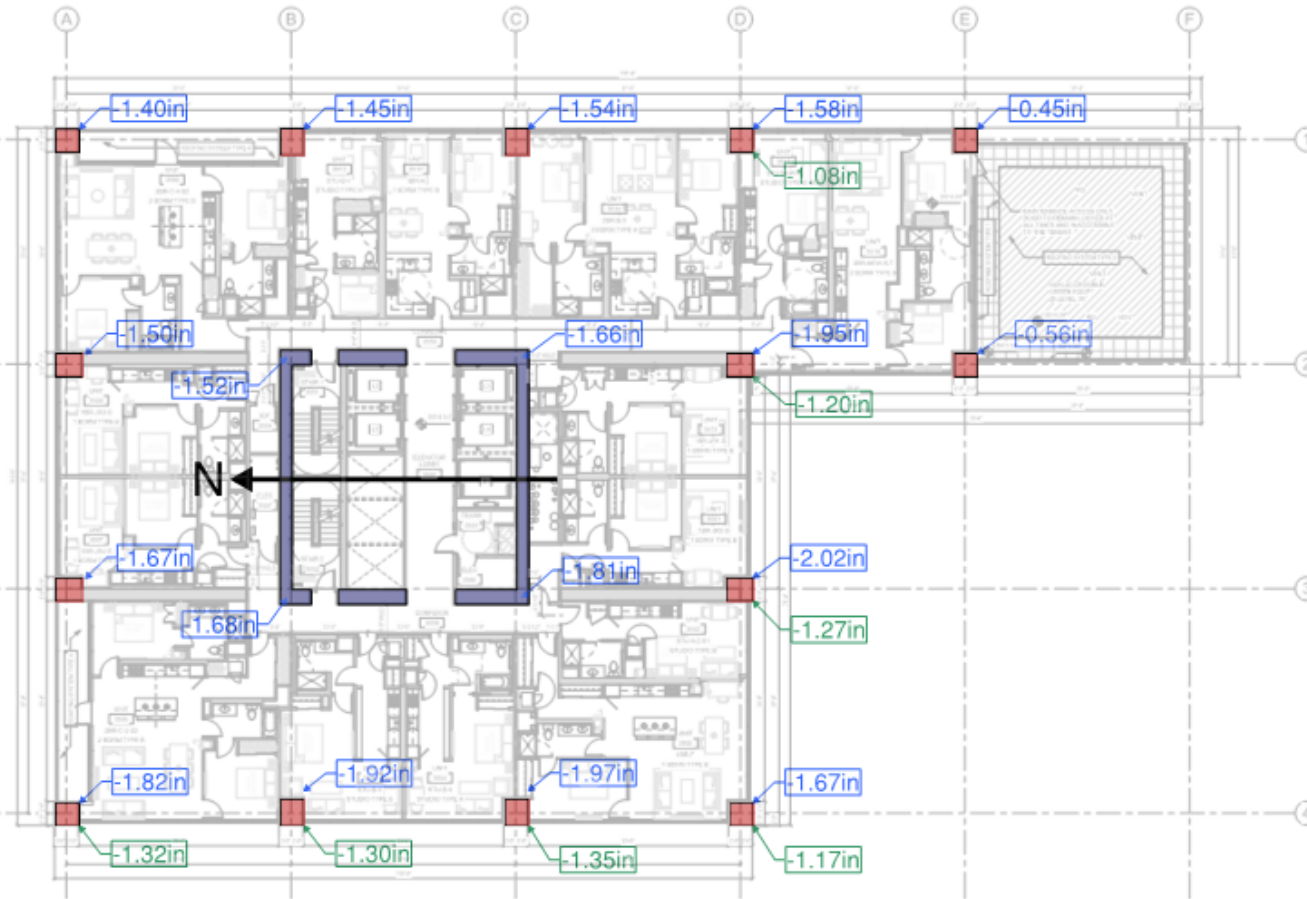
COLUMN D-3

Column D3	Height (ft)	Area (sq ft)	Volume (cu ft)
180	892-11	892-11.172	172
179	882-5	882-5.172	172
178	872-11.172	872-10	172
177	862-11.172	862-10	172
176	852-5.314	852-5.172	172
175	842-7.172	842-8	172
174	832-11.172	832-10	172
173	822-7.172	822-7	172
172	812-7.172	812-7	172
171	802-7.174	802-7.318	172
170	792-2.172	792-2.318	172
169	782-6.174	782-6.318	172
168	772-6.174	772-6.318	172
167	762-11.174	762-11.318	172
166	752-11.174	752-11.318	172
165	742-4.174	742-4.718	172
164	732-8	732-8.318	172
163	722-11.172	722-11.318	172
162	712-11.172	712-11.318	172
161	702-4.174	702-4.718	172
160	692-7.172	692-7.318	172
159	682-9.314	682-10.172	172
158	672-11.174	672-11.318	172
157	662-5.174	662-5.318	172
156	652-9.174	652-9.318	172
155	642-11.174	642-11.318	172
154	632-2.174	632-2.318	172
153	622-6.174	622-6.318	172
152	612-10.172	612-10.318	172
151	602-11.172	602-11.318	172
150	592-4.174	592-4.318	172
149	582-8.174	582-8.318	172
148	572-11.174	572-11.318	172
147	562-5.174	562-5.318	172
146	552-9.174	552-9.318	172
145	542-11.174	542-11.318	172
144	532-2.174	532-2.318	172
143	522-6.174	522-6.318	172
142	512-10.172	512-10.318	172
141	502-11.172	502-11.318	172
140	492-4.174	492-4.318	172
139	482-8.174	482-8.318	172
138	472-11.174	472-11.318	172
137	462-5.174	462-5.318	172
136	452-9.174	452-9.318	172
135	442-11.174	442-11.318	172
134	432-2.174	432-2.318	172
133	422-6.174	422-6.318	172
132	412-10.172	412-10.318	172
131	402-11.172	402-11.318	172
130	392-4.174	392-4.318	172
129	382-8.174	382-8.318	172
128	372-11.174	372-11.318	172
127	362-5.174	362-5.318	172
126	352-9.174	352-9.318	172
125	342-11.174	342-11.318	172
124	332-2.174	332-2.318	172
123	322-6.174	322-6.318	172
122	312-10.172	312-10.318	172
121	302-11.172	302-11.318	172
120	292-4.174	292-4.318	172
119	282-8.174	282-8.318	172
118	272-11.174	272-11.318	172
117	262-5.174	262-5.318	172
116	252-9.174	252-9.318	172
115	242-11.174	242-11.318	172
114	232-2.174	232-2.318	172
113	222-6.174	222-6.318	172
112	212-10.172	212-10.318	172
111	202-11.172	202-11.318	172
110	192-4.174	192-4.318	172
109	182-8.174	182-8.318	172
108	172-11.174	172-11.318	172
107	162-5.174	162-5.318	172
106	152-9.174	152-9.318	172
105	142-11.174	142-11.318	172
104	132-2.174	132-2.318	172
103	122-6.174	122-6.318	172
102	112-10.172	112-10.318	172
101	102-11.172	102-11.318	172
100	92-4.174	92-4.318	172

COLUMN D-4

Column D4	Height (ft)	Area (sq ft)	Volume (cu ft)
174	794-2.172	794-2.318	308
173	784-5.174	784-5.318	308
172	774-8.176	774-8.318	308
171	764-11.178	764-11.318	308
170	754-14.180	754-14.318	308
169	744-17.182	744-17.318	308
168	734-20.184	734-20.318	308
167	724-23.186	724-23.318	308
166	714-26.188	714-26.318	308
165	704-29.190	704-29.318	308
164	694-32.192	694-32.318	308
163	684-35.194	684-35.318	308
162	674-38.196	674-38.318	308
161	664-41.198	664-41.318	308
160	654-44.200	654-44.318	308
159	644-47.202	644-47.318	308
158	634-50.204	634-50.318	308
157	624-53.206	624-53.	

