

abaa2024 building enclosure conference

Buildings Move, Buildings Leak: Revisiting the Critical Link Between Engineering Mechanics and Enclosure Performance

Jon Porter, PE, Assoc. AIA
Kraus-Anderson Construction Company

AIA
Continuing
Education
Provider



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.



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.

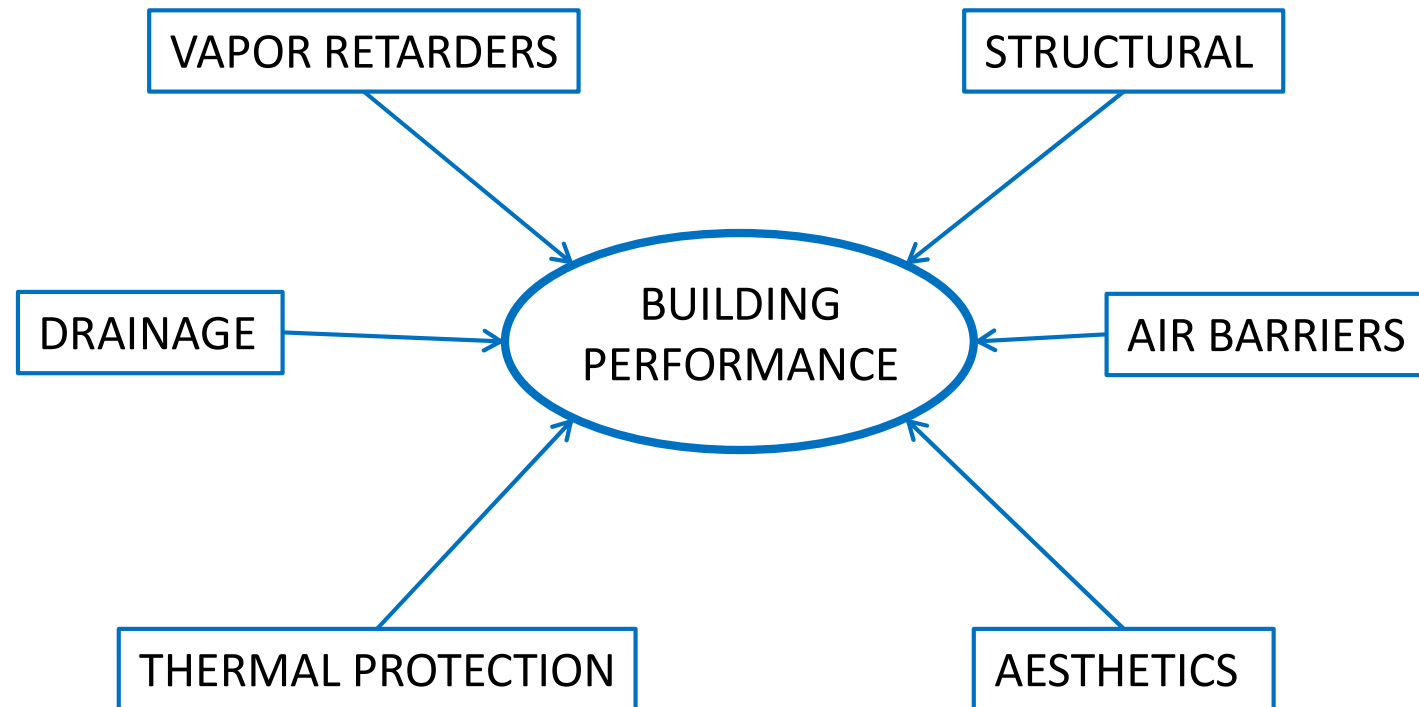


Buildings Move, Buildings Leak

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

Buildings Move, Buildings Leak

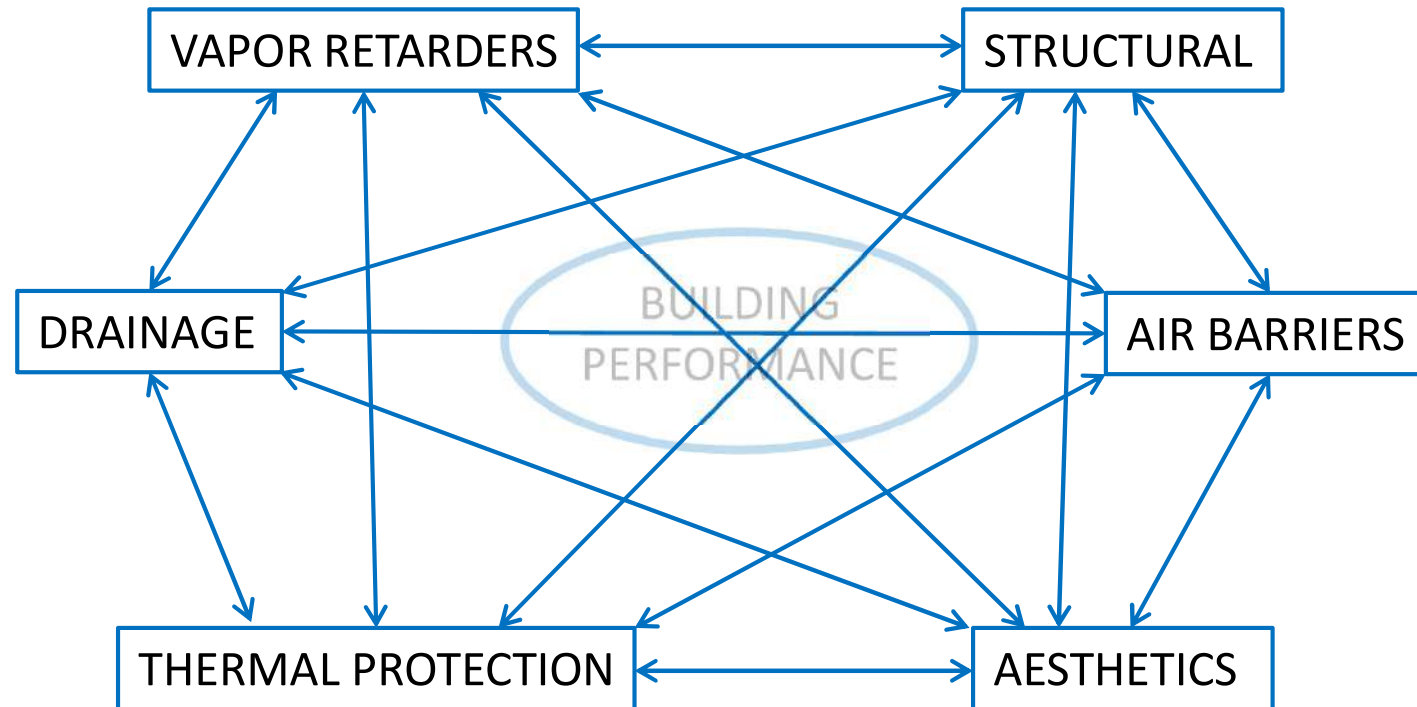
- Topic Overview, or “Why are we Here?”



SYSTEMS THINKING???

Buildings Move, Buildings Leak

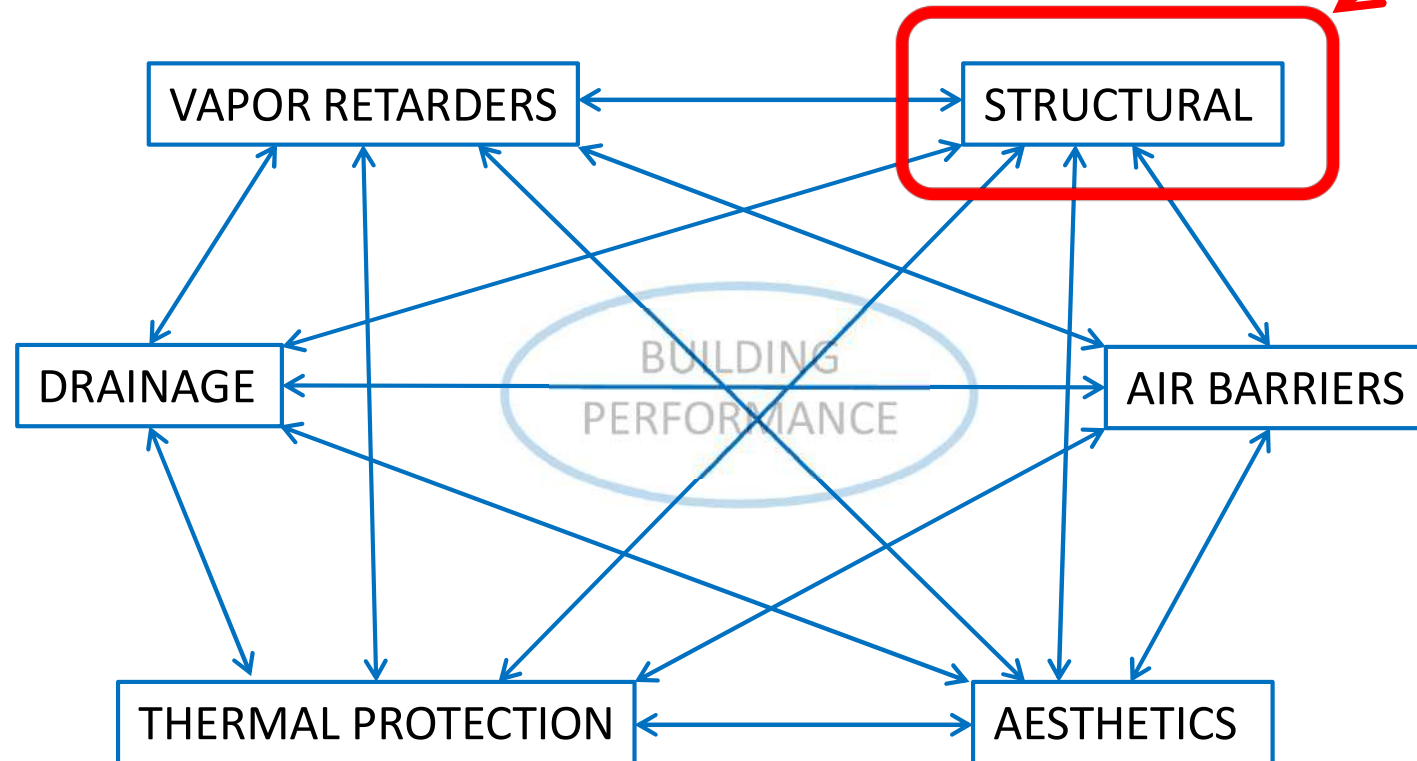
- Topic Overview, or “Why are we Here?”



SYSTEMS THINKING!!!

Buildings Move, Buildings Leak

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



**THIS NEEDS TO BE
CONSIDERED TOO!**

SYSTEMS THINKING!!!

Buildings Move, Buildings Leak

- 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?

Buildings Move, Buildings Leak

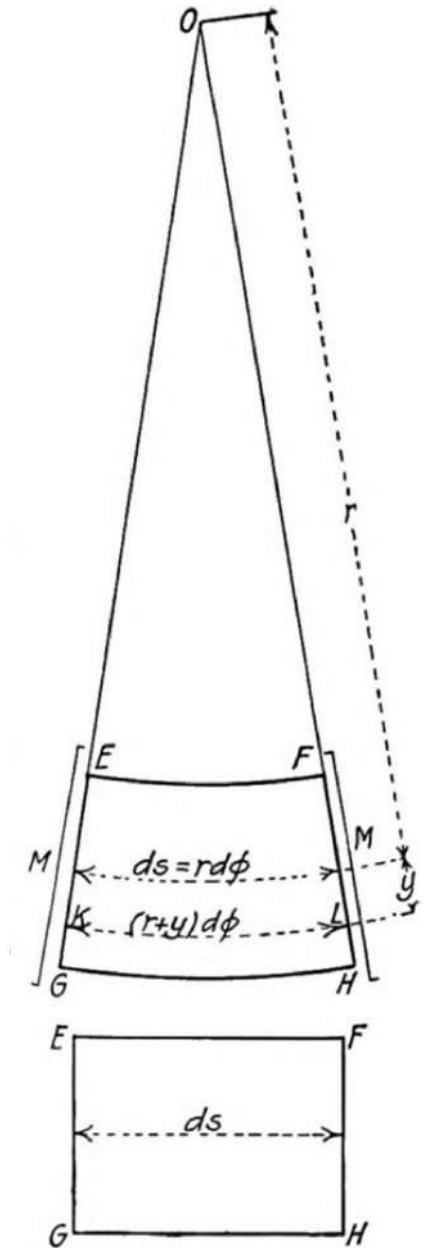
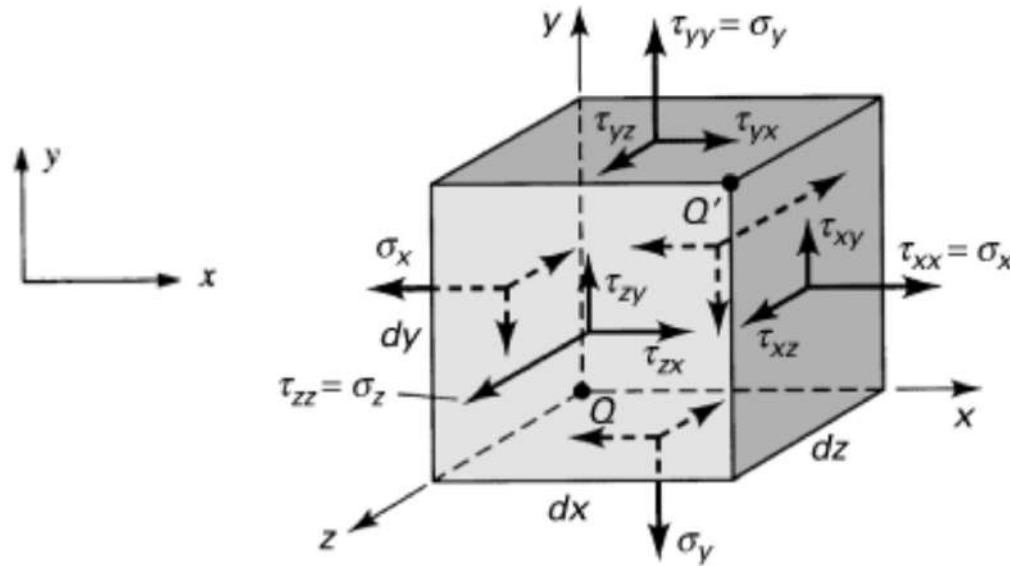
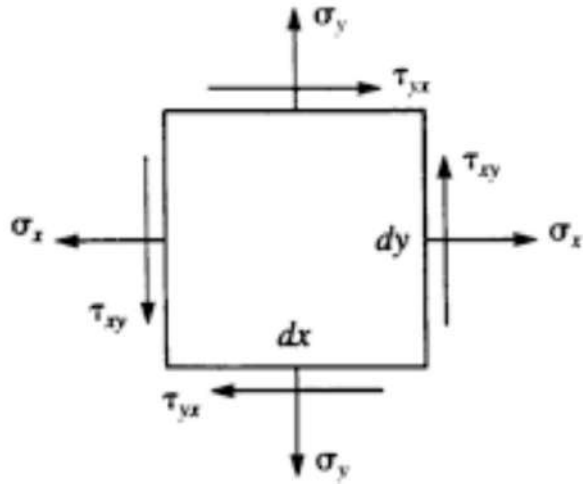
- Topic Overview, or “Why are we Here?”
 - *One of the more significant functional aspects that regularly receives inadequate consideration in the design and construction of building enclosures are structural and movement effects on the building enclosure itself*

Buildings Move, Buildings Leak

- 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

Buildings Move, Buildings Leak

- Structural Loadings and Engineering Mechanics 101



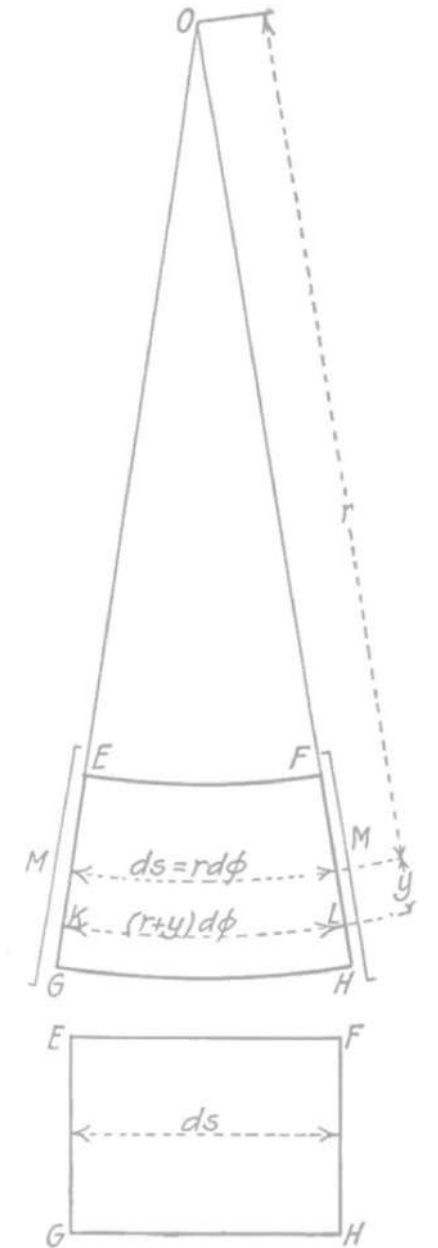
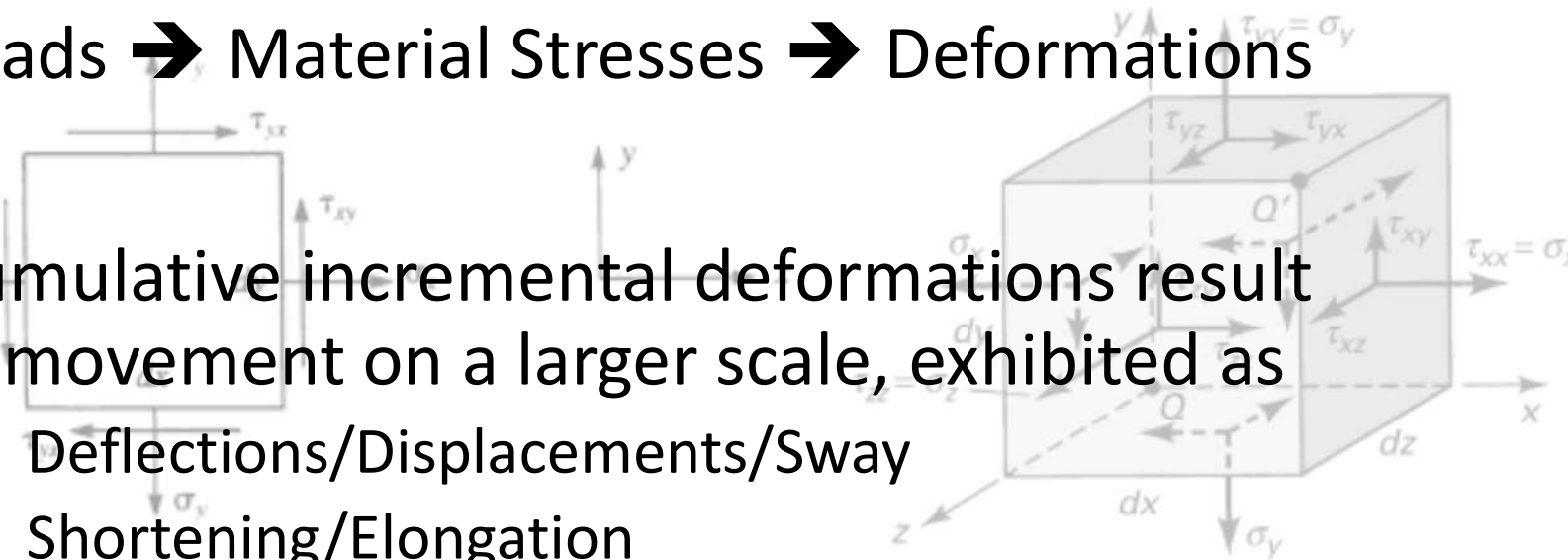
Buildings Move, Buildings Leak

