abaa2024 building enclosure conference

Buildings Move, Buildings Leak:

Revisiting the Critical Link Between Engineering Mechanics and Enclosure Performance

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AIA Continuing Education Provider

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Buildings Move, Buildings Leak:

Revisiting the Critical Link Between Engineering Mechanics and Enclosure Performance

"Systems thinking" is a term that is discussed at times in Building Science. But what if systems thinking asks us to consider more factors in the long term viability of enclosure integrity? While the relationship between structural movement and a structure's usefulness to its intended purpose has been well developed throughout the history of design and construction, that understanding has not always translated well into satisfactory enclosure performance.

Drawing on experiences in post-construction forensic investigations, troubleshooting during construction, and efforts to influence design detailing, this presentation will discuss key factors in applying engineering mechanics for the benefit (or detriment) of enclosure performance. Specific aspects to be shared will include the cross-party dynamics in design and construction that give rise to current challenges, case studies of failures as a result of insufficient consideration, and areas for improvement across the design and construction industry.

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Learning Objectives

1. Participants will develop a better understanding of the relationship between movement of materials and enclosure integrity.
2. Participants will gain perspective around what should be considered minimum baseline requirements for performance specifications particular to accommodating movement.
3. Participants will learn about case studies where enclosure systems were compromised or even failed as a result of limited awareness around building movement.
4. Participants will see examples that reinforce the connection between effective project collaboration and desired performance of the enclosure.

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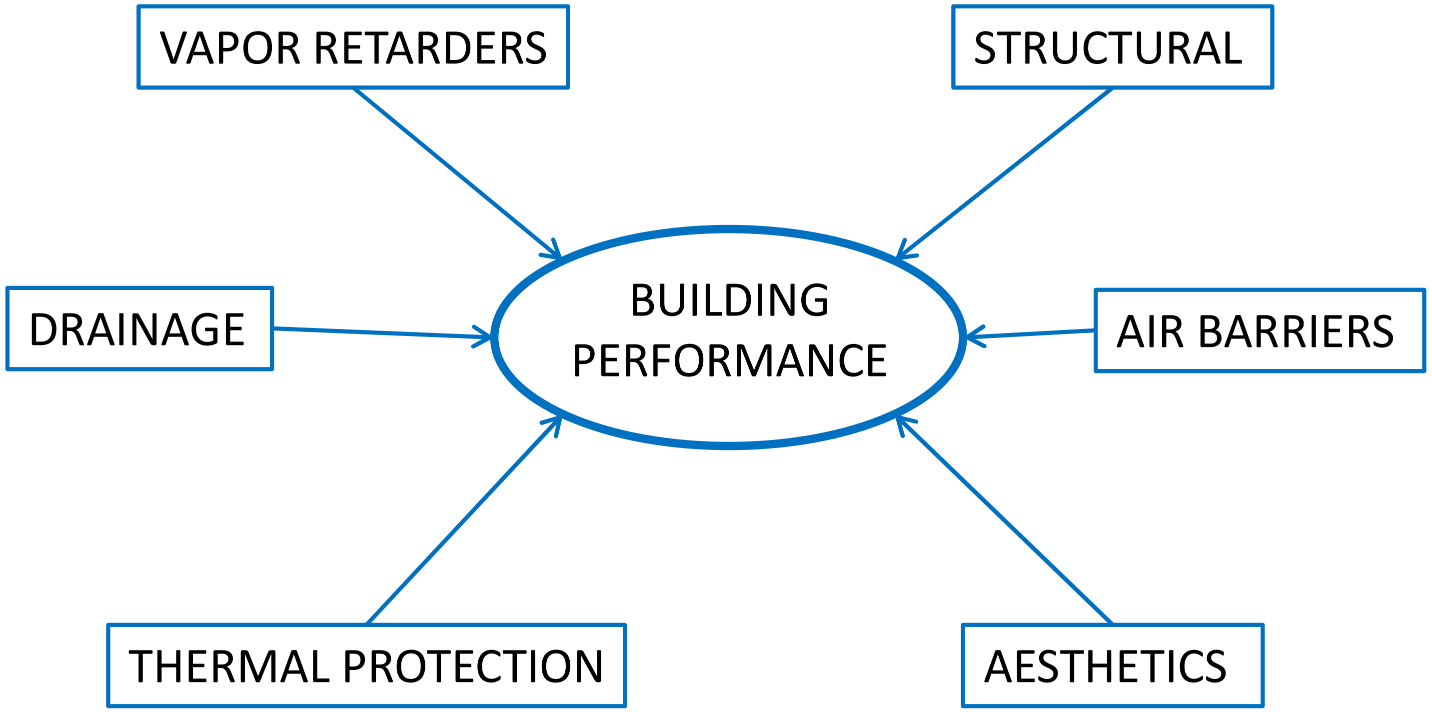
Buildings Move, Buildings Leak

- Agenda
  - Introduction/Topic Overview
  - Structural Principles
  - Process Gaps
  - Case Studies
  - Recommendations/Conclusions

Buildings Move, Buildings Leak

- Topic Overview, or "Why are we Here?"



SYSTEMS THINKING???

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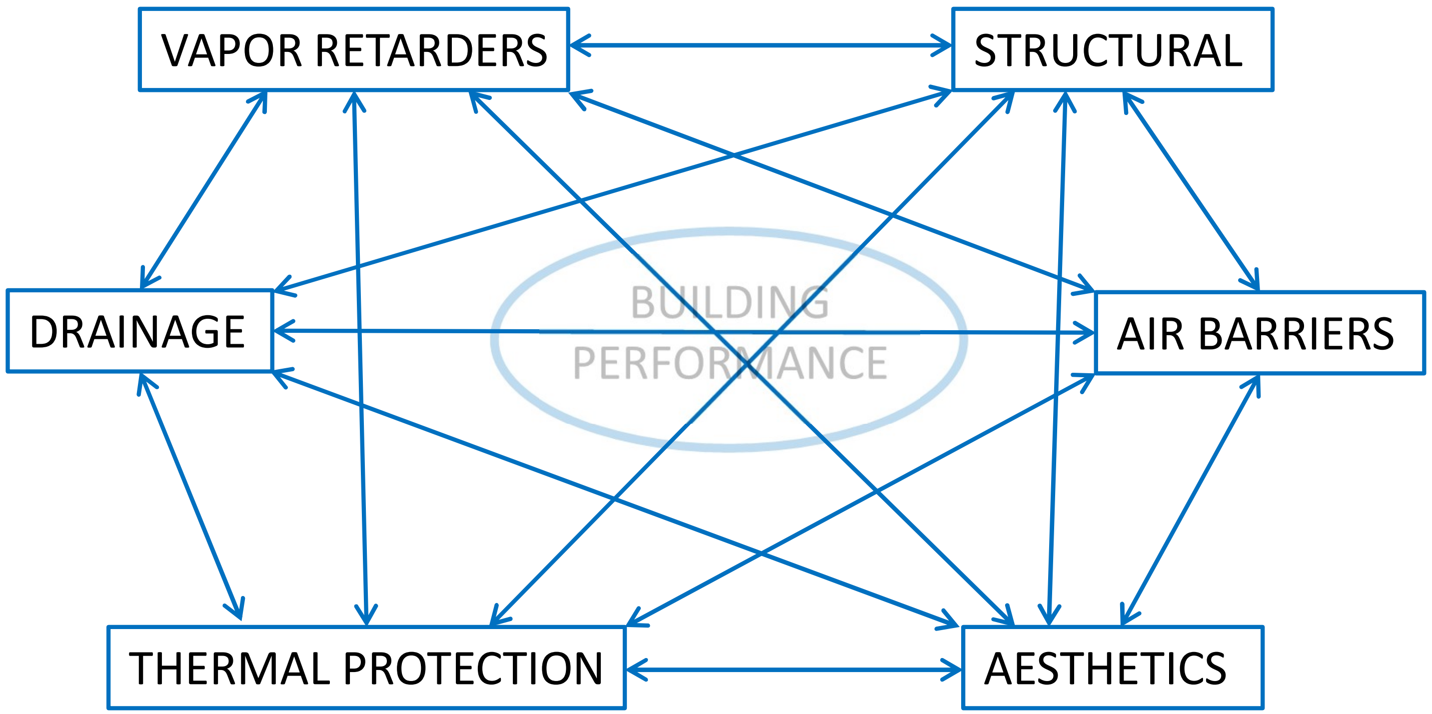
- Topic Overview, or "Why are we Here?"



SYSTEMS THINKING!!!

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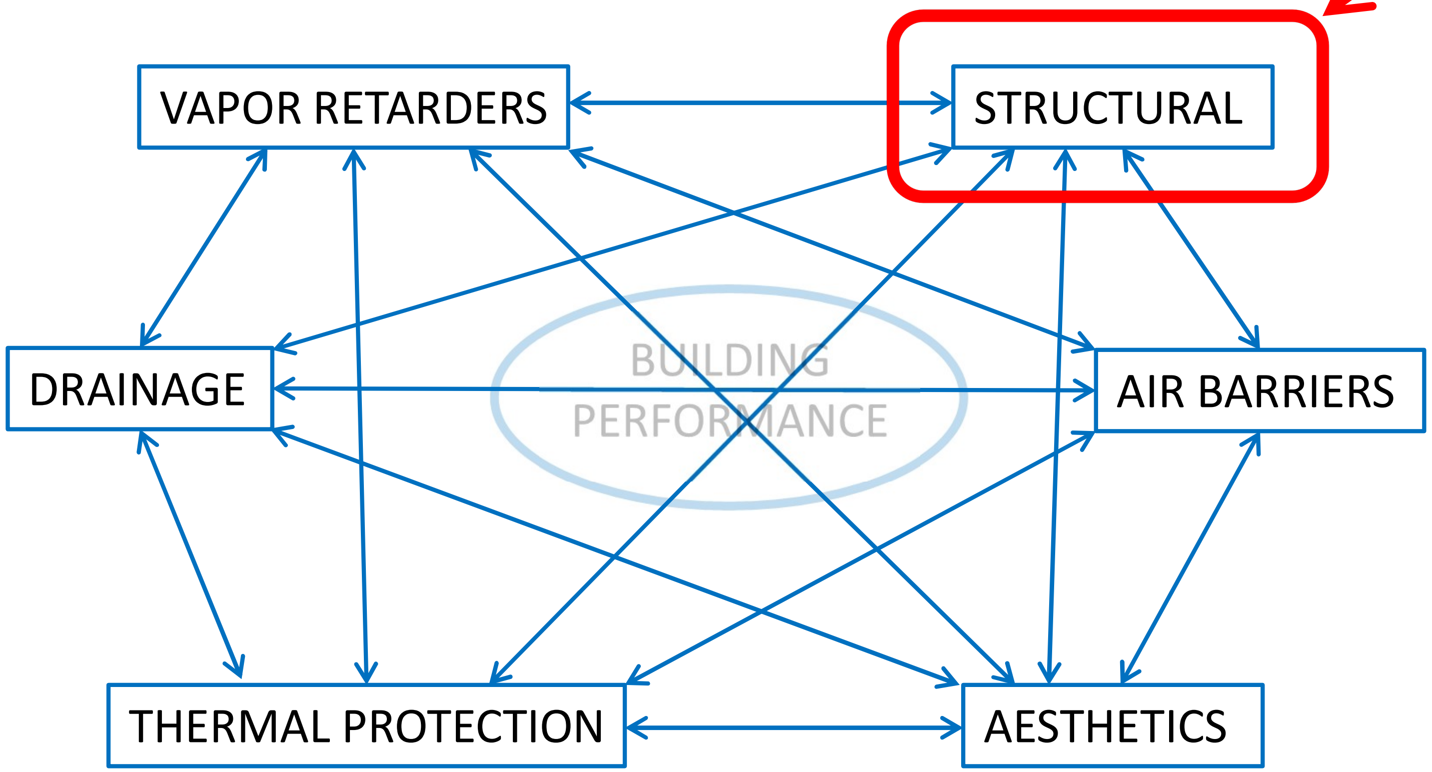
- Topic Overview, or “Why are we Here?”

THIS NEEDS TO BE CONSIDERED TOO!



SYSTEMS THINKING!!!

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- Topic Overview, or “Why are we Here?”

  - Conventional Paradigm of Systems Thinking: Being concerned that inadequate consideration of enclosure control layers will result in a compromised structure.

  - Broader Paradigm of Systems Thinking: What if inadequate consideration of structural movement (and engineering mechanics movement in general) results in compromised control layers?

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- Topic Overview, or "Why are we Here?"
  - *One of the more significant functional aspects that regularly receives inadequate consideration in the design and construction of building enclosures are structural and movement effects on the building enclosure itself*

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- Structural Loadings and Engineering Mechanics 101
(don't worry – we will keep it brief!)
    - Structural Engineering: Design/Analysis of the Bones and Joints
    - Engineering Mechanics: Study of behavior of materials based on
        - Properties of the Material
        - Forces applied to the Material

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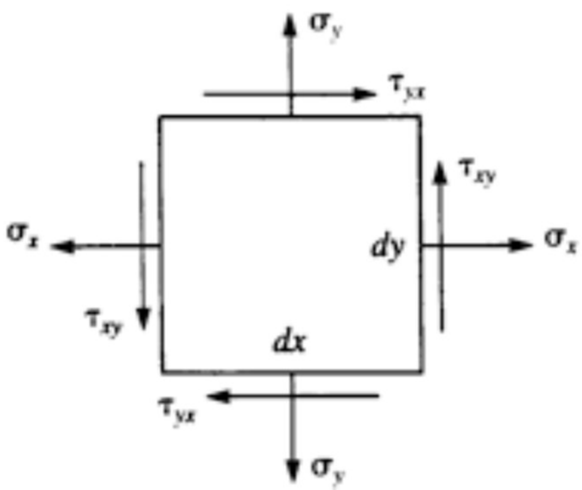
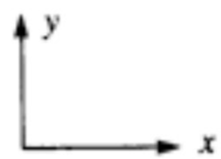
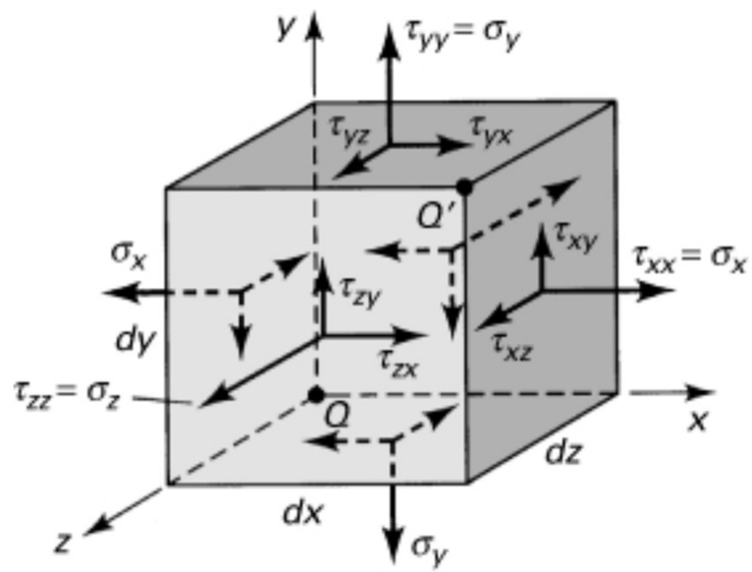
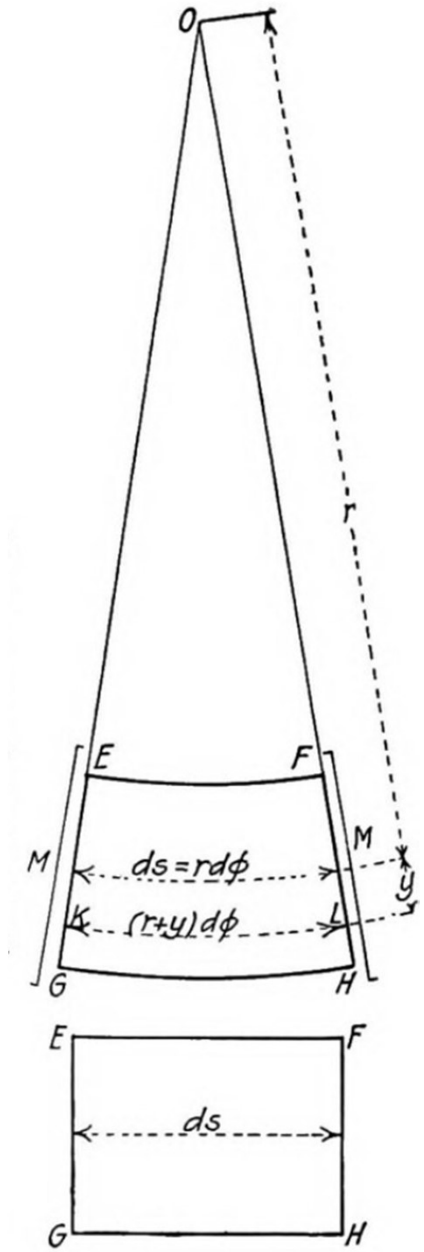
- **Structural Loadings and Engineering Mechanics 101**









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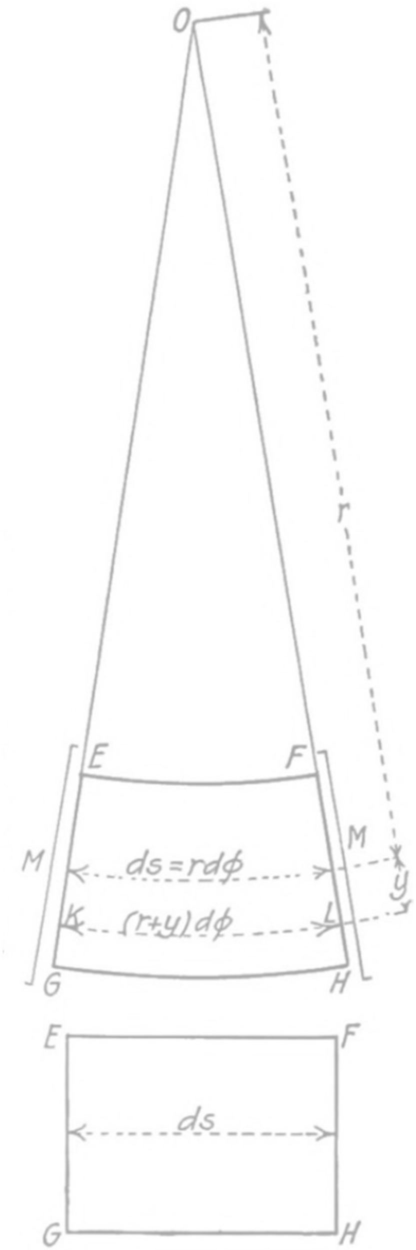
- Structural Loadings and Engineering Mechanics 101

- Loads ➔ Material Stresses ➔ Deformations

- Cumulative incremental deformations result in movement on a larger scale, exhibited as
  - Deflections/Displacements/Sway
  - Shortening/Elongation



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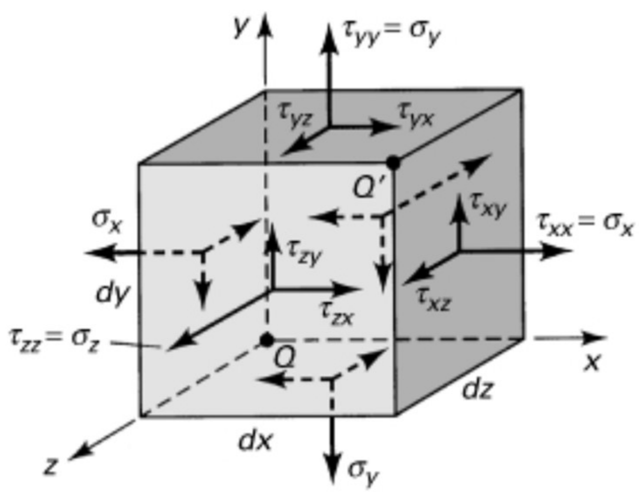
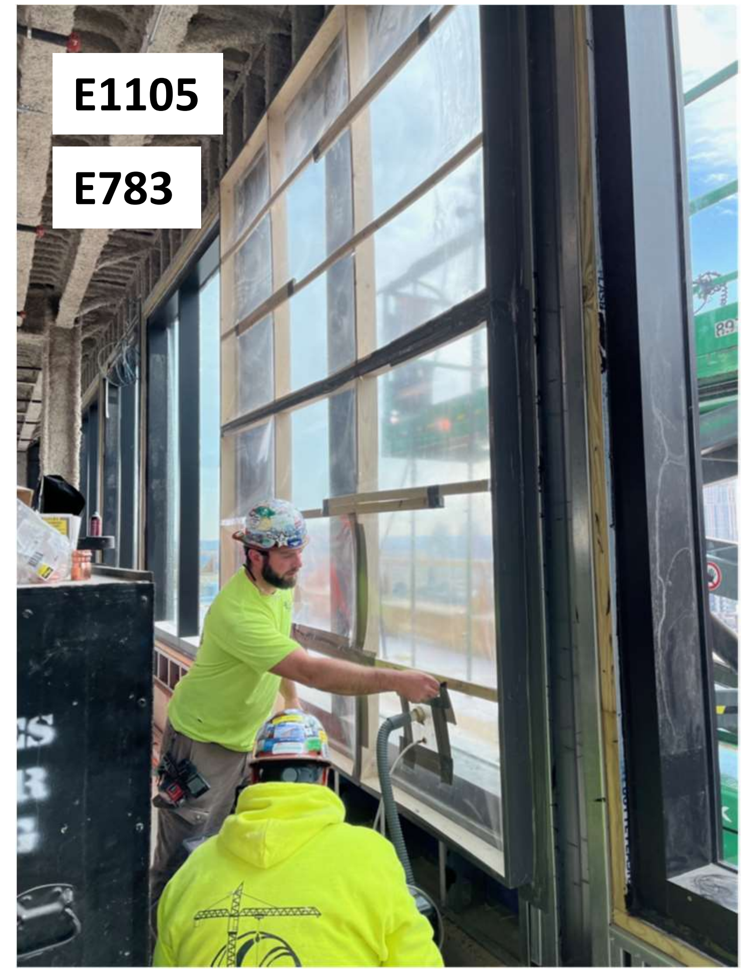
- Structural Loadings and Engineering Mechanics 101

- Unit stresses: hidden in plain sight!





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- **Reference:**
  John F. Straube and Eric F. P. Burnett, *Building Science for Building Enclosures* (Building Science Press 2005) 38.

Table 2.4: General category of loadings and related functions

Causal phenomenon or loading	Specific loadings	Interior Finish	Support	Control	Exterior finish
Essentially structural	Gravity – Dead (assembly, etc.)		●		
	Gravity – Live (people, snow, etc.)		●		
	Wind		●	○	
	Ground Movement (seismic, settlement, etc.)		●		
	Explosion		●		
	Rheological (creep, shrinkage, etc.)		●		○
	Impact (vehicles, missiles, people, etc.)	•	●		•
	Fire	•	○	●	•
Essentially environmental	Heat (thermal, etc.)		○	●	
	Air (pressure, movement, leakage, etc.)		○	●	
	Moisture (built-in, rain, condensation, etc)		○	●	○
	Smoke			●	
	Solar radiation (incident, reflected, etc.)			●	○
	Chemical attack/atmospheric (acid rain, etc.)			●	○
	Particulate matter (dust, VOC's, etc.)			●	
	People (wear & tear, etc.)	●	○		●
	Insects, birds, animals, (termites, rodents, etc.)			●	○
Essentially perceptual	Light (natural, incandescent, fluorescent, etc.)			●	
	Sound	○	•	●	○
	Visual – local	●			●
	Visual – contextual	●			●

Primary significance ●
Secondary significance ○
Tertiary significance •

Buildings Move, Buildings Leak

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	Fire	•	○	●	•
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	Smoke			●	
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Straube and Burnett 38.