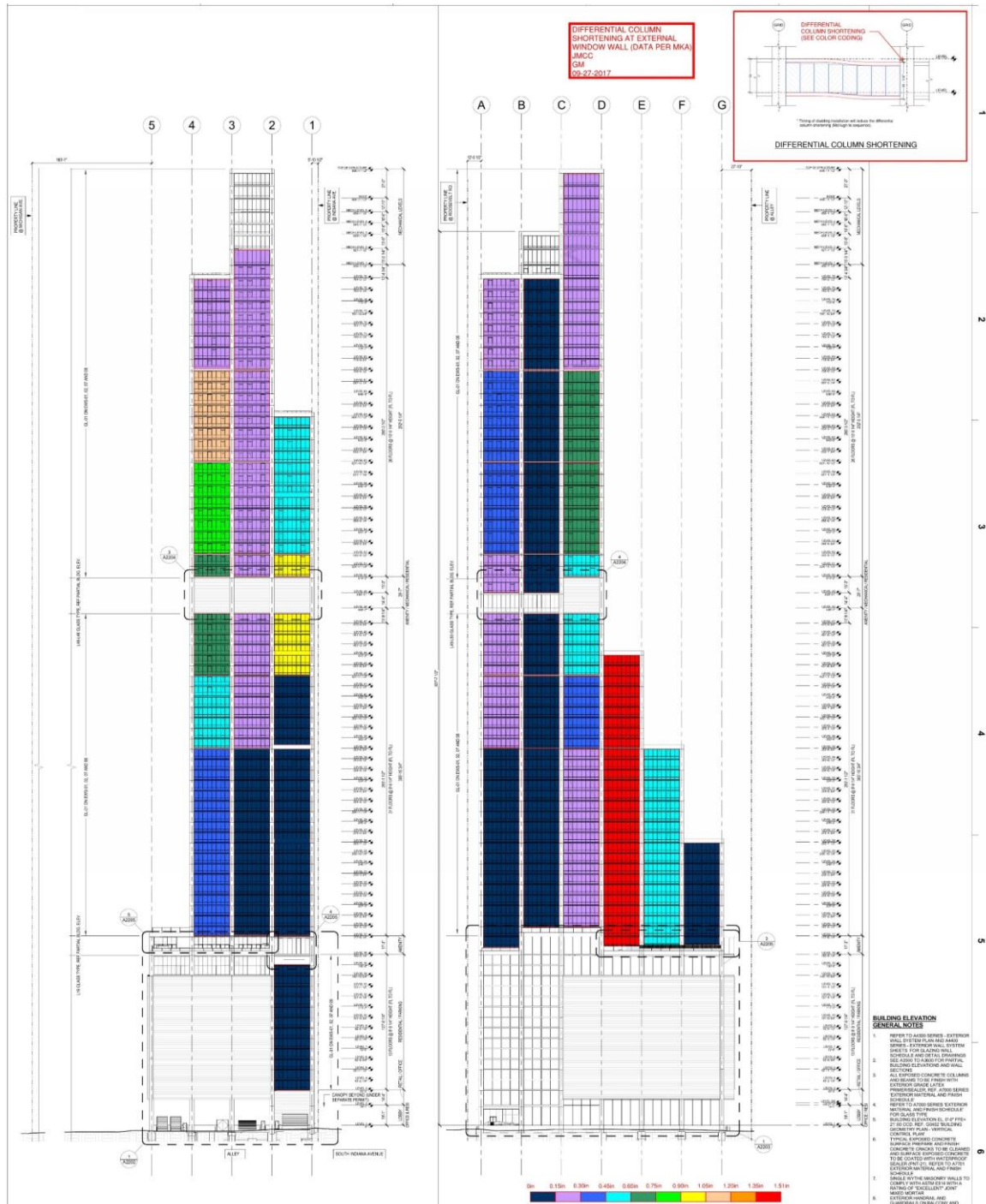
Level 35



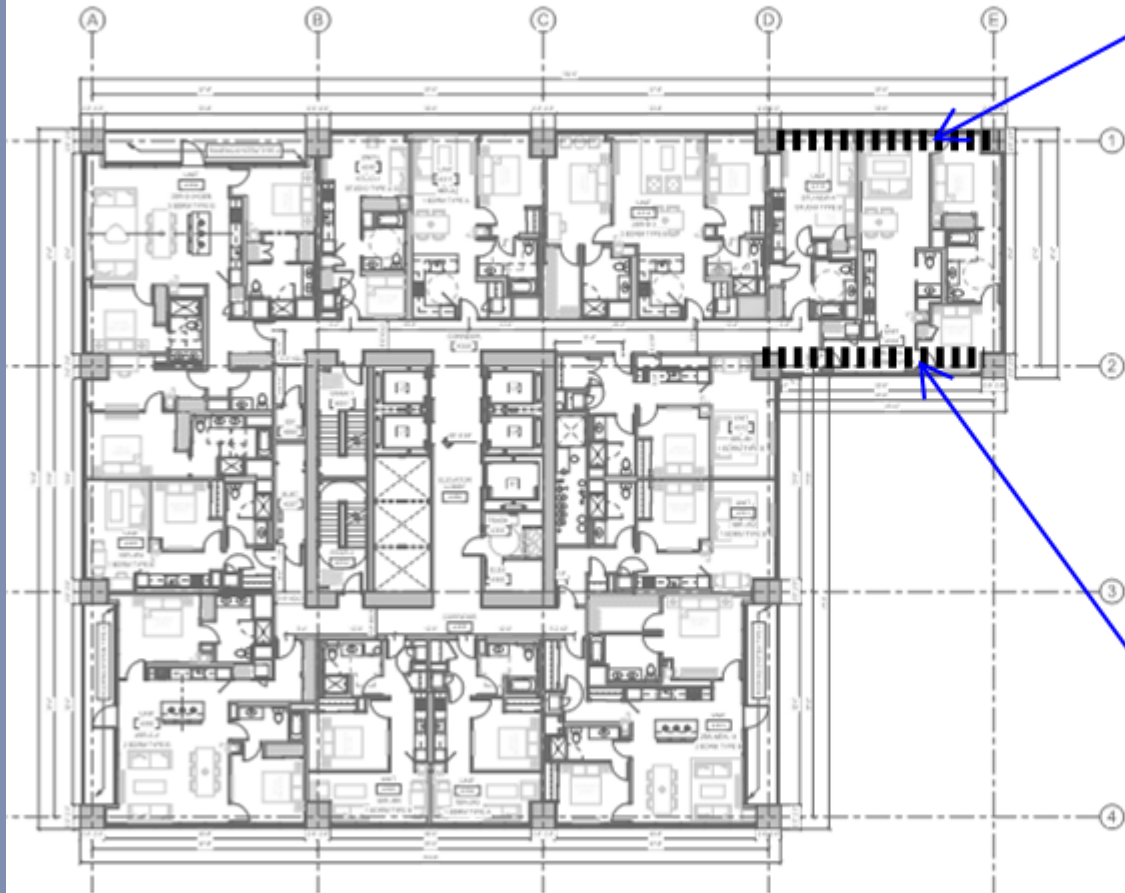
↳ XXin Represents deformation after camber.
Note: L/X values determined using corrected deformation after camber