- Structural Loadings and Engineering Mechanics 101

- Loads → Material Stresses → Deformations

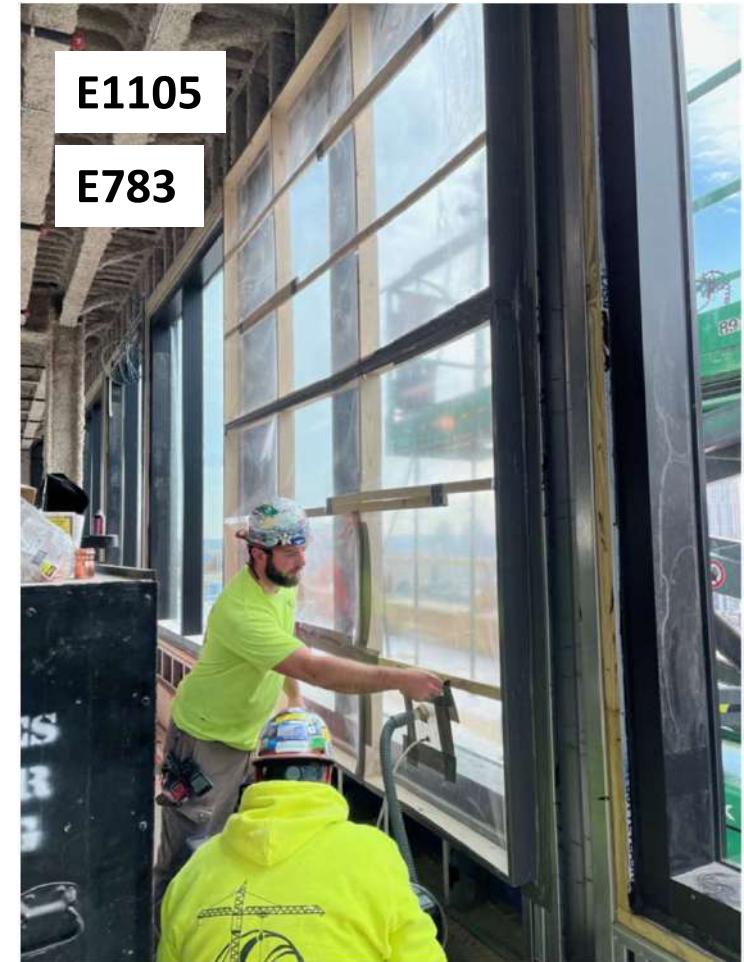
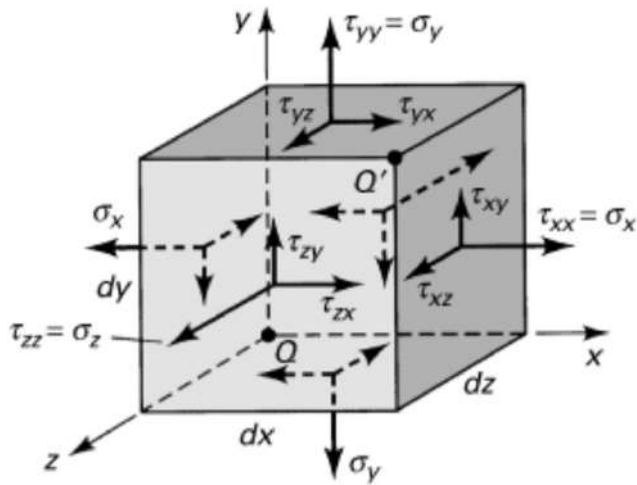
- Cumulative incremental deformations result in movement on a larger scale, exhibited as

- Deflections/Displacements/Sway
- Shortening/Elongation



Buildings Move, Buildings Leak

- Structural Loadings and Engineering Mechanics 101
- Unit stresses: hidden in plain sight!



Buildings Move, Buildings Leak

- 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						
		Specific loadings	Category of functions			
			Interior Finish	Support	Control	Exterior finish
Causal phenomenon or loading	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			●			

Buildings Move, Buildings Leak

Table 2.4: General category of loadings and related functions						
		Specific loadings	Category of functions			
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		Wind		●	○	
		Ground Movement (seismic, settlement, etc.)		●		
		Explosion		●		
		Rheological (creep, shrinkage, etc.)		●		○
		Impact (vehicles, missiles, people, etc.)	●	●		●
	Essentially environmental	Fire	●	○	●	●
		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.)			●	
Essentially perceptual	Sound	○	●	●	○	
	Visual – local	●			●	
	Visual – contextual	●			●	

Primary significance ●

Secondary significance ○

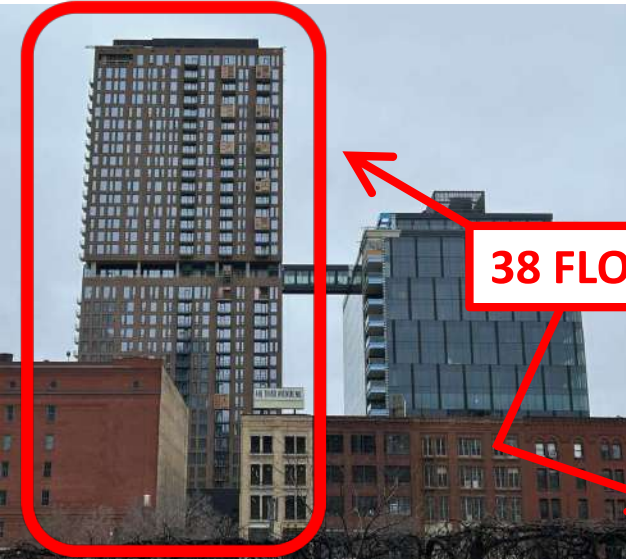
Tertiary significance ●

Buildings Move, Buildings Leak



		Specific loadings
Causal phenomenon or loading	Essentially structural	Gravity – Dead (assembly, etc.)
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		Wind
		Ground Movement (seismic, settlement, etc.)
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		Sound
		Visual – local
	Visual – contextual	

Buildings Move, Buildings Leak



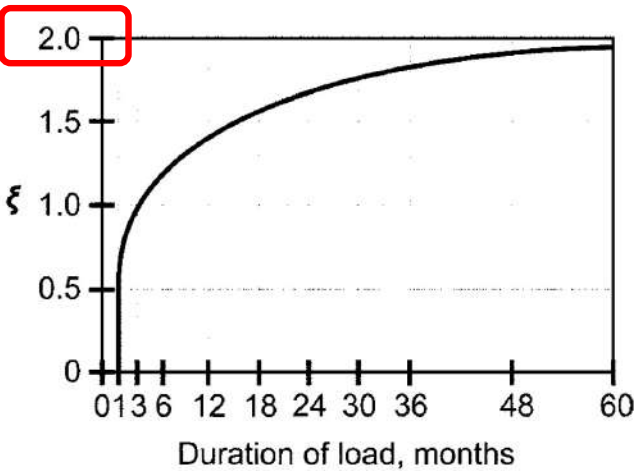
38 FLOORS = 5"

- 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)
 2. PER 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")

		Specific loadings
Causal phenomenon or loading	Essentially structural	Gravity – Dead (assembly, etc.)
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		Explosion
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		Impact (vehicles, missiles, people, etc.)
		Fire
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		Moisture (built-in, rain, condensation, etc.)
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		Solar radiation (incident, reflected, etc.)
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		Insects, birds, animals, (termites, rodents, etc.)
		Light (natural, incandescent, fluorescent, etc.)
		Sound
		Visual – local
		Visual – contextual

Buildings Move, Buildings Leak

- Common structural materials that creep:
 - Concrete
 - Wood



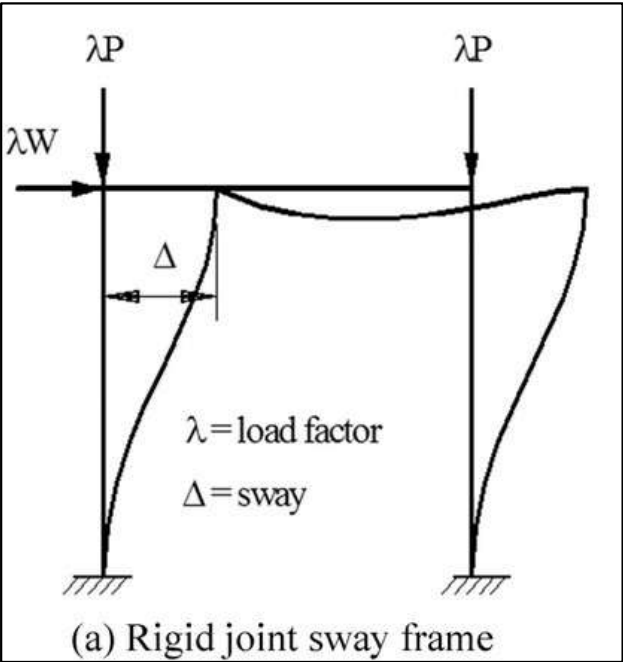
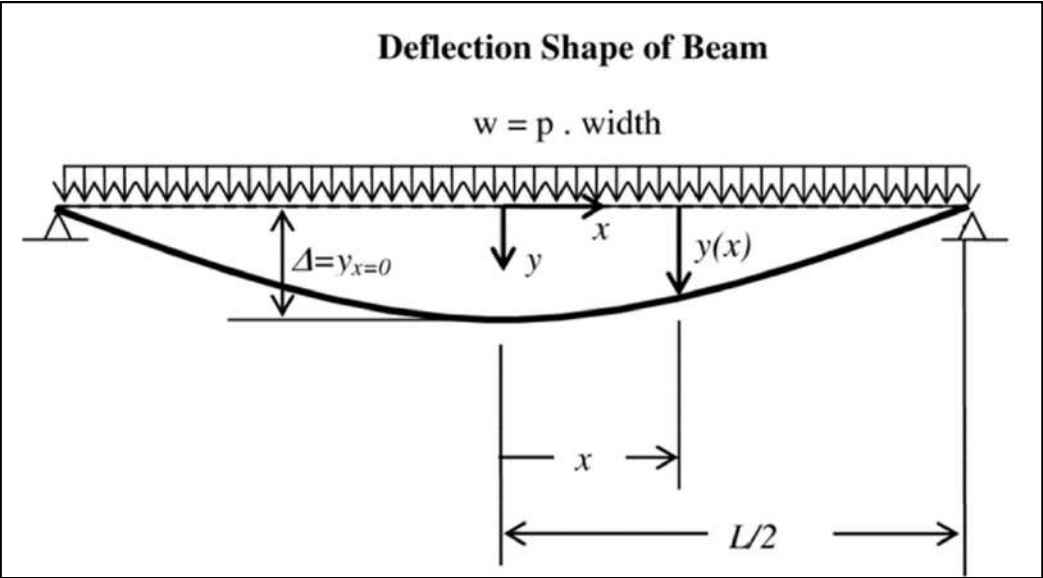
The creep deflection varies anywhere from zero to twice the initial deflection. This means that the total deflection can vary from the initial deflection to as much as three times the initial deflection.

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

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		Wind
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		Explosion
		Rheological (creep, shrinkage, etc.)
	Essentially environmental	Impact (vehicles, missiles, people, etc.)
		Fire
		Heat (thermal, etc.)
		Air (pressure, movement, leakage, etc.)
		Moisture (built-in, rain, condensation, etc.)
		Smoke
	Essentially perceptual	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
		Visual – local
		Visual – contextual

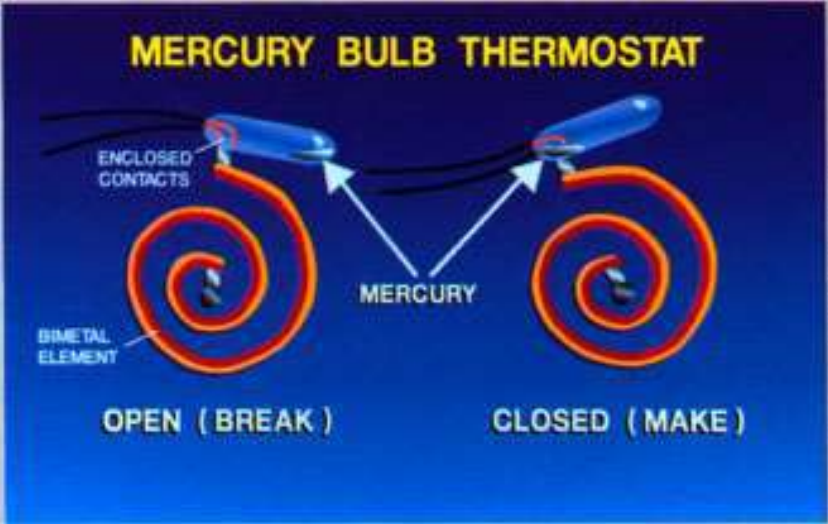
Buildings Move, Buildings Leak

- Deflections/Displacements/Sway



		Specific loadings
Causal phenomenon or loading	Essentially structural	Gravity – Dead (assembly, etc.)
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		Wind
		Ground Movement (seismic, settlement, etc.)
		Explosion
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	Essentially environmental	Fire
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		Air (pressure, movement, leakage, etc.)
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		Sound
	Visual – local	
	Visual – contextual	

Buildings Move, Buildings Leak

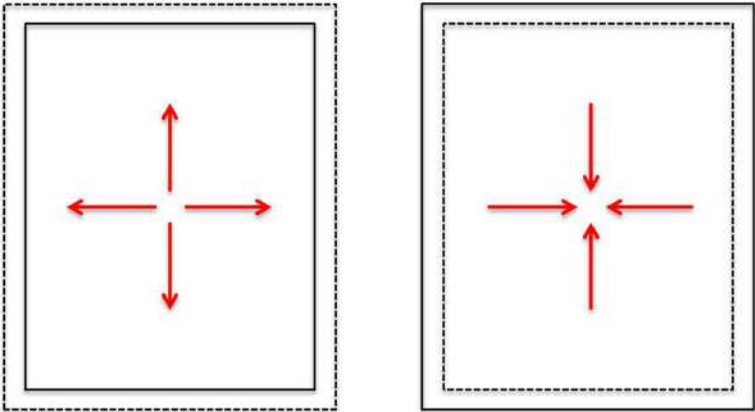


Causal phenomenon or loading		Specific loadings
Essentially structural	Causal phenomenon or loading	Gravity – Dead (assembly, etc.)
		Gravity – Live (people, snow, etc.)
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		Ground Movement (seismic, settlement, etc.)
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		Heat (thermal, etc.)
		Air (pressure, movement, leakage, etc.)
Essentially environmental	Causal phenomenon or loading	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
		Visual – local
Essentially perceptual	Causal phenomenon or loading	Visual – contextual

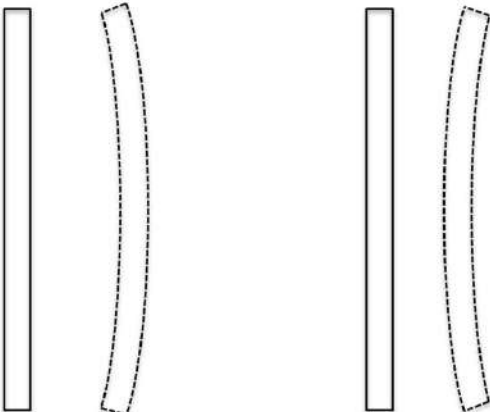
Buildings Move, Buildings Leak

- Shortening/Elongation

ABSOLUTE VOLUME CHANGE



DIFFERENTIAL VOLUME CHANGE



Causal phenomenon or loading		Specific loadings
Essentially structural	Essentially structural	Gravity – Dead (assembly, etc.)
		Gravity – Live (people, snow, etc.)
		Wind
		Ground Movement (seismic, settlement, etc.)
		Explosion
		Rheological (creep, shrinkage, etc.)
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		Insects, birds, animals, (termites, rodents, etc.)
Essentially perceptual	Essentially perceptual	Light (natural, incandescent, fluorescent, etc.)
		Sound
		Visual – local
		Visual – contextual

Buildings Move, Buildings Leak

- 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

		Category of functions			
		Interior Finish	Support	Control	Exterior finish
Cause of phenomenon or loading	Specific loadings				
	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	●	○	●	●
	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	●			●

Essentially structural

Essentially environmental

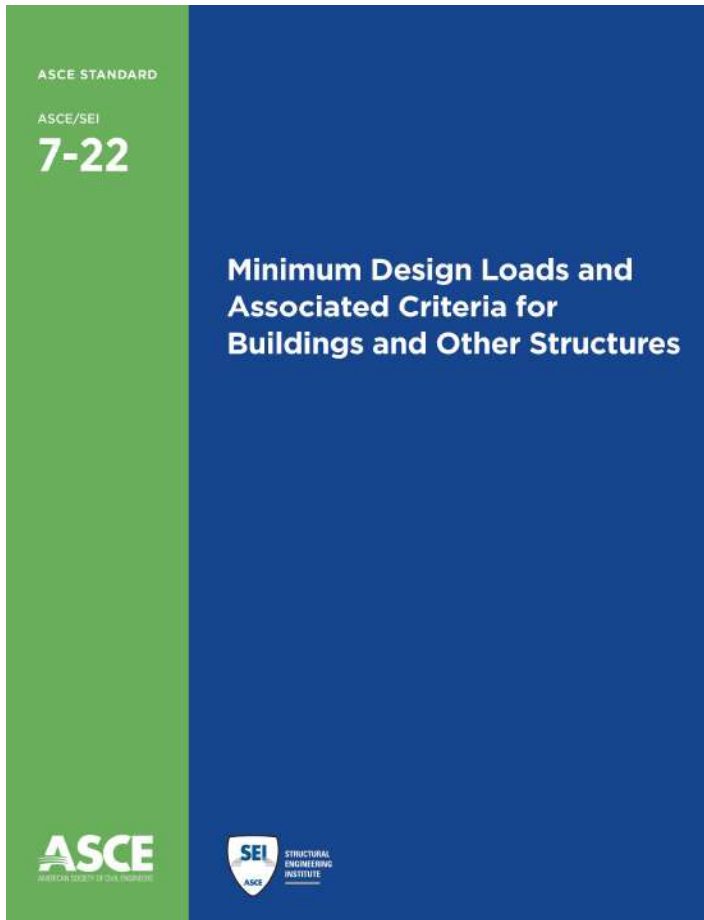
Primary significance ●

Secondary significance ○

Tertiary significance ●

Buildings Move, Buildings Leak

- 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**

**EXAMPLE OF VOLUME
CHANGE INDUCED 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



Buildings Move, Buildings Leak

- 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”

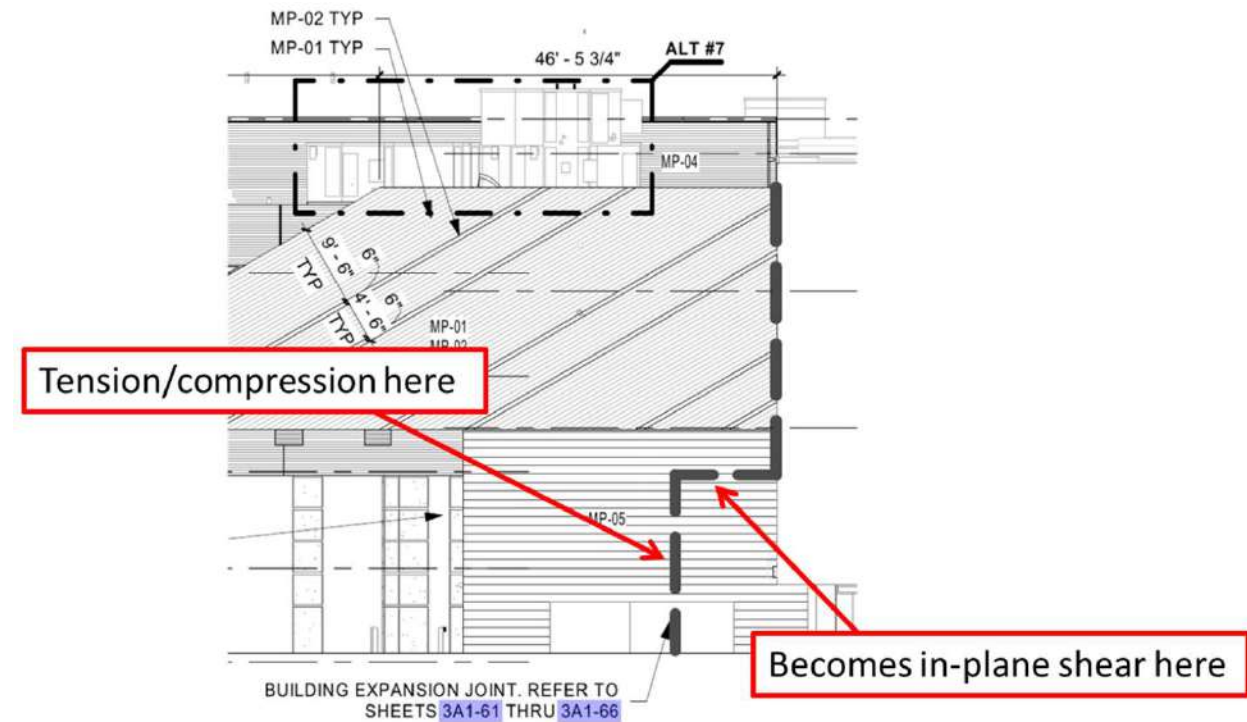


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- Process Gaps – where can/do things go wrong?