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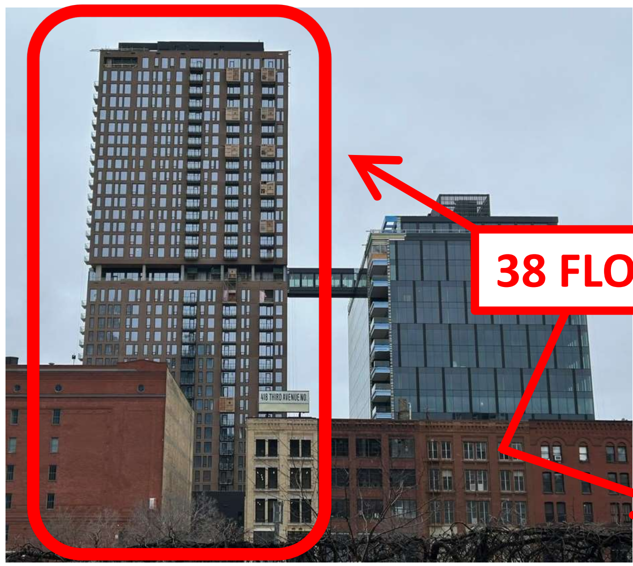

DESIGN STRUCTURAL MOVEMENTS:

1. STORY DRIFTS UNDER WIND LOADS

a. OFFICE TOWER: H/500 (50-YEAR WIND), H/700 (10-YEAR WIND)
b. RESIDENTIAL TOWER: H/350 (50-YEAR WIND), H/500 (10-YEAR WIND)
c. ONE-STORY F+B BUILDING: H/300 (50-YEAR WIND), H/400 (10-YEAR WIND)

ER SLAB DEFLECTION (LONG-TERM)

a. OFFICE TOWER: 1/2"
b. RESIDENTIAL TOWER: 1/2"

3. LONG-TERM CREEP AT PERIMETER RC COLUMNS (RESIDENTIAL TOWER)

a. 1/8" MAX PER FLOOR (FLOOR HEIGHT <= 11'-0")
b. 1/4" MAX PER FLOOR (FLOOR HEIGHT > 11'-0")

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Essentially perceptual		Light (natural, incandescent, fluorescent, etc.)
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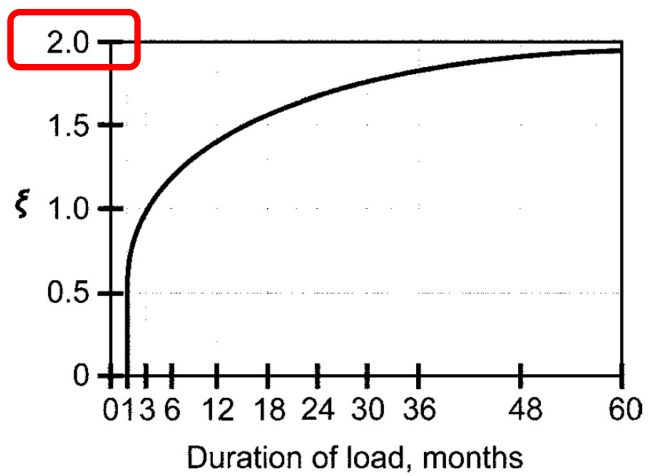
Straube and Burnett 38.

Buildings Move, Buildings Leak

- Common structural materials that creep:
  - Concrete
  - Wood



> The creep deflection varies anywhere from zero to twice the initial deflection. This means that the total deflection can vary from the initial deflection to as much as three times the initial deflection.

-AMERICAN WOOD COUNCIL WEBSITE
https://awc.org/faq/what-is-creep-and-how-can-i-address-it/

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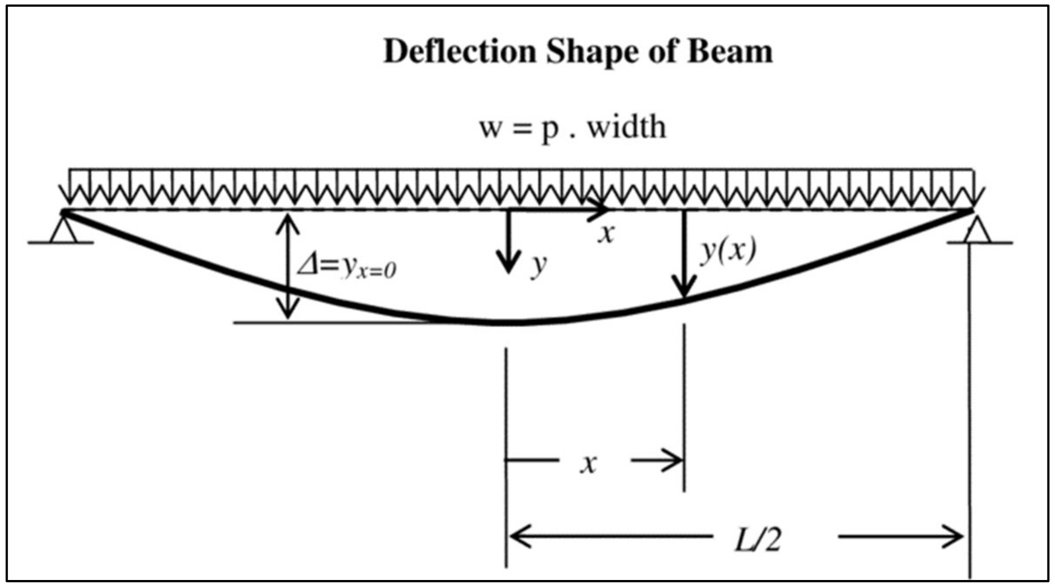
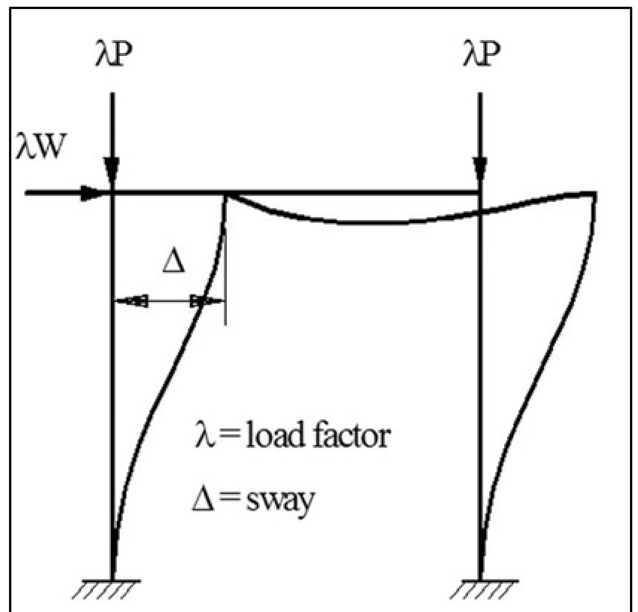
- Deflections/Displacements/Sway





(a) Rigid joint sway frame

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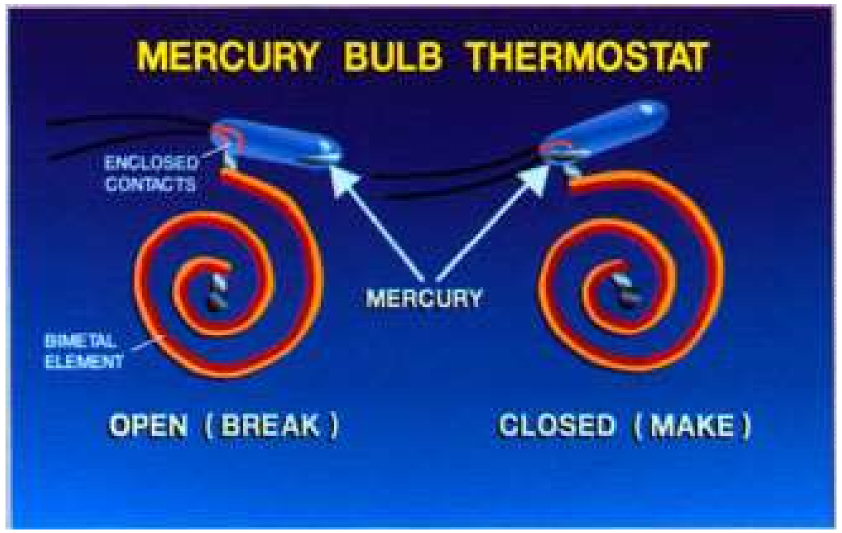

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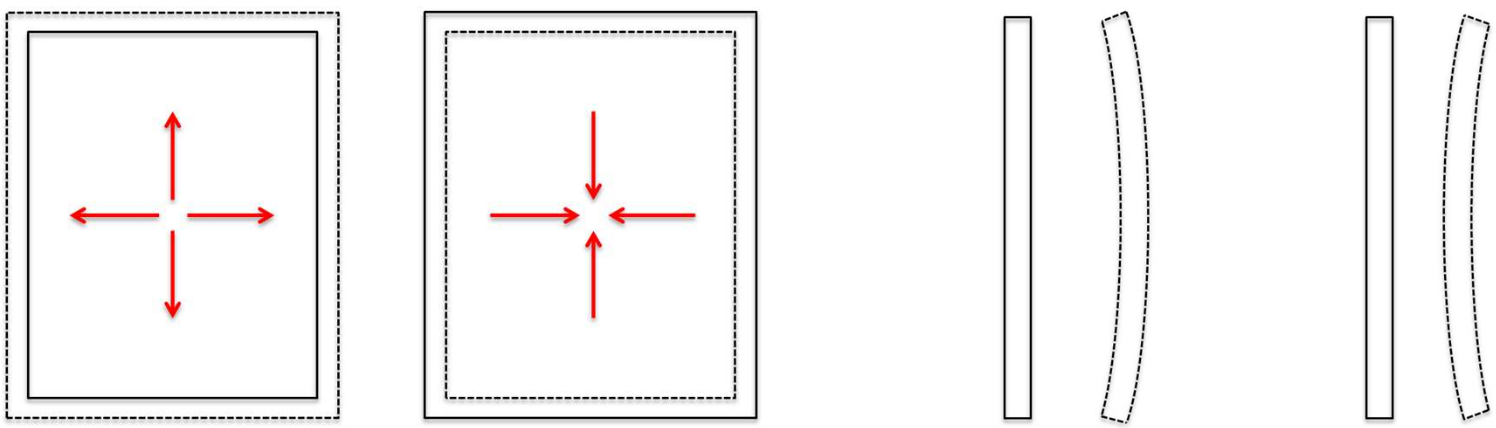
- Shortening/Elongation

ABSOLUTE VOLUME CHANGE **DIFFERENTIAL VOLUME CHANGE**



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- Volume Change oriented Loadings affect virtually ALL materials, even those not typically affected by other types of structural loadings

- Both structural deflection and material volume change can occur in one, two or three dimensions

Table 2.4: General category of loadings and related functions

Causal phenomenon or loading	Specific loadings	Interior Finish	Support	Control	Exterior finish
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	Light (natural, incandescent, fluorescent, etc.)			●	
Essentially perceptual	Sound	○	•	●	○
	Visual – local	●			●
	Visual – contextual	●			●

Category of functions: Interior Finish, Support, Control, Exterior finish

Primary significance ●
Secondary significance ○
Tertiary significance •

Straube and Burnett 38.

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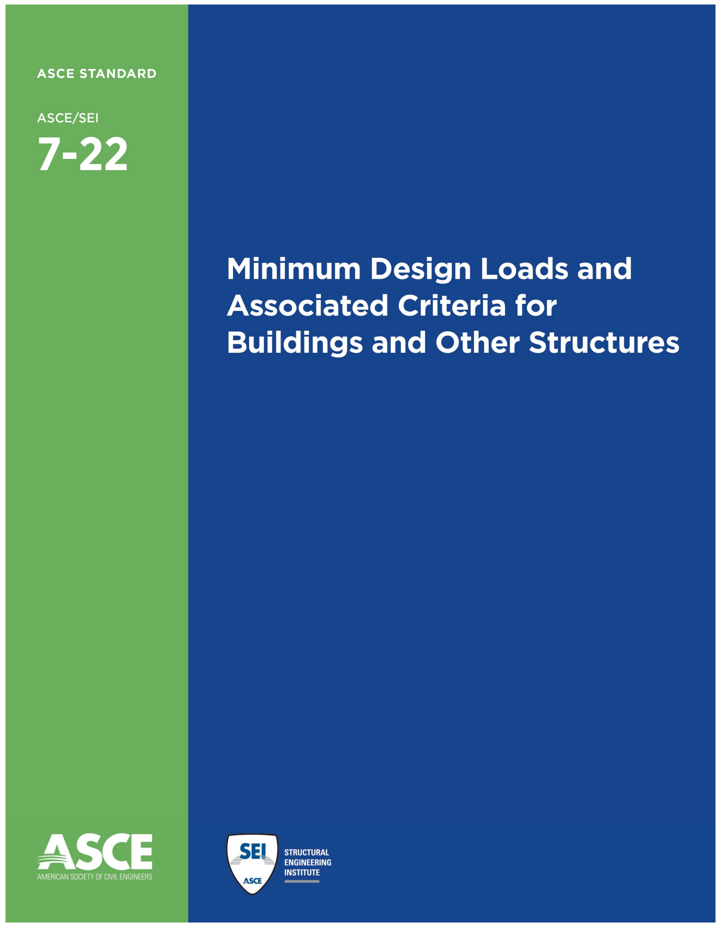
- Coincidentally, Structural Engineers are required to consider most of these effects but only to the extent that it impacts their structure



2.2 SYMBOLS

A_k = load or load effect arising from extra ordinary event A
D = dead load
D_i = weight of ice
E = earthquake load
F = load due to fluids with well-defined pressures and maximum heights
F_a = flood load
H = load due to lateral earth pressure, ground water pressure, or pressure of bulk materials
L = live load
L_r = roof live load
R = rain load
S = snow load
T = self-straining load
W = wind load
W_i = wind-on-ice determined in accordance with Chapter 10

EXAMPLE OF TYPICAL/ EXTERNALLY APPLIED LOAD (→ L = live load)

EXAMPLE OF VOLUME CHANGE INDUCED LOAD (→ T = self-straining load)

Buildings Move, Buildings Leak

- Process Gaps – where can/do things go wrong?

1) When performance criteria related to movement is not adequately specified/communicated (or followed!)

   - Importance of communication might not be understood by the specifier
   - A material might be new to the industry
   - The specifier might not have experience with a particular material, or understand its limits

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- Process Gaps – where can/do things go wrong?

2) When there is inadequate consideration to movement behavior

- Dichotomous thinking

  "material B is better than material A, therefore I no longer need to worry about ____________"

  "material B is more dimensionally stable than material A, therefore I no longer need to worry about material B"

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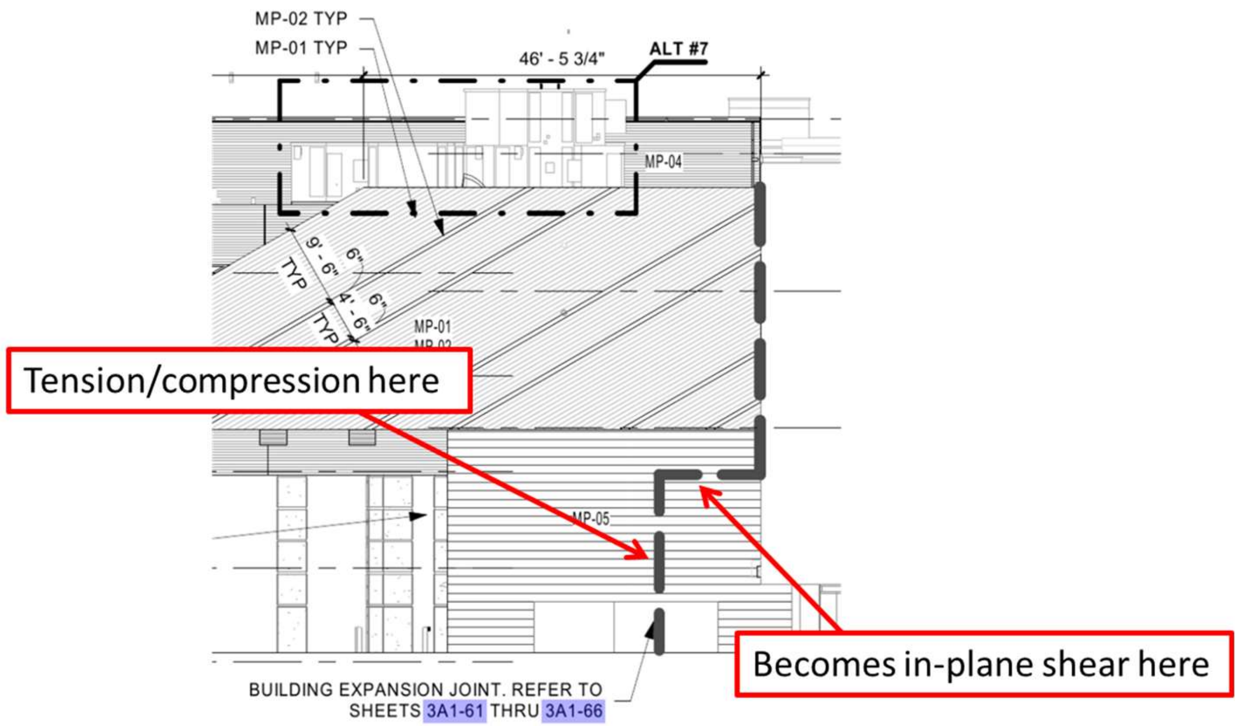
- Process Gaps – where can/do things go wrong?

2) When there is inadequate consideration to movement behavior

  - Overlooking how a material might respond



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- Enough of this Blah Blah Blah, let's get to the case studies

  - Category A: Structural Frame Deflection (Deflections/Displacements/Sway) impacting Enclosure Control Layers

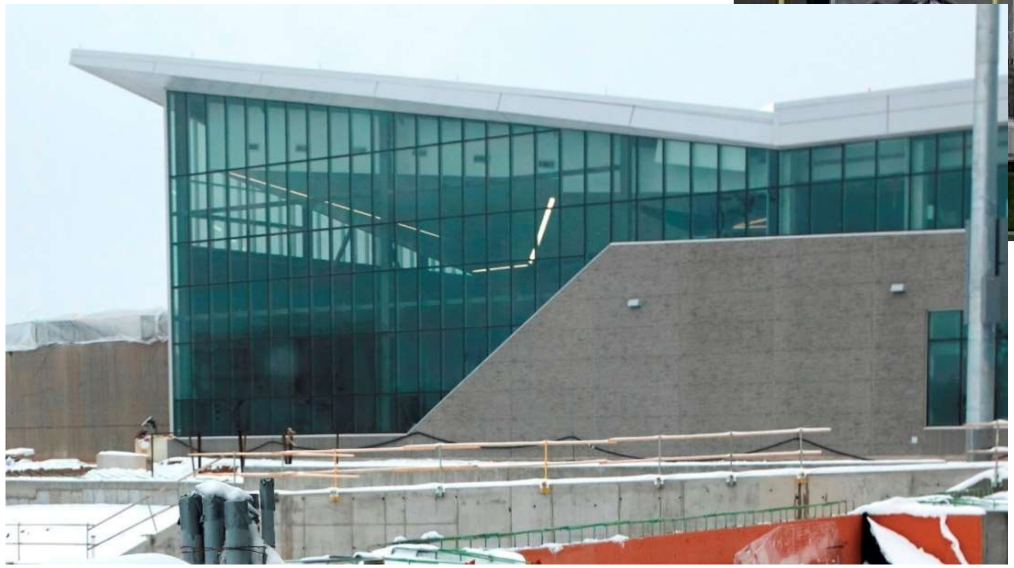
  - Category B: Material Volume Change (Shortening/Elongation) impacting Enclosure Control Layers

Buildings Move, Buildings Leak

- Category A: Structural Frame Deflection (Deflections/Displacements/Sway) impacting Enclosure Control Layers

Buildings Move, Buildings Leak

- Case Study 1: Compounded Deflections and Curtain Wall



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- Case Study 1: Compounded Deflections and Curtain Wall

PART 2 - PRODUCTS

2.1 PERFORMANCE REQUIREMENTS

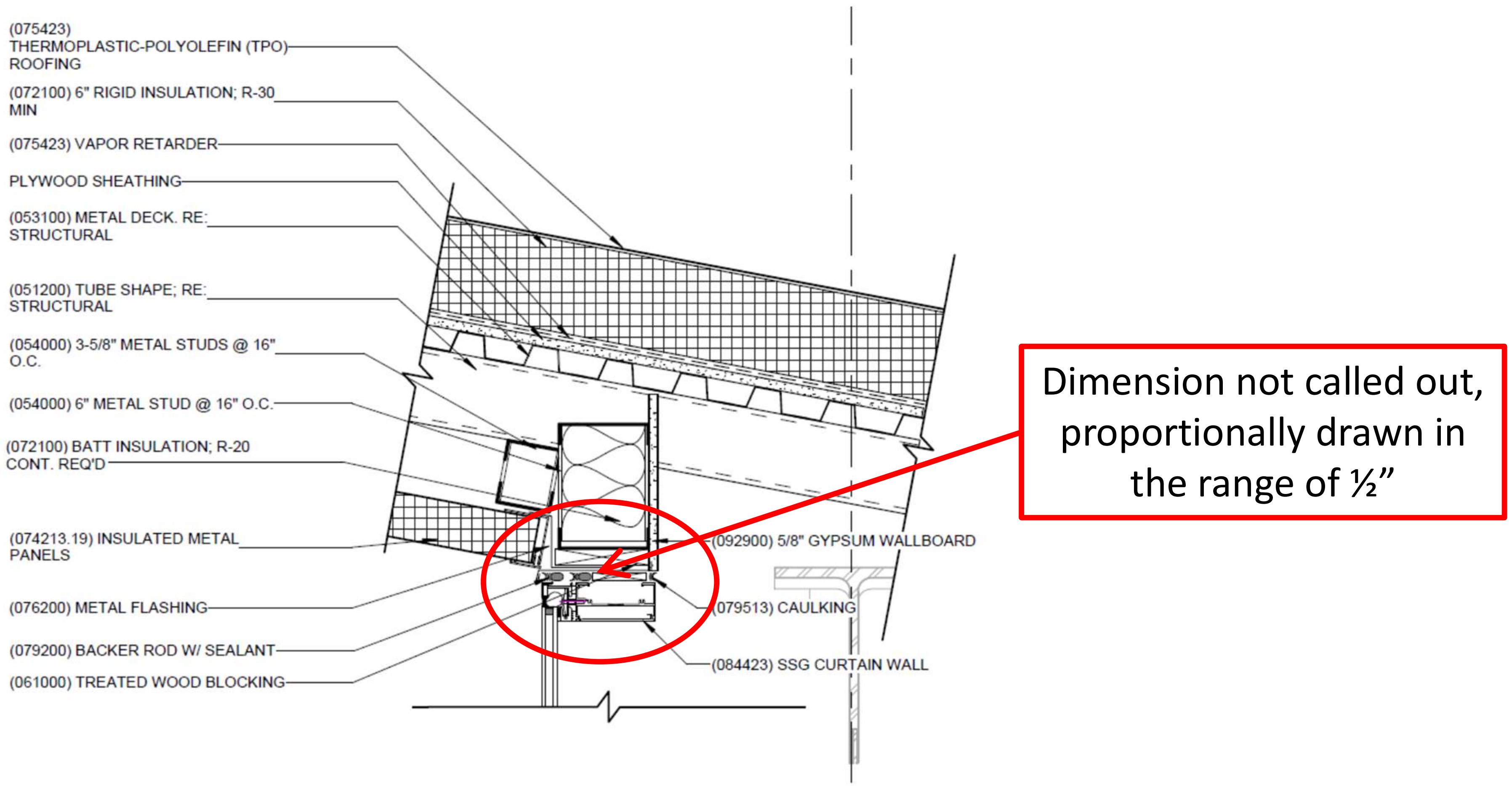
A. Delegated Design: Engage a qualified professional engineer licensed in the State of Minnesota, as defined in Section 01 40 00 "Quality Requirements," to design glazed aluminum curtain walls.

B. General Performance: Comply with performance requirements specified, as determined by testing of glazed aluminum curtain walls representing those indicated for this Project without failure due to defective manufacture, fabrication, installation, or other defects in construction.

1. Glazed aluminum curtain walls shall withstand movements of supporting structure including, but not limited to, story drift, twist, column shortening, long-term creep, and deflection from uniformly distributed and concentrated live loads.