Long Term Deformation
Subsequent to Casting
Level 35

Differential column shortening



LONGTERM MOVEMENT-CLADDING EXTRA CARE



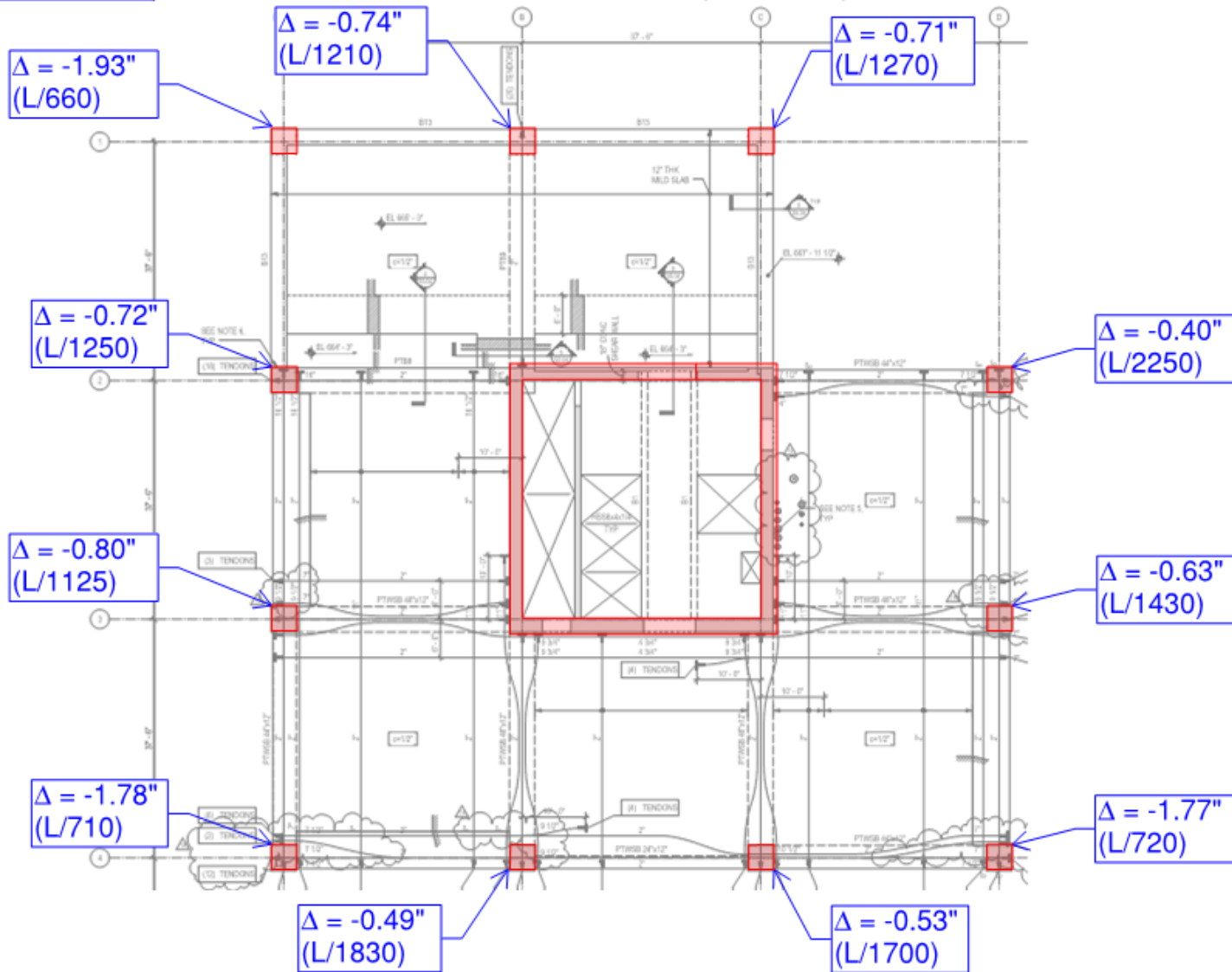
Allow 1-1/2" movement over 37'-6" span

Allow 1" movement over 37'-6" span

SEOR PREDICTED THERMAL MOVEMENTS

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

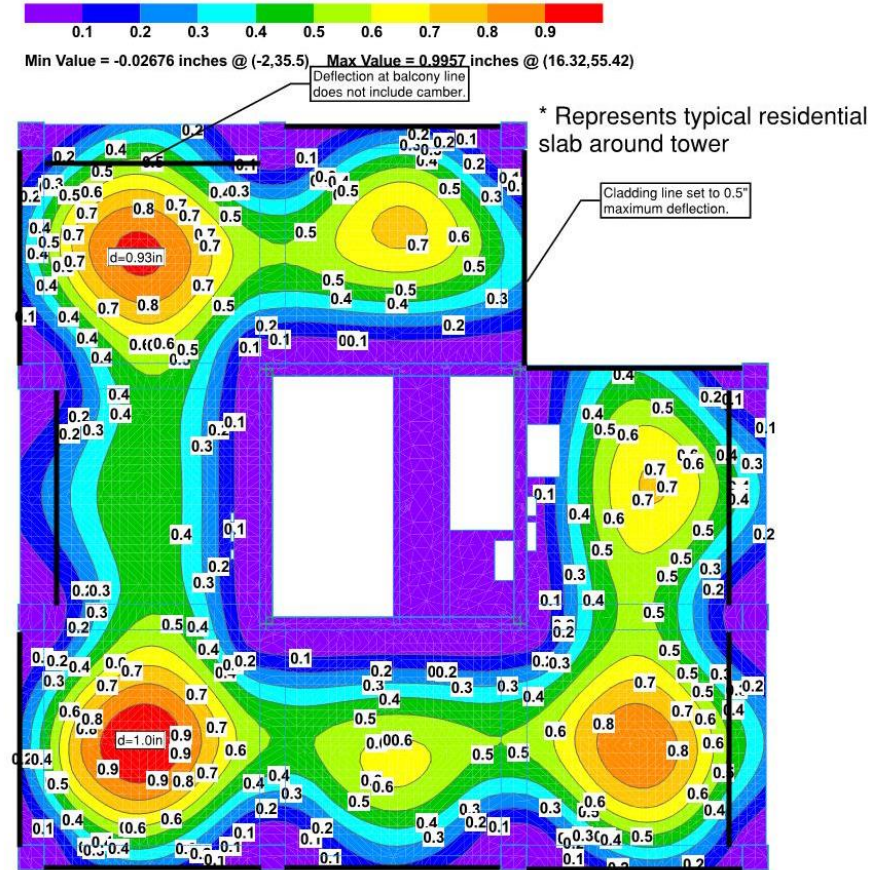
**SERVICE MODEL (TSD) - LEVEL 64 COLUMN DEFLECTIONS
RELATIVE TO CORE (-62.5 DEG)**