2) When there is inadequate consideration to movement behavior

- Overlooking how a material might respond



Buildings Move, Buildings Leak

- 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



Buildings Move, Buildings Leak

- Case Study 1: Compounded Deflections and Curtain Wall

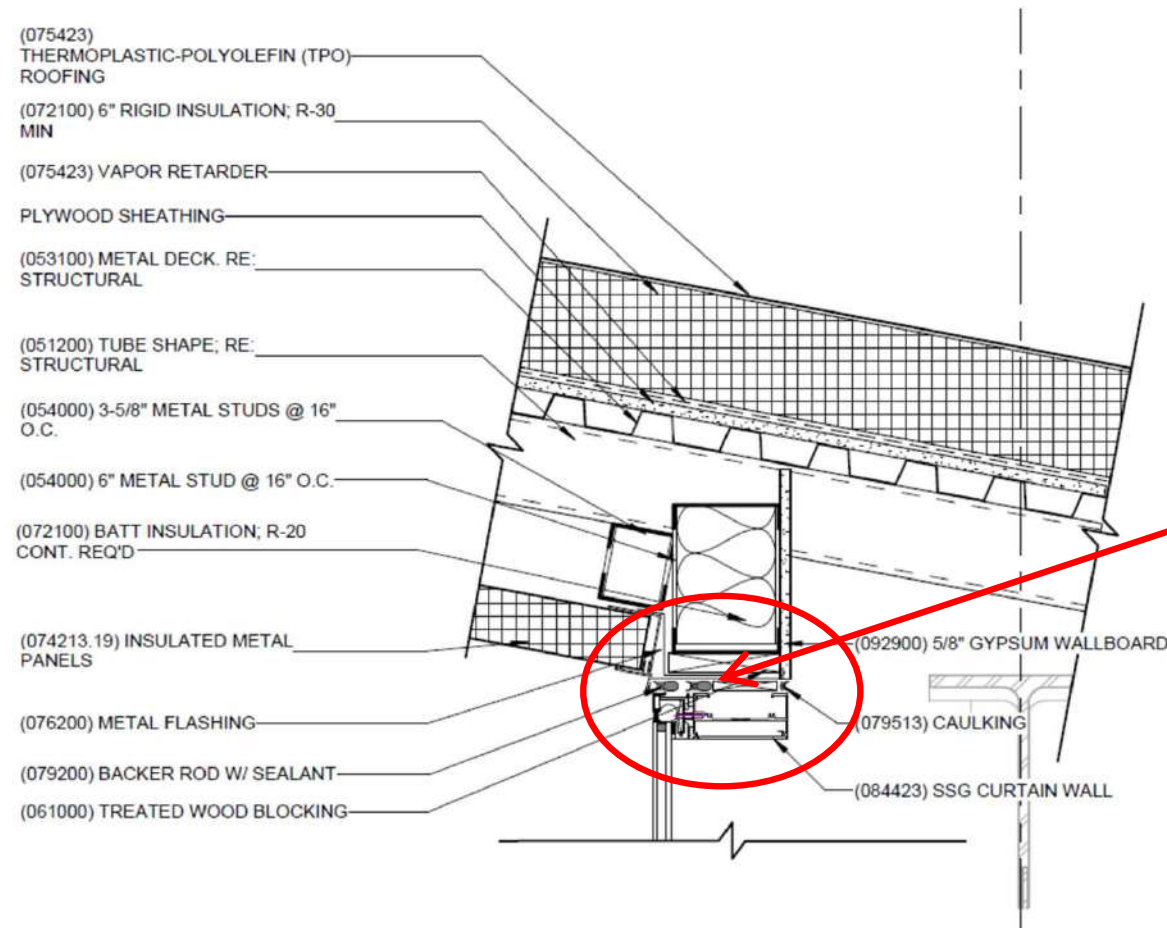
PART 2 - PRODUCTS

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



Dimension not called out,
proportionally drawn in
the range of ½"

Buildings Move, Buildings Leak

- 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

Buildings Move, Buildings Leak

- Case Study 1: Compounded Deflections and Curtain Wall



Buildings Move, Buildings Leak

- Case Study 1: Compounded Deflections and Curtain Wall



Buildings Move, Buildings Leak

- Case Study 1: Compounded Deflections and Curtain Wall

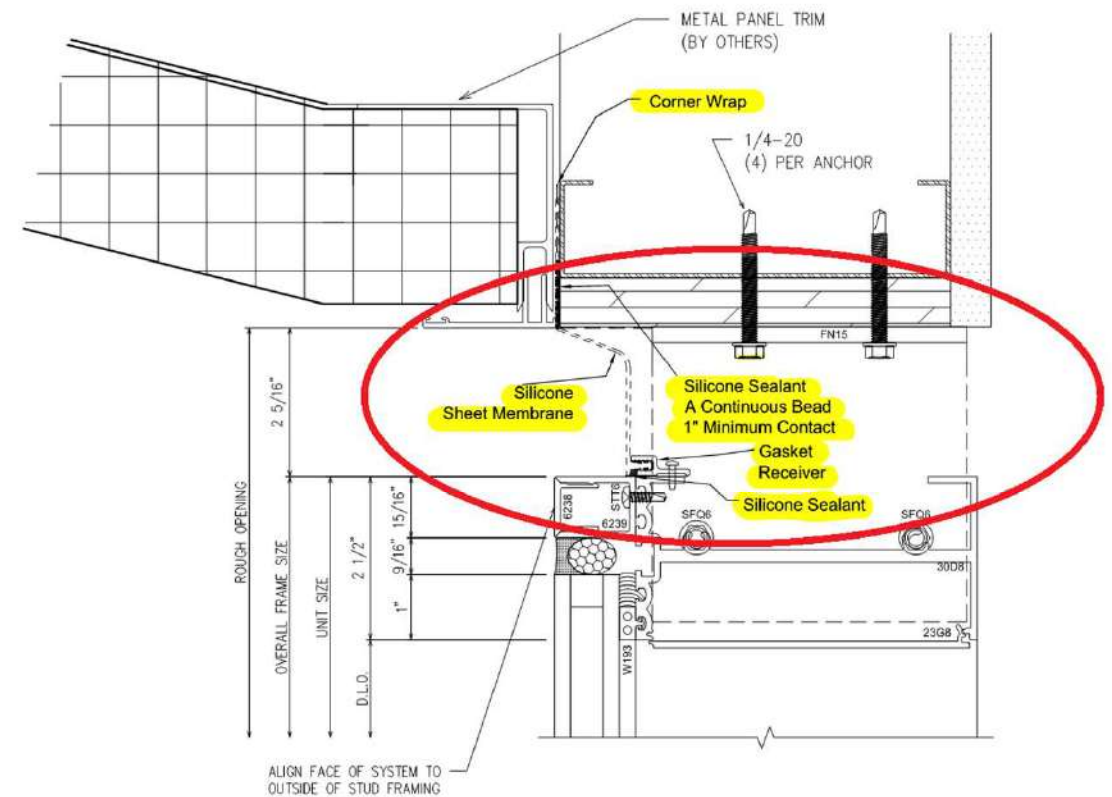
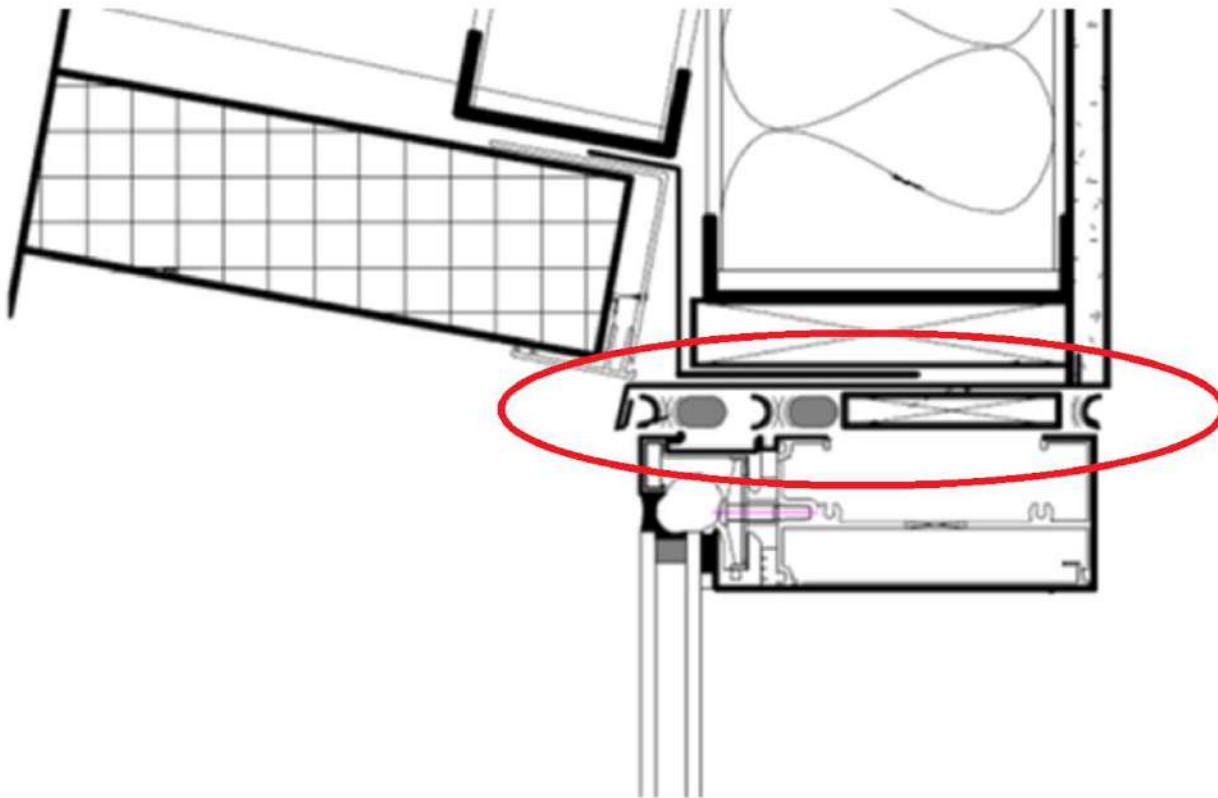


Buildings Move, Buildings Leak

- 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

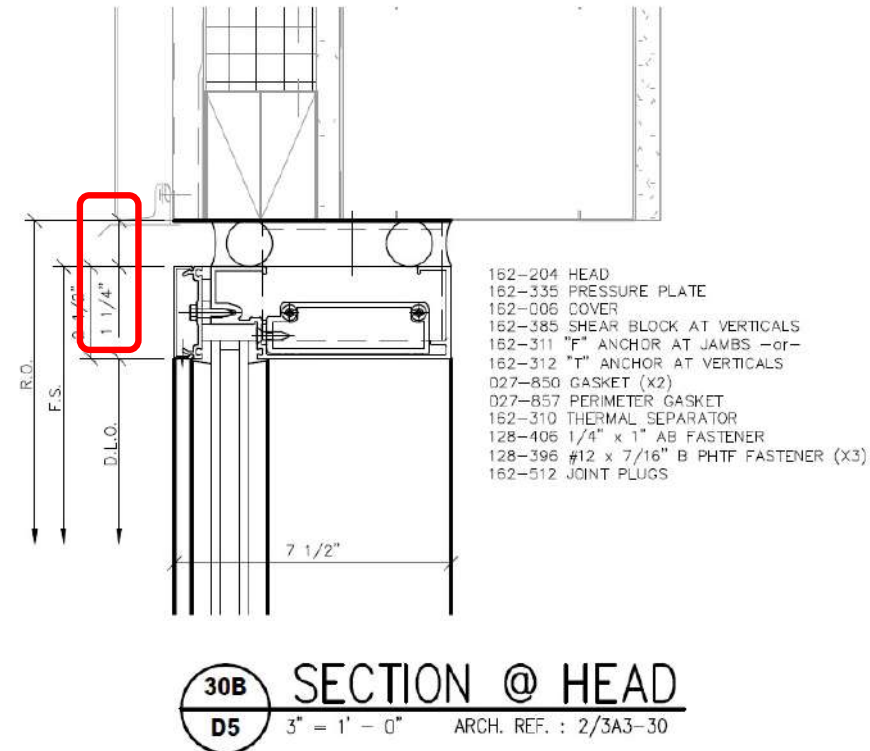
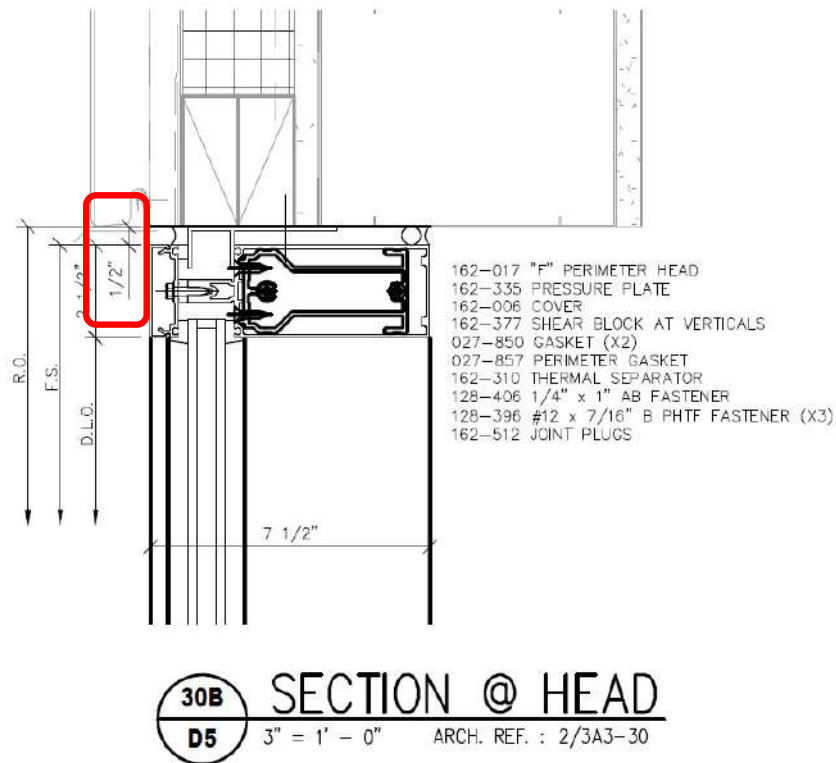


Buildings Move, Buildings Leak

- 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

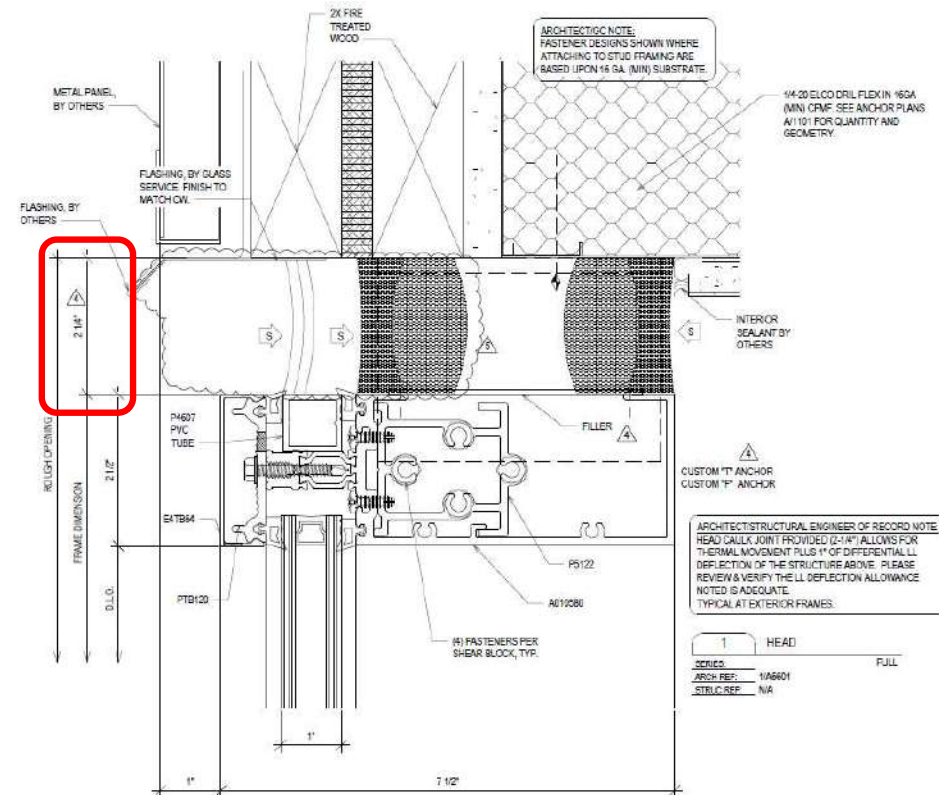
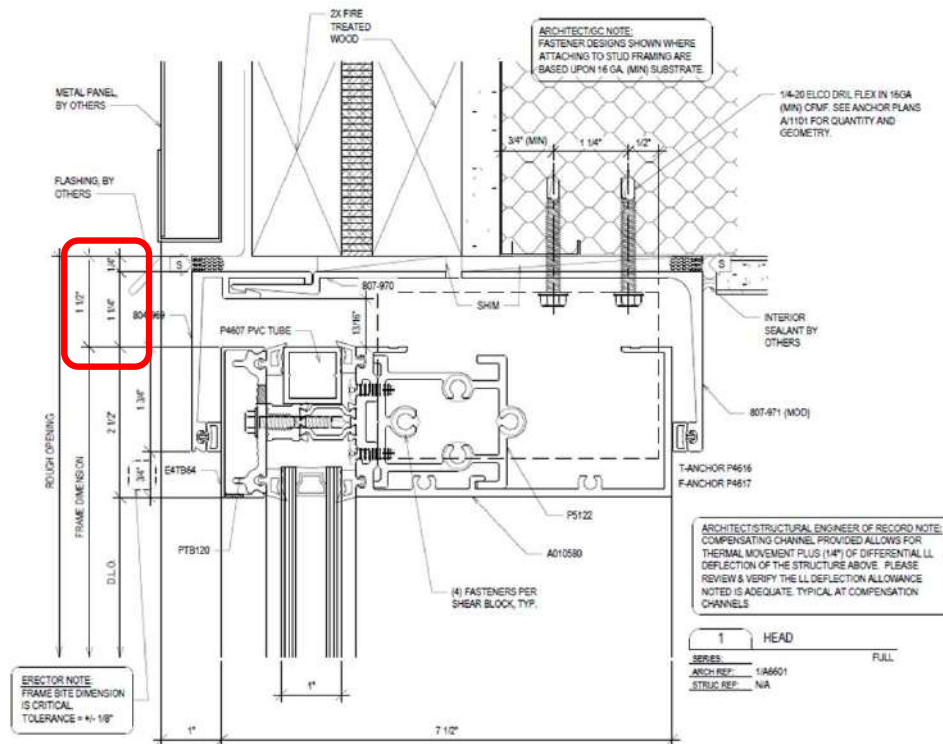
Buildings Move, Buildings Leak

- 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?