Buildings Move, Buildings Leak

- Case Study 1: Compounded Deflections and Curtain Wall



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- Case Study 1: Compounded Deflections and Curtain Wall
- RFI Question #1: How much movement of structure should the head of curtainwall accommodate?
- RFI Response #1: Use L/360 to determine joint size

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- Case Study 1: Compounded Deflections and Curtain Wall

Buildings Move, Buildings Leak

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Buildings Move, Buildings Leak

- Case Study 1: Compounded Deflections and Curtain Wall

Buildings Move, Buildings Leak

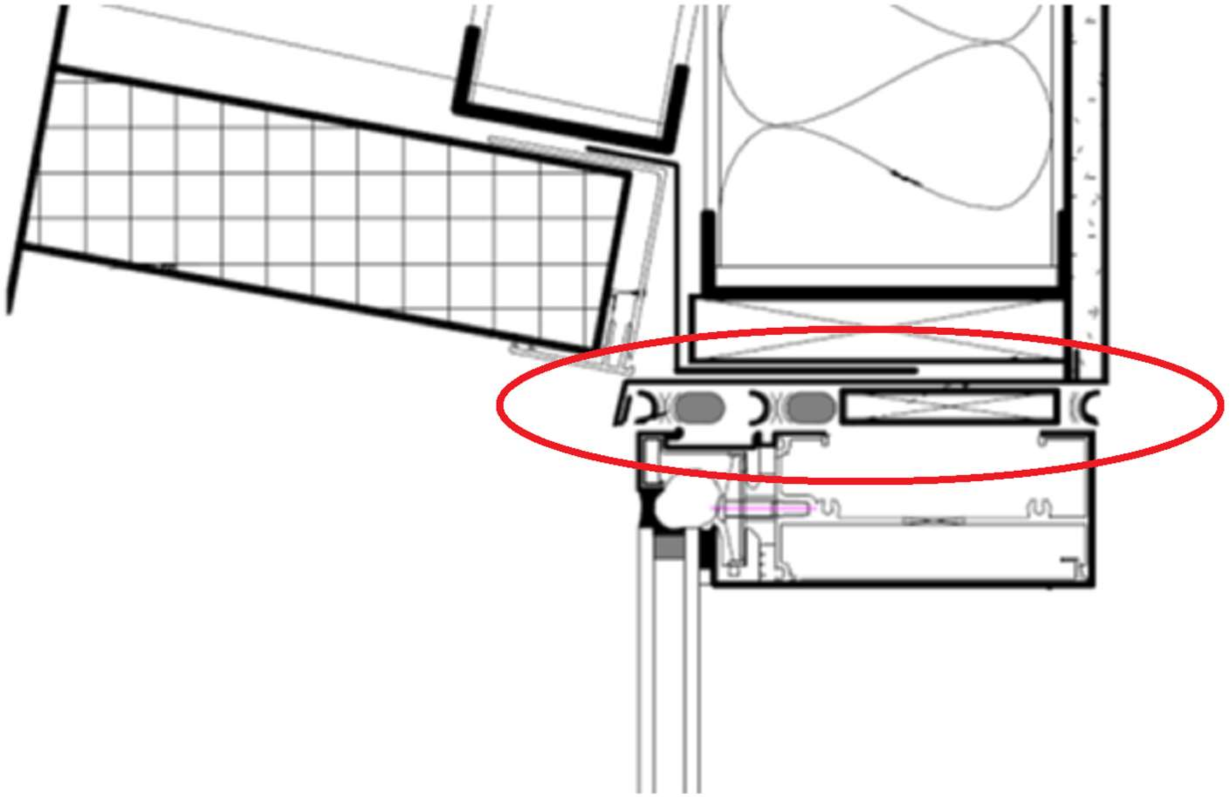
- Case Study 1: Compounded Deflections and Curtain Wall

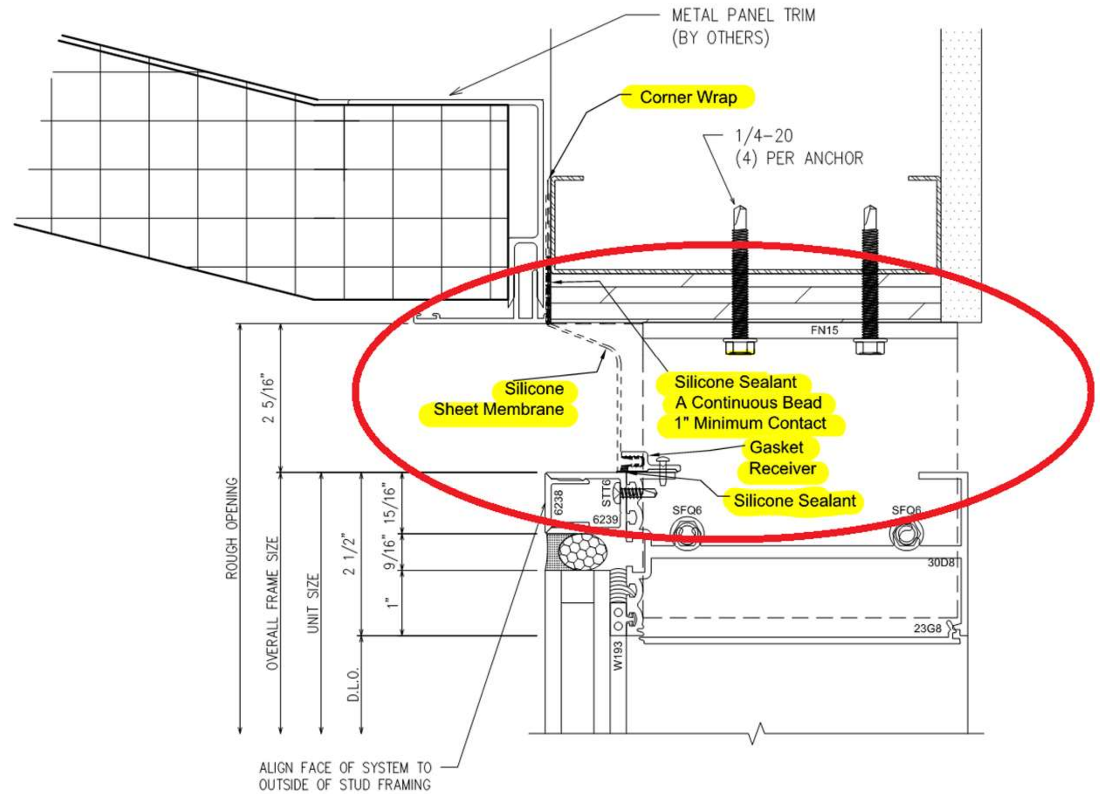
- RFI Question #2: Are you sure?

- RFI Response #2: Use 2-5/16”
  (L/360 at the largest span was 1”)

Buildings Move, Buildings Leak

- Case Study 1: Compounded Deflections and Curtain Wall





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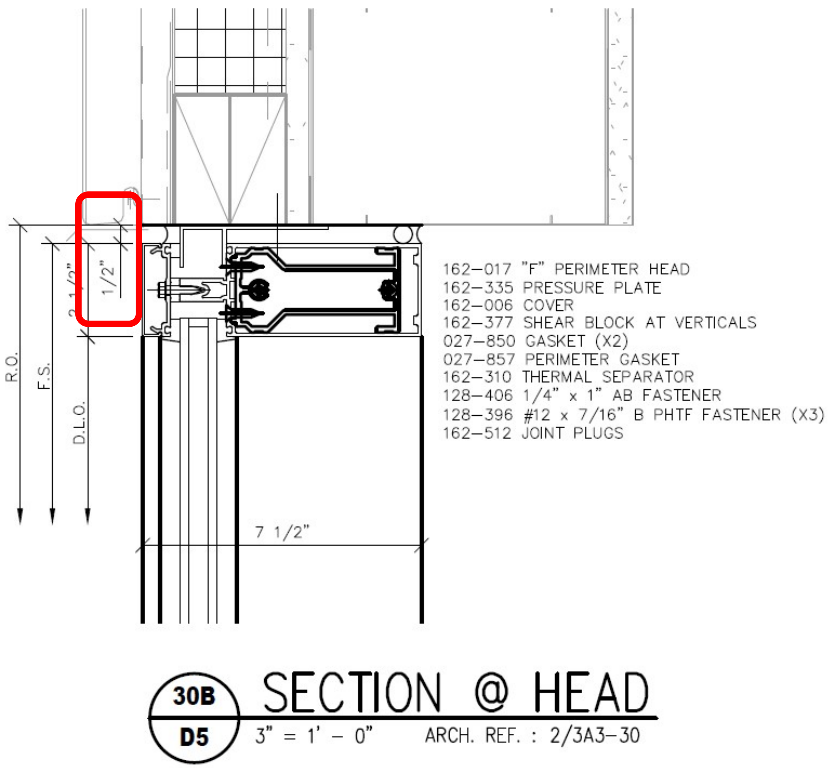
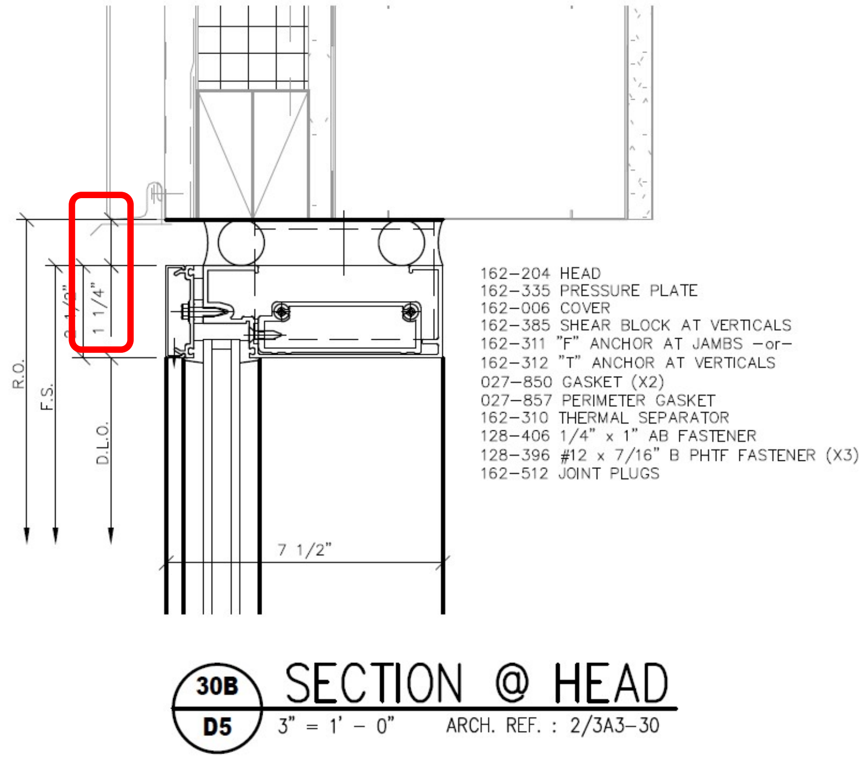
- Case Study 1: Compounded Deflections and Curtain Wall
  - 6-week delay (RFI process and coordination)
  - Change order
- Optimal Scenario: movement is defined in contract documents before bidding
- Last Call Scenario: movement is coordinated during shop drawing phase
  - The sooner everyone knows what needs to happen, the more efficiently they can act upon it

Buildings Move, Buildings Leak

- Case Study 1: Compounded Deflections and Curtain Wall
- Isolated incident? Not really

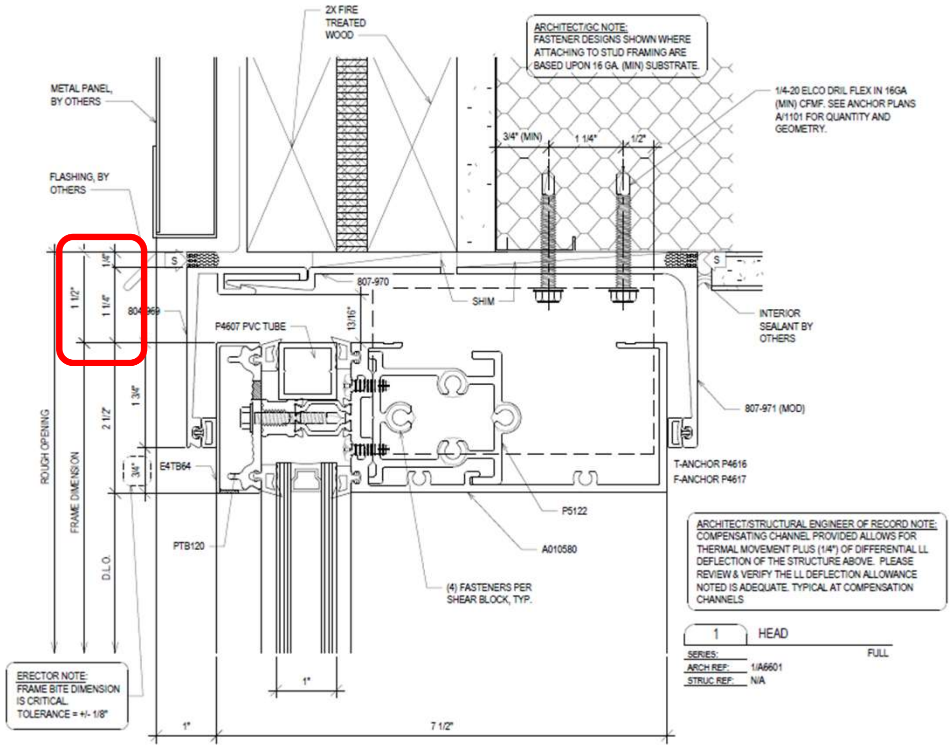


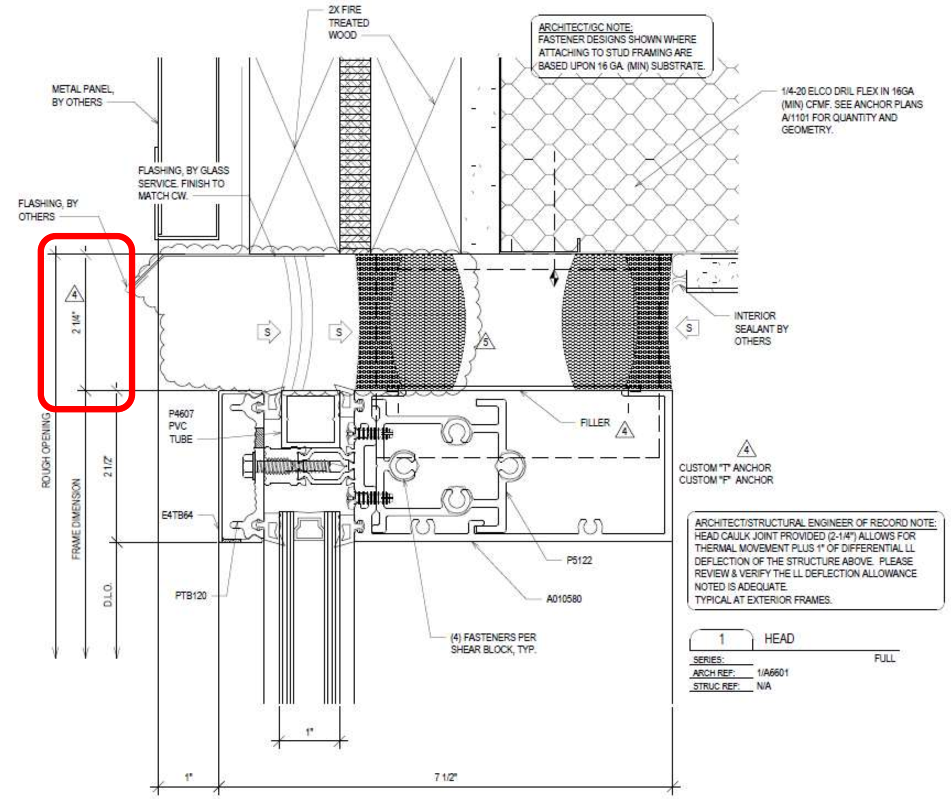


Buildings Move, Buildings Leak

- Case Study 1: Compounded Deflections and Curtain Wall

- If I was an investor, I would call this a growth market





Buildings Move, Buildings Leak

- Building Science Game Show Time!

- Case Study 1: which loadings were involved?

Table 2.4: General category of loadings and related functions

Causal phenomenon or loading		Specific loadings	Interior Finish	Support	Control	Exterior finish
	Essentially structural	Gravity – Dead (assembly, etc.)		●		
		Gravity – Live (people, snow, etc.)		●		
		Wind		●	○	
		Ground Movement (seismic, settlement, etc.)		●		
		Explosion		●		
		Rheological (creep, shrinkage, etc.)		●		○
		Impact (vehicles, missiles, people, etc.)	•	●		•
		Fire	•	○	●	•
	Essentially environmental	Heat (thermal, etc.)		○	●	
		Air (pressure, movement, leakage, etc.)		○	●	
		Moisture (built-in, rain, condensation, etc)		○	●	○
		Smoke			●	
		Solar radiation (incident, reflected, etc.)			●	○
		Chemical attack/atmospheric (acid rain, etc.)			●	○
		Particulate matter (dust, VOC's, etc.)			●	
		People (wear & tear, etc.)	●	○		●
		Insects, birds, animals, (termites, rodents, etc.)			●	○
	Essentially perceptual	Light (natural, incandescent, fluorescent, etc.)			●	
		Sound	○	•	●	○
		Visual – local	●			●
		Visual – contextual	●			●

Category of functions: Interior Finish, Support, Control, Exterior finish

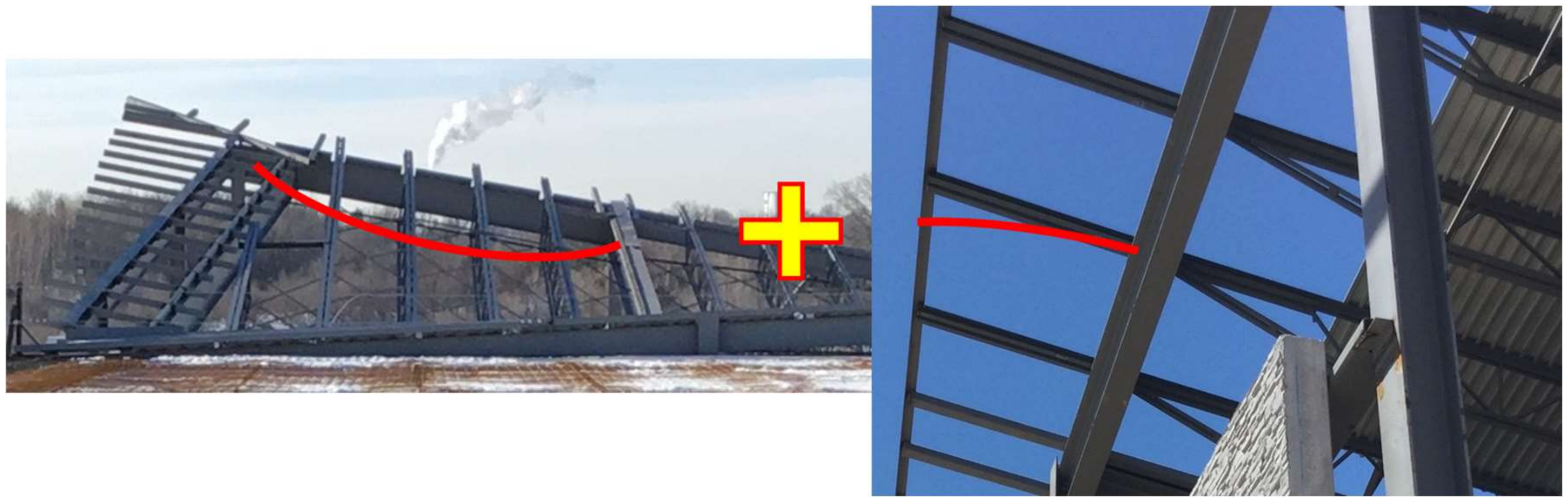
Primary significance ●
Secondary significance ○
Tertiary significance •

Straube and Burnett 38.

Buildings Move, Buildings Leak

- Building Science Game Show Time!

- Case Study 1: which loadings were involved?



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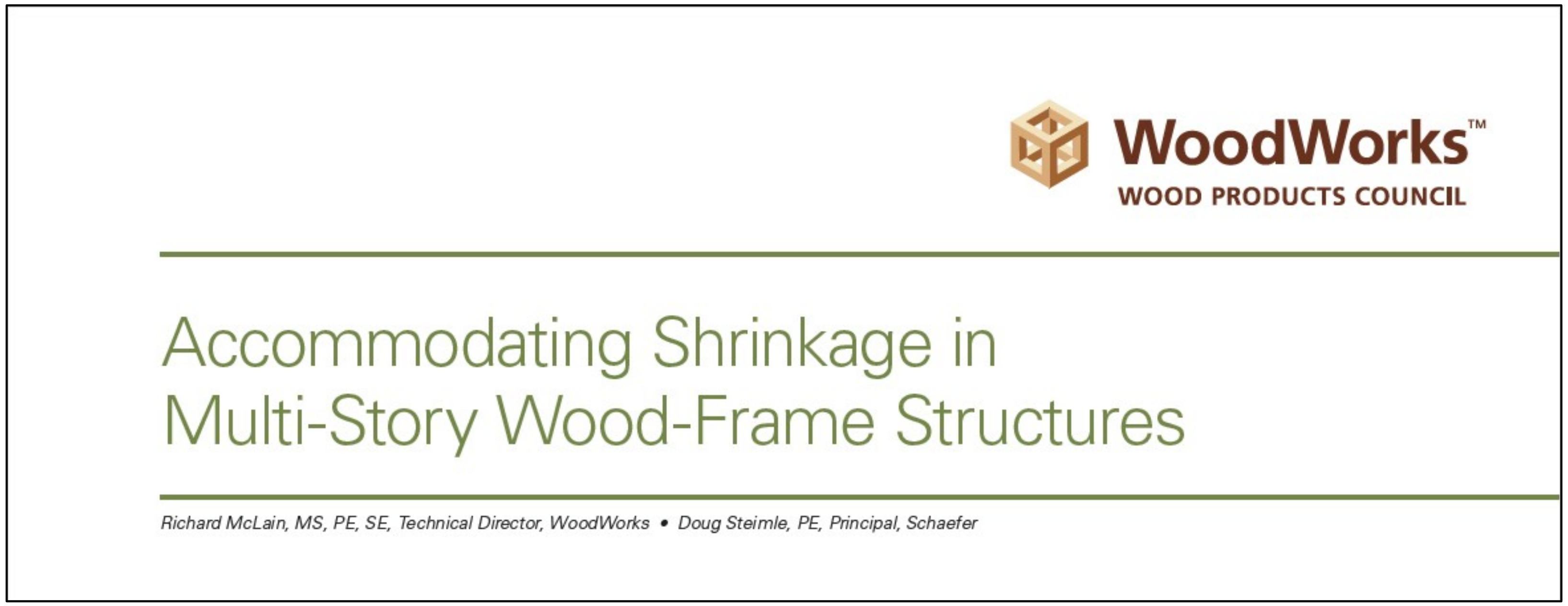
	Ground Movement (seismic, settlement, etc.)		●		
	Explosion		●		
	Rheological (creep, shrinkage, etc.)		●		○
	Impact (vehicles, missiles, people, etc.)	•	●		•
	Fire	•	○	●	•
Essentially environmental	Heat (thermal, etc.)		○	●	
	Air (pressure, movement, leakage, etc.)		○	●	
	Moisture (built-in, rain, condensation, etc)		○	●	○
	Smoke			●	
	Solar radiation (incident, reflected, etc.)			●	○
	Chemical attack/atmospheric (acid rain, etc.)			●	○
	Particulate matter (dust, VOC's, etc.)			●	
	People (wear & tear, etc.)	●	○		●
	Insects, birds, animals, (termites, rodents, etc.)			●	○
Essentially perceptual	Light (natural, incandescent, fluorescent, etc.)			●	
	Sound	○	•	●	○
	Visual – local	●			●
	Visual – contextual	●			●

Primary significance ●
Secondary significance ○
Tertiary significance •

Straube and Burnett 38.