SEOR PREDICTED SLAB DEFLECTIONS

Levels58-63.cpt - 2/27/2017

Levels 58-63: Typical Tower Floor

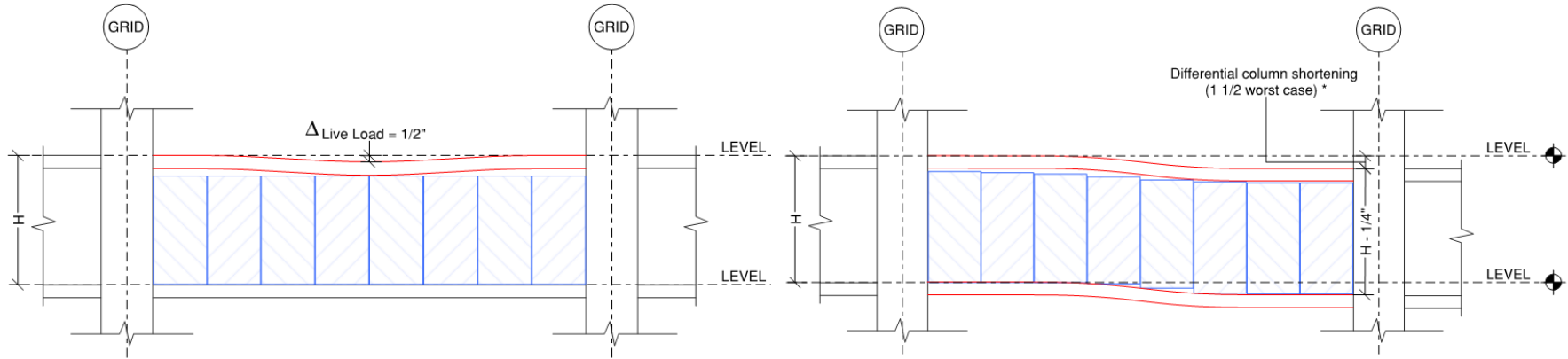


MAXIMUM LONG TERM DEFLECTION MINUS SELF WEIGHT

-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.