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		Gravity – Live (people, snow, etc.)		●		
		Wind		●	○	
		Ground Movement (seismic, settlement, etc.)		●		
		Explosion		●		
	Essentially environmental	Rheological (creep, shrinkage, etc.)		●		○
		Impact (vehicles, missiles, people, etc.)	●	●		●
		Fire	●	○	●	●
		Heat (thermal, etc.)		○	●	
		Air (pressure, movement, leakage, etc.)		○	●	
Essentially perceptual	Essentially environmental	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

- Building Science Game Show Time!
- Case Study 1: which loadings were involved?



Table 2.4: General category of loadings and related functions

		Category of functions			
		Interior Finish	Support	Control	Exterior finish
Causal phenomenon or loading	Essentially structural	Gravity - Dead (assembly, etc.)	●		
		Gravity - Live (people, snow, etc.)	●		
		Wind	●	○	
		Ground Movement (seismic, settlement, etc.)	●		
		Explosion	●		
	Essentially environmental	Rheological (creep, shrinkage, etc.)	●		○
		Impact (vehicles, missiles, people, etc.)	●		●
		Fire	●	○	●
		Heat (thermal, etc.)	○	●	
		Air (pressure, movement, leakage, etc.)	○	●	
	Essentially perceptual	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	○	●	○
		Visual - local	●		●

Primary significance ●
Secondary significance ○
Tertiary significance •

Buildings Move, Buildings Leak

- Case Study 2: Wood Framed Stealth Deflections



Accommodating Shrinkage in Multi-Story Wood-Frame Structures

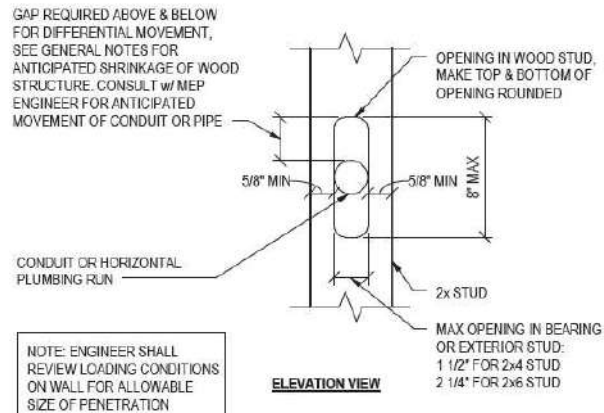
Richard McLain, MS, PE, SE, Technical Director, WoodWorks • Doug Steimle, PE, Principal, Schaefer

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:

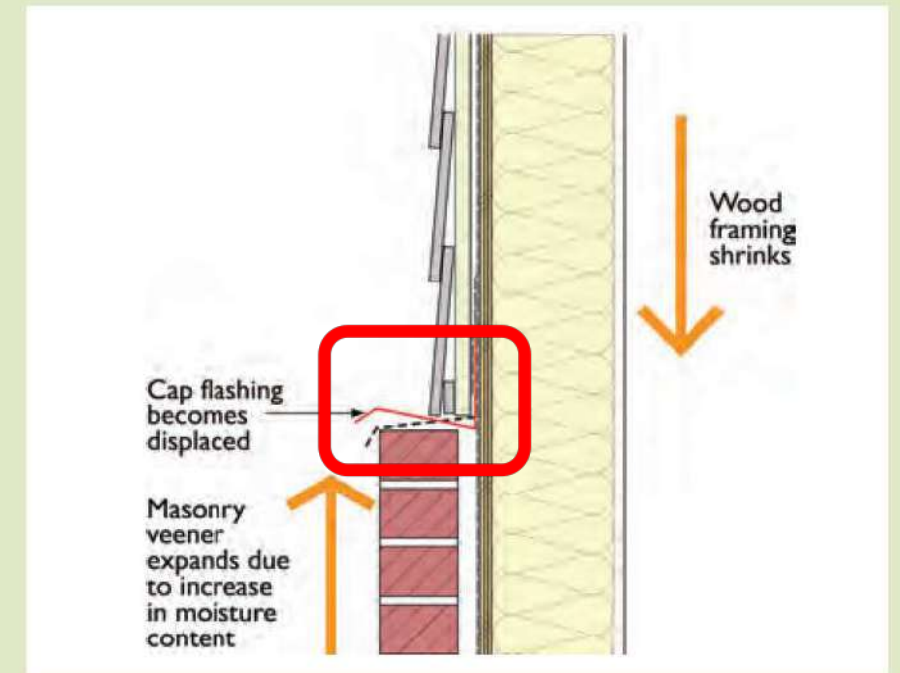
Example detail and photo showing the hole in a wood stud added to accommodate shrinkage around plumbing



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

FIGURE 13:

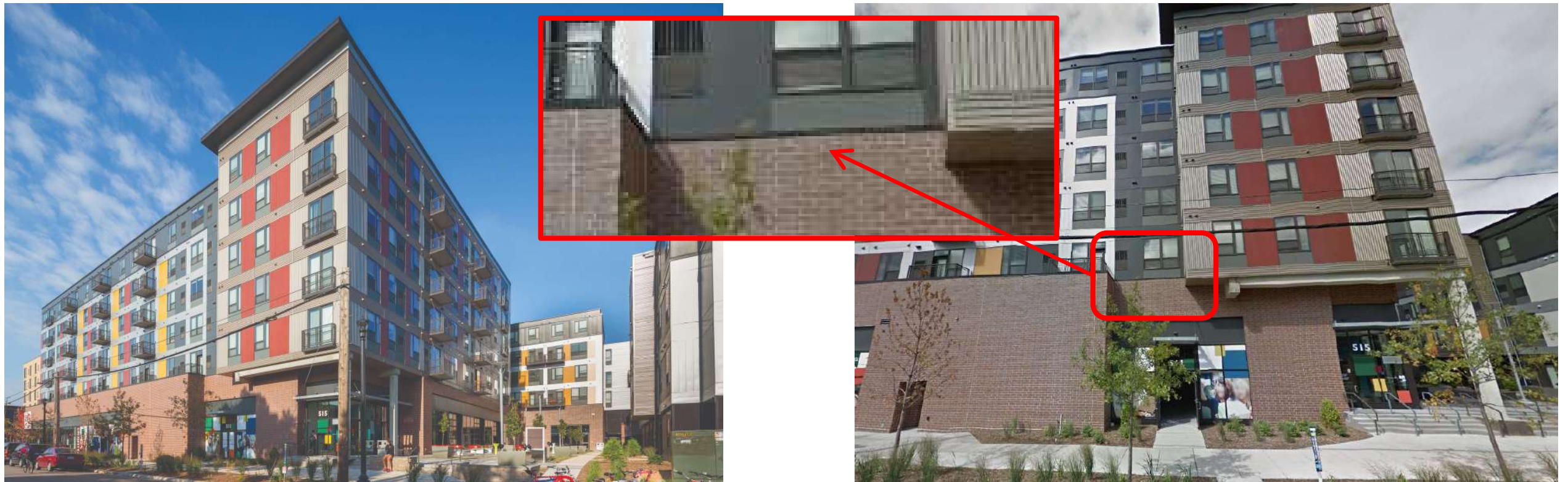
Veneer transition issues due to lack of shrinkage accommodation



Source: RDH Building Science Inc.

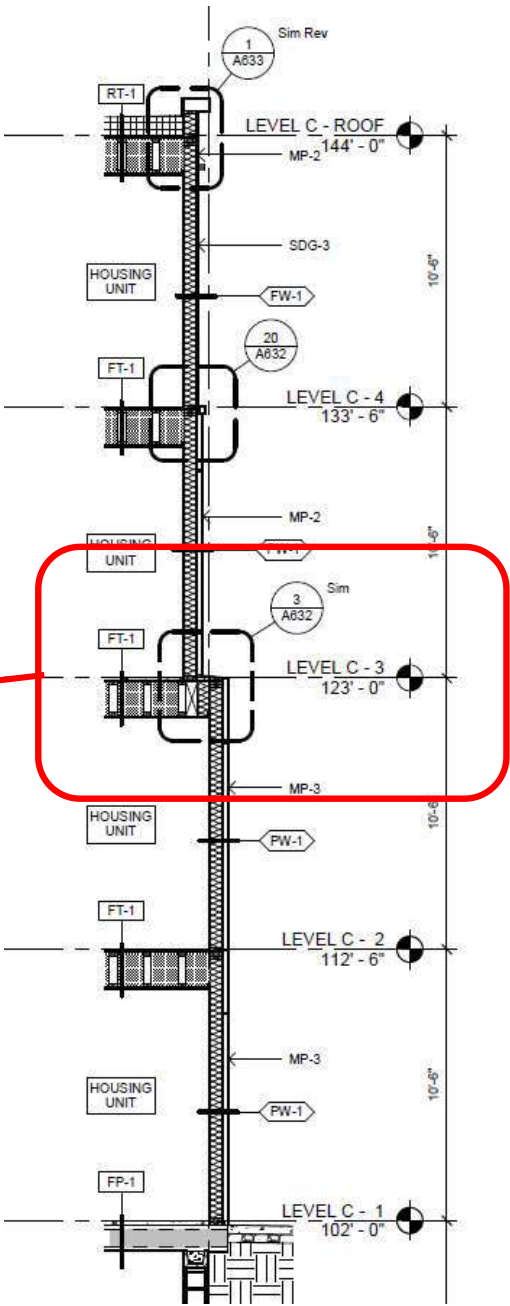
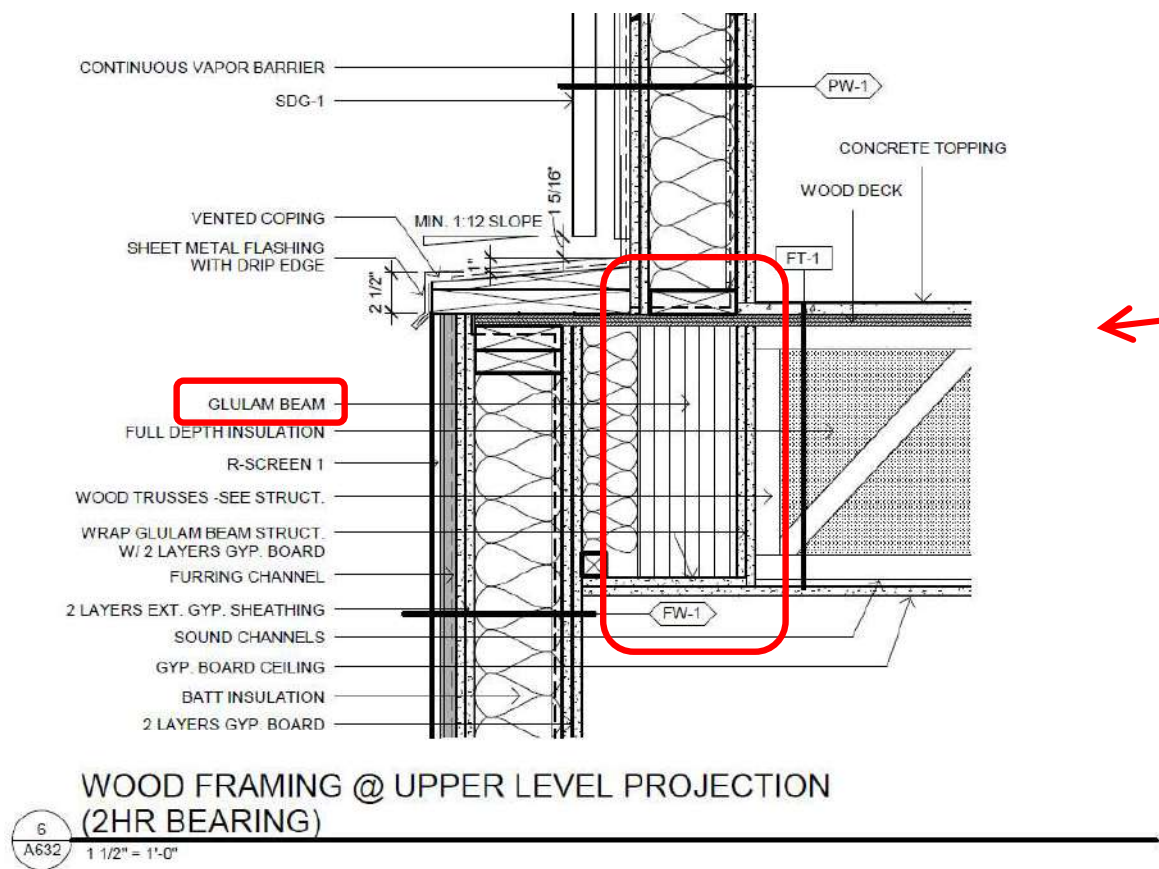
Buildings Move, Buildings Leak