Buildings Move, Buildings Leak

- Case Study 2: Wood Framed Stealth Deflections


WoodWorks™
WOOD PRODUCTS COUNCIL

Accommodating Shrinkage in
Multi-Story Wood-Frame Structures

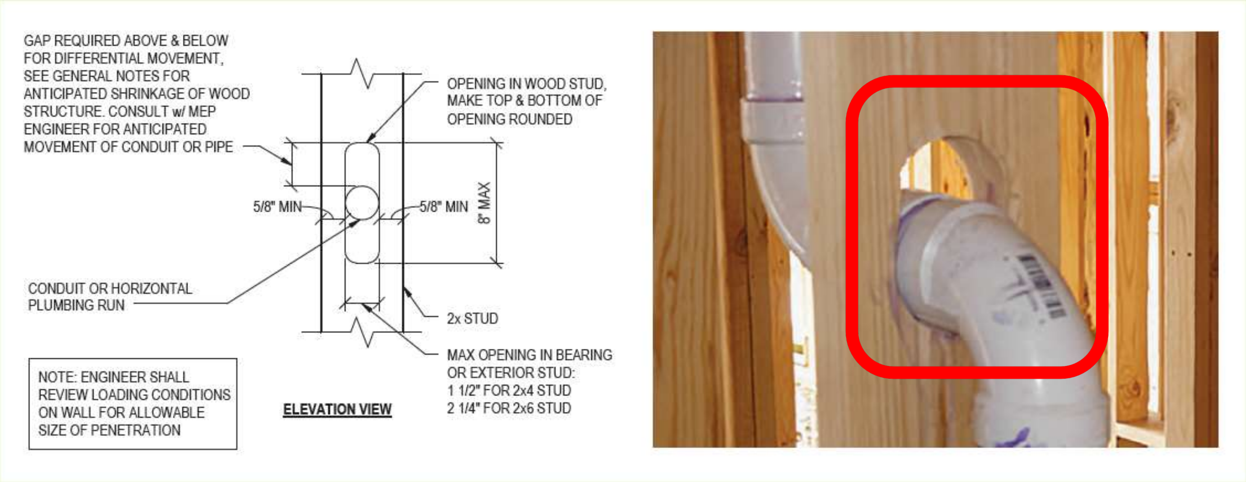
Richard McLain, MS, PE, SE, Technical Director, WoodWorks • Doug Steimle, PE, Principal, Schaefer

Buildings Move, Buildings Leak

- Case Study 2: Wood Framed Stealth Deflections

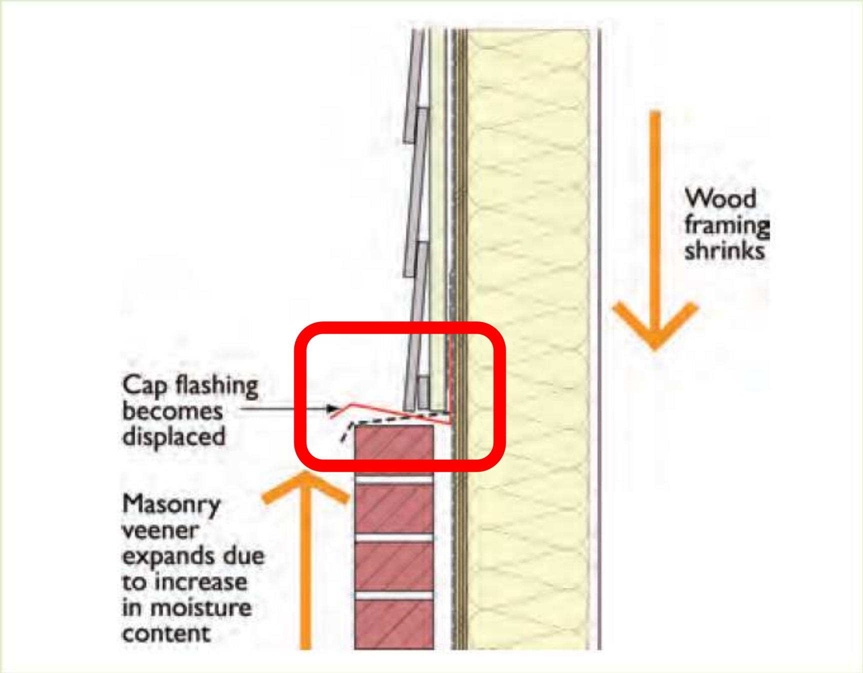
- Most of the usual suspects for shrinkage in mid-rise wood framed construction have been known for at least 10± years

FIGURE 19:
Example detail and photo showing the hole in a wood stud added to accommodate shrinkage around plumbing



Sources: (left) Schaefer; (right) Louisiana-Pacific Corporation

FIGURE 13:
Veneer transition issues due to lack of shrinkage accommodation



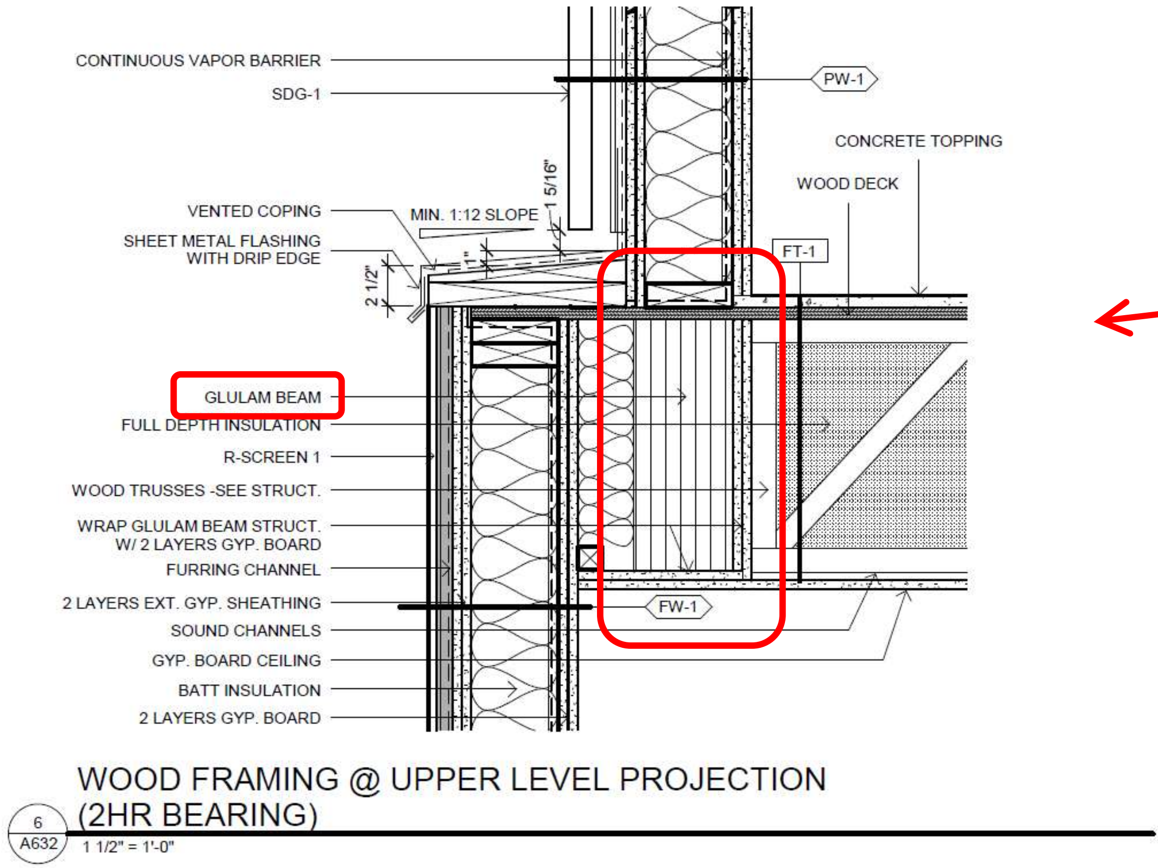
Source: RDH Building Science Inc.

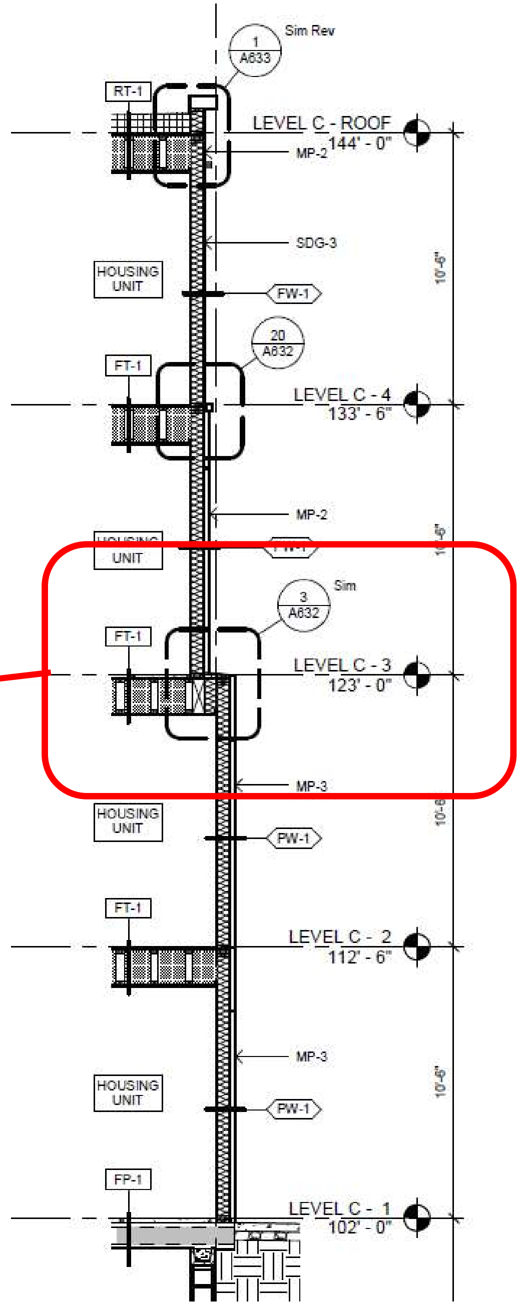
Buildings Move, Buildings Leak

- Case Study 2: Wood Framed Stealth Deflections
- Sometime the movement potential is not as obvious

Buildings Move, Buildings Leak

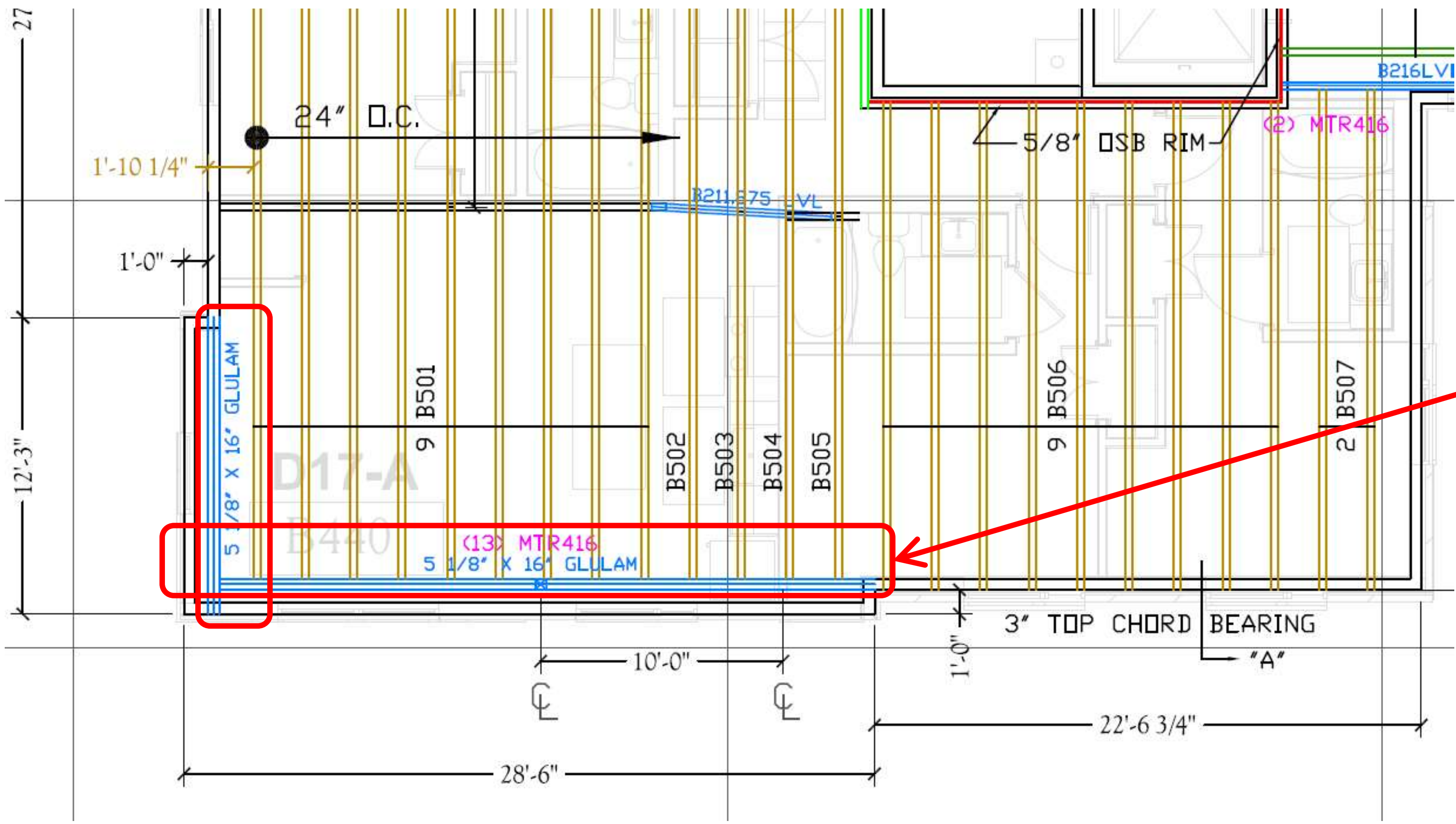
- Case Study 2: Wood Framed Stealth Deflections





Buildings Move, Buildings Leak

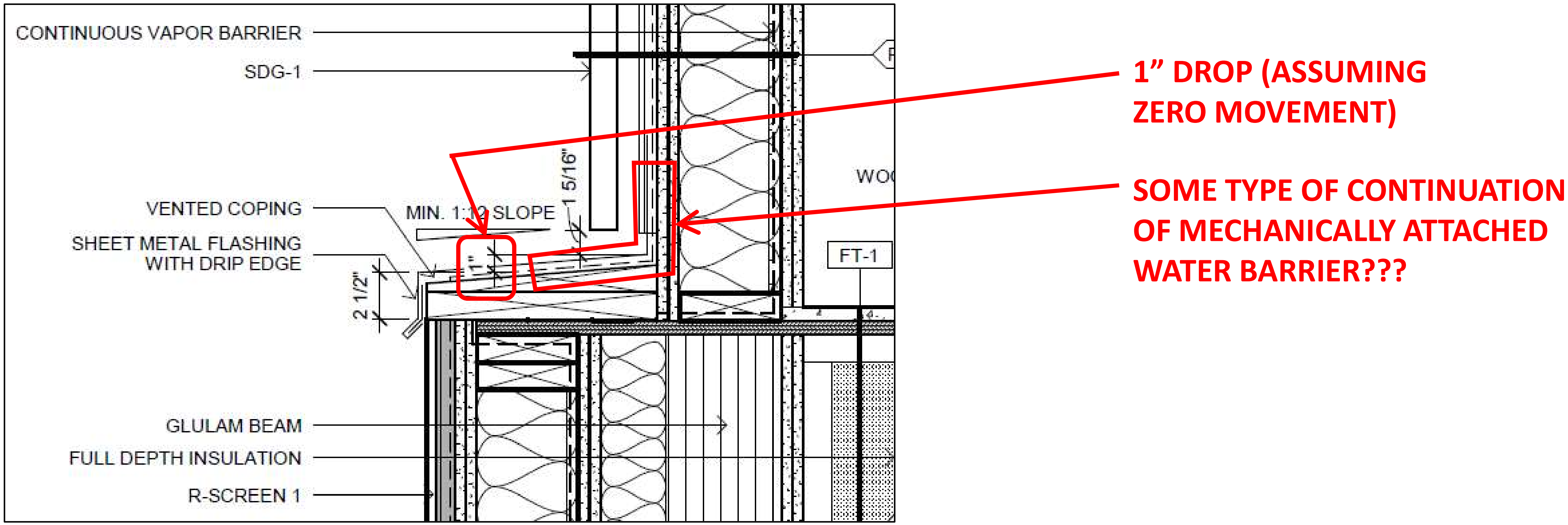
- Case Study 2: Wood Framed Stealth Deflections



28' LONG GLULAM BEAM TAKING AS MUCH AS 4 FLOORS WORTH OF LOADBEARING WALL WEIGHT

Buildings Move, Buildings Leak

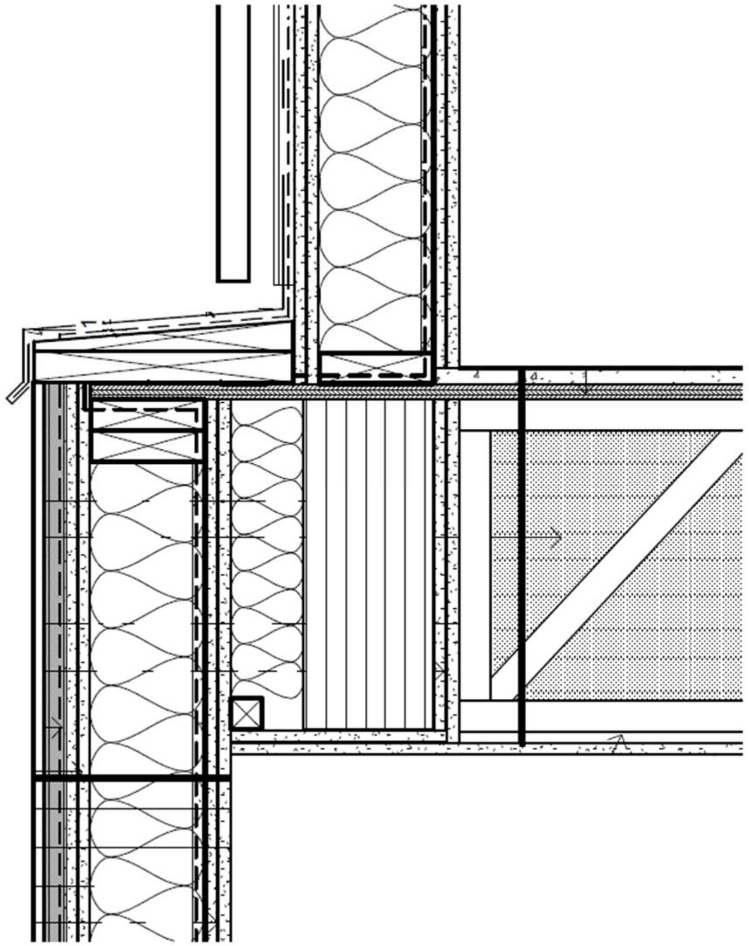
- Case Study 2: Wood Framed Stealth Deflections



AS – BUILT DETAIL

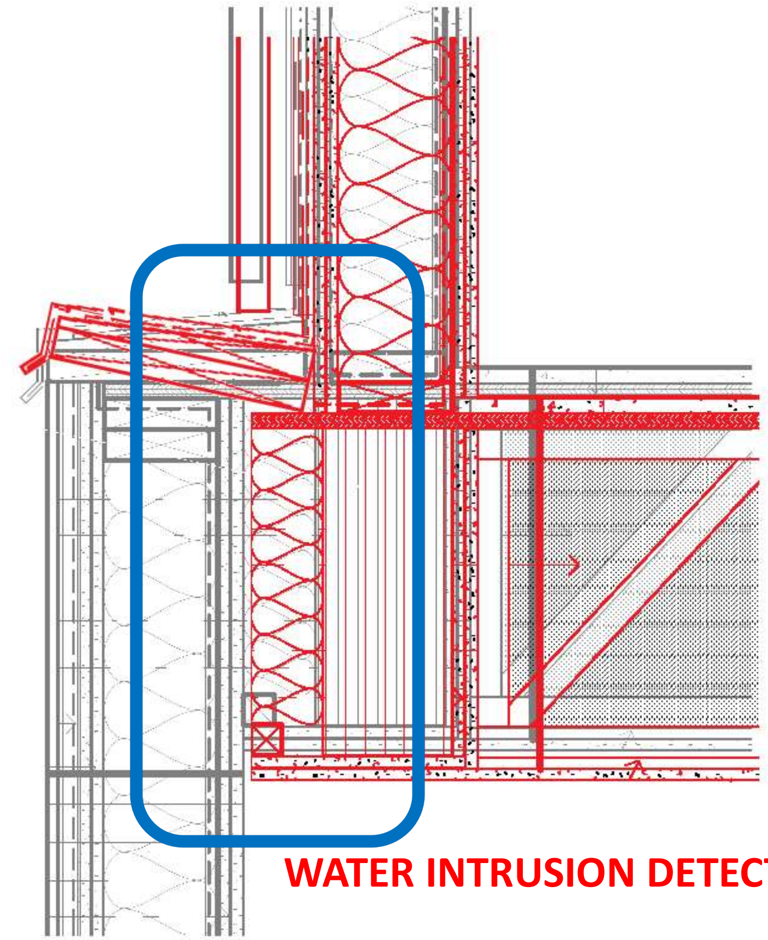
Buildings Move, Buildings Leak

- Case Study 2: Wood Framed Stealth Deflections



CONDITION AT TIME OF COMPLETION

CONDITION AFTER 4½ YEARS



WATER INTRUSION DETECTED

Buildings Move, Buildings Leak

- Case Study 2: Wood Framed Stealth Deflections

- Repairs made at all setback locations
  - New pitch of 2:12
  - High temp self adhered membrane flashing approved for use on low slope surfaces

Buildings Move, Buildings Leak

- Case Study 2: which loadings were involved?

Table 2.4: General category of loadings and related functions

Causal phenomenon or loading	Specific loadings	Interior Finish	Support	Control	Exterior finish
Essentially structural	Gravity – Dead (assembly, etc.)		●		
	Gravity – Live (people, snow, etc.)		●		
	Wind		●	○	
	Ground Movement (seismic, settlement, etc.)		●		
	Explosion		●		
	Rheological (creep, shrinkage, etc.)		●		○
	Impact (vehicles, missiles, people, etc.)	•	●		•
	Fire	•	○	●	•
Essentially environmental	Heat (thermal, etc.)		○	●	
	Air (pressure, movement, leakage, etc.)		○	●	
	Moisture (built-in, rain, condensation, etc)		○	●	○
	Smoke			●	
	Solar radiation (incident, reflected, etc.)			●	○
	Chemical attack/atmospheric (acid rain, etc.)			●	○
	Particulate matter (dust, VOC's, etc.)			●	
	People (wear & tear, etc.)	●	○		●
Essentially perceptual	Insects, birds, animals, (termites, rodents, etc.)			●	○
	Light (natural, incandescent, fluorescent, etc.)			●	
	Sound	○	•	●	○
	Visual – local	●			●
	Visual – contextual	●			●

Category of functions: Interior Finish, Support, Control, Exterior finish

Primary significance ●
Secondary significance ○
Tertiary significance •

Straube and Burnett 38.

Buildings Move, Buildings Leak

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		Explosion		●		
		Rheological (creep, shrinkage, etc.)		●		○
		Impact (vehicles, missiles, people, etc.)	•	●		•
		Fire	•	○	●	•
	Essentially environmental	Heat (thermal, etc.)		○	●	
		Air (pressure, movement, leakage, etc.)		○	●	
		Moisture (built-in, rain, condensation, etc)		○	●	○
		Smoke			●	
		Solar radiation (incident, reflected, etc.)			●	○
		Chemical attack/atmospheric (acid rain, etc.)			●	○
		Particulate matter (dust, VOC's, etc.)			●	
	Essentially perceptual	People (wear & tear, etc.)	●	○		●
		Insects, birds, animals, (termites, rodents, etc.)			●	○
		Light (natural, incandescent, fluorescent, etc.)			●	
		Sound	○	•	●	○
		Visual – local	●			●
		Visual – contextual	●			●

Primary significance ●
Secondary significance ○
Tertiary significance •

Straube and Burnett 38.

Buildings Move, Buildings Leak

- Case Study 3: Stacked Ribbon Window/Steel Stud Infill

- 2-story elementary school

  - Exterior wall assembly not interrupted by 2nd Floor slab edge or roof deck edge

  - Steel stud backup

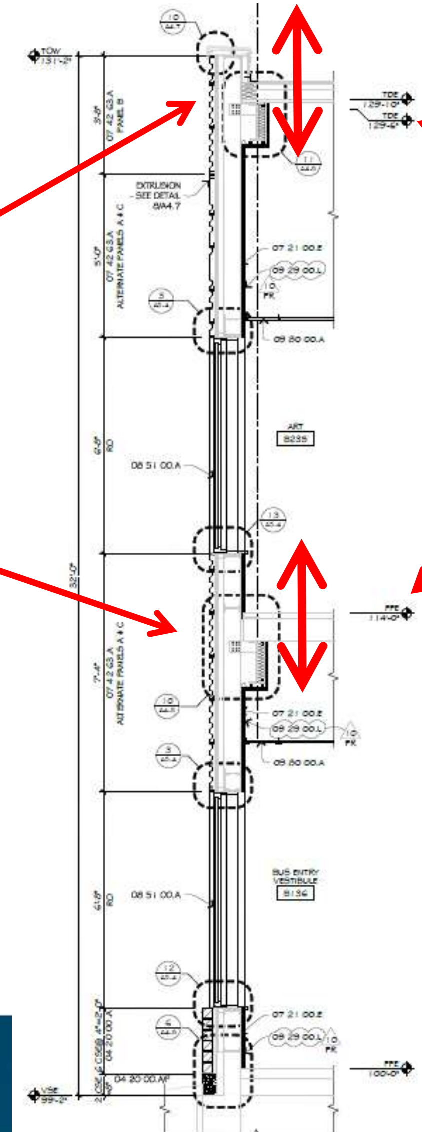
  - Opaque wall areas received metal panel cladding

abaa building enclosure conference

Buildings Move, Buildings Leak

- Case Study 3: Stacked Ribbon Window/Steel Stud Infill

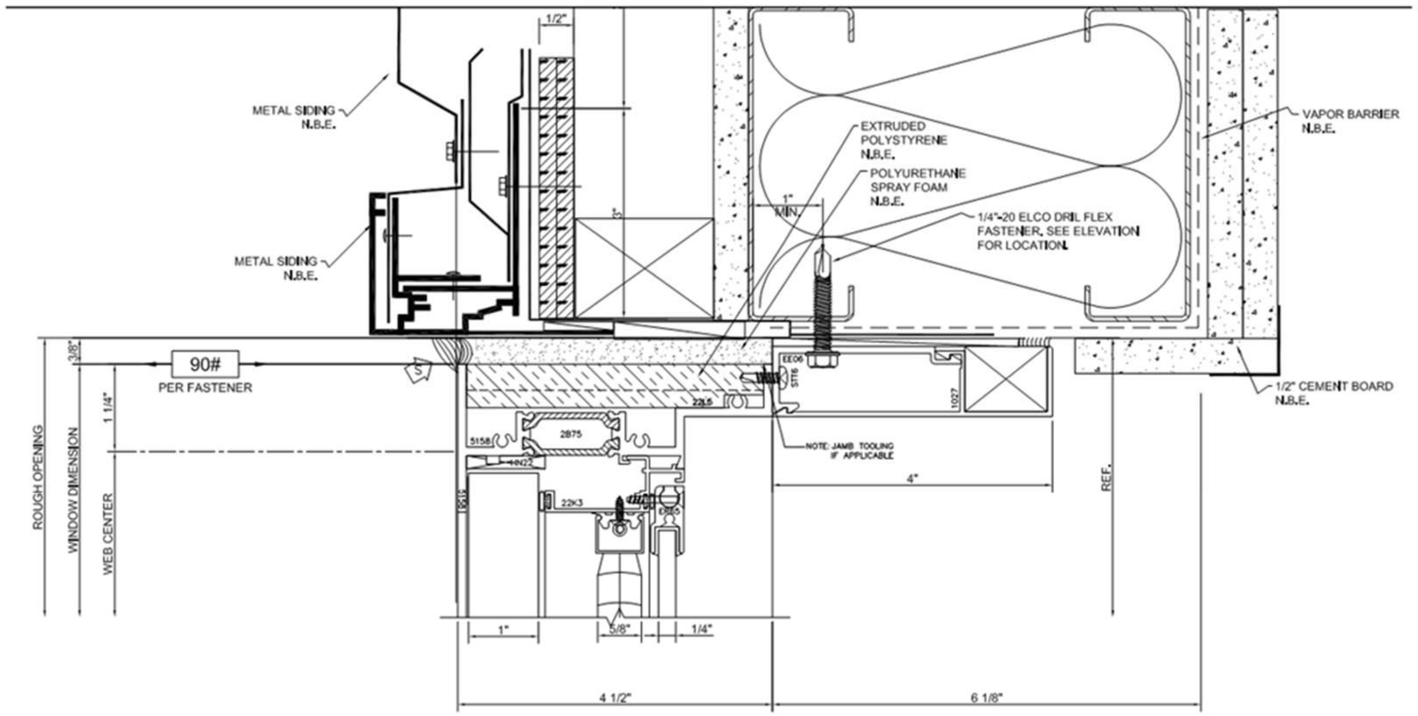
Wind load/deflection connection only at steel stud to slab or deck edge