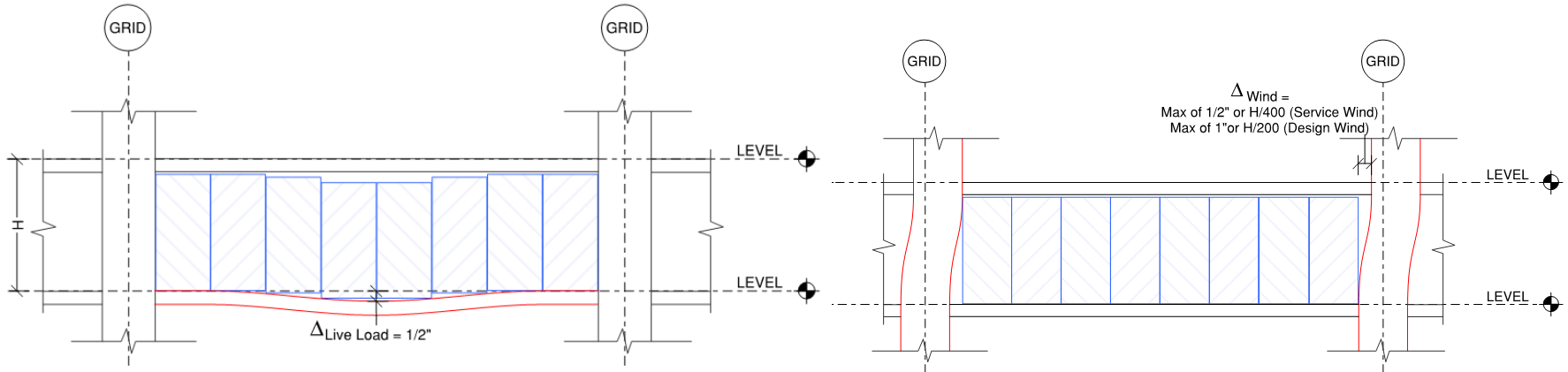
Building Deformation Problems



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

LIVE LOAD DEFLECTION - TYPE 1

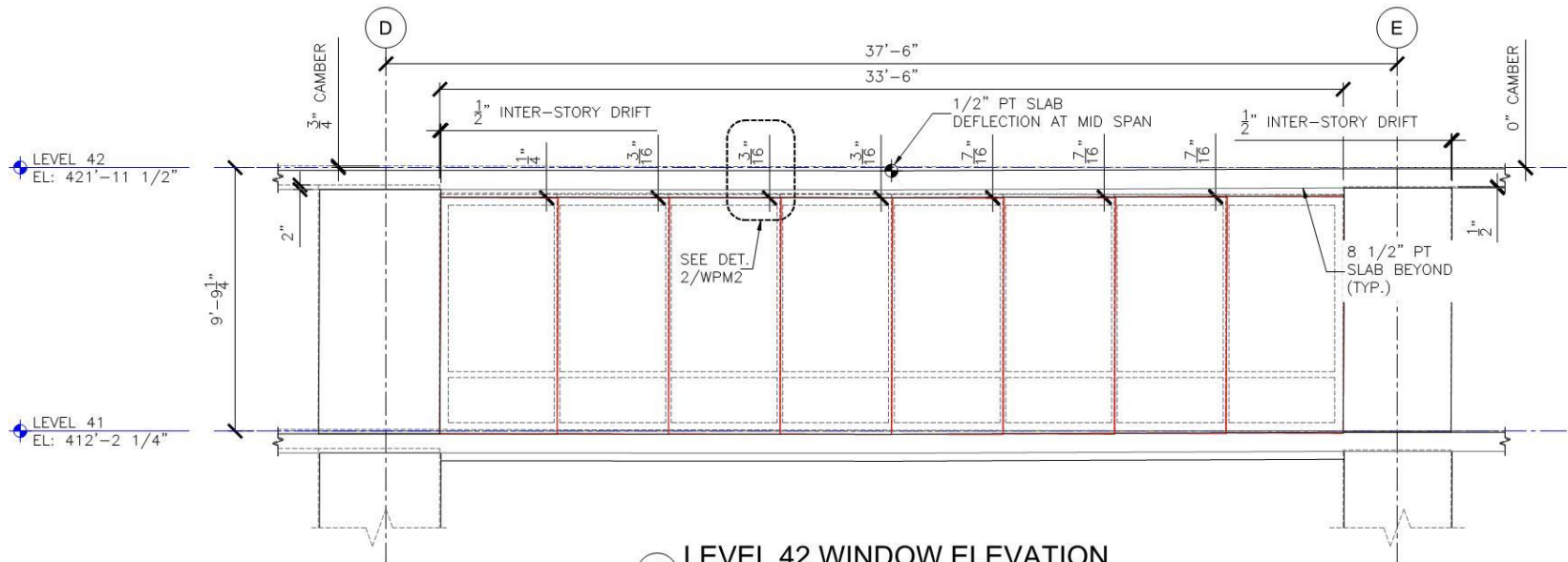
DIFFERENTIAL COLUMN SHORTENING



LIVE LOAD DEFLECTION - TYPE 2

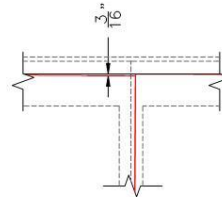
INTERSTORY WIND DRIFT

Building Deformation Problems



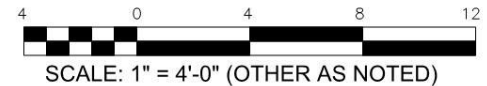
1 LEVEL 42 WINDOW ELEVATION

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



2 DETAIL

SCALE: 1" = 1'-0"



GENERAL NOTES:

- DEFLECTED SHAPE OF LEVEL 42 WINDOW WALL ON GRID LINE 2 AND BETWEEN D & E CONSIDERS:
 - COLUMN DEFLECTION AT LEVEL 42 AS PER MKA
 - COLUMN SHORTENING PER STORY
 - MAX. SLAB DEFLECTION OF 0.5" AT CLADDING LINE, PER MKA
 - MAX. LATERAL INTER-STORY DRIFT OF 0.5" PER MKA
- 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