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



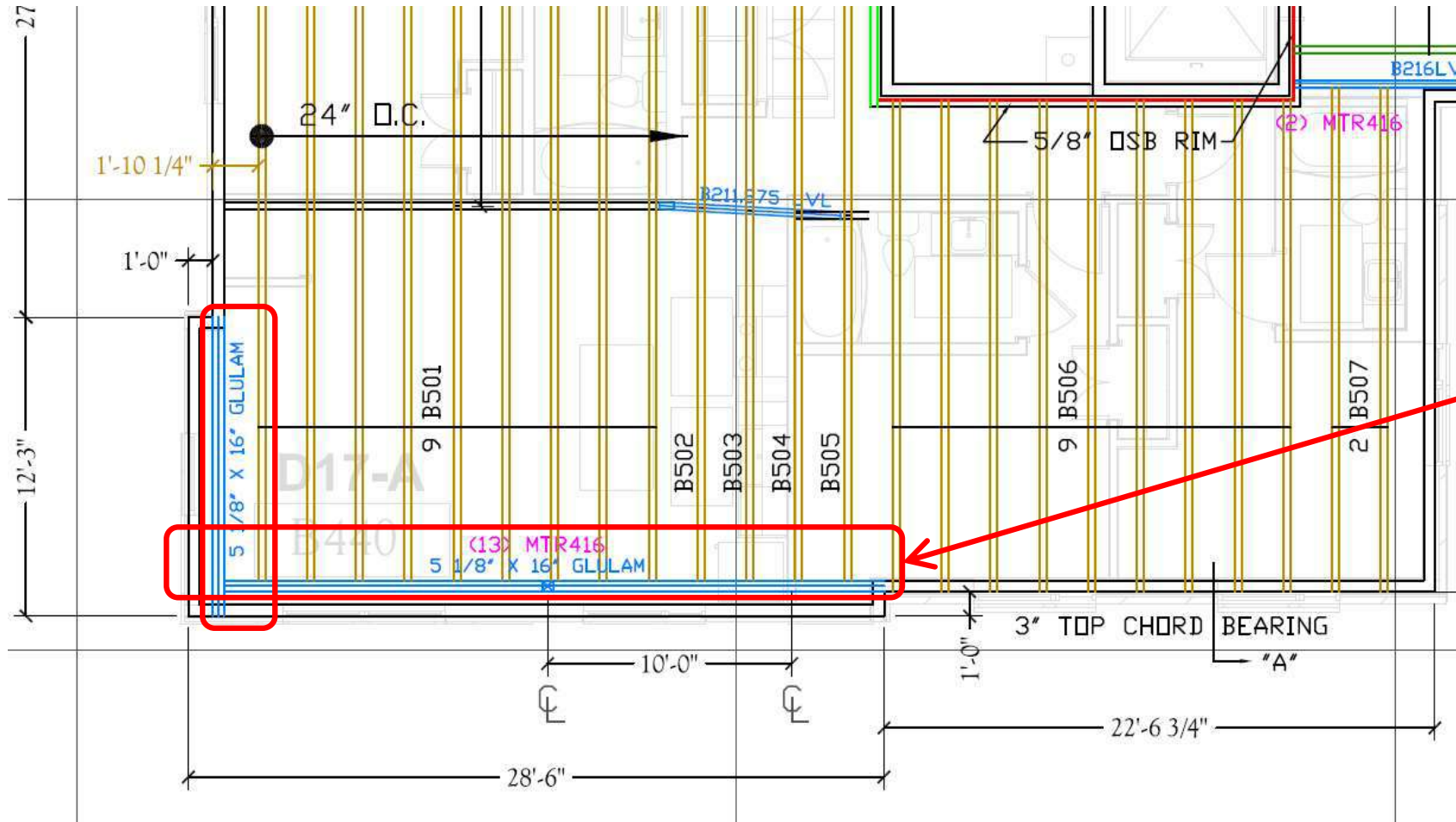
Buildings Move, Buildings Leak

- Case Study 2: Wood Framed Stealth Deflections



Buildings Move, Buildings Leak

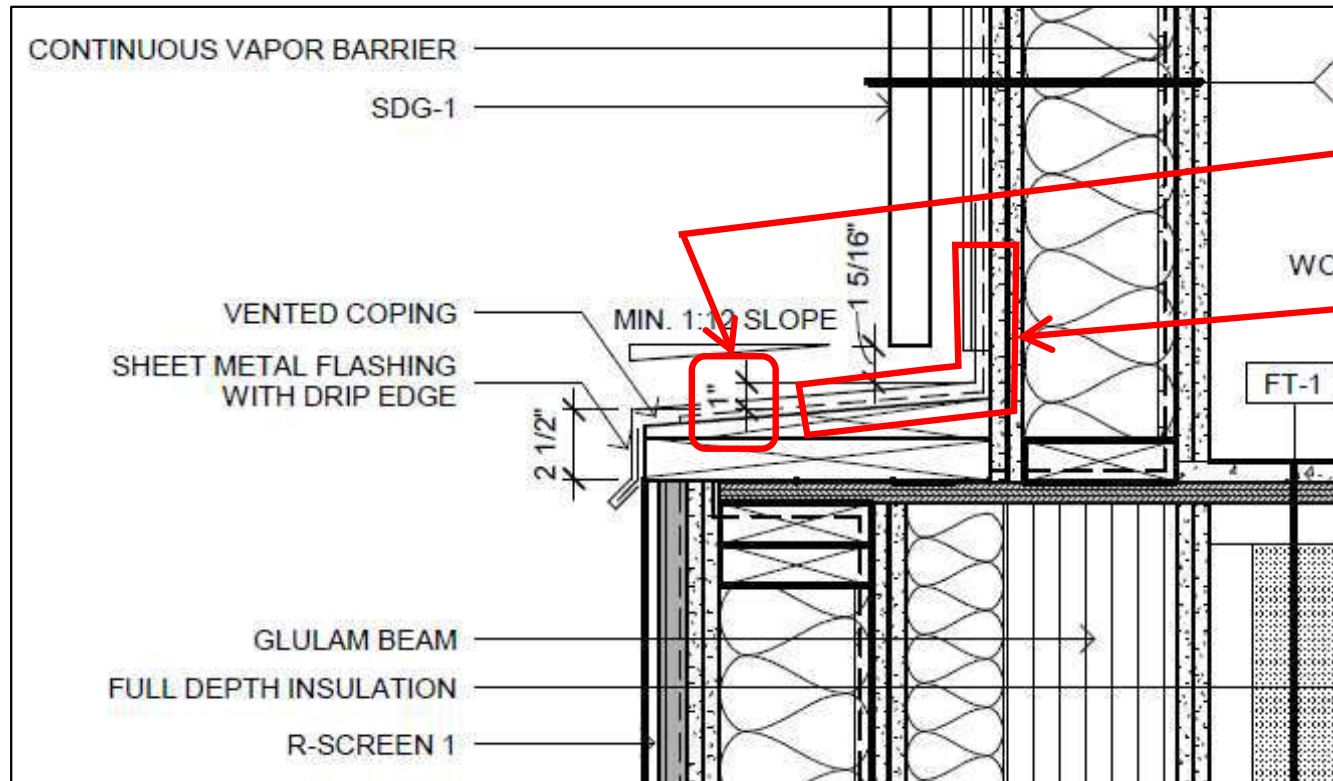
- Case Study 2: Wood Framed Stealth Deflections



**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



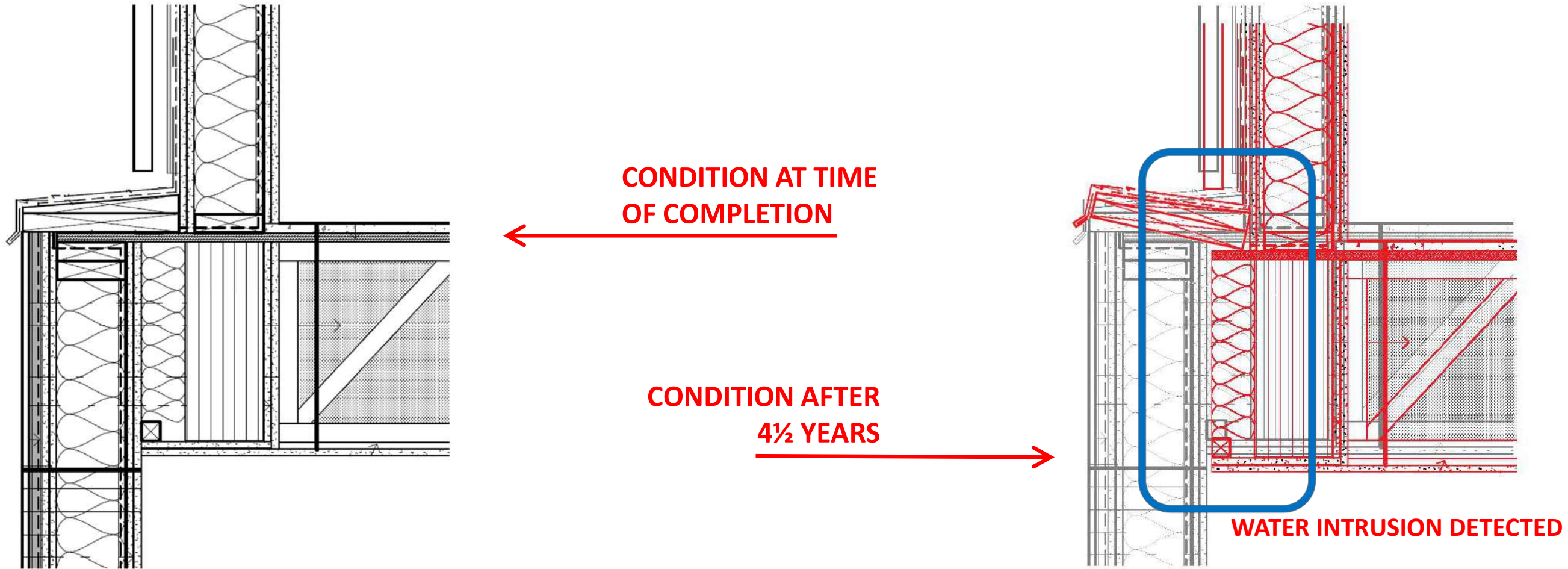
**1" DROP (ASSUMING
ZERO MOVEMENT)**

**SOME TYPE OF CONTINUATION
OF MECHANICALLY ATTACHED
WATER BARRIER???**

AS – BUILT DETAIL

Buildings Move, Buildings Leak

- Case Study 2: Wood Framed Stealth Deflections



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

		Category of functions			
		Interior Finish	Support	Control	Exterior finish
Causal phenomenon or loading	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 ●

Buildings Move, Buildings Leak

- Case Study 2: which loadings were involved?



Table 2.4: General category of loadings and related functions

		Category of functions				
		Interior Finish	Support	Control	Exterior finish	
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		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			●			

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

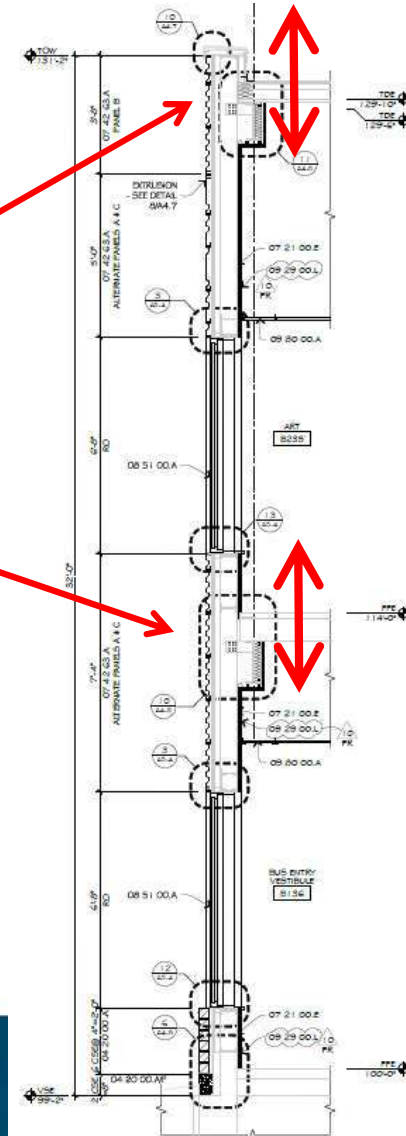


Buildings Move, Buildings Leak

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

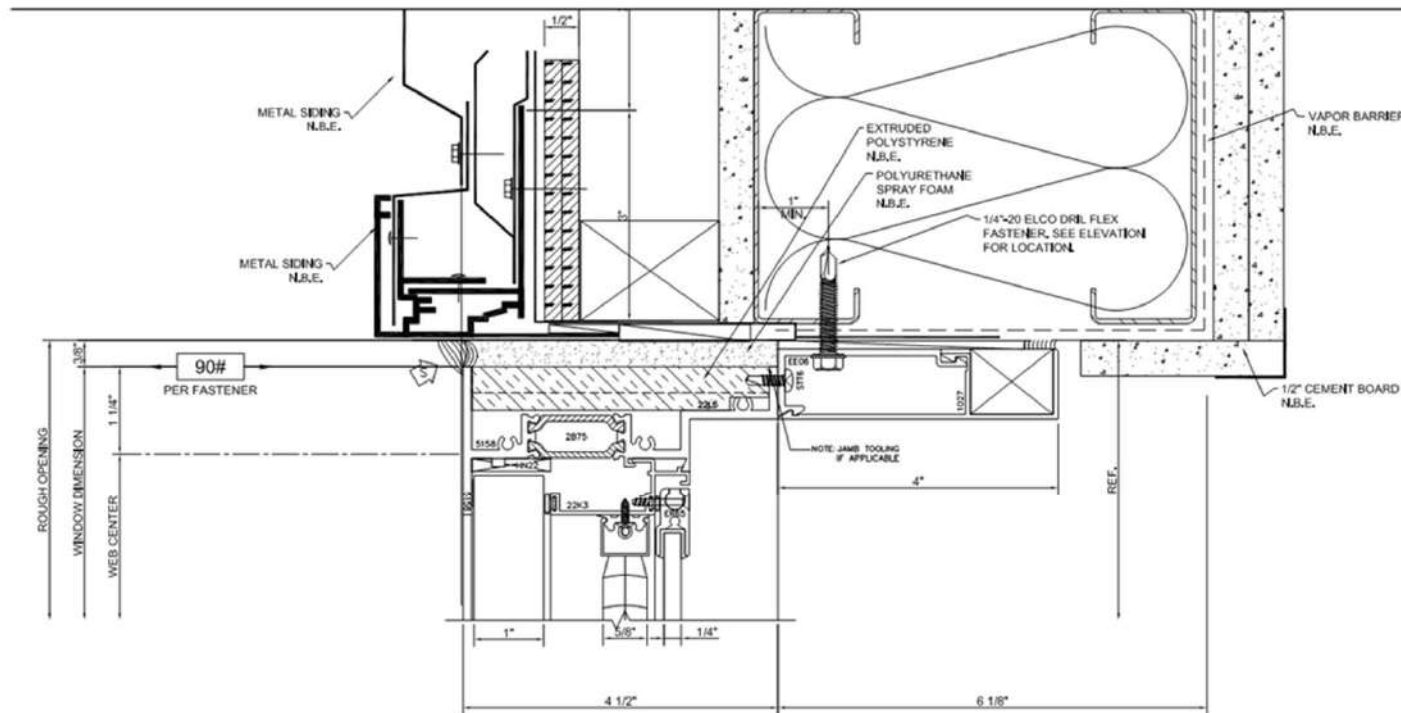
Wind load/deflection
connection only at steel
stud to slab or deck edge

Structure free to
deflect independent of
exterior wall assembly



Buildings Move, Buildings Leak

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

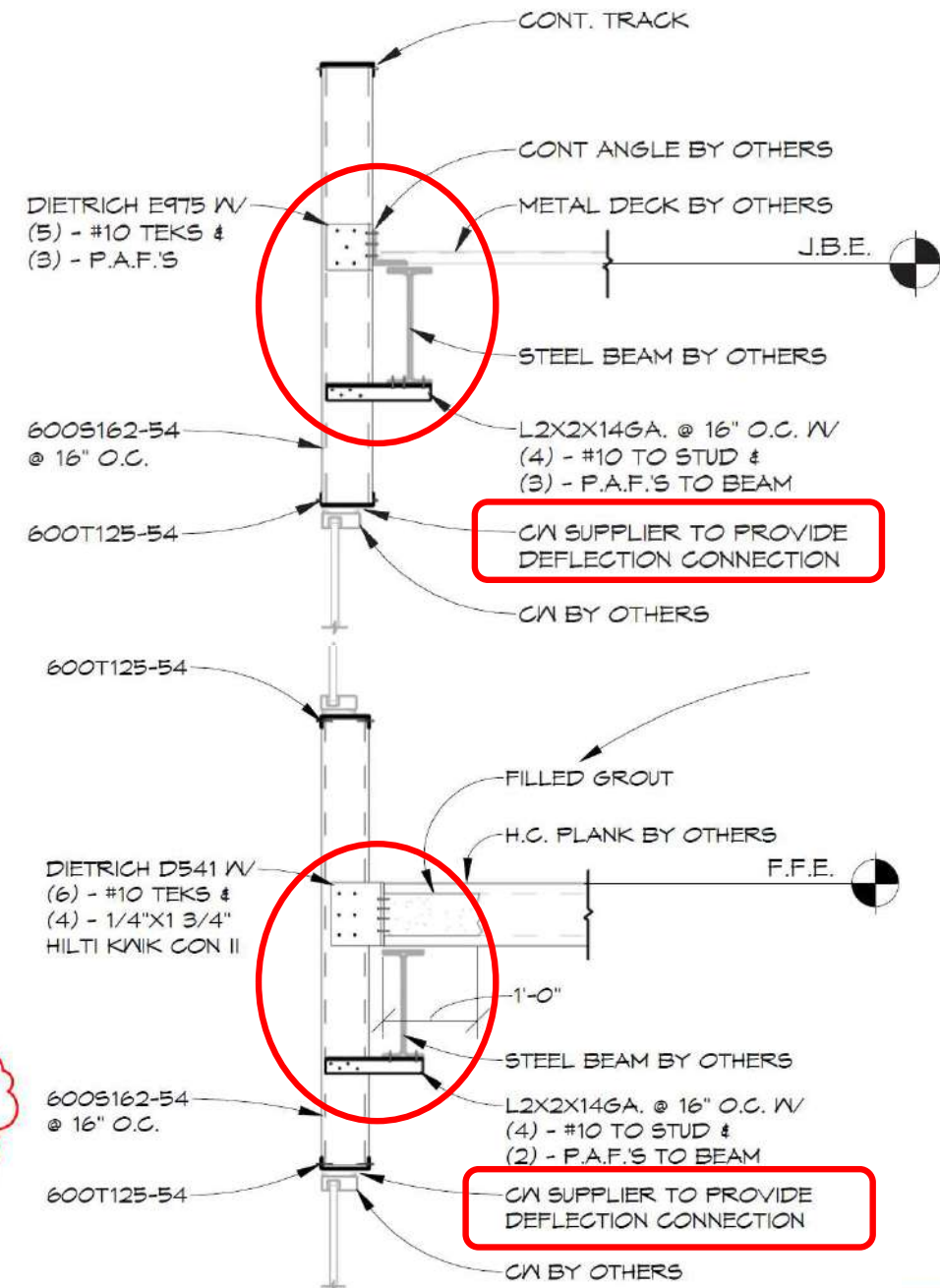


Window supplier's drawings showed static head joint consistent with contract documents

Buildings Move, Buildings Leak

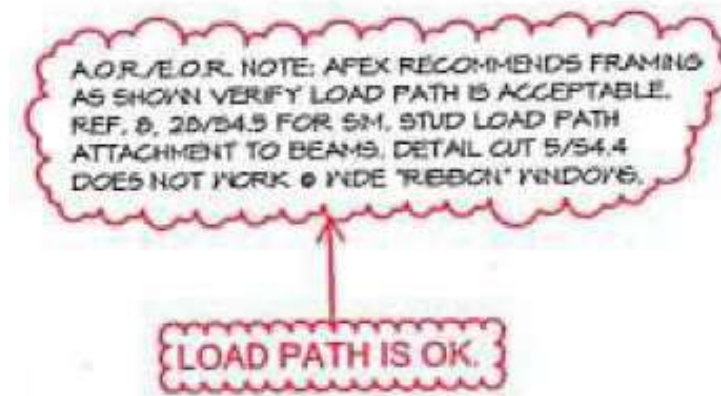
- Case Study 3: Stacked Ribbon Window/Steel
 - But steel stud supplier's shop drawings
 - Requested change to fixed connection between studs and supporting structure
 - Requested that window supplier provide movement accommodation at their head framing condition

A.O.R./E.O.R. NOTE: APEX RECOMMENDS FRAMING AS SHOWN VERIFY LOAD PATH IS ACCEPTABLE. REF. 3, 23/54.5 FOR SIM. STUD LOAD PATH ATTACHMENT TO BEAMS. DETAIL CUT 5/54.4 DOES NOT WORK @ WIDE "RIBBON" WINDOWS.



Buildings Move, Buildings Leak

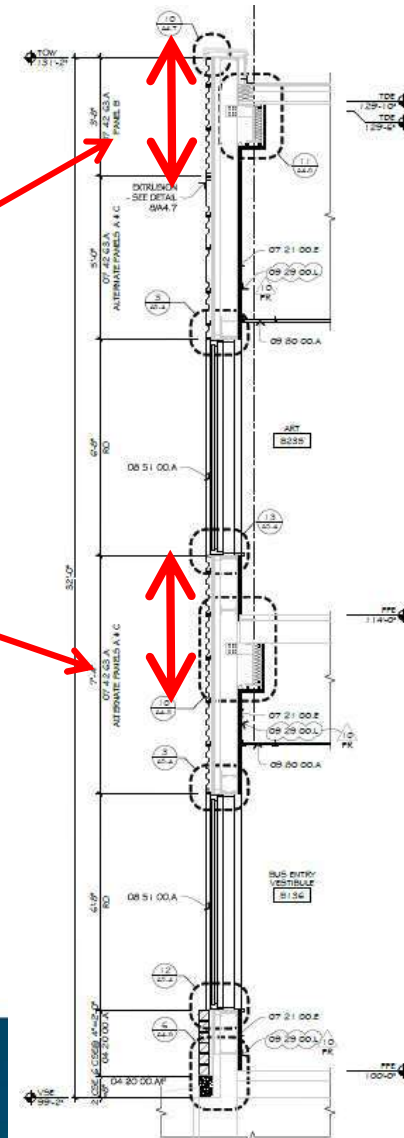
- Case Study 3: Stacked Ribbon Window/Steel Stud Infill
 - Architect approved request, but change was not communicated to any other parties affected by the decision
 - Particularly the window supplier with a static head joint



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



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

		Category of functions				
		Interior Finish	Support	Control	Exterior finish	
		Specific loadings				
Causal phenomenon or loading	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		●				

Buildings Move, Buildings Leak

- Case Study 3: which loadings were involved?