Structure free to deflect independent of exterior wall assembly

Buildings Move, Buildings Leak

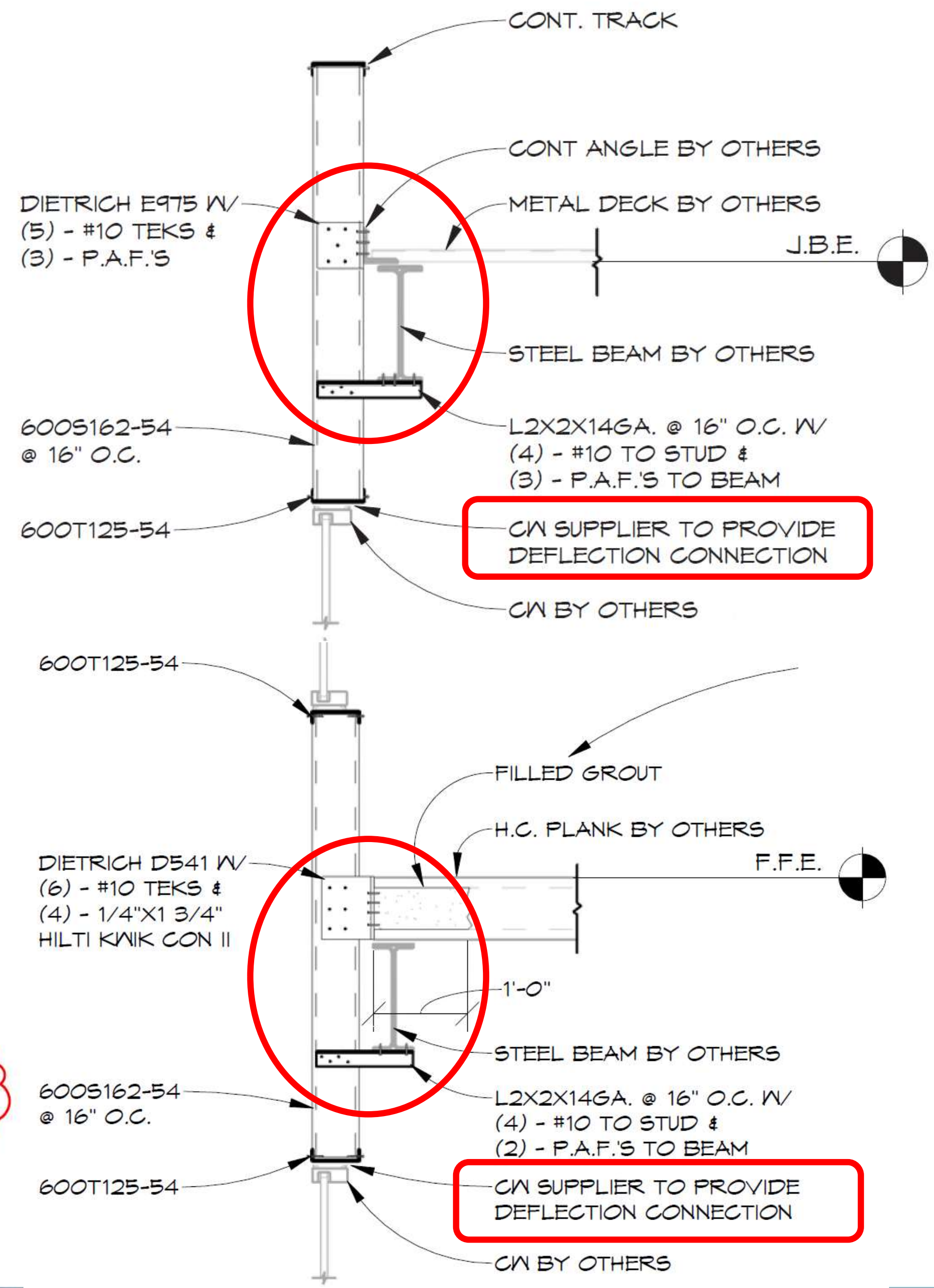
- Case Study 3: Stacked Ribbon Window/Steel Stud Infill



Window supplier's drawings showed static head joint consistent with contract documents

Buildings Move, Buildings Leak

- Case Study 3: Stacked Ribbon Window/Steel
  - But steel stud supplier's shop drawings
    - Requested change to fixed connection between studs and supporting structure
    - Requested that window supplier provide movement accommodation at their head framing condition



A.O.R./E.O.R. NOTE: APEX RECOMMENDS FRAMING AS SHOWN VERIFY LOAD PATH IS ACCEPTABLE. REF. 8, 28/S4.5 FOR SIM. STUD LOAD PATH ATTACHMENT TO BEAMS. DETAIL CUT 5/S4.4 DOES NOT WORK @ WIDE "RIBBON" WINDOWS.

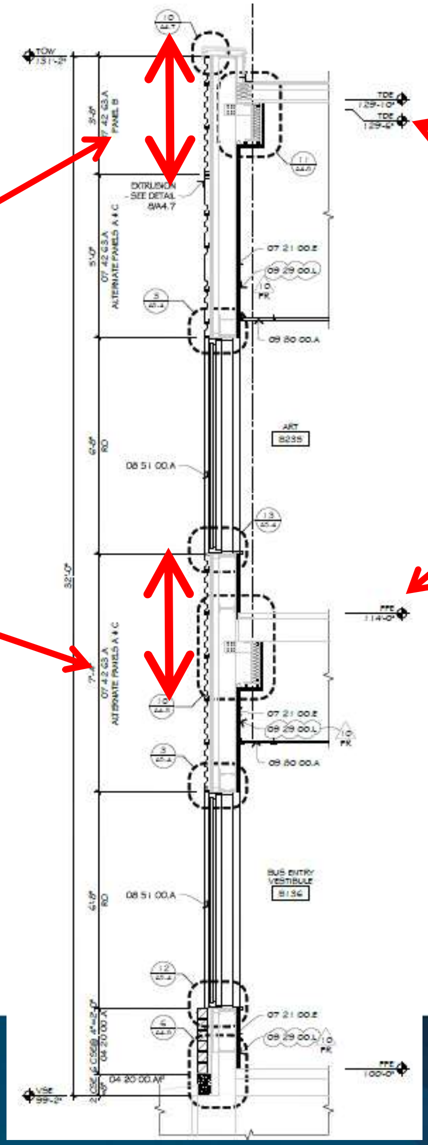
Buildings Move, Buildings Leak

- Case Study 3: Stacked Ribbon Window/Steel Stud Infill
  - Architect approved request, but change was not communicated to any other parties affected by the decision
    - Particularly the window supplier with a static head joint

Buildings Move, Buildings Leak

- Case Study 3: Stacked Ribbon Window/Steel Stud Infill

Deflection connection is now a fixed connection at steel stud to slab or deck edge



Structure deflection now will load exterior wall assembly

Buildings Move, Buildings Leak

- Case Study 3: Stacked Ribbon Window/Steel Stud Infill
  - Window head conditions would leak early spring after seasonal cycle of winter snow load deflection followed by spring snow melt relaxation

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Buildings Move, Buildings Leak

- Case Study 3: Stacked Ribbon Window/Steel Stud Infill

- Multiple breakdowns in the QA/QC process:
  - Design team and window supplier
    - Did not recognize original stacked wall configuration would be problematic
  - Steel stud supplier
    - Identified issue but did not request change through proper documentation (RFI)
  - Design team
    - Did not issue change to contract documents
  - Construction manager
    - Did not coordinate change between all trades affected

Buildings Move, Buildings Leak

- Case Study 3: Stacked Ribbon Window/Steel Stud Infill

- Highlights the need to properly communicate and validate the continuity of decisions
  - Design
  - Documentation
  - Implementation

Buildings Move, Buildings Leak

- Case Study 3: which loadings were involved?

Table 2.4: General category of loadings and related functions

Causal phenomenon or loading	Specific loadings	Interior Finish	Support	Control	Exterior finish
Essentially structural	Gravity – Dead (assembly, etc.)		●		
	Gravity – Live (people, snow, etc.)		●		
	Wind		●	○	
	Ground Movement (seismic, settlement, etc.)		●		
	Explosion		●		
	Rheological (creep, shrinkage, etc.)		●		○
	Impact (vehicles, missiles, people, etc.)	•	●		•
	Fire	•	○	●	•
Essentially environmental	Heat (thermal, etc.)		○	●	
	Air (pressure, movement, leakage, etc.)		○	●	
	Moisture (built-in, rain, condensation, etc)		○	●	○
	Smoke			●	
	Solar radiation (incident, reflected, etc.)			●	○
	Chemical attack/atmospheric (acid rain, etc.)			●	○
	Particulate matter (dust, VOC's, etc.)			●	
	People (wear & tear, etc.)	●	○		●
	Insects, birds, animals, (termites, rodents, etc.)			●	○
Essentially perceptual	Light (natural, incandescent, fluorescent, etc.)			●	
	Sound	○	•	●	○
	Visual – local	●			●
	Visual – contextual	●			●

Category of functions: Interior Finish, Support, Control, Exterior finish

Primary significance ●
Secondary significance ○
Tertiary significance •

Straube and Burnett 38.

Buildings Move, Buildings Leak

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	Rheological (creep, shrinkage, etc.)		●		○
	Impact (vehicles, missiles, people, etc.)	•	●		•
	Fire	•	○	●	•
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	Air (pressure, movement, leakage, etc.)		○	●	
	Moisture (built-in, rain, condensation, etc)		○	●	○
	Smoke			●	
	Solar radiation (incident, reflected, etc.)			●	○
	Chemical attack/atmospheric (acid rain, etc.)			●	○
	Particulate matter (dust, VOC's, etc.)			●	
	People (wear & tear, etc.)	●	○		●
	Insects, birds, animals, (termites, rodents, etc.)			●	○
	Light (natural, incandescent, fluorescent, etc.)			●	
	Sound	○	•	●	○
Essentially perceptual	Visual – local	●			●
	Visual – contextual	●			●

Category of functions: Interior Finish, Support, Control, Exterior finish

Primary significance ●
Secondary significance ○
Tertiary significance •

Straube and Burnett 38.

Buildings Move, Buildings Leak

- Case Study 4: Parking Deck Surface Slopes/Water Infiltration

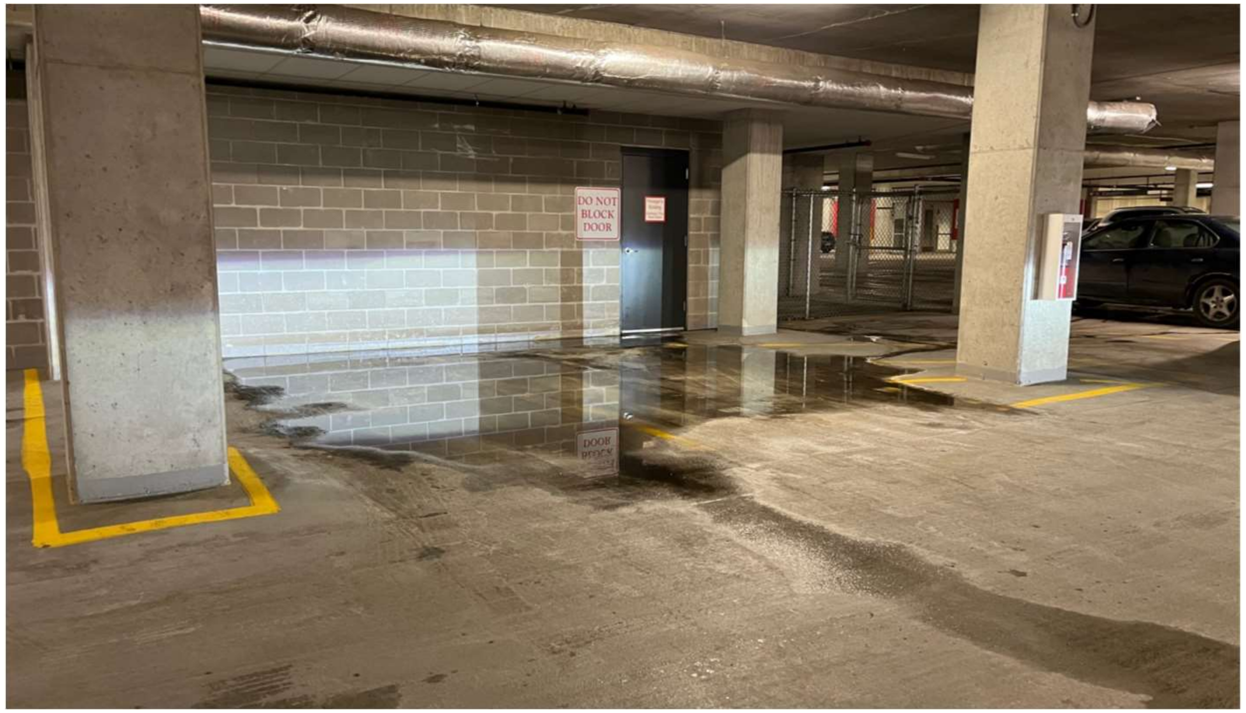
- American Concrete Institute (ACI) Committee for Parking Structures
  - Slope slabs surfaces so that positive water flow occurs without ponding

- Industry best practice is to design to 1½% - 2% minimum
  - Intent is after deducting slope for construction tolerances and deflections, positive water flow will still occur (not less than 1%)

Buildings Move, Buildings Leak

- Case Study 4: Parking Deck Surface Slopes/Water Infiltration

- Primary goal for ACI is to prevent standing water, which will reduce
  - Water intrusion INTO slab thickness
  - Accelerated deterioration of reinforcing and concrete



Buildings Move, Buildings Leak

- Case Study 4: Parking Deck Surface Slopes/Water Infiltration

- Concrete section not exposed to atmosphere has high alkali content (pH 12.5±)

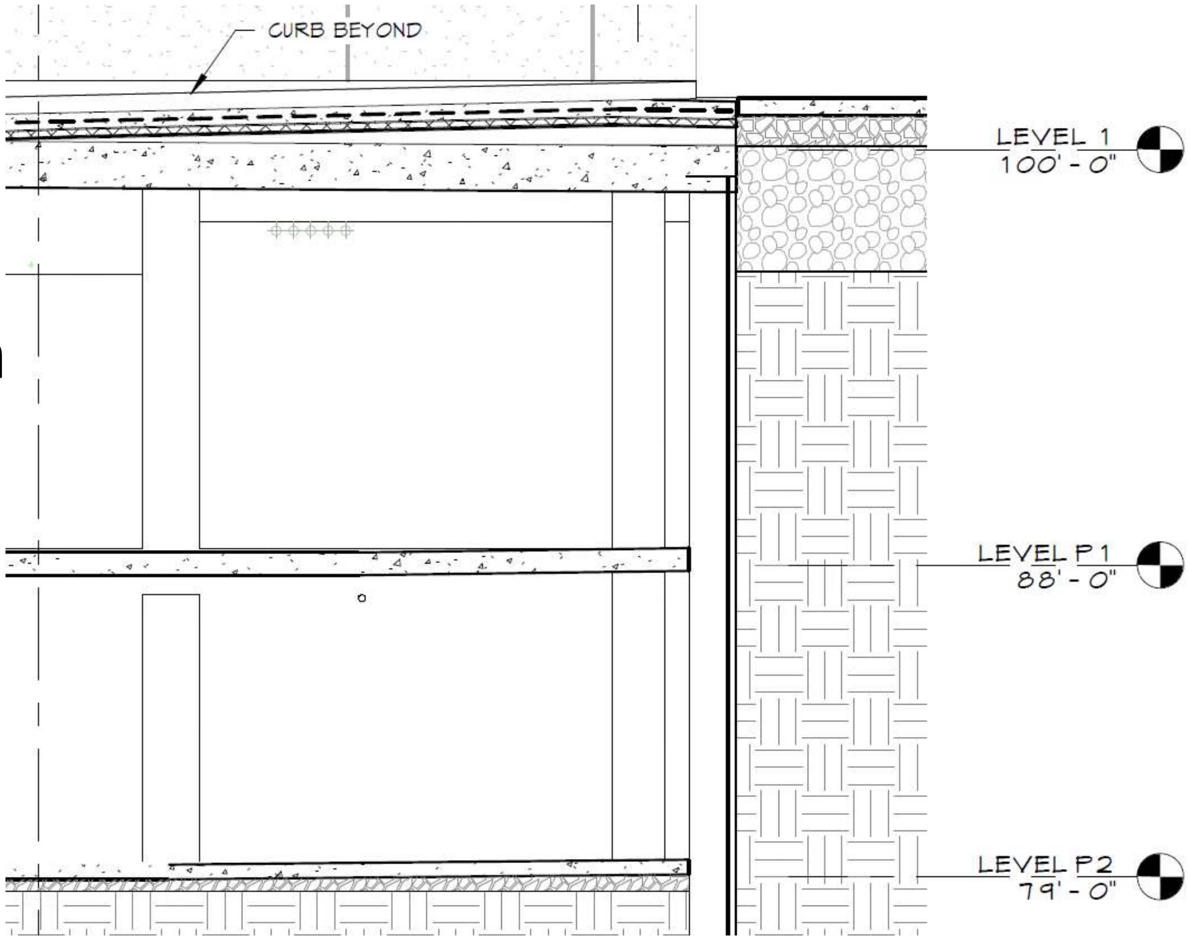
- Water that percolates through slabs can convert from neutral solution to caustic solution

Buildings Move, Buildings Leak

- Case Study 4: Parking Deck Surface Slopes/Water Infiltration

- Multi-level parking structure below grade

- Owner goal of minimizing excavation depths motivated design team to reduce surface slopes
  - Range of 1% - 1 ½%



Buildings Move, Buildings Leak

- Case Study 4: Parking Deck Surface Slopes/Water Infiltration

- After one seasonal cycle, car finishes on lower level began to show damage

Buildings Move, Buildings Leak

- Case Study 4: Parking Deck Surface Slopes/Water Infiltration

- Movement of slab changed surface slope from adequate to inadequate
  - Enclosure no longer protected cars below

- Persistent standing water on upper ramp level throughout winter months

Buildings Move, Buildings Leak

- Case Study 4: Parking Deck Surface Slopes/Water Infiltration

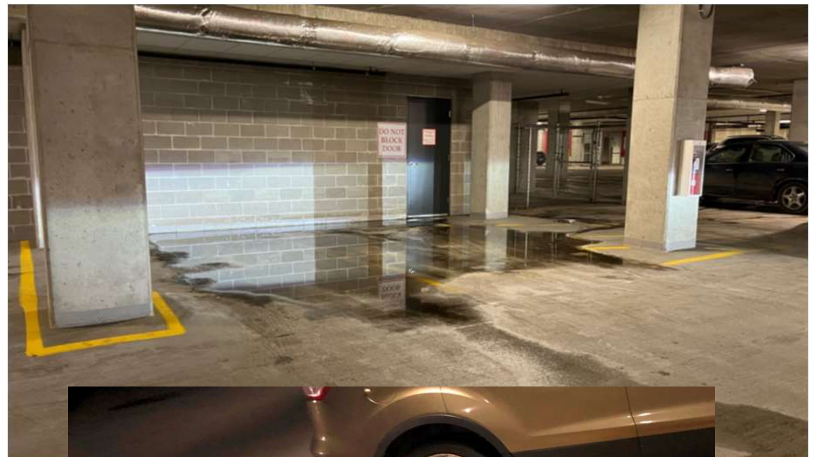
- Moisture runoff changed from neutral to alkaline

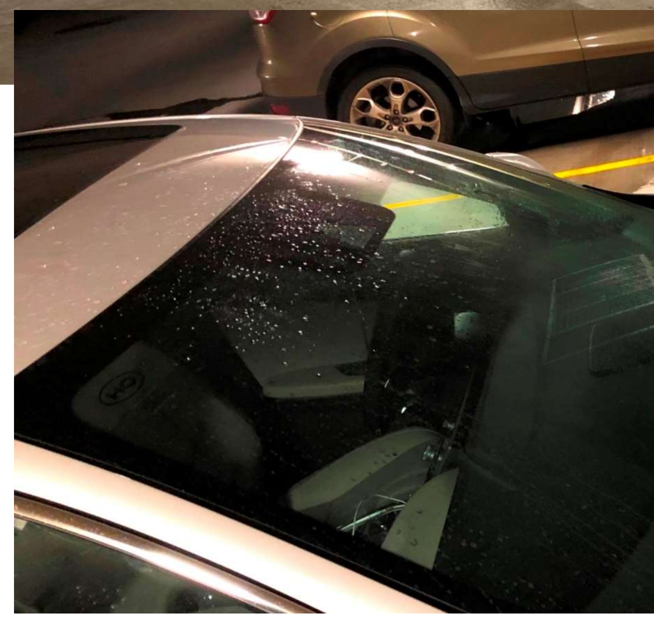
- Vehicle owners changed from happy to upset

  - Parking structure owner paid for auto finish repair work
  - Vehicular traffic coating added ~ $355,000

Buildings Move, Buildings Leak

- Case Study 4: which loadings were involved?





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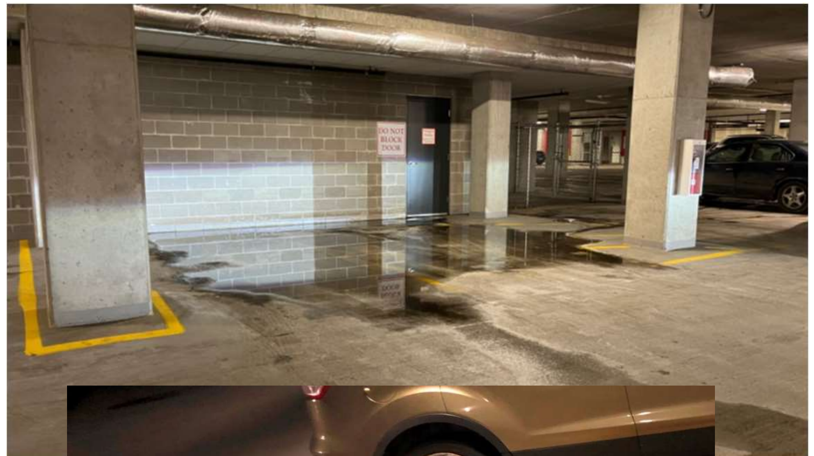
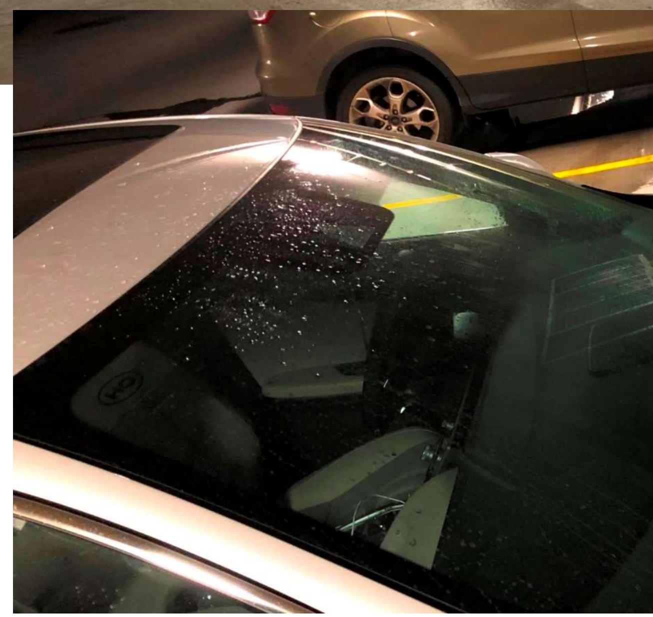
	Explosion		●		
	Rheological (creep, shrinkage, etc.)		●		○
	Impact (vehicles, missiles, people, etc.)	•	●		•
	Fire	•	○	●	•
Essentially environmental	Heat (thermal, etc.)		○	●	
	Air (pressure, movement, leakage, etc.)		○	●	
	Moisture (built-in, rain, condensation, etc)		○	●	○
	Smoke			●	
	Solar radiation (incident, reflected, etc.)			●	○
	Chemical attack/atmospheric (acid rain, etc.)			●	○
	Particulate matter (dust, VOC's, etc.)			●	
	People (wear & tear, etc.)	●	○		●
	Insects, birds, animals, (termites, rodents, etc.)			●	○
Essentially perceptual	Light (natural, incandescent, fluorescent, etc.)			●	
	Sound	○	•	●	○
	Visual – local	●			●
	Visual – contextual	●			●

Primary significance ●
Secondary significance ○
Tertiary significance •

Buildings Move, Buildings Leak

- Case Study 4: which loadings were involved?