McHUGH

WINDOW PANEL MOVEMENT

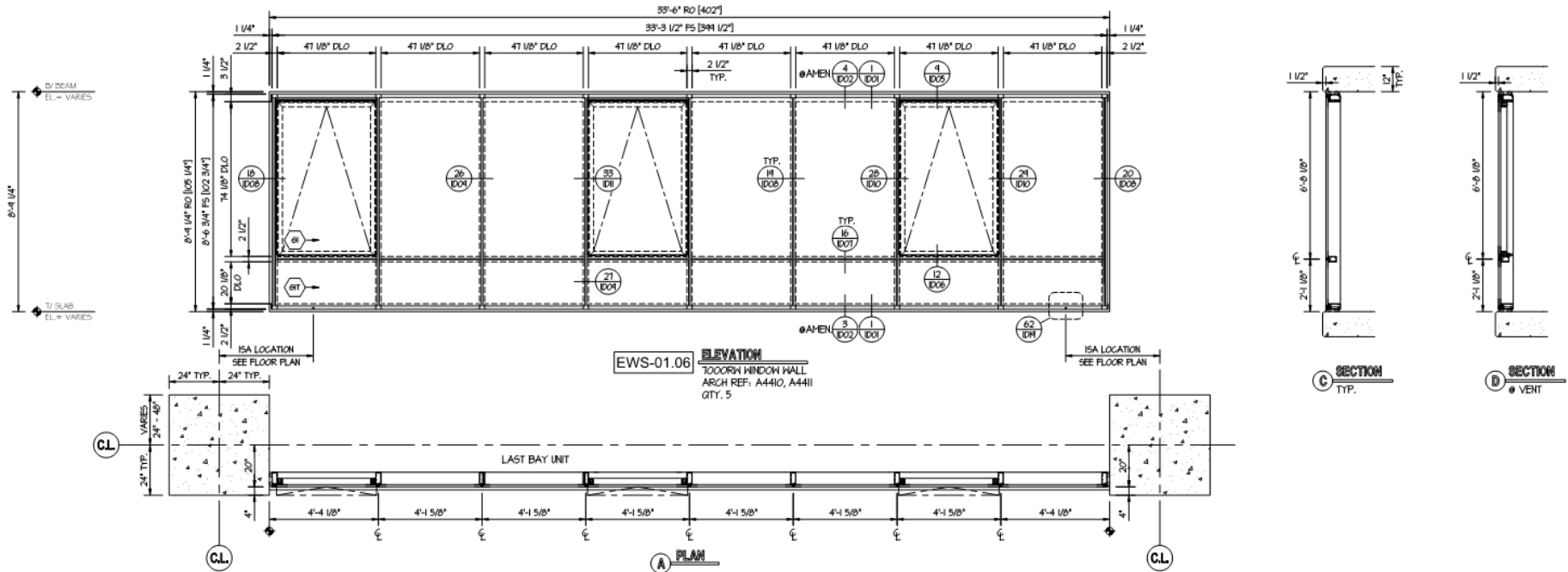
1200 S. INDIANA AVE. CHICAGO, ILLINOIS

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

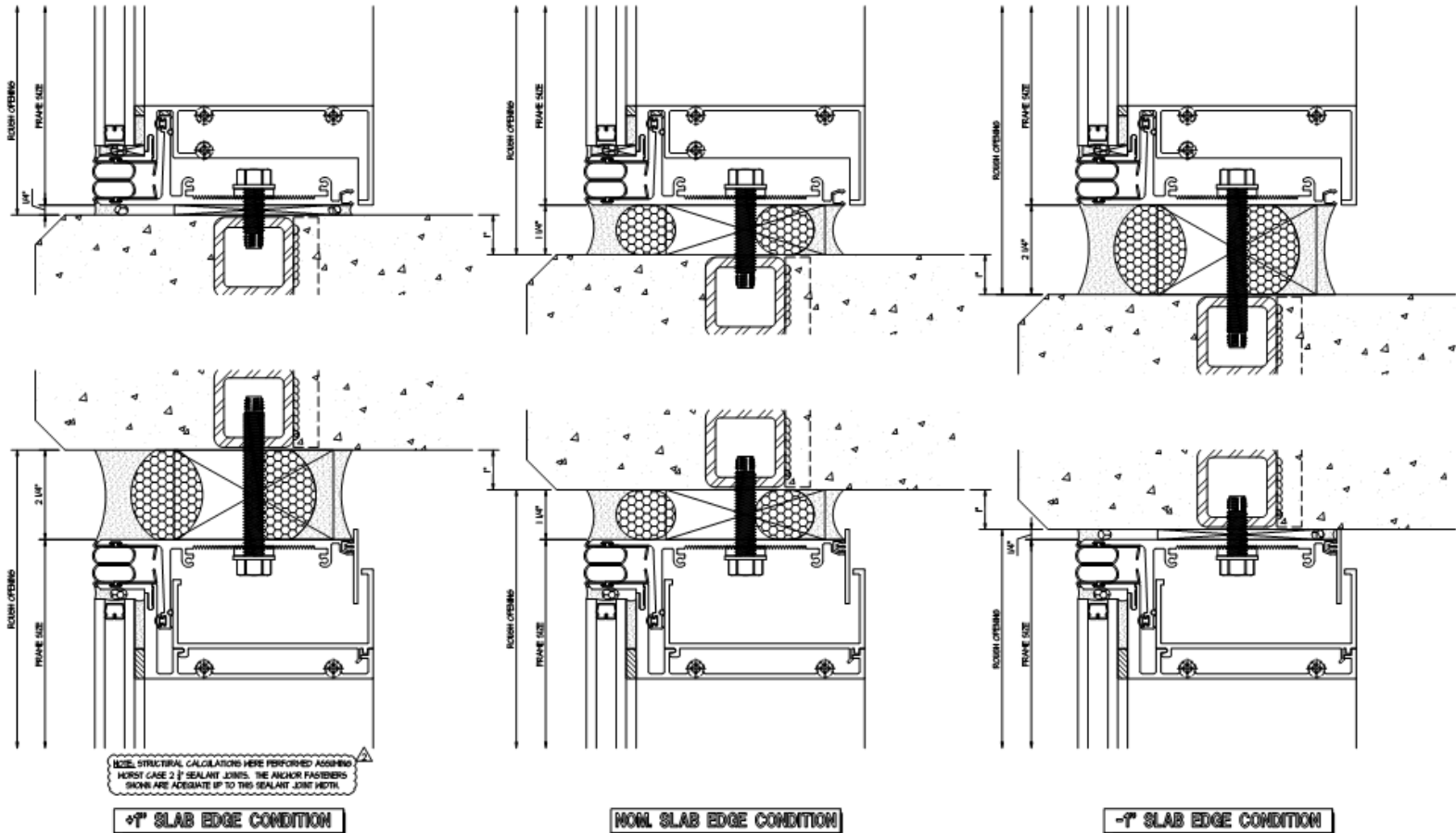


CONSTRUCTION TOLERANCE OF +/-1"

ENTEKK WINDOW WALL SYSTEM VERTICAL CONCRETE SLAB CONSTRUCTION TOLERANCE

△ SEEKS AND PROJECT SPECIFIC
ANCHORS ADDED FOR CLARITY

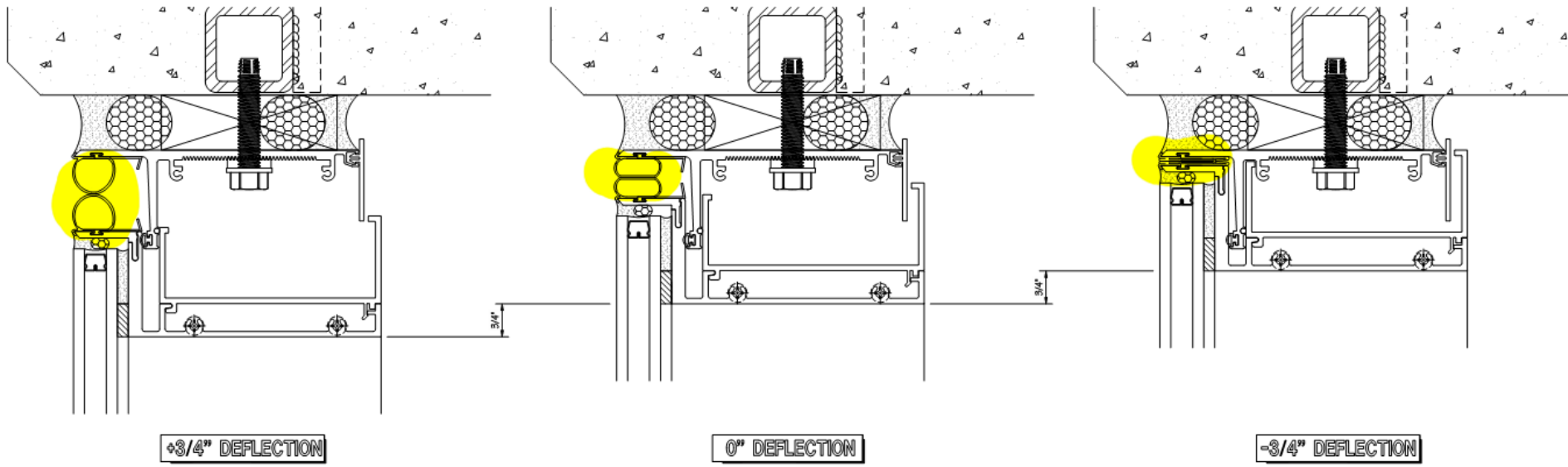
NOTE: STRUCTURAL CALCULATIONS WERE PERFORMED ASSUMING
WORST CASE 2" SEALANT JOINTS. THE ANCHOR FASTENERS
SHOWN ARE ADEQUATE UP TO THIS SEALANT JOINT WIDTH.