Table 2.4: General category of loadings and related functions

		Category of functions			
		Interior Finish	Support	Control	Exterior finish
Causal phenomenon or loading	Essentially structural	Specific loadings			
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		Wind	●	○	
		Ground Movement (seismic, settlement, etc.)	●		
		Explosion	●		
		Rheological (creep, shrinkage, etc.)	●		○
		Impact (vehicles, missiles, people, etc.)	●		●
		Fire	●	○	●
		Heat (thermal, etc.)		○	●
	Essentially environmental	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	●		

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

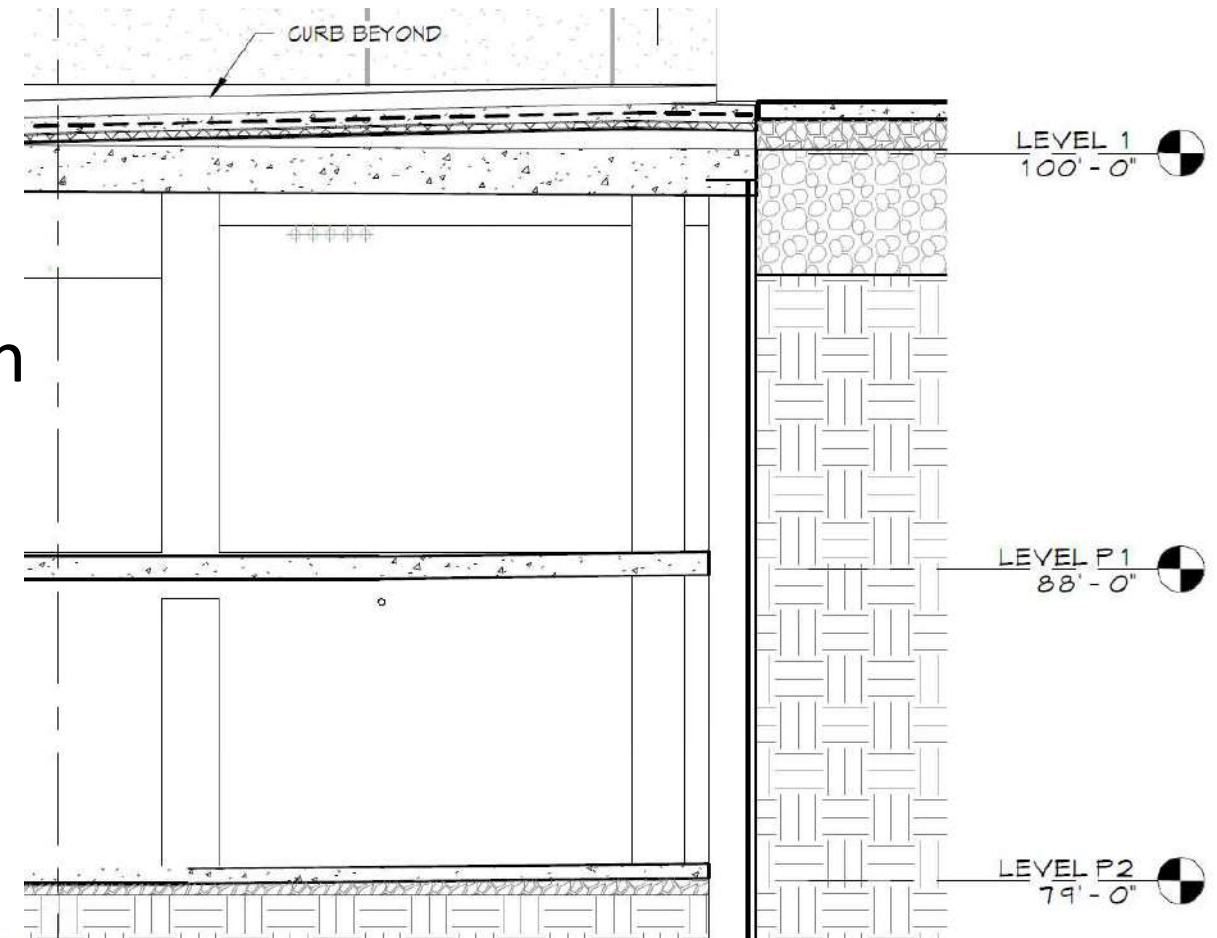


Buildings Move, Buildings Leak

- 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

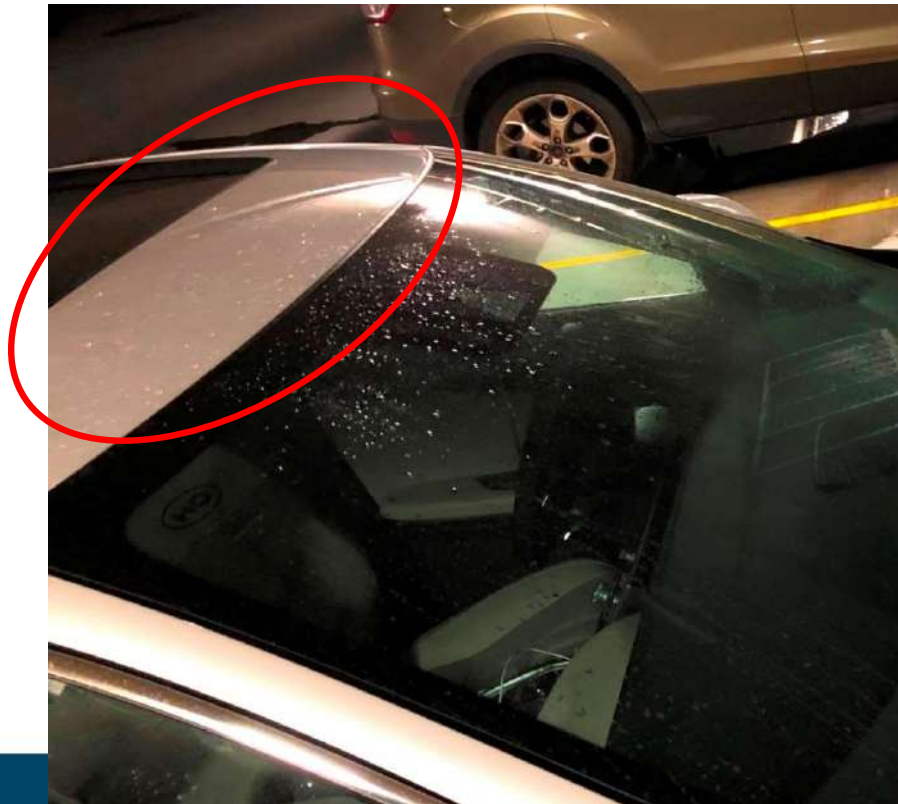
Buildings Move, Buildings Leak

- 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?

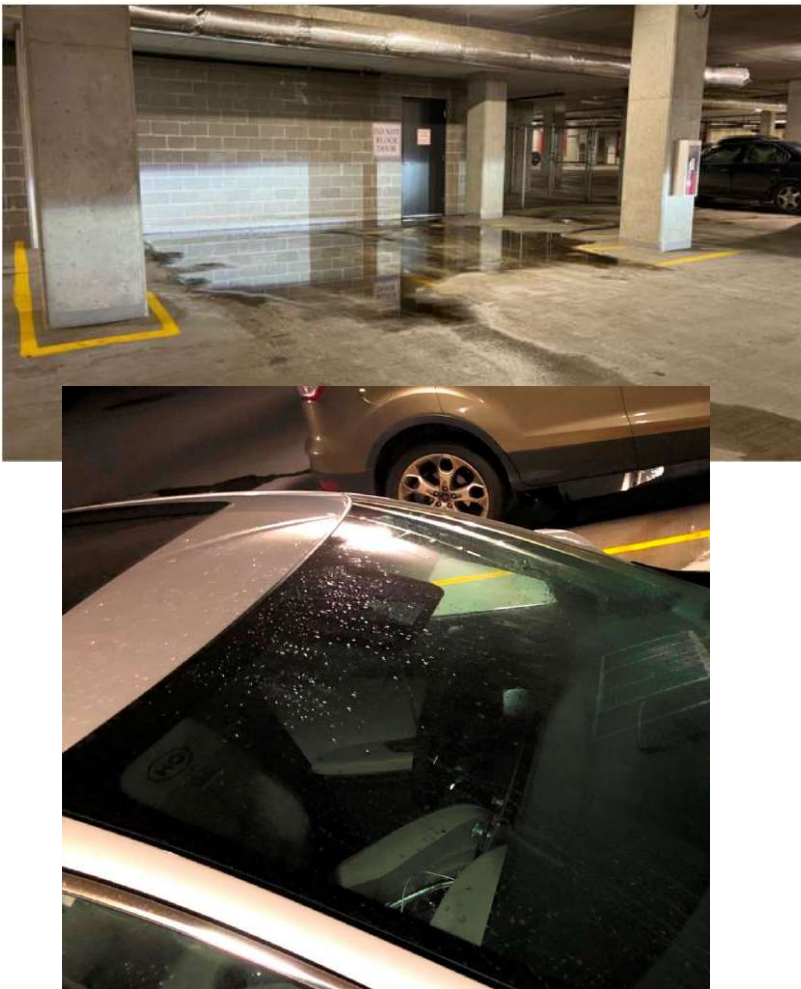


Table 2.4: General category of loadings and related functions

		Category of functions				
		Interior Finish	Support	Control	Exterior finish	
		Specific loadings				
Causal phenomenon or loading	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.)	●	●		●
	Essentially environmental	Fire	●	○	●	●
		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.)			●	○
	Essentially perceptual	Particulate matter (dust, VOC's, etc.)			●	
		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 4: which loadings were involved?

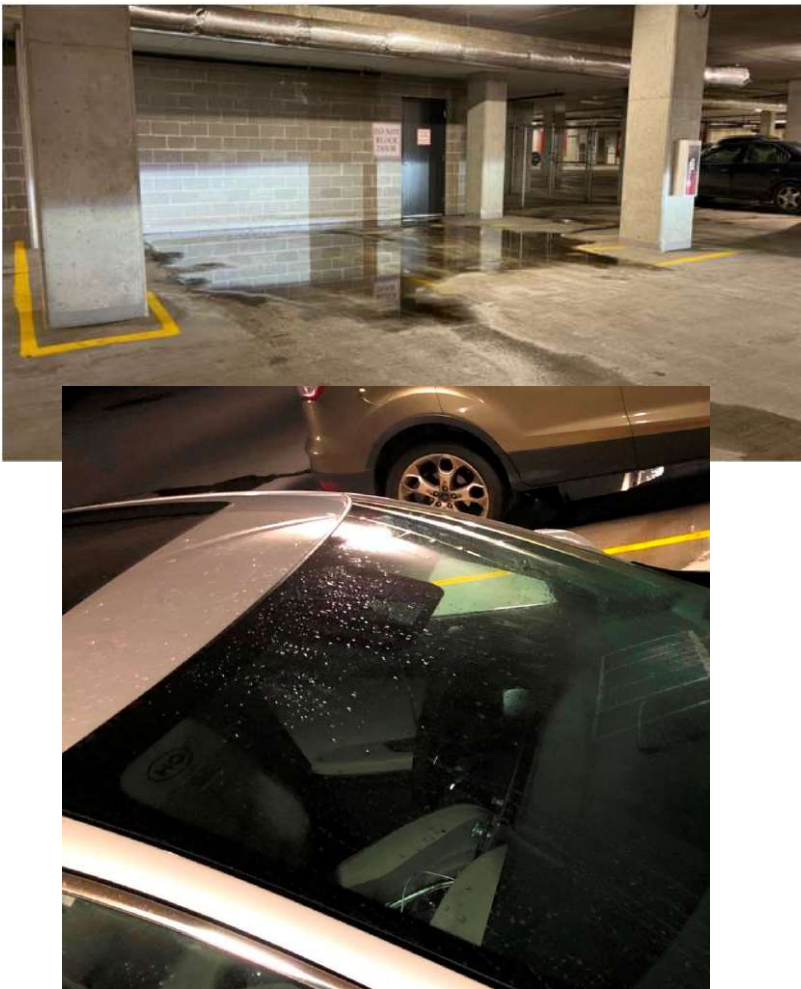


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		Wind		●	○	
		Ground Movement (seismic, settlement, etc.)		●		
		Explosion		●		
		Rheological (creep, shrinkage, etc.)		●		○
		Impact (vehicles, missiles, people, etc.)	●	●		●
	Essentially environmental	Fire	●	○	●	●
		Heat (thermal, etc.)		○	●	
		Air (pressure, movement, leakage, etc.)		○	●	
		Moisture (built-in, rain, condensation, etc.)		○	●	○
		Smoke			●	
		Solar radiation (incident, reflected, etc.)			●	○
		Chemical attack/atmospheric (acid rain, etc.)			●	○
Essentially perceptual	Particulate matter (dust, VOC's, etc.)			●		
	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 5: Roof Ponding/Adaptive Reuse Project



Buildings Move, Buildings Leak

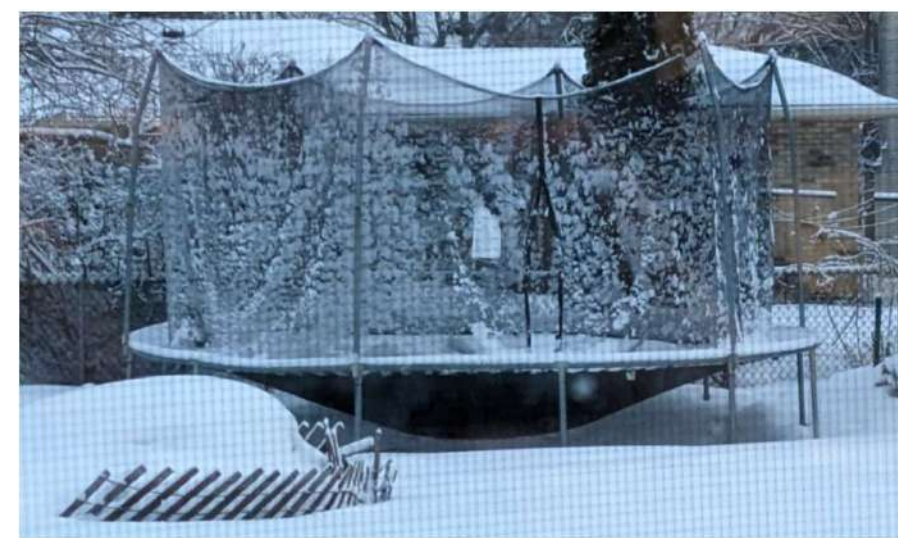
- Case Study 5: Roof Ponding/Adaptive Reuse Project
- New buildings: all code provisions for structural design apply
- Existing building modifications: retrofitting of structure is governed by code provisions for existing buildings
 - Varying thresholds of retrofit scope triggered by degree of modifications

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

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		Wind	●	○	
		Ground Movement (seismic, settlement, etc.)	●		
		Explosion	●		
		Rheological (creep, shrinkage, etc.)	●		○
		Impact (vehicles, missiles, people, etc.)	●		●
	Essentially environmental	Fire	●	○	●
		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.)			●
	Essentially perceptual	Particulate matter (dust, VOC's, etc.)			●
		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 5: which loadings were involved?



Table 2.4: General category of loadings and related functions

		Category of functions				
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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.)	●	○		●
	Essentially perceptual	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

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

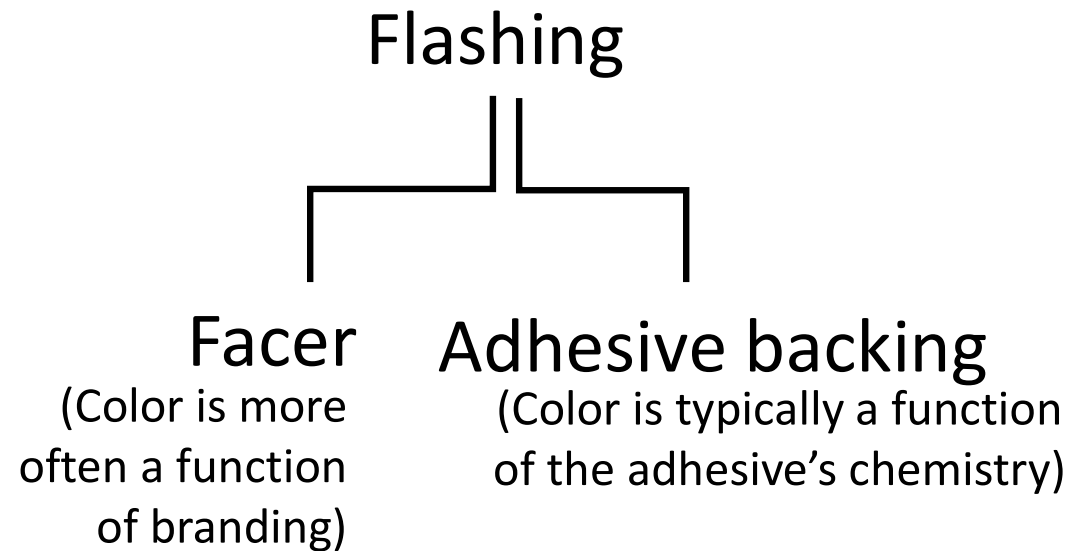
Buildings Move, Buildings Leak

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



Buildings Move, Buildings Leak

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



- 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

		Category of functions			
		Interior Finish	Support	Control	Exterior finish
Causal phenomenon or loading	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 •

Buildings Move, Buildings Leak

- Case Study 6: which loadings were involved?