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		Explosion		●		
		Rheological (creep, shrinkage, etc.)		●		○
		Impact (vehicles, missiles, people, etc.)	•	●		•
		Fire	•	○	●	•
	Essentially environmental	Heat (thermal, etc.)		○	●	
		Air (pressure, movement, leakage, etc.)		○	●	
		Moisture (built-in, rain, condensation, etc)		○	●	○
		Smoke			●	
		Solar radiation (incident, reflected, etc.)			●	○
		Chemical attack/atmospheric (acid rain, etc.)			●	○
		Particulate matter (dust, VOC's, etc.)			●	
		People (wear & tear, etc.)	●	○		●
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	Essentially perceptual	Light (natural, incandescent, fluorescent, etc.)			●	
		Sound	○	•	●	○
		Visual – local	●			●
		Visual – contextual	●			●

Primary significance ●
Secondary significance ○
Tertiary significance •

Straube and Burnett 38.

Buildings Move, Buildings Leak

- Case Study 5: Roof Ponding/Adaptive Reuse Project

Buildings Move, Buildings Leak

- Case Study 5: Roof Ponding/Adaptive Reuse Project
- New buildings: all code provisions for structural design apply
- Existing building modifications: retrofitting of structure is governed by code provisions for existing buildings
  - Varying thresholds of retrofit scope triggered by degree of modifications

Buildings Move, Buildings Leak

- Case Study 5: Roof Ponding/Adaptive Reuse Project

- New buildings: Roofs designed to less than ¼" per foot slope analyzed for progressive deflection from ponding instability

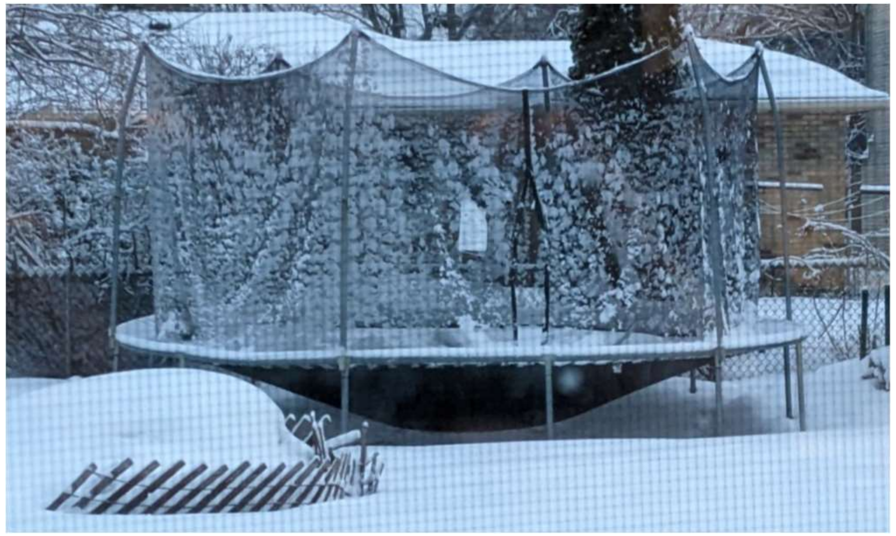
  - Local jurisdictions might prohibit shallower slopes

  - Manufacturers warranties might exclude shallower slopes

Buildings Move, Buildings Leak

- Case Study 5: Roof Ponding/Adaptive Reuse Project

- Progressive deflection from ponding instability



Buildings Move, Buildings Leak

- Case Study 5: Roof Ponding/Adaptive Reuse Project

- Existing roof structure design was only marginally above original code minimums
  - Open web steel joists
  - Roof framing sloped 1/8” per foot
  - Existing roof assembly saturated

Buildings Move, Buildings Leak

- Case Study 5: Roof Ponding/Adaptive Reuse Project
- Local Code allowed for roof slopes shallower than ¼” per foot
- Modifications did not trigger extensive retrofit requirements
    - Ponding analysis was not performed by design team

Buildings Move, Buildings Leak

- Case Study 5: Roof Ponding/Adaptive Reuse Project

Buildings Move, Buildings Leak

- Case Study 5: Roof Ponding/Adaptive Reuse Project

- Design team went back and performed ponding analysis
  - Existing framing confirmed to be stable under sustained loads

Buildings Move, Buildings Leak

- Case Study 5: Roof Ponding/Adaptive Reuse Project

- There were early warning signs
  - Construction team could have alerted structural engineer to birdbaths

Buildings Move, Buildings Leak

- Case Study 5: Roof Ponding/Adaptive Reuse Project
- This particular instance did not result in a critical life-safety issue
- Nevertheless –
  - Cumulative roof ponding as a result of not considering building movement is a serious issue that has resulted many roof collapses
  - Slopes shallower than ¼” per foot always warrant careful consideration, regardless of code requirements.

Buildings Move, Buildings Leak

- Case Study 5: which loadings were involved?

Table 2.4: General category of loadings and related functions

Causal phenomenon or loading	Specific loadings	Category of functions: Interior Finish	Support	Control	Exterior finish
Essentially structural	Gravity – Dead (assembly, etc.)		●		
	Gravity – Live (people, snow, etc.)		●		
	Wind		●	○	
	Ground Movement (seismic, settlement, etc.)		●		
	Explosion		●		
	Rheological (creep, shrinkage, etc.)		●		○
	Impact (vehicles, missiles, people, etc.)	•	●		•
	Fire	•	○	●	•
Essentially environmental	Heat (thermal, etc.)		○	●	
	Air (pressure, movement, leakage, etc.)		○	●	
	Moisture (built-in, rain, condensation, etc)		○	●	○
	Smoke			●	
	Solar radiation (incident, reflected, etc.)			●	○
	Chemical attack/atmospheric (acid rain, etc.)			●	○
	Particulate matter (dust, VOC's, etc.)			●	
	People (wear & tear, etc.)	●	○		●
Essentially perceptual	Insects, birds, animals, (termites, rodents, etc.)			●	○
	Light (natural, incandescent, fluorescent, etc.)			●	
	Sound	○	•	●	○
	Visual – local	●			●
	Visual – contextual	●			●

Primary significance ●
Secondary significance ○
Tertiary significance •

Straube and Burnett 38.

Buildings Move, Buildings Leak

- Case Study 5: which loadings were involved?

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Primary significance ●
Secondary significance ○
Tertiary significance •

Straube and Burnett 38.

Buildings Move, Buildings Leak

- Category B: Material Volume Change (Shortening/Elongation) impacting Enclosure Control Layers

Buildings Move, Buildings Leak

- Case Study 6: Solar Heat Gain/Self-Adhered Membrane Flashing

Buildings Move, Buildings Leak

- Case Study 6: Solar Heat Gain/Self-Adhered Membrane Flashing

Flashing

Facer
(Color is more often a function of branding)

Adhesive backing
(Color is typically a function of the adhesive's chemistry)

- Material color influences ability to reflect, absorb, and transmit heat

Buildings Move, Buildings Leak

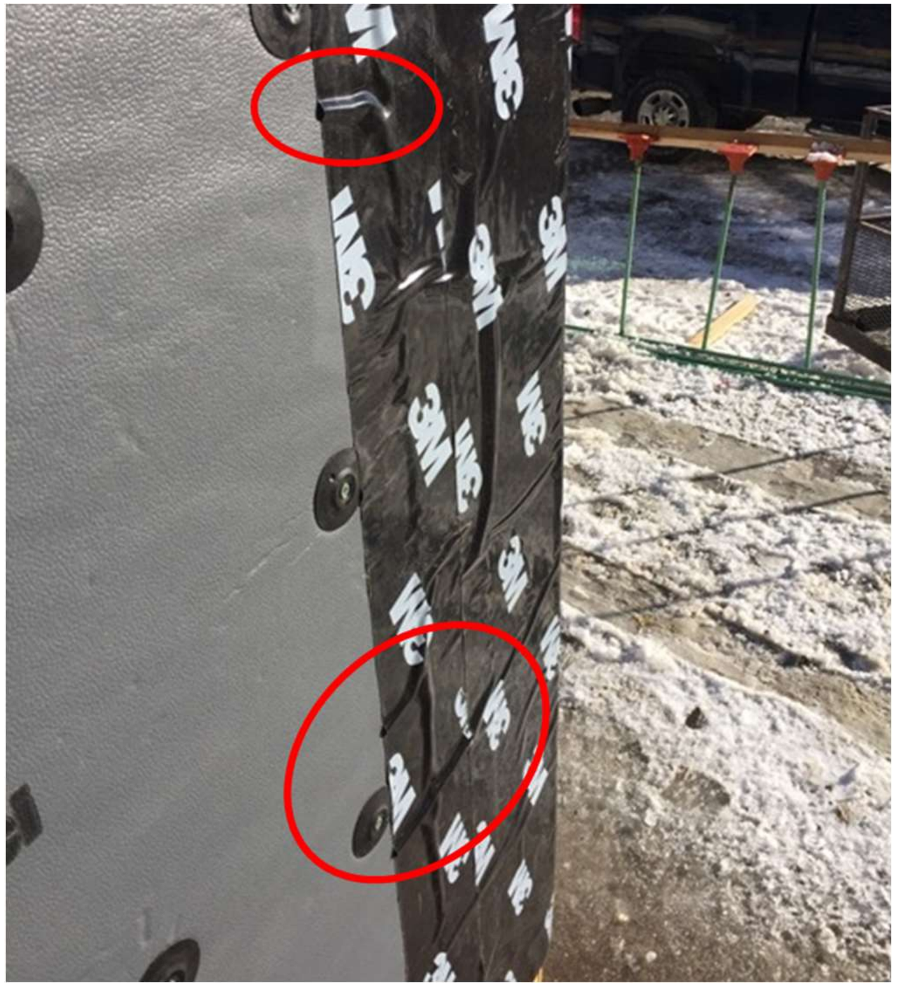
- Case Study 6: Solar Heat Gain/Self-Adhered Membrane Flashing

  - Integrated sheathing system
  - Non-loadbearing steel stud wall
  - Board joints/corners/openings required treatment for water and air control layer
    - Fluid applied flashing considered but ultimately not chosen
    - 15-mil acrylic-based flashing selected

Buildings Move, Buildings Leak

- Case Study 6: Solar Heat Gain/Self-Adhered Membrane Flashing

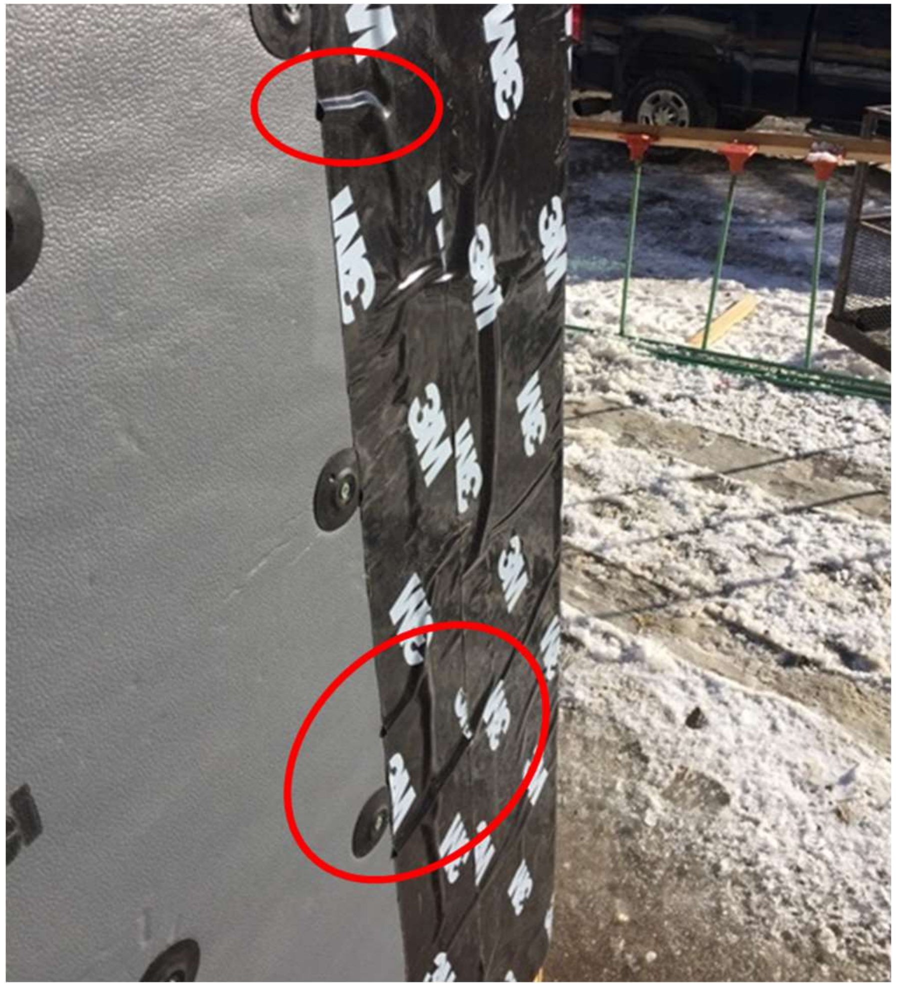
- Enclosure work occurred throughout winter (Climate Zone 6a)
  - End of December during installation, gapping or "fish mouthing" was discovered at outer edges of flashing
  - Raised folds also discovered in field of material



Buildings Move, Buildings Leak

- Case Study 6: Solar Heat Gain/Self-Adhered Membrane Flashing

- Flashing would
  - be flat/smooth before direct morning sunlight
  - gap open when exposed to sun
  - Then return to flat after sun set in afternoon



Buildings Move, Buildings Leak

- Case Study 6: Solar Heat Gain/Self-Adhered Membrane Flashing

Buildings Move, Buildings Leak

- Case Study 6: Solar Heat Gain/Self-Adhered Membrane Flashing

- Surface temperature readings taken
- Days with direct sunlight the surface temperatures would exceed 130 degrees
  - Ambient air temperatures around 30 degrees

Buildings Move, Buildings Leak

- Case Study 6: Solar Heat Gain/Self-Adhered Membrane Flashing

  Facer color

  ➔ solar heat gain

  ➔ material expanded at a rate greater than substrate

  ➔ expansion overcame adhesive force

- Any fish mouths terminating on an upward edge determined to be a moisture infiltration risk

Buildings Move, Buildings Leak

- Case Study 6: Solar Heat Gain/Self-Adhered Membrane Flashing

- Remedial options considered

Buildings Move, Buildings Leak

- Case Study 6: Solar Heat Gain/Self-Adhered Membrane Flashing

- Remedial options considered

Buildings Move, Buildings Leak

- Case Study 6: Solar Heat Gain/Self-Adhered Membrane Flashing

  - Option selected was validated through water testing

  - Project delay not significant, however
    - Labor and material cost increase ~ $30,000 from contingency
    - Overall install schedule prolonged

Buildings Move, Buildings Leak

- Case Study 6: Solar Heat Gain/Self-Adhered Membrane Flashing

- Recommendations provided to manufacturer
  - Produce flashing material in a lighter color?

- Other best practice reminders for material use
  - J-roller or plastic spreader
  - Do not push limits of UV exposure

Buildings Move, Buildings Leak

- Case Study 6: which loadings were involved?

Table 2.4: General category of loadings and related functions

Causal phenomenon or loading		Specific loadings	Category of functions: Interior Finish	Support	Control	Exterior finish
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		Explosion		●		
		Rheological (creep, shrinkage, etc.)		●		○
		Impact (vehicles, missiles, people, etc.)	•	●		•
		Fire	•	○	●	•
	Essentially environmental	Heat (thermal, etc.)		○	●	
		Air (pressure, movement, leakage, etc.)		○	●	
		Moisture (built-in, rain, condensation, etc)		○	●	○
		Smoke			●	
		Solar radiation (incident, reflected, etc.)			●	○
		Chemical attack/atmospheric (acid rain, etc.)			●	○
		Particulate matter (dust, VOC's, etc.)			●	
		People (wear & tear, etc.)	●	○		●
		Insects, birds, animals, (termites, rodents, etc.)			●	○
	Essentially perceptual	Light (natural, incandescent, fluorescent, etc.)			●	
		Sound	○	•	●	○
		Visual – local	●			●
		Visual – contextual	●			●

Primary significance ●
Secondary significance ○
Tertiary significance •

Straube and Burnett 38.

Buildings Move, Buildings Leak

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Primary significance ●
Secondary significance ○
Tertiary significance •

abaa building enclosure conference

Straube and Burnett 38.

Buildings Move, Buildings Leak

- Case Study 7: Spray Polyurethane Foam (SPF) Shrinkage

Buildings Move, Buildings Leak

- Case Study 7: Spray Polyurethane Foam (SPF) Shrinkage

- Site-manufactured SPF
  - Two base components are produced by material manufacturer
  - Part "A" and Part "B" combined on-site during spraying operation to create foam plastic
    - Cellular structure/entrapped voids are result of site operation

- Very common on job-sites
  - Thermal control
  - Air control
  - Vapor control

Buildings Move, Buildings Leak

- Case Study 7: Spray Polyurethane Foam (SPF) Shrinkage

- Quality control measures required before/during installation
  - Material shipping/handling/storage controls
  - Installation equipment maintenance and calibration
  - Processing controls – temperature/pressure/humidity
    - For material, substrate AND ambient

Buildings Move, Buildings Leak

- Case Study 7: Spray Polyurethane Foam (SPF) Shrinkage

- Possible install failure is excessive shrinkage after placement
  - Can initiate anywhere from several days to several months after placement

- Concern can be minor to major
  - Depends on intended control function of SPF and degree of shrinkage
  - Thermal control layer breached = relatively minor
  - Air control layer breached = bigger deal
  - Shrinkage damages other control layers = very big deal

Buildings Move, Buildings Leak

- Case Study 7: Spray Polyurethane Foam (SPF) Shrinkage

- Project 1

  - Exterior steel stud wall
  - Fluid applied air/water resistive barrier on exterior sheathing
  - Stud walls ran past second floor slab and roof deck edge

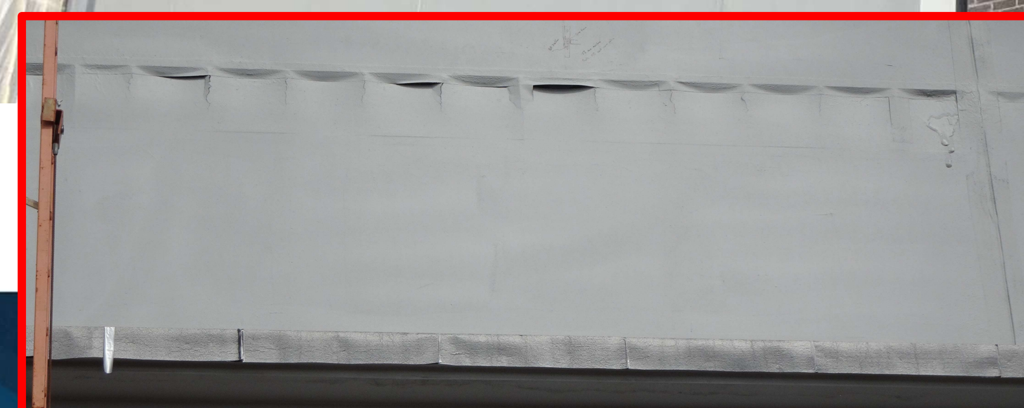
  - At stud bypass of second floor and roof, SPF “plugs” placed in stud cavity to prevent air bypass reaching parapet cavity

Buildings Move, Buildings Leak

- Case Study 7: Spray Polyurethane Foam (SPF) Shrinkage

- Distress first observed on outside face of exterior sheathing at roof deck elevation

- Inspection openings created on rear side of parapet wall



Buildings Move, Buildings Leak

- Case Study 7: Spray Polyurethane Foam (SPF) Shrinkage

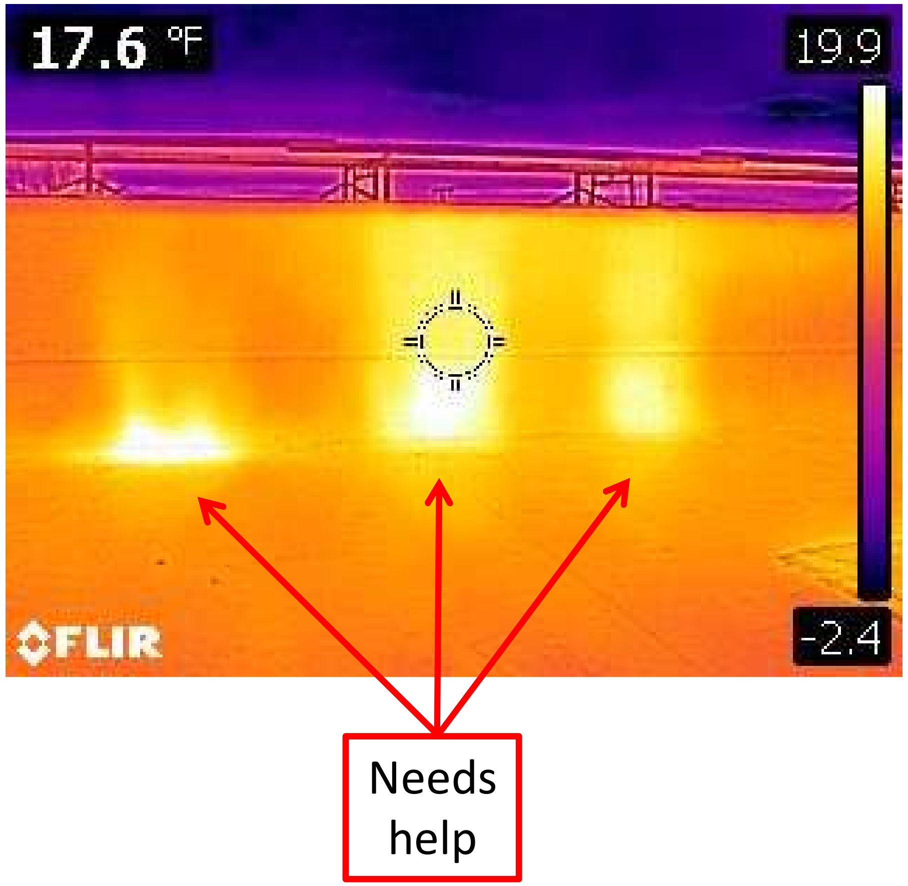
- Condition also discovered at second floor slab edge

- Shrinkage pulled SPF away from studs and slab edge face
  - Unacceptable air bypass condition

Buildings Move, Buildings Leak

- Case Study 7: Spray Polyurethane Foam (SPF) Shrinkage

- Fix determined:
  - Determine areas needing repair
    - IR imaging
  - Create relief cut in existing plug
  - Install new cap layer over top
    - With renewed focus on processing and placement controls
  - Validate repair with IR imaging



Buildings Move, Buildings Leak

- Case Study 6: Spray Polyurethane Foam (SPF) Shrinkage

- Project 2
  - Exterior steel stud wall
  - Fluid applied air/vapor/water barrier (WRB) on exterior sheathing
    - Sheathing joints treated with flashing-adhered membrane flashing

  - SPF applied full height in stud cavity as part of thermal control

Buildings Move, Buildings Leak

- Case Study 7: Spray Polyurethane Foam (SPF) Shrinkage

- Distress observed on outside face of sheathing
  - First noted ~3 months after install

  - Sheathing bowed inward
  - WRB cracked
  - Sheathing facer cracked

Buildings Move, Buildings Leak

- Case Study 7: Spray Polyurethane Foam (SPF) Shrinkage

- Inspection Openings Made
  - SPF shrinkage confirmed
- Site visit from both SPF Manufacturer & WRB Manufacturer

Buildings Move, Buildings Leak

- Case Study 7: Spray Polyurethane Foam (SPF) Shrinkage
- SPF condition determined acceptable
- WRB condition required repair
  - Cracks treated with additional flashing material

Buildings Move, Buildings Leak

- Case Study 7: Spray Polyurethane Foam (SPF) Shrinkage

- Both Projects:
  - Several months of additional work
  - Combined additional costs exceeding $100,000
  - Due to the amount of controls required for installation, difficult to identify a singular root cause of shrinkage

Buildings Move, Buildings Leak

- Case Study 7: Spray Polyurethane Foam (SPF) Shrinkage

- Recommendations
  - For SPF applied in stud cavities, look for inward bowing or “scalloping” of exterior sheathing as sign that shrinkage has occurred

Buildings Move, Buildings Leak

- Case Study 7: Spray Polyurethane Foam (SPF) Shrinkage

- Recommendations – Proper Quality Control
  - Components kept at manufacturer’s recommended temperature ranges during storage & handling
  - Spraying equipment calibrated to correct mixing ratio, line temperatures, pressures
  - Environmental conditions (temperature & humidity) of air and receiving substrate within manufacturer’s recommended ranges

Buildings Move, Buildings Leak

- Case Study 7: which loadings were involved?