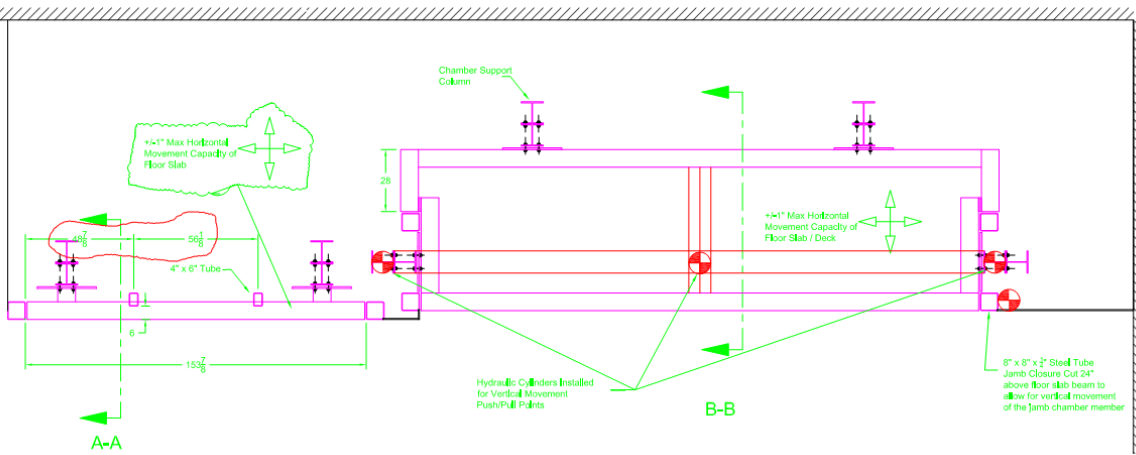
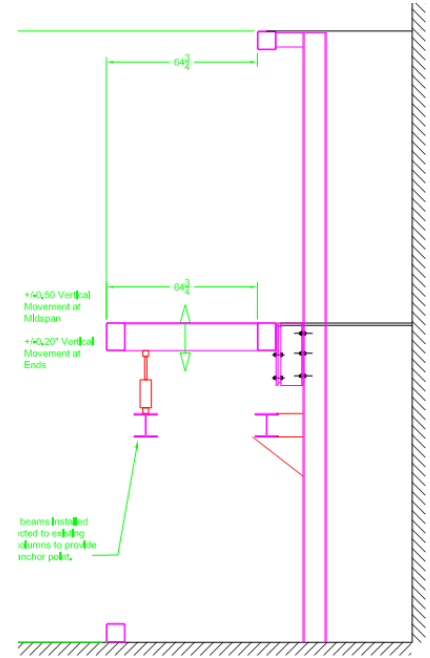
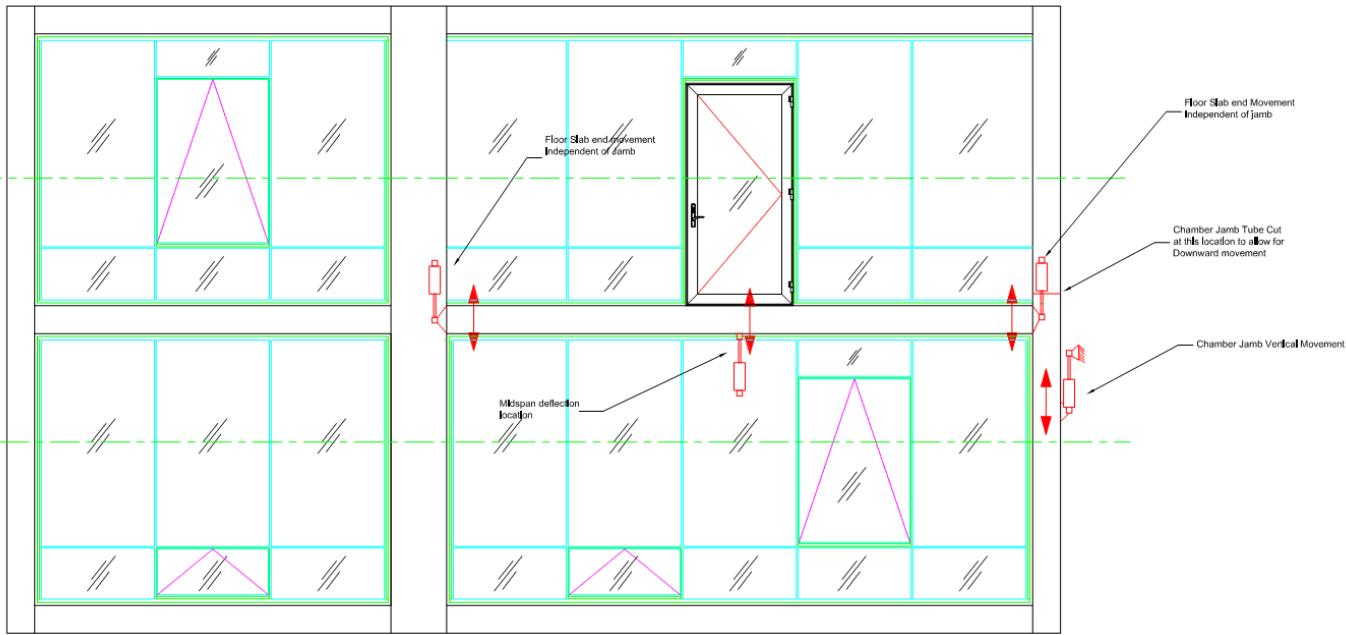
VERTICAL LIVE LOAD DEFLECTION

ENTEKK WINDOW WALL SYSTEM VERTICAL LIVE LOAD DEFLECTION TOLERANCE

△ SPEEDS AND PROJECT S
ANCHORING ADDED FOR



WINDOW TESTING



Mid Level Plan

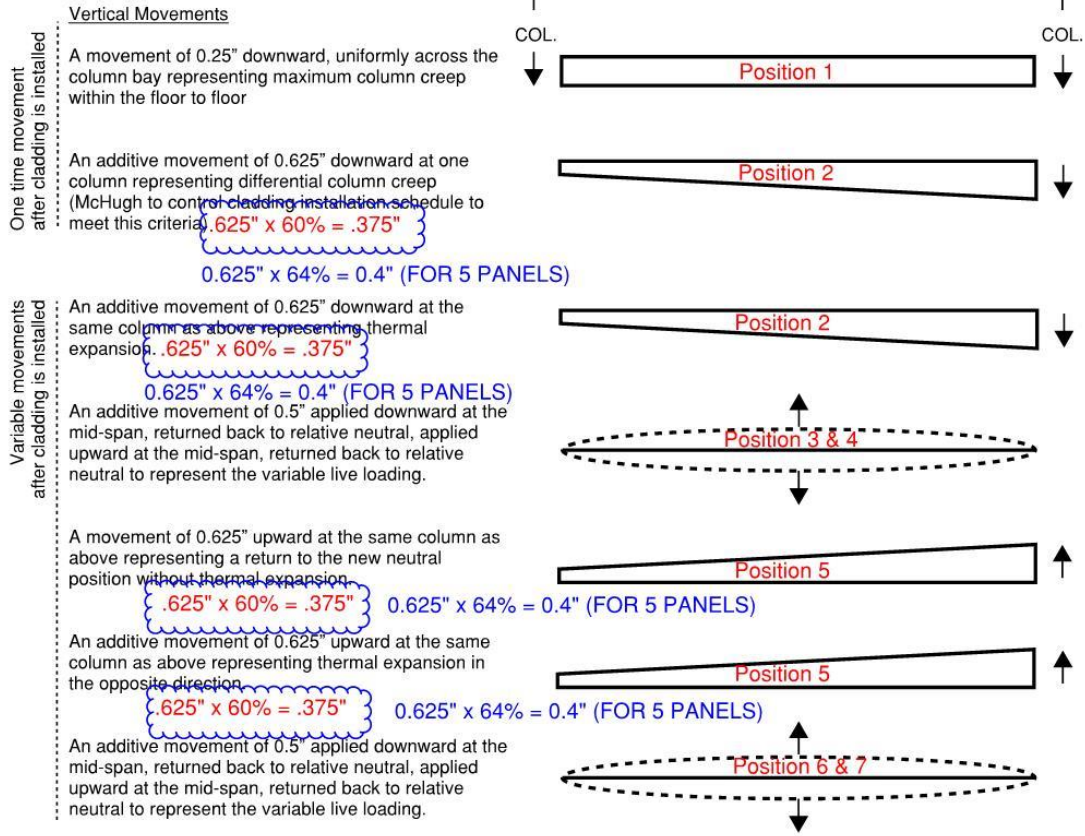
WINDOW TESTING

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

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

Total length of 5 test panels
 Actual length of 8 panels between columns

Clear Between Columns
 33'-6"



Lateral movements:

Service level lateral inner-story wind drift: maximum of 1/2" either direction (remains water tight and without damage)