Table 2.4: General category of loadings and related functions

		Category of functions			
		Interior Finish	Support	Control	Exterior finish
Causal phenomenon or loading	Specific loadings				
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	●	○	●	●
	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.)			●	○
Essentially environmental	Particulate matter (dust, VOC's, etc.)			●	
	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 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

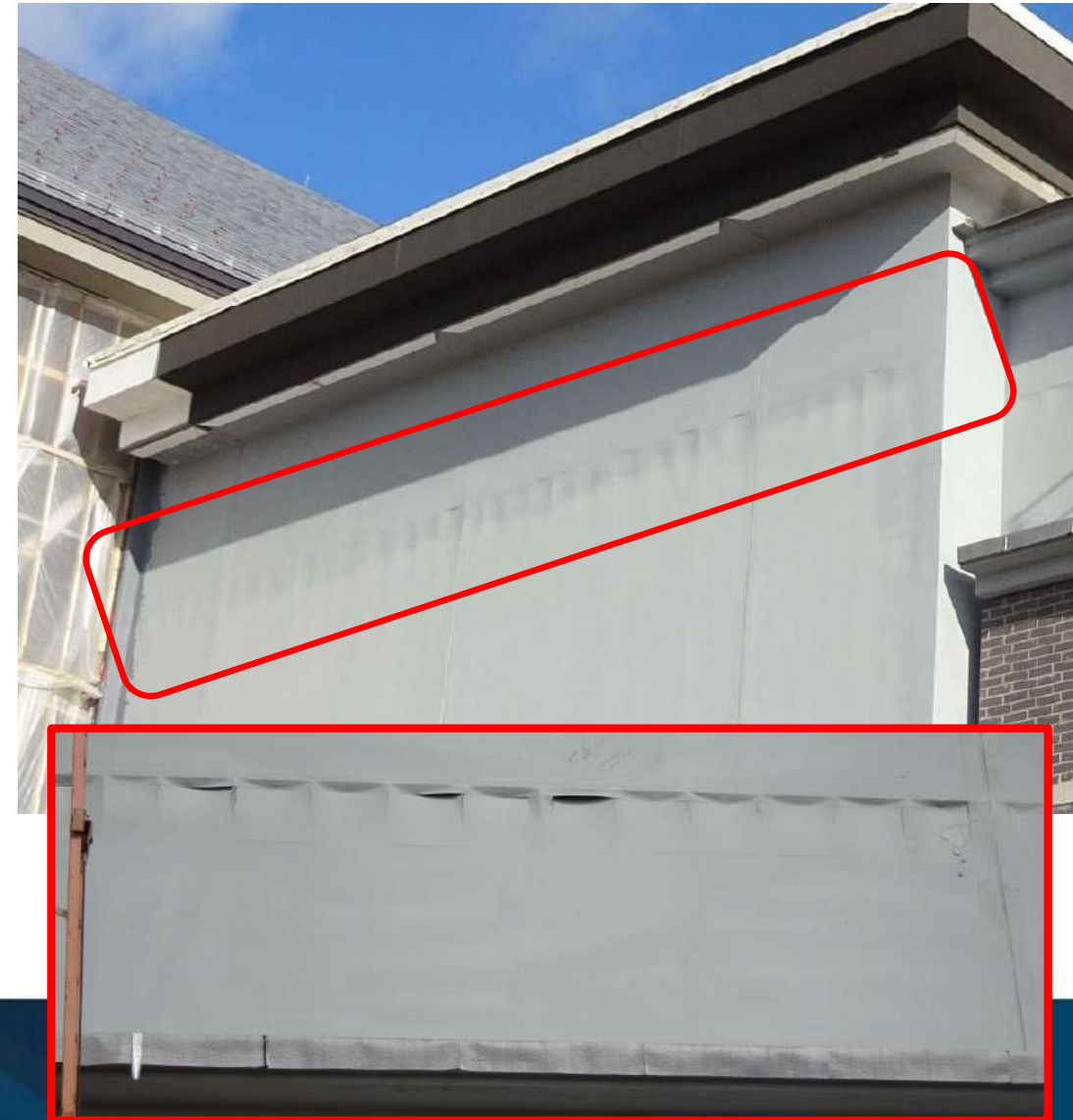


Buildings Move, Buildings Leak

- 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



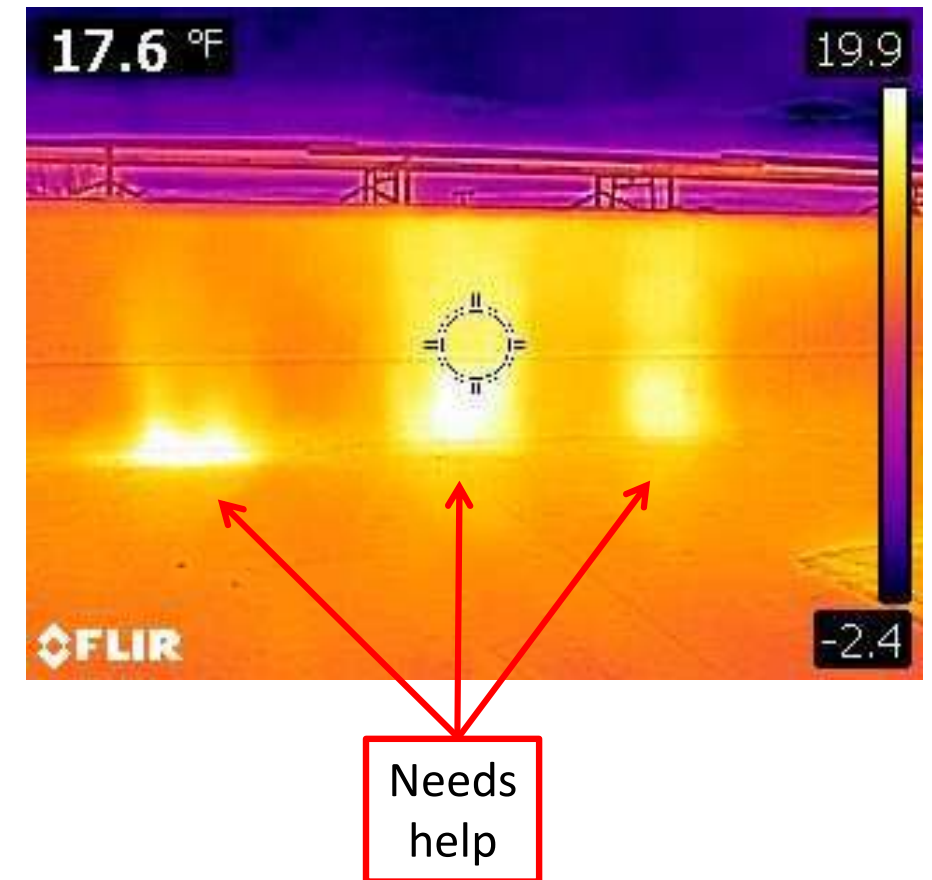
Buildings Move, Buildings Leak

- 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?



Table 2.4: General category of loadings and related functions

		Category of functions			
		Interior Finish	Support	Control	Exterior finish
Causal phenomenon or loading	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

●

○

●

Buildings Move, Buildings Leak

- Case Study 7: which loadings were involved?



MAYBE?

Table 2.4: General category of loadings and related functions					
	Specific loadings	Category of functions			
		Interior Finish	Support	Control	Exterior finish
Causal phenomenon or loading	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	●	○	●	●
	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.)			●	
Essentially perceptual	Sound	○	●	●	○
	Visual – local	●			●
	Visual – contextual	●			●

Primary significance

Secondary significance

Tertiary significance

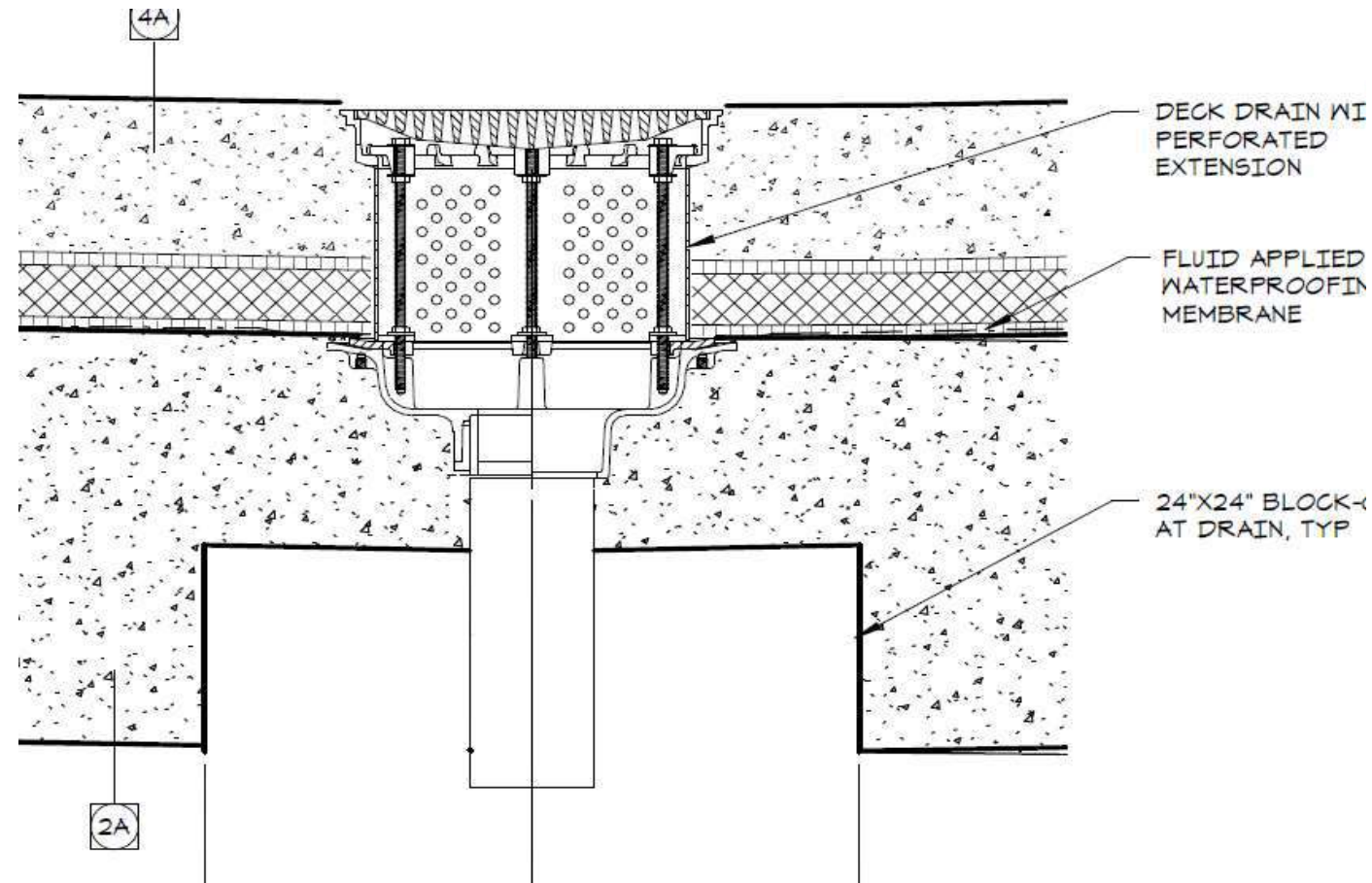
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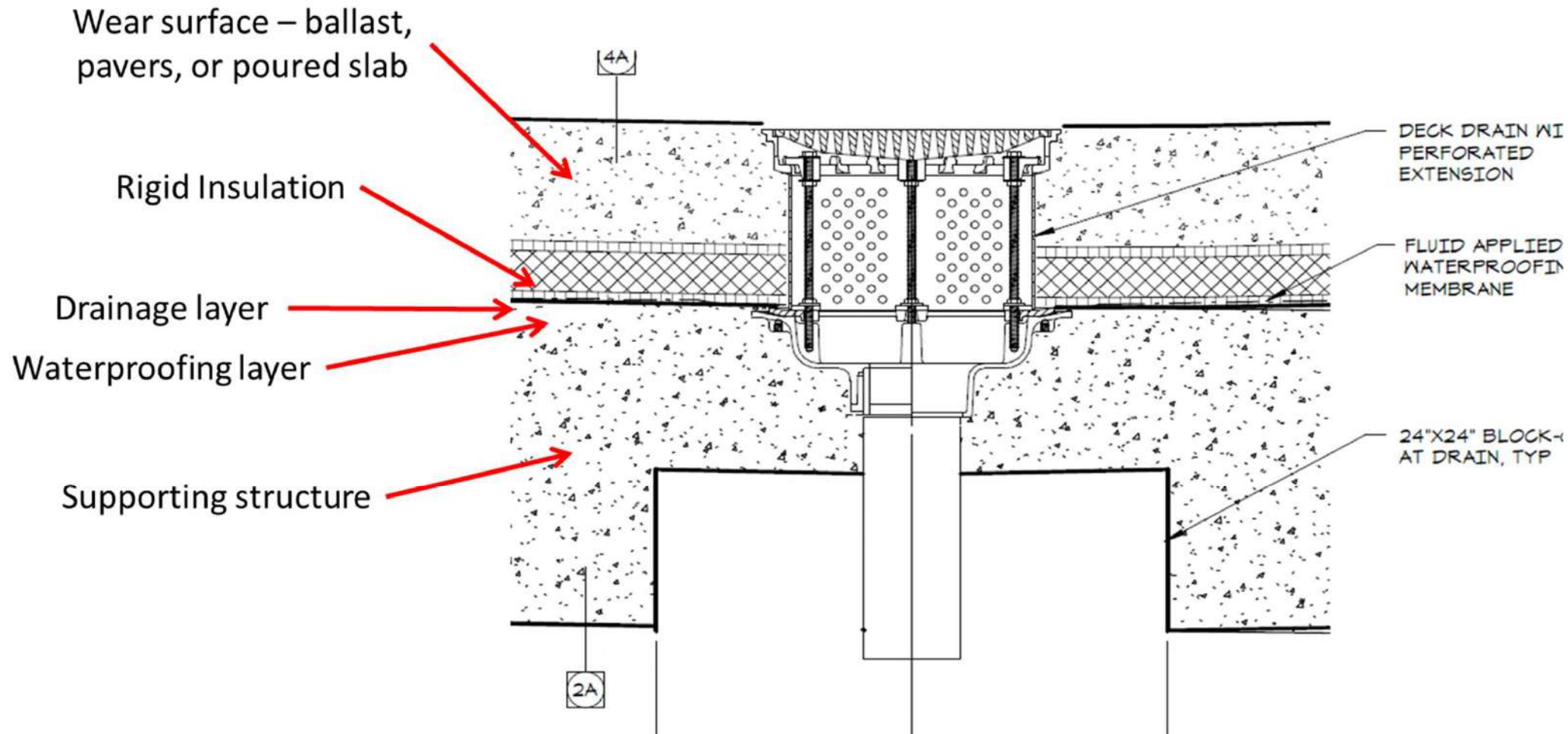
Buildings Move, Buildings Leak

- 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

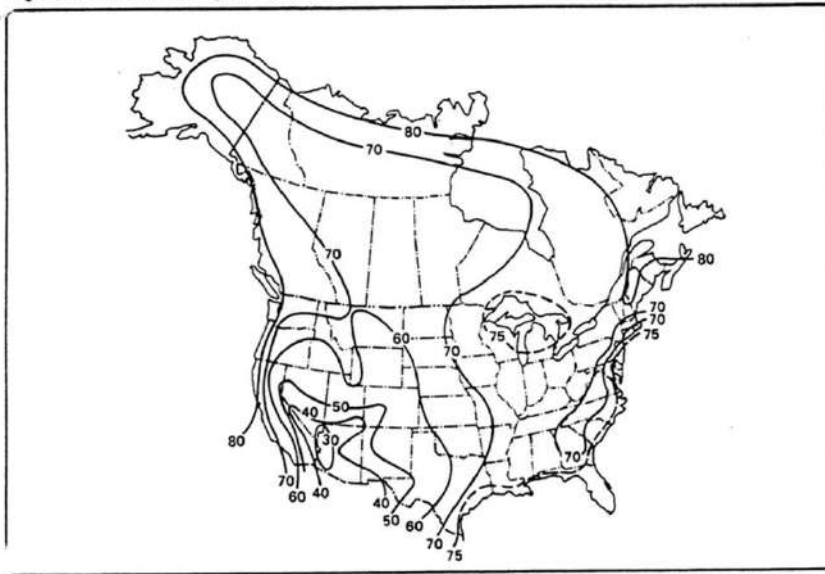
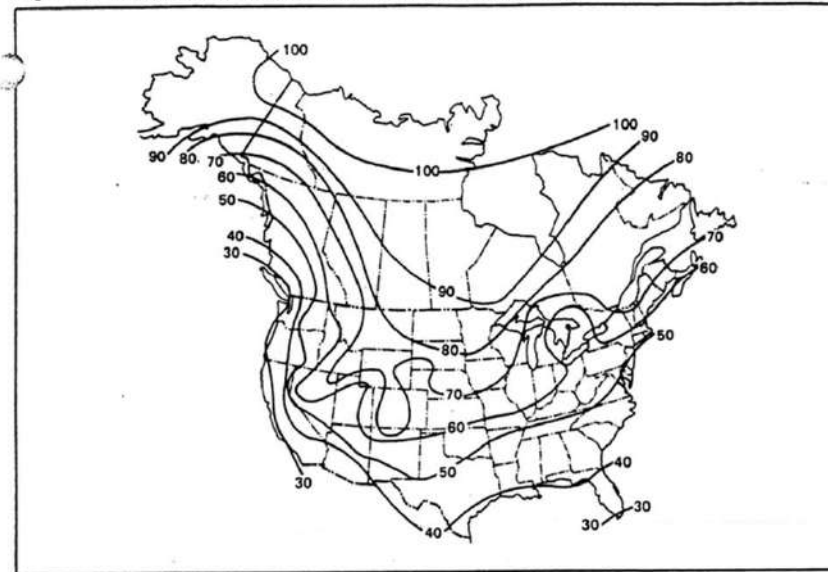


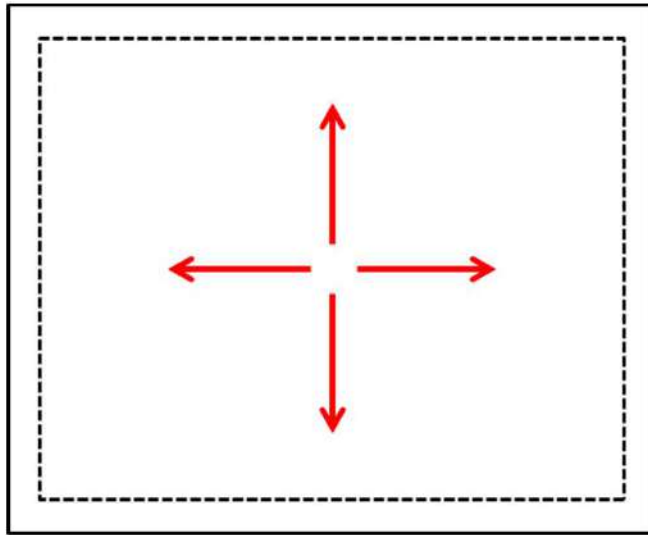
Fig. 3.3.1 Maximum seasonal climatic temperature change, deg F



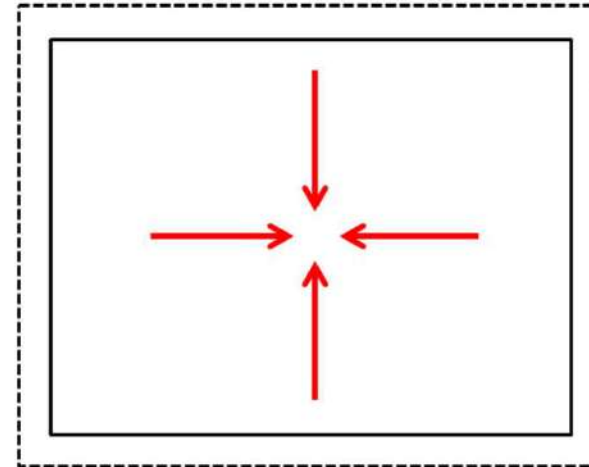
From PCI Design Handbook 3rd Ed., 1985

Buildings Move, Buildings Leak

- Case Study 8: Slab Jacking/Plaza Deck Assembly
- Wear slab detailing must accommodate movement