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	Rheological (creep, shrinkage, etc.)		●		○
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	Air (pressure, movement, leakage, etc.)		○	●	
	Moisture (built-in, rain, condensation, etc)		○	●	○
	Smoke			●	
	Solar radiation (incident, reflected, etc.)			●	○
	Chemical attack/atmospheric (acid rain, etc.)			●	○
	Particulate matter (dust, VOC's, etc.)			●	
	People (wear & tear, etc.)	●	○		●
Essentially perceptual	Insects, birds, animals, (termites, rodents, etc.)			●	○
	Light (natural, incandescent, fluorescent, etc.)			●	
	Sound	○	•	●	○
	Visual – local	●			●
	Visual – contextual	●			●

Primary significance ●
Secondary significance ○
Tertiary significance •

Straube and Burnett 38.

Buildings Move, Buildings Leak

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		Sound	○	•	●	○
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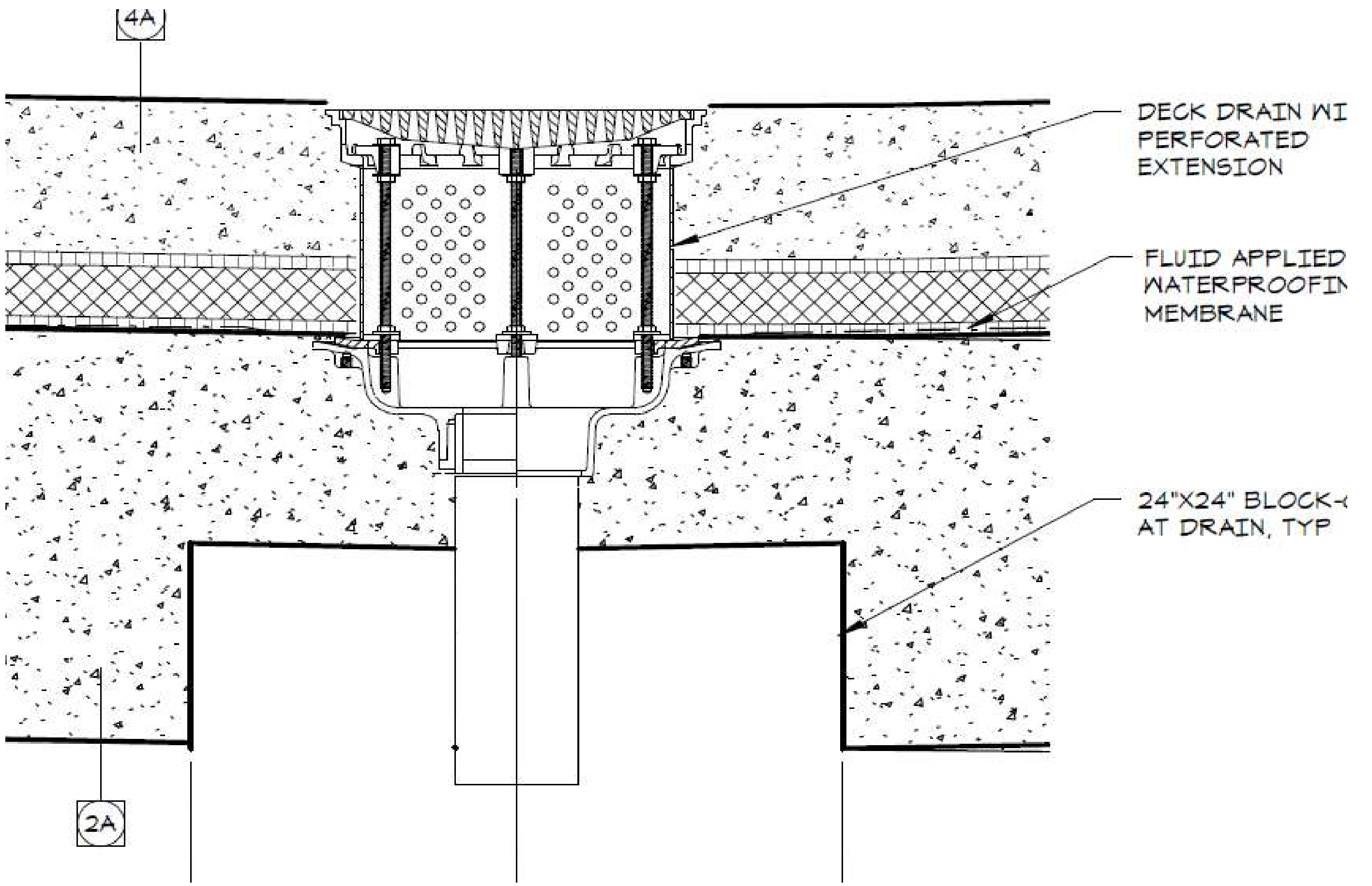
Primary significance ●
Secondary significance ○
Tertiary significance •

MAYBE?

Buildings Move, Buildings Leak

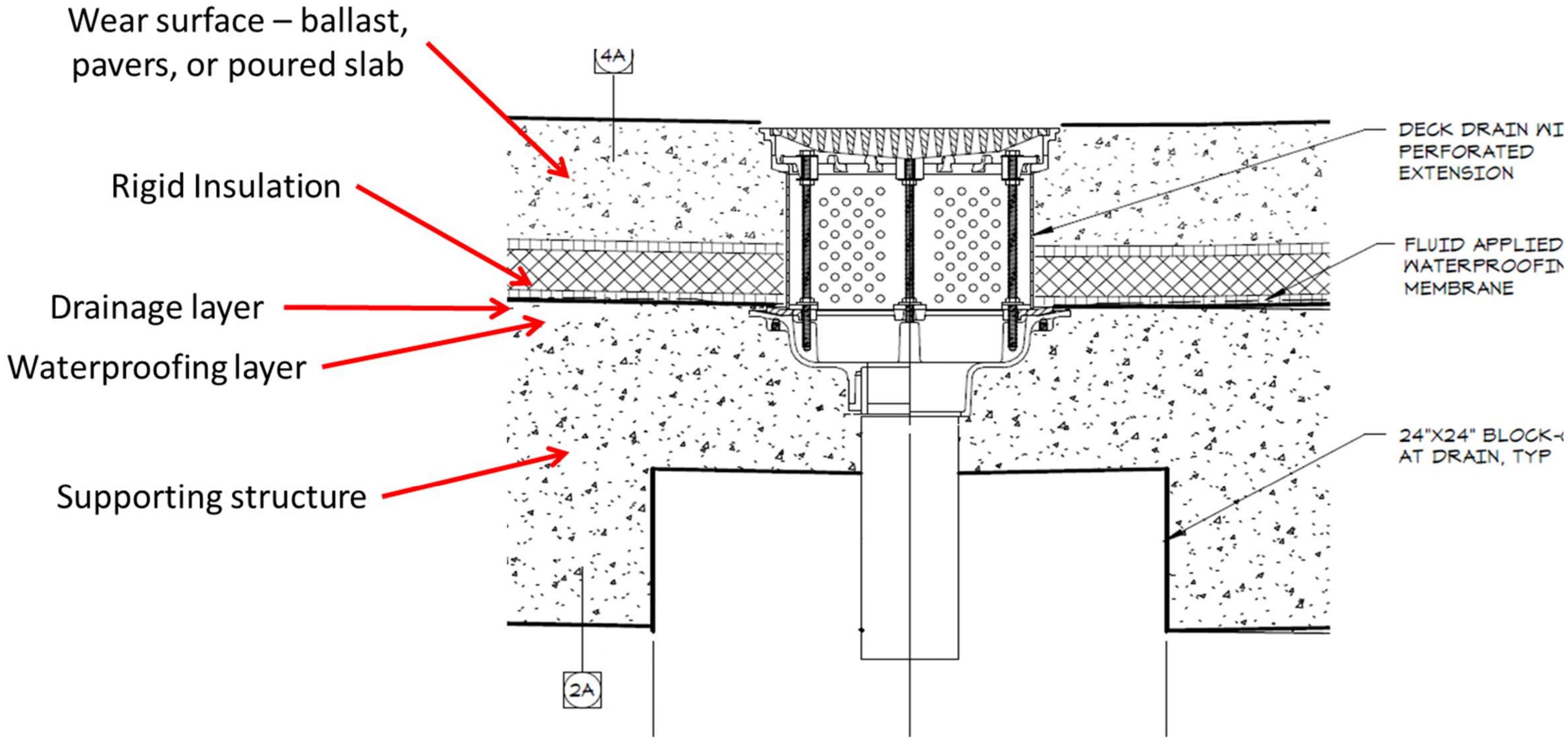
- Case Study 8: Slab Jacking/Plaza Deck Assembly

- Plaza decks used as horizontal mediator between exterior above and interior below
- Also known as
  - Inverted roofs (IRMAs)
  - Protected roof membranes (PMRs)
  - Split slabs



Buildings Move, Buildings Leak

- Case Study 8: Slab Jacking/Plaza Deck Assembly



Buildings Move, Buildings Leak

- Case Study 8: Slab Jacking/Plaza Deck Assembly

- Case study will focus on cast-in-place concrete wear slabs for parking on top surface

Buildings Move, Buildings Leak

- Case Study 8: Slab Jacking/Plaza Deck Assembly

- Wear slabs ➔ outside of control layers ➔ subject to seasonal changes of exterior climate

Fig. 3.3.2 Annual average ambient relative humidity, percent

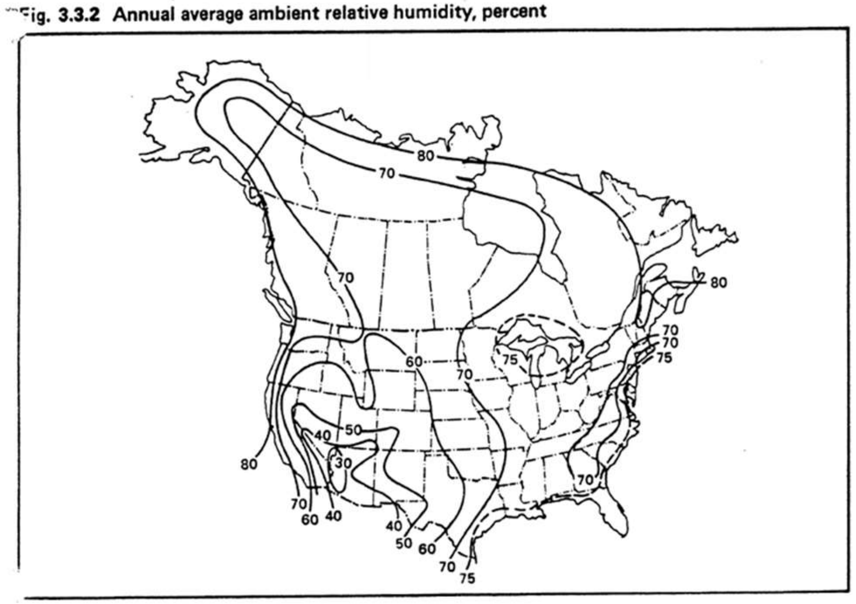
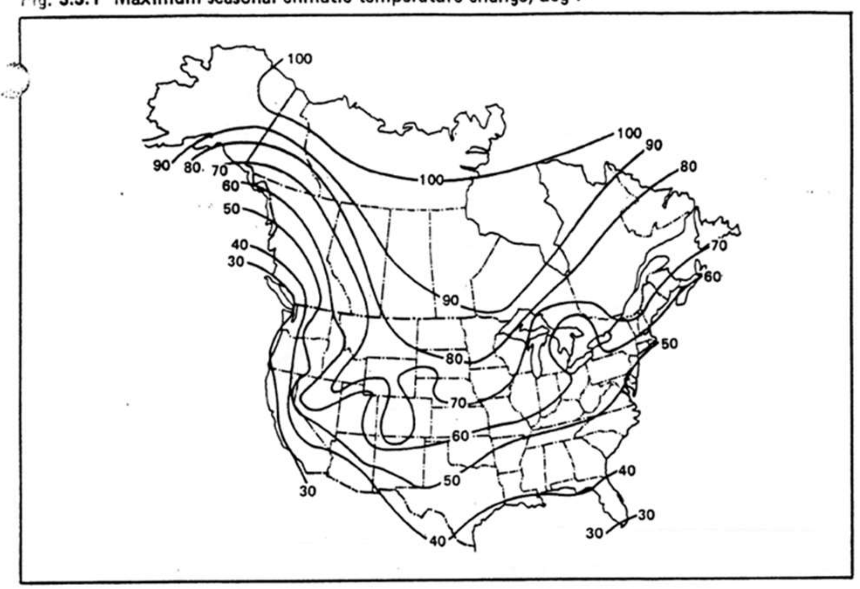


Fig. 3.3.1 Maximum seasonal climatic temperature change, deg F

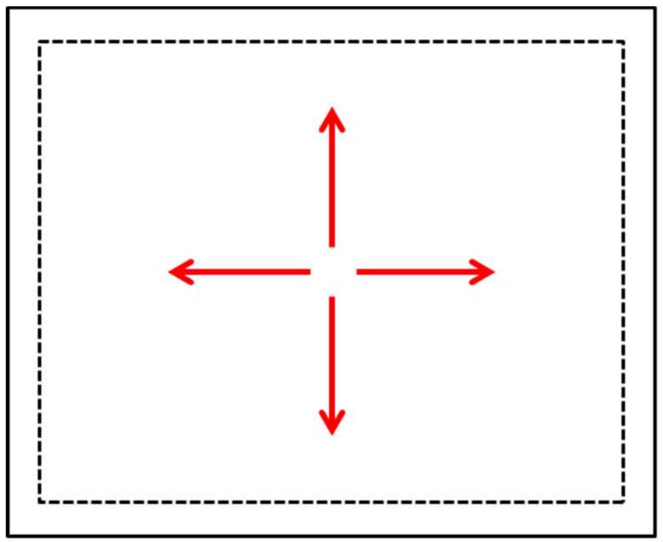


From PCI Design Handbook 3rd Ed., 1985

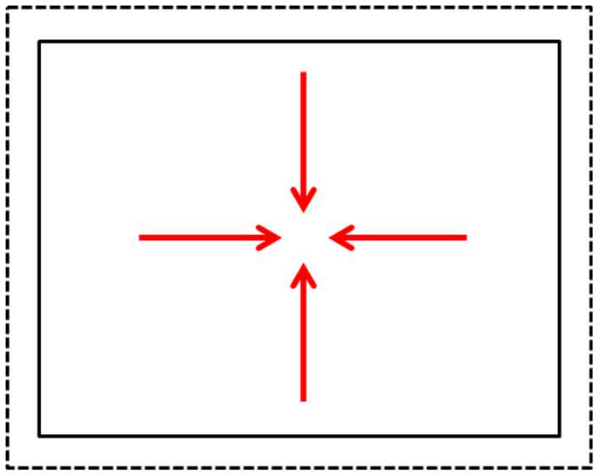
Buildings Move, Buildings Leak

- Case Study 8: Slab Jacking/Plaza Deck Assembly

- Wear slab detailing must accommodate movement



<u>Increase</u> in temperature or moisture content



<u>Decrease</u> in temperature or moisture content

Buildings Move, Buildings Leak

- Case Study 8: Slab Jacking/Plaza Deck Assembly

- Areas where waterproofing (WP) layer intersects wear slab must be protected from wear slab movement
  - Where WP turns up vertical surfaces – walls, light pole bases, steps in structural slab

Buildings Move, Buildings Leak

- Case Study 8: Slab Jacking/Plaza Deck Assembly

- Project 1
  - Typical Assembly Construction, but WP layer was 60 mil EPDM (not ideal)
  - Parking deck above auto dealership for auto storage

Buildings Move, Buildings Leak

- Case Study 8: Slab Jacking/Plaza Deck Assembly

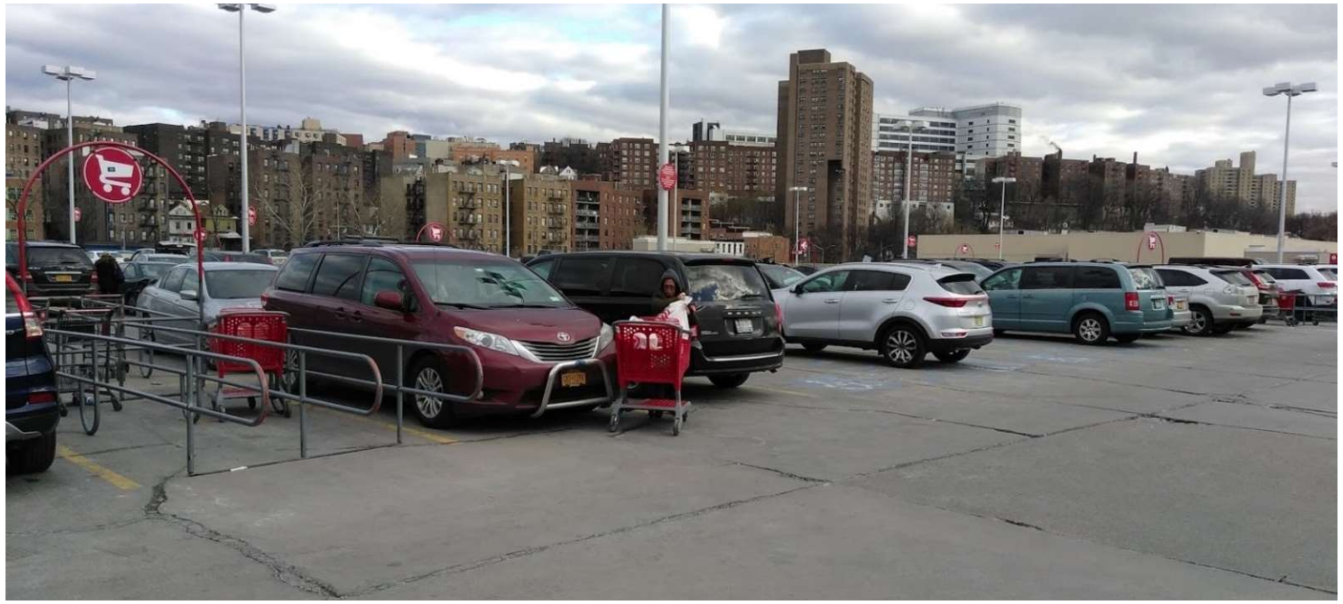
- Original construction complete ~ 2006
  - Leaking first observed ~ 2008
  - Substantial exterior wall cracking/movement at building corners
  - Accelerated wear slab deterioration

  - Numerous other issues, primarily structure-related

Buildings Move, Buildings Leak

- Case Study 8: Slab Jacking/Plaza Deck Assembly

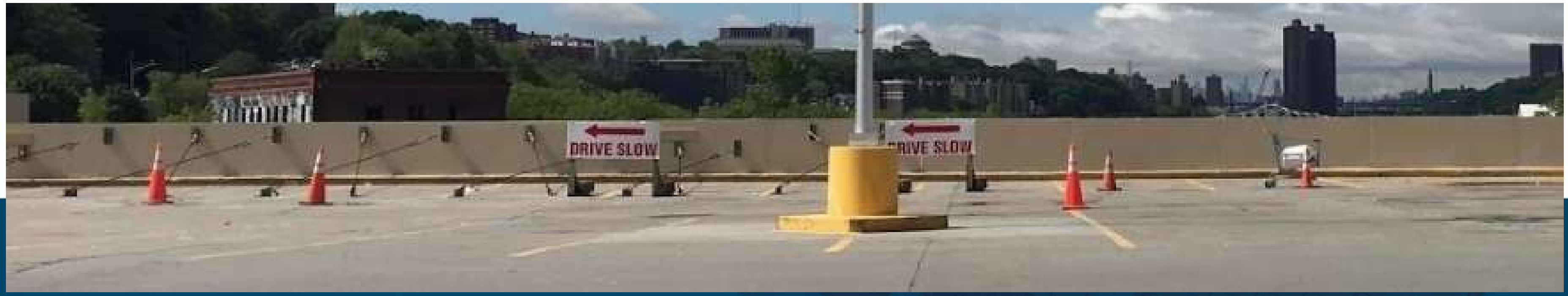
- Project 2
  - Typical Assembly Construction, WP layer 215 mil hot rubberized asphalt (HRA)
  - Parking deck above retail



Buildings Move, Buildings Leak

- Case Study 8: Slab Jacking/Plaza Deck Assembly

- Original construction complete ~ 2005
  - Leaking first observed ~ 2011
  - Substantial exterior wall outward movement
  - Accelerated wear slab deterioration
  - Tilting light pole bases

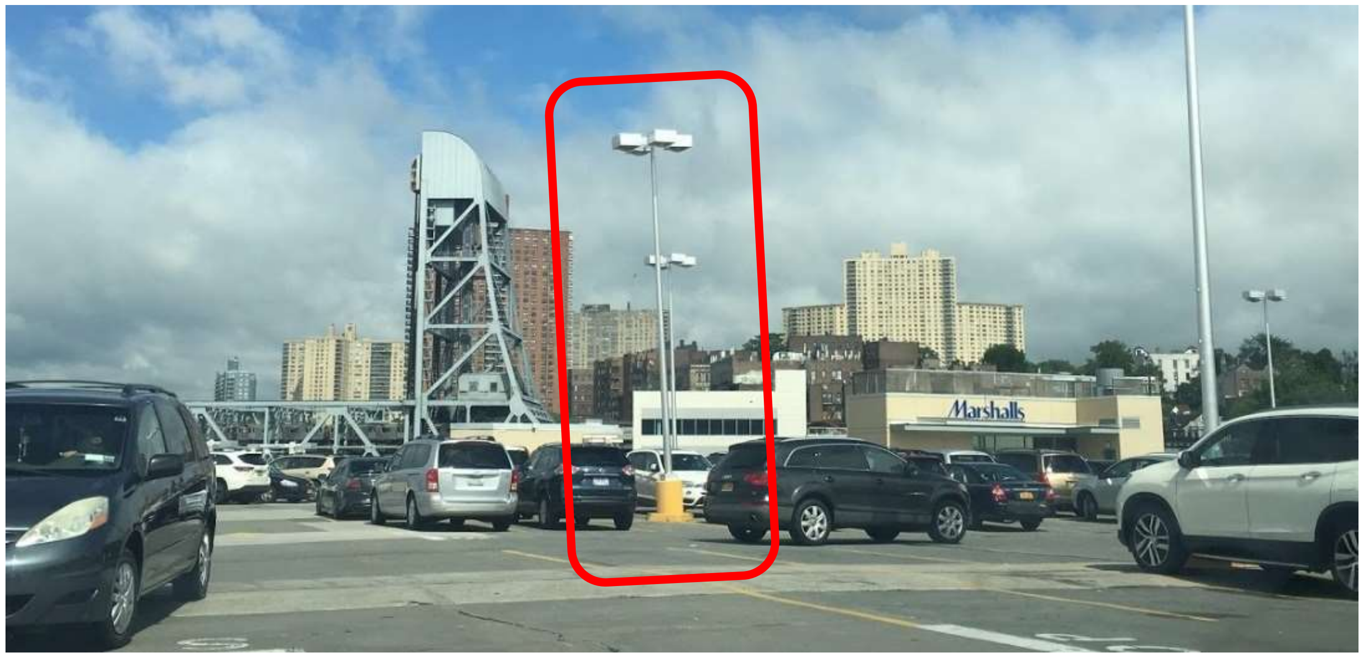


Buildings Move, Buildings Leak

- Case Study 8: Slab Jacking/Plaza Deck Assembly

Buildings Move, Buildings Leak

- Case Study 8: Slab Jacking/Plaza Deck Assembly



Buildings Move, Buildings Leak

- Case Study 8: Slab Jacking/Plaza Deck Assembly

- Inadequate amount of expansion joints & sealed control joints
  ➔ majority of wear slab expansion occurring at outer edges & corners
    ➔ slab movement distressing waterproofing layer to failure

Buildings Move, Buildings Leak

- Case Study 8: Slab Jacking/Plaza Deck Assembly

- Progressive failure mechanism – Wear slab
  - Shrink over winter months
  - Open up untreated control joints & new tensile cracks
  - Gaps fill with debris/roadway grit
  - Swell over summer months
  - Expand against debris-filled gaps
  - Each successive seasonal cycle would establish new baseline of overall horizontal dimension
- Eventually force of jacking on vertical waterproofing surfaces would cause breach