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

JMCC MARK-UP
 10-05-2017

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

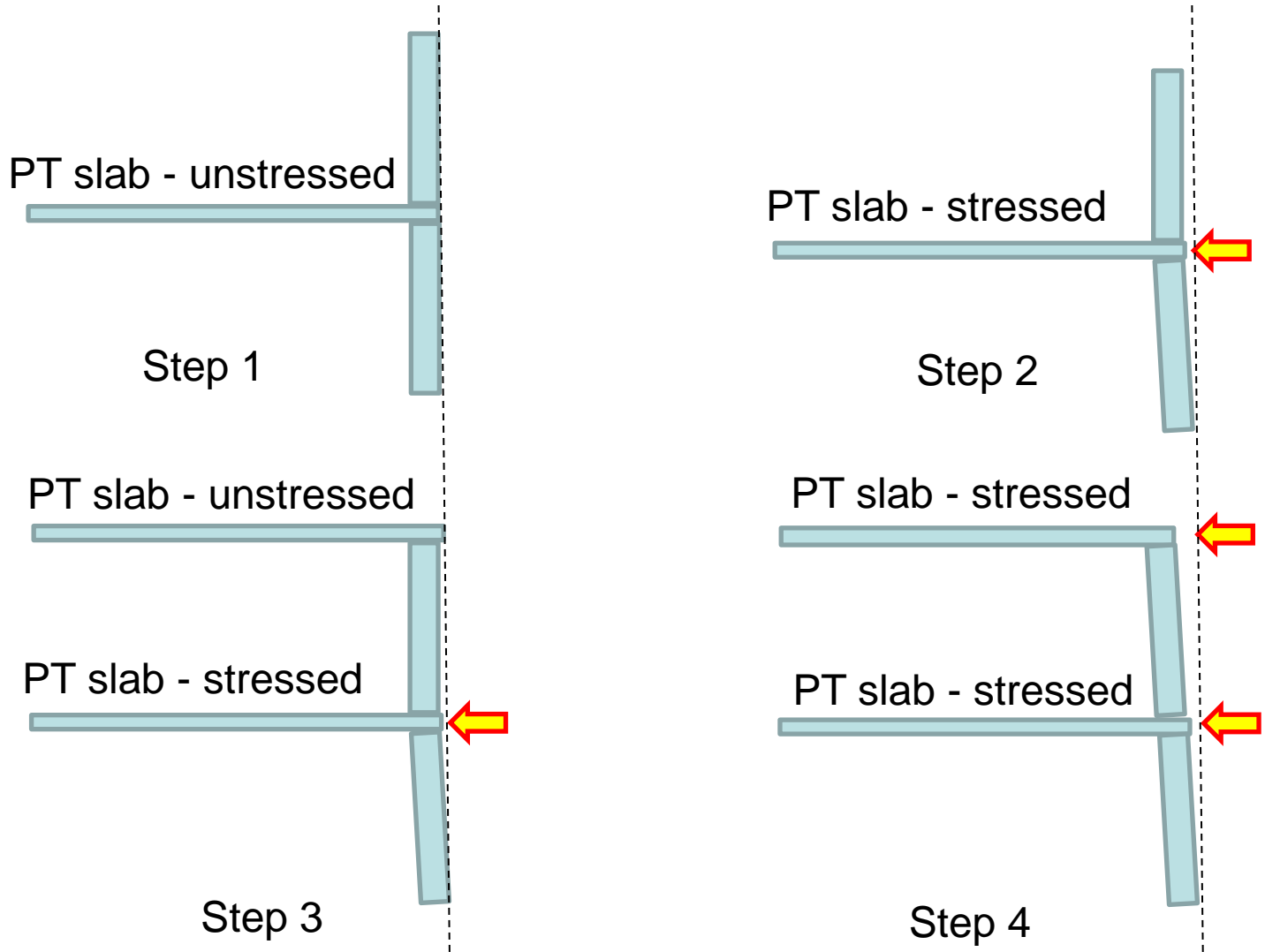
WINDOW FRAMES HIGHLIGHT SLAB SHORTENING ISSUES

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

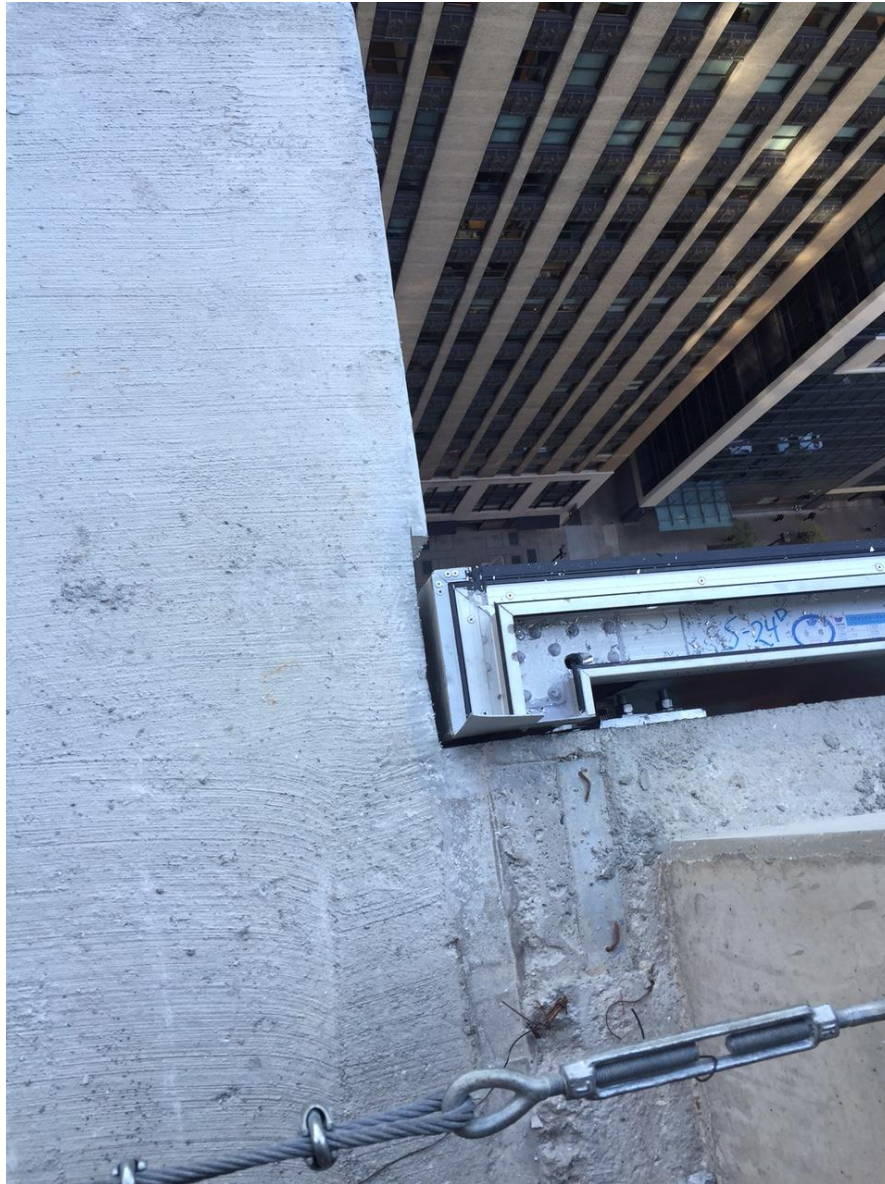
Displaced & Leaning Columns



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®

Guide for Tolerance
Compatibility in Concrete
Construction

Reported by ACI Committee 117

ACI 117.1R-14



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!!

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