Increase in temperature
or moisture content



Decrease 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



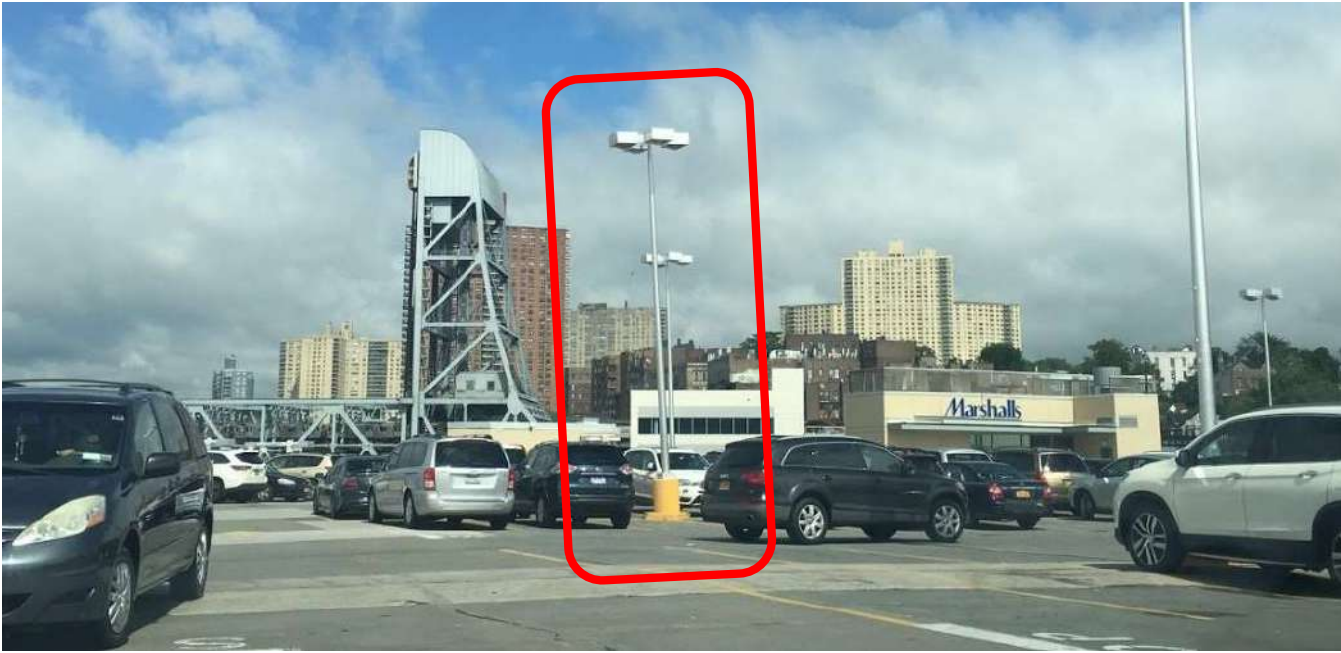
Buildings Move, Buildings Leak

- 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

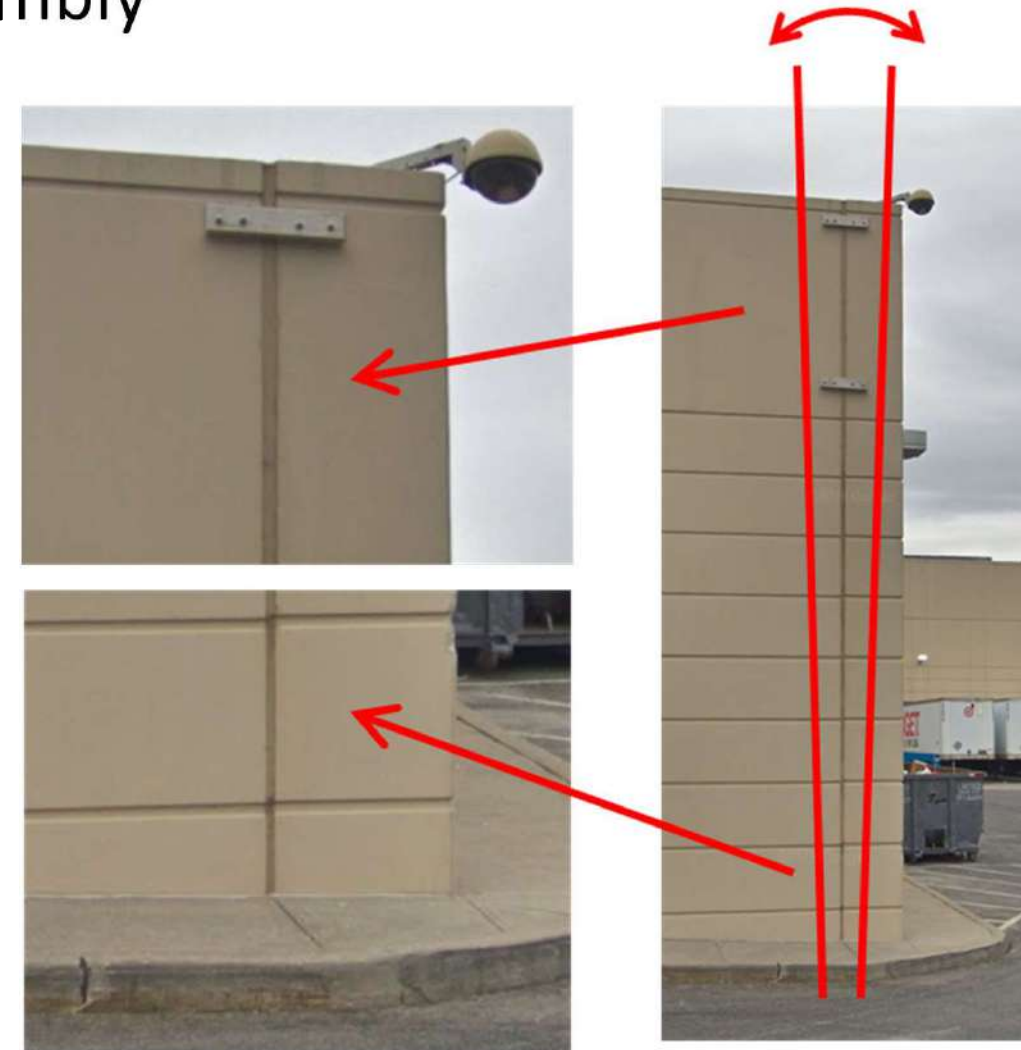
Buildings Move, Buildings Leak

- Case Study 8: Slab Jacking/Plaza Deck Assembly



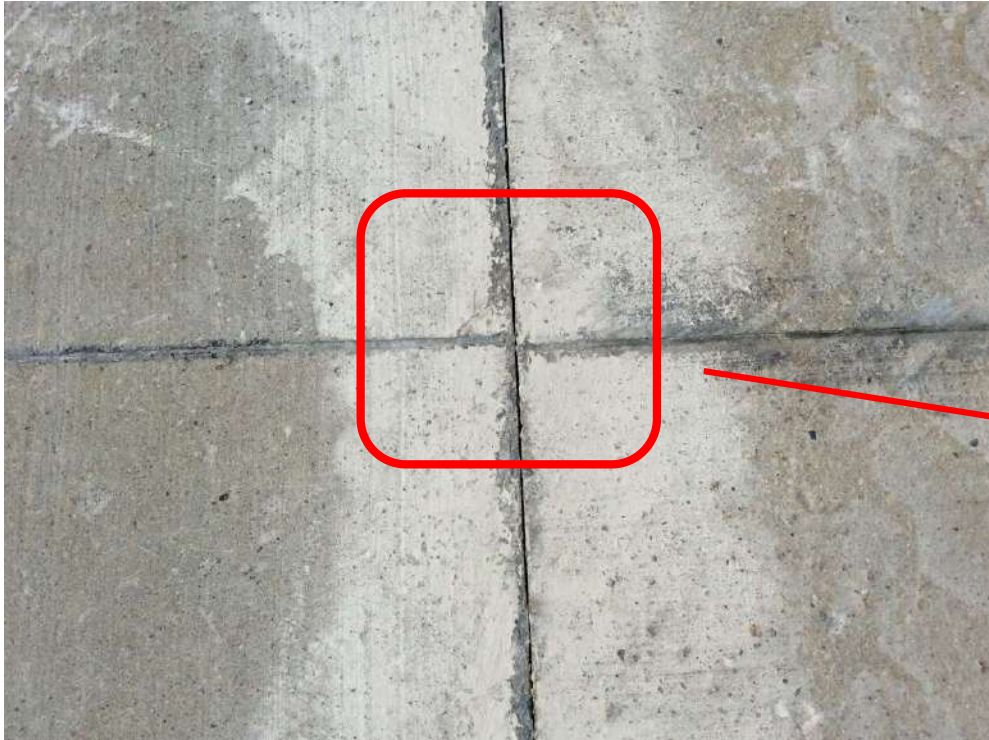
Buildings Move, Buildings Leak

- 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 **above** 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						
		Category of functions				
		Specific loadings	Interior Finish	Support	Control	Exterior finish
Causal phenomenon or loading	Essentially structural	Gravity – Dead (assembly, etc.)		●		
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		Wind		●	○	
		Ground Movement (seismic, settlement, etc.)		●		
		Explosion		●		
		Rheological (creep, shrinkage, etc.)		●		○
		Impact (vehicles, missiles, people, etc.)	●	●		●
	Essentially environmental	Fire	●	○	●	●
		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.)			●	○
	Essentially perceptual	Particulate matter (dust, VOC's, etc.)			●	
		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?



Table 2.4: General category of loadings and related functions					
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		Ground Movement (seismic, settlement, etc.)	●		
		Explosion	●		
		Rheological (creep, shrinkage, etc.)	●		○
		Impact (vehicles, missiles, people, etc.)	●		●
		Fire	●	○	●
		Heat (thermal, etc.)	○	●	
	Essentially environmental	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

- 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”~~

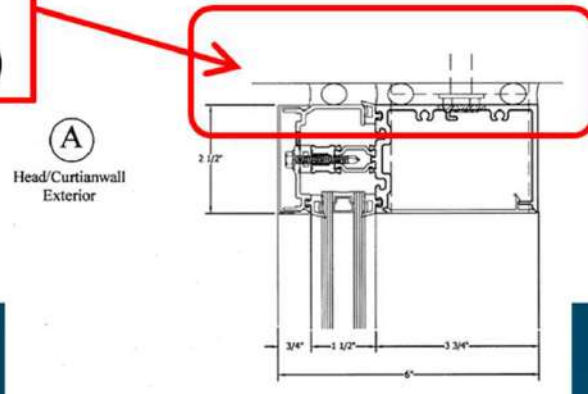
Buildings Move, Buildings Leak

- 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

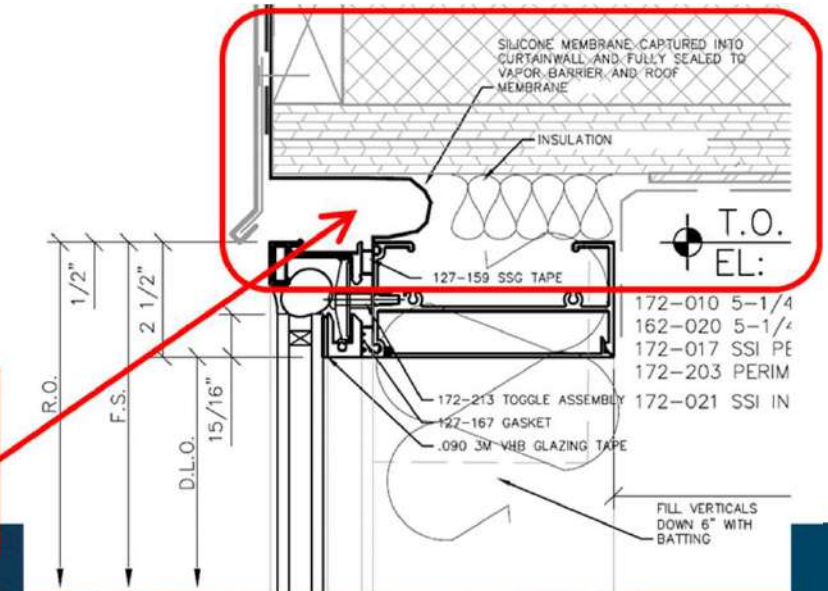
Buildings Move, Buildings Leak

- 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)

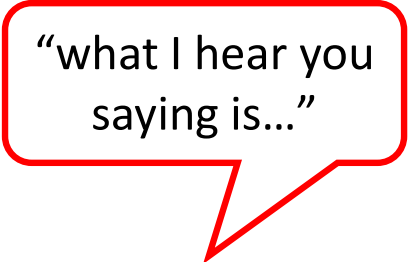


Much better, but we still
don't know how much
you think it will move



Buildings Move, Buildings Leak

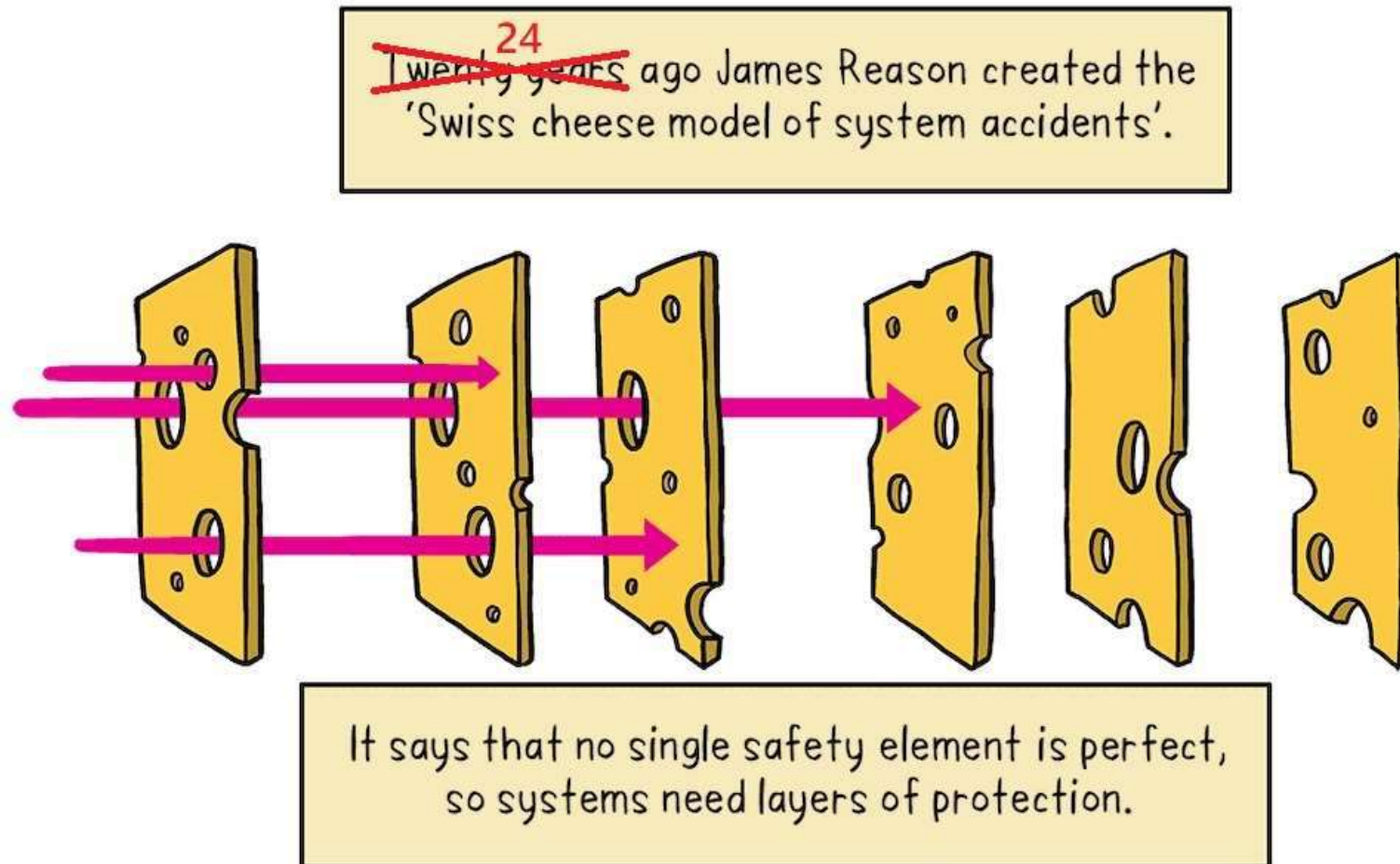
- Conclusion
- General Recommendations
 - Use steps in the documentation and approval process as tollgates
 - Communicate and Validate!



“what I hear you saying is...”

Buildings Move, Buildings Leak

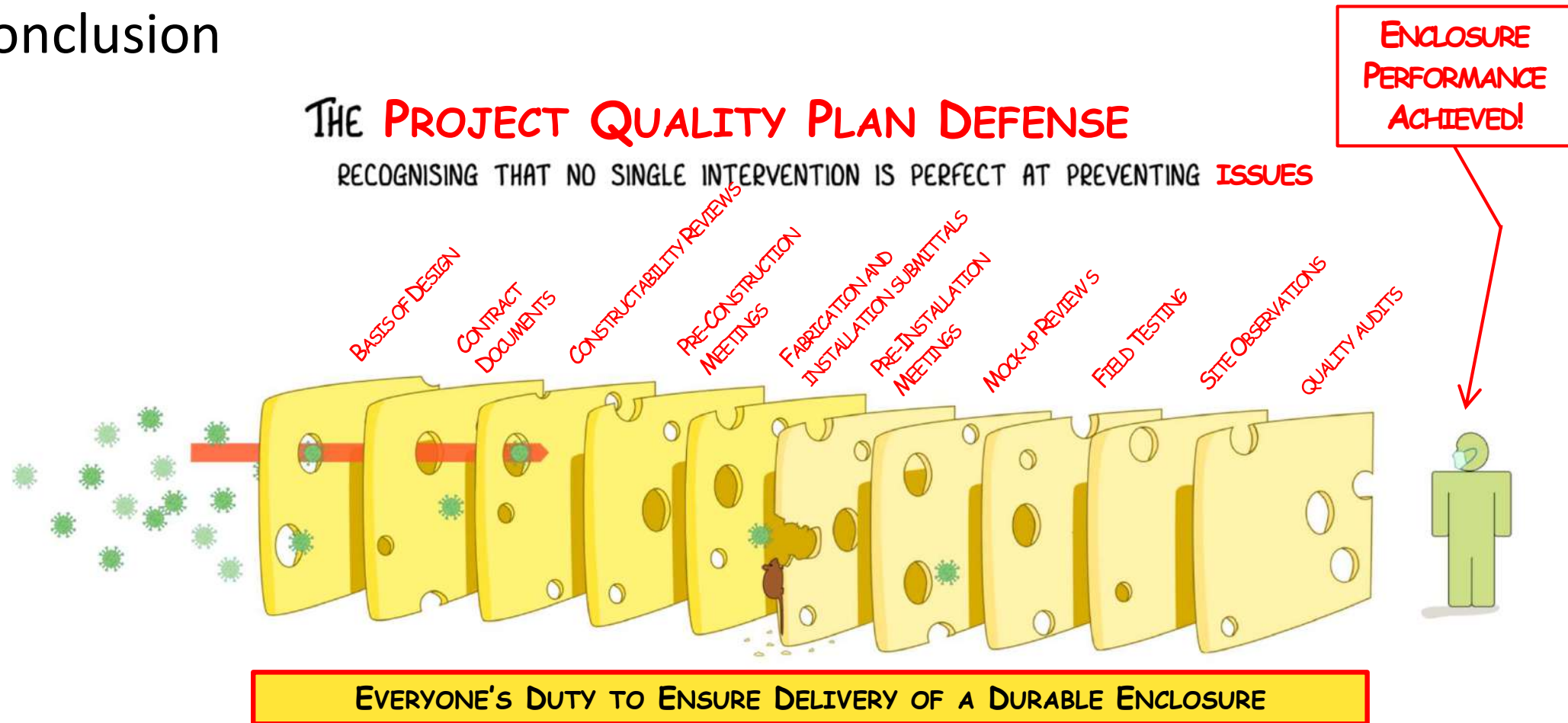
- Conclusion



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Buildings Move, Buildings Leak

- Conclusion



EACH INTERVENTION (LAYER) HAS IMPERFECTIONS (HOLES).
MULTIPLE LAYERS IMPROVE SUCCESS.

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



Quality is never an accident; it is always the result of high intention, sincere effort, intelligent direction and skillful execution; it represents the wise choice of many alternatives.

(William A. Foster)

Thank You!

jon.porter@krausanderson.com

612-979-3554

<https://www.linkedin.com/in/jonathan-porter-pe-assoc-aia-65451712/>



Jon Porter





abaa2024

building
enclosure
conference