Buildings Move, Buildings Leak

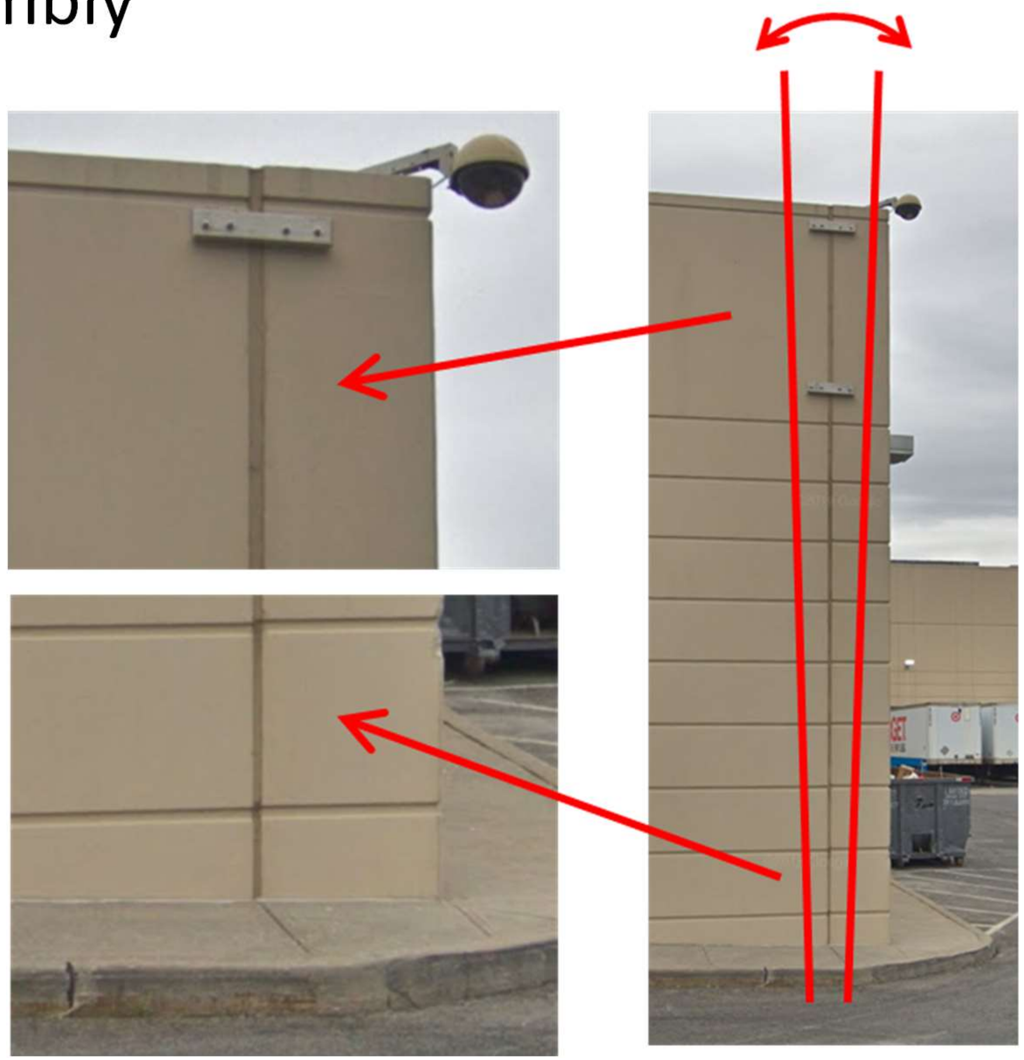
- Case Study 8: Slab Jacking/Plaza Deck Assembly

Buildings Move, Buildings Leak

- Case Study 8: Slab Jacking/Plaza Deck Assembly

- Volume change ➔ compression and shear force

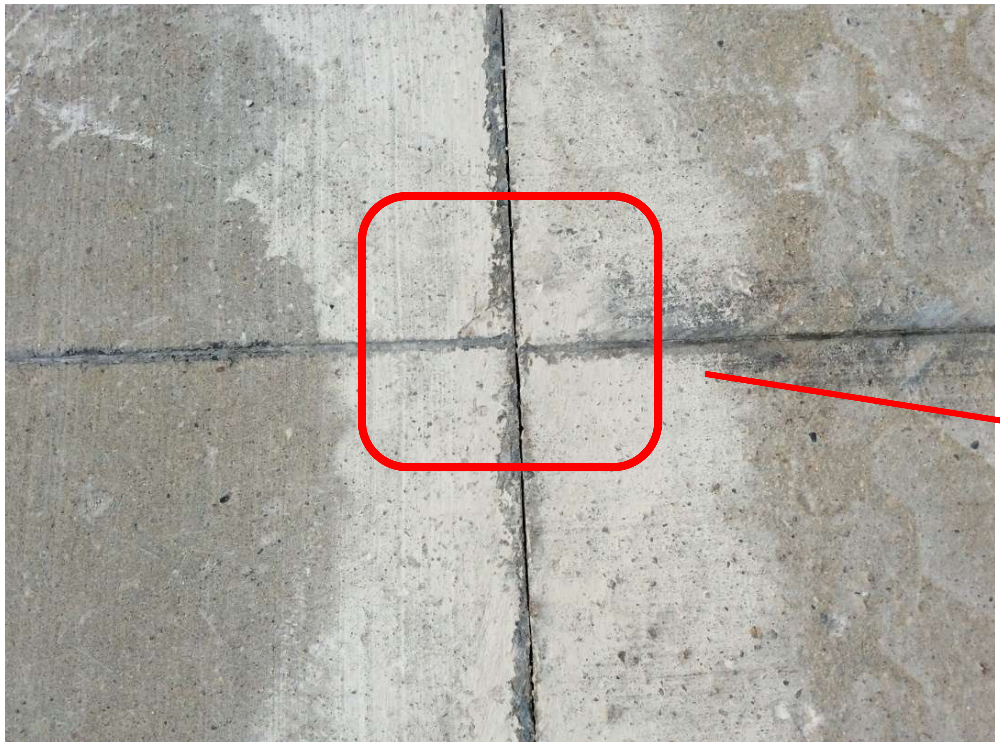
- Findings were controversial on project 2 – "It has to be the snow plow impact force!"

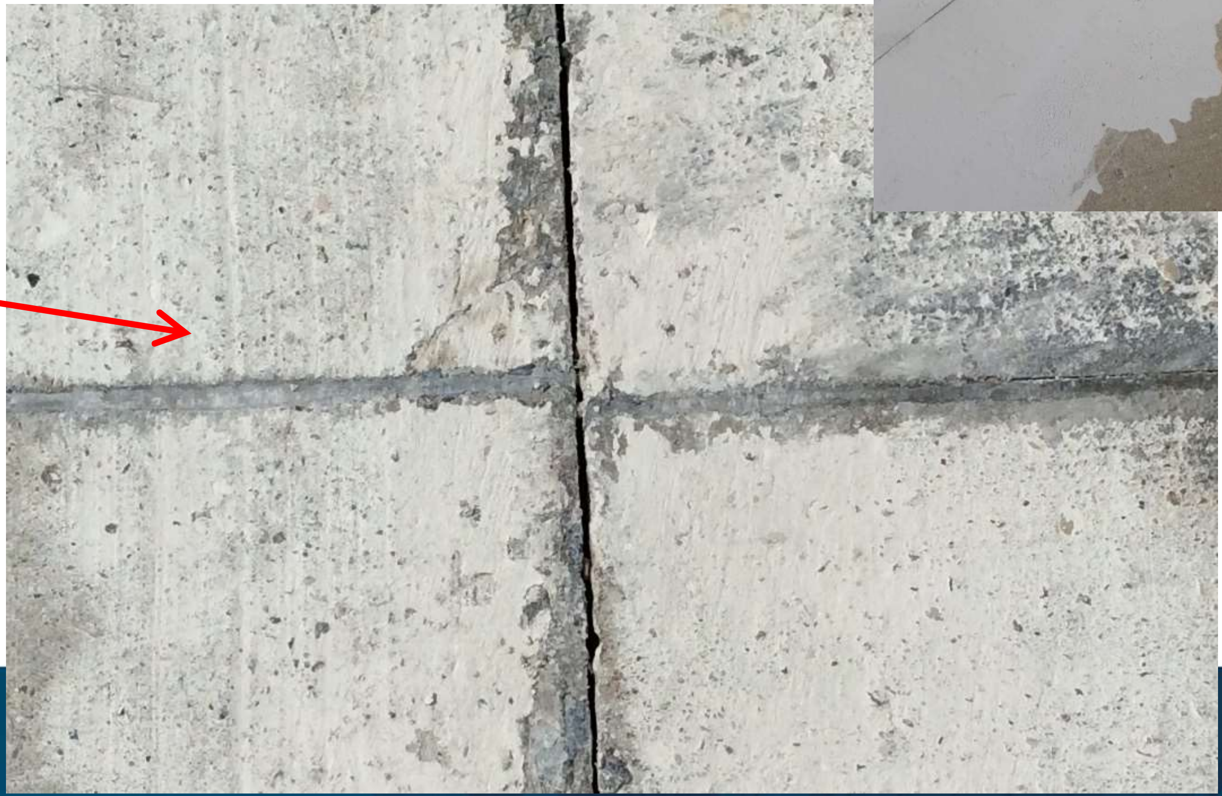


Buildings Move, Buildings Leak

- Case Study 8: Slab Jacking/Plaza Deck Assembly

- Horizontal forces in project 1 were significant





Buildings Move, Buildings Leak

- Case Study 8: Slab Jacking/Plaza Deck Assembly

- Full removal & replacement on project 1 ~ $7,000,000
- Limited removal & repair on project 2 ~ $3,500,000

Buildings Move, Buildings Leak

- Case Study 8: Slab Jacking/Plaza Deck Assembly
    - Remove assemblies down to structural slab
    - Replace WP layer (215 mil HRA)
    - Rebuild of rest of plaza assembly above
        - Additional drainage layer included above insulation
    - New wear course slabs
        - Much tighter pattern of control joints, ALL SEALED
        - Additional expansion joints
    - Followed by maintenance program recommendations
    - Regular surface sweeping
    - Wash down of decks in spring and fall
    - Regular inspection of construction and control joints

Buildings Move, Buildings Leak

- Case Study 8: Slab Jacking/Plaza Deck Assembly

- Follow up thoughts
  - Insist on drainage layer both **<u>above</u>** and below insulation
  - Be wary of using single ply or hybrid systems with poured wear slab
  - Protect vertical regions of WP when abutting wear slab
    - Metal flashing
    - Rigid insulation
    - Asphalt impregnated board
  - Dual layer drains and ¼" per foot slope
  - Always recommend a maintenance program!

Buildings Move, Buildings Leak

- Case Study 8: which loadings were involved?

Table 2.4: General category of loadings and related functions

Causal phenomenon or loading	Specific loadings	Category of functions: Interior Finish	Support	Control	Exterior finish
Essentially structural	Gravity – Dead (assembly, etc.)		●		
	Gravity – Live (people, snow, etc.)		●		
	Wind		●	○	
	Ground Movement (seismic, settlement, etc.)		●		
	Explosion		●		
	Rheological (creep, shrinkage, etc.)		●		○
	Impact (vehicles, missiles, people, etc.)	•	●		•
	Fire	•	○	●	•
Essentially environmental	Heat (thermal, etc.)		○	●	
	Air (pressure, movement, leakage, etc.)		○	●	
	Moisture (built-in, rain, condensation, etc)		○	●	○
	Smoke			●	
	Solar radiation (incident, reflected, etc.)			●	○
	Chemical attack/atmospheric (acid rain, etc.)			●	○
	Particulate matter (dust, VOC's, etc.)			●	
Essentially perceptual	People (wear & tear, etc.)	●	○		●
	Insects, birds, animals, (termites, rodents, etc.)			●	○
	Light (natural, incandescent, fluorescent, etc.)			●	
	Sound	○	•	●	○
	Visual – local	●			●
	Visual – contextual	●			●

Primary significance ●
Secondary significance ○
Tertiary significance •

Buildings Move, Buildings Leak

- Case Study 8: which loadings were involved?

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	Impact (vehicles, missiles, people, etc.)	•	●		•
	Fire	•	○	●	•
Essentially environmental	Heat (thermal, etc.)		○	●	
	Air (pressure, movement, leakage, etc.)		○	●	
	Moisture (built-in, rain, condensation, etc)		○	●	○
	Smoke			●	
	Solar radiation (incident, reflected, etc.)			●	○
	Chemical attack/atmospheric (acid rain, etc.)			●	○
	Particulate matter (dust, VOC's, etc.)			●	
	People (wear & tear, etc.)	●	○		●
	Insects, birds, animals, (termites, rodents, etc.)			●	○
	Light (natural, incandescent, fluorescent, etc.)			●	
	Sound	○	•	●	○
Essentially perceptual	Visual – local	●			●
	Visual – contextual	●			●

Primary significance ●
Secondary significance ○
Tertiary significance •

Straube and Burnett 38.

Buildings Move, Buildings Leak

- Conclusion

MOWING AT LIMITS
OF YARD SCOPE:
BY OTHERS

Buildings Move, Buildings Leak

- Conclusion

- Continued effective control of heat, air and moisture is not possible if building movement is not considered

- Thoughtful – Deliberate – Intentional
  - ~~"somebody else will figure it out"~~

Buildings Move, Buildings Leak

- Conclusion

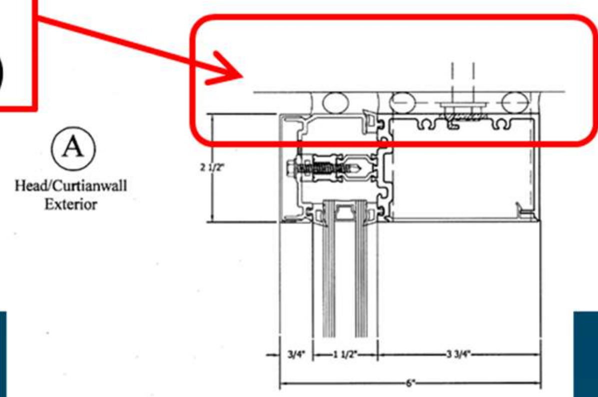
- General Recommendations
  - Effective performance specifications
    - If design is delegated, the assignee needs enough information to succeed
    - Literal, project-specific magnitudes of movement accommodation
    - Less information shared = less chances that expectations will be met

Buildings Move, Buildings Leak

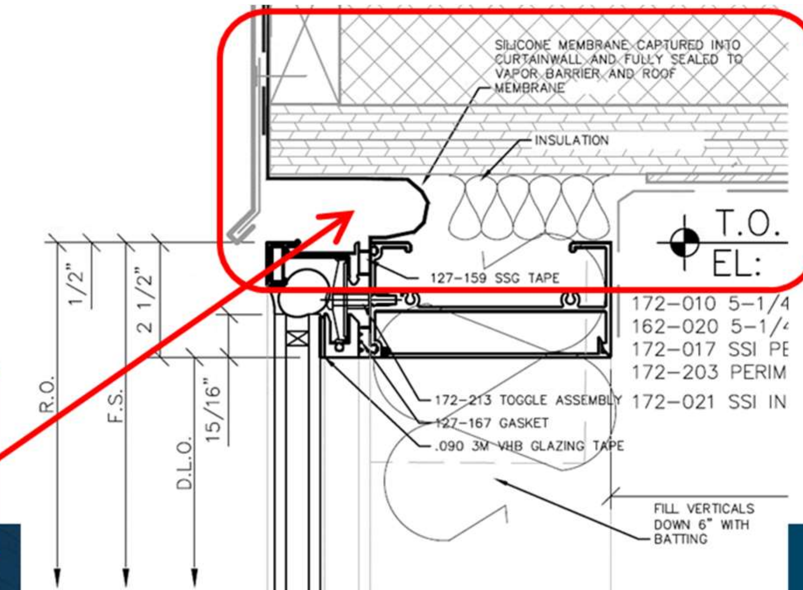
- Conclusion

- General Recommendations
  - Include Movement Information on Field Use Drawings
    - Common failure point = interface between work performed by different trades
    - Draw beyond the line of "by others", all the way to the point where the control layer(s) have been successfully handed off to the next trade

Needs help (actual detail from submittal)



Much better, but we still don't know how much you think it will move



Buildings Move, Buildings Leak

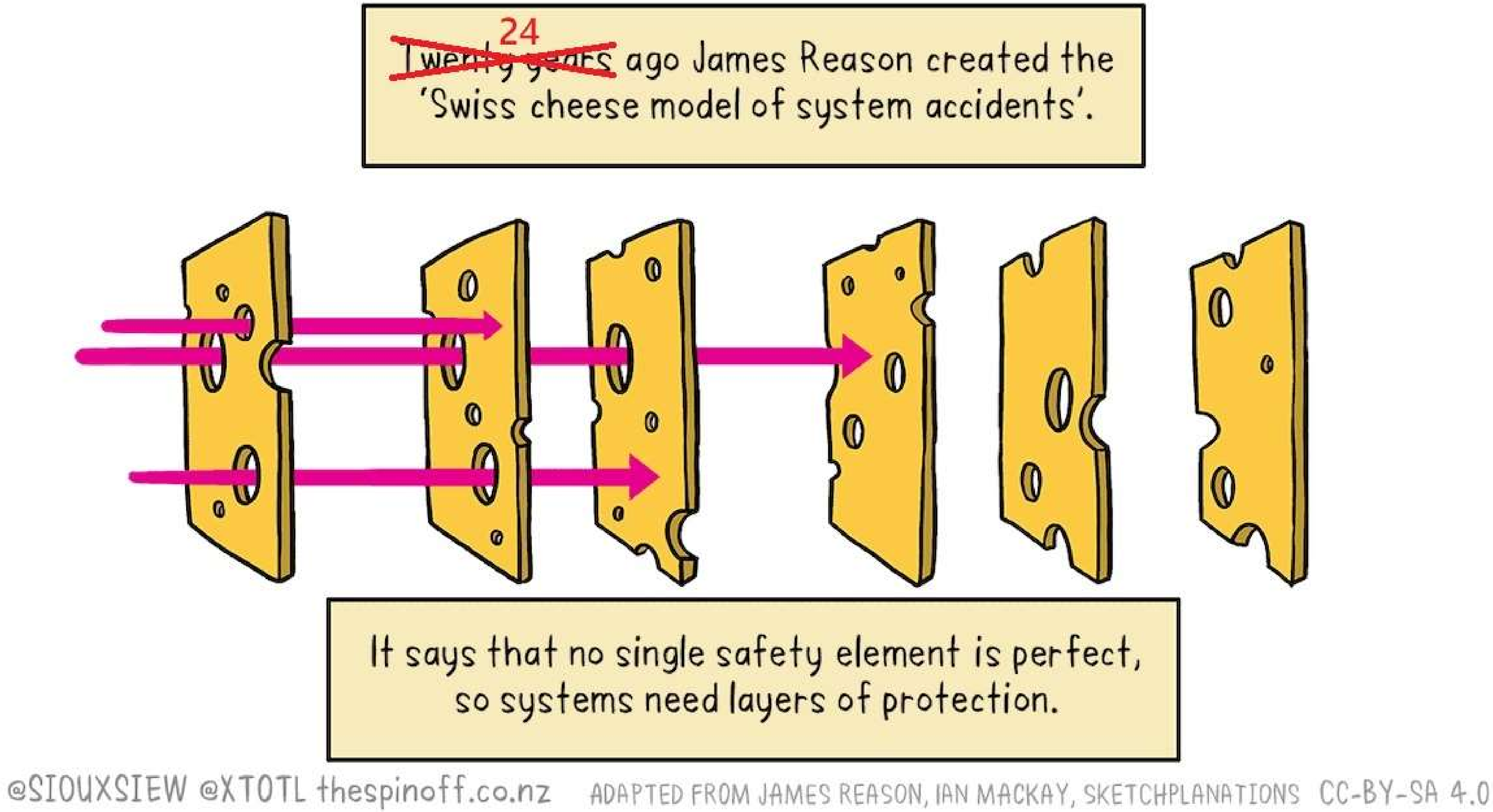
- Conclusion

- General Recommendations
  - Use steps in the documentation and approval process as tollgates
  - Communicate and Validate!

"what I hear you saying is…"

Buildings Move, Buildings Leak

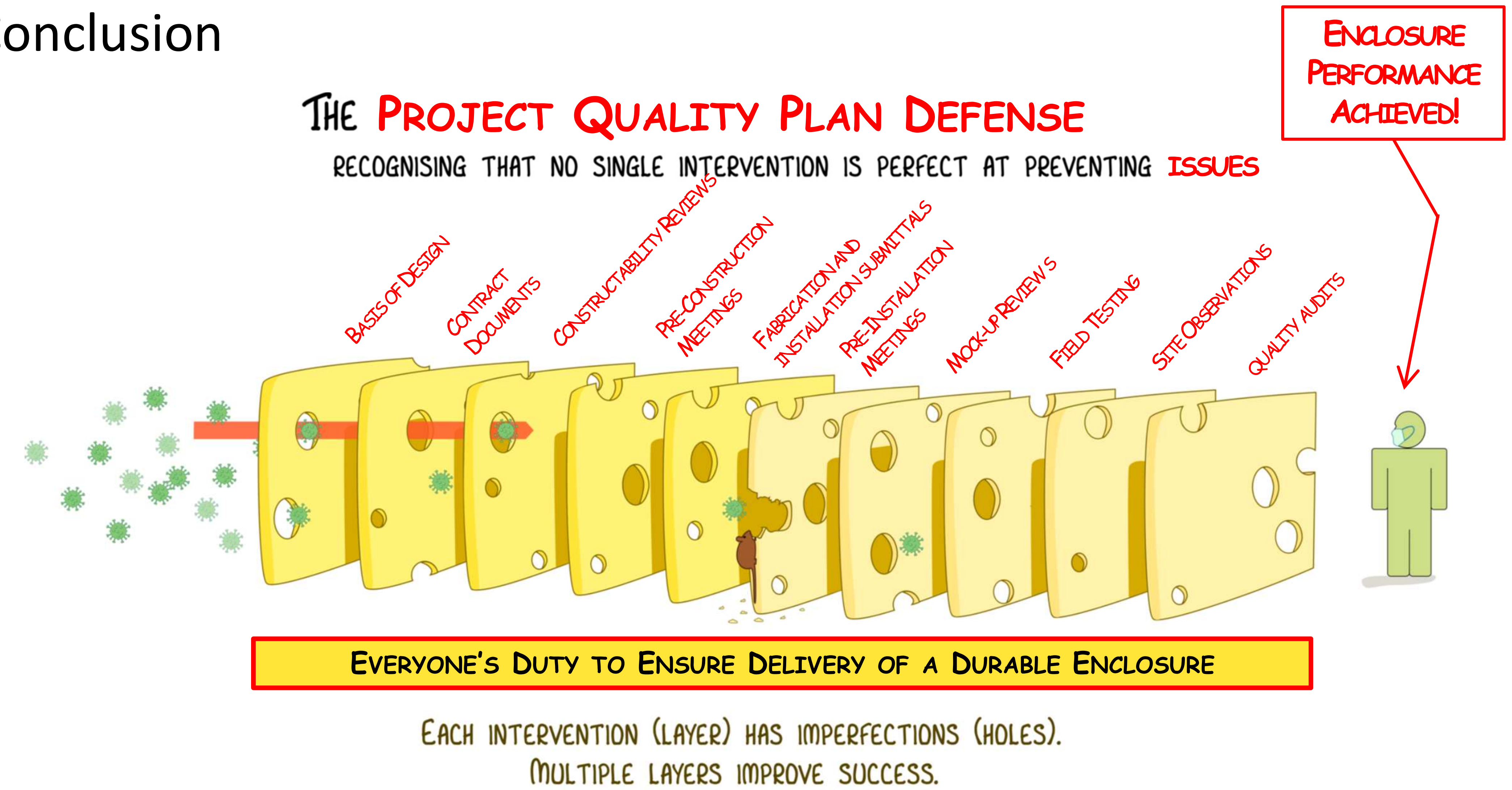
- Conclusion



abaa building enclosure conference

Buildings Move, Buildings Leak

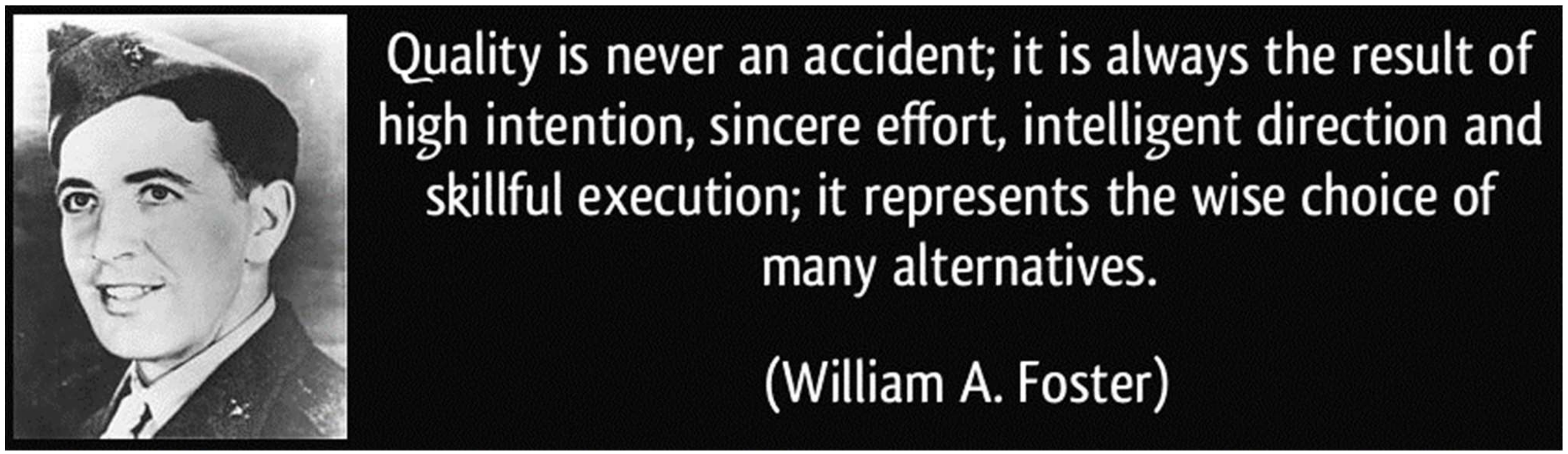
- Conclusion



Buildings Move, Buildings Leak

- Conclusion

- Building enclosures can be successfully delivered and perform under the movement that they experience – with proper commitment from both design and construction professionals



Thank You!

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