BUILDING SCIENCE LIVE
OCTOBER 27, 2021

Balconies and Guards: "Safe-Guard" Your Railing Design

David C. Young | PE

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- Please use chat for housekeeping questions. Some FAQs:
  - You will get a follow-up email re. how to access the recording and a pdf of slides
  - **If you need a certificate or AIA or AIBC credits**, please follow the link in the chat box to confirm.
- Please use Q&A box for questions for the speaker
  - We will break partway and at the end for questions
  - Use upvote feature to let us know what you're most curious about!

More questions? Please contact us at onlinelearning@rdh.com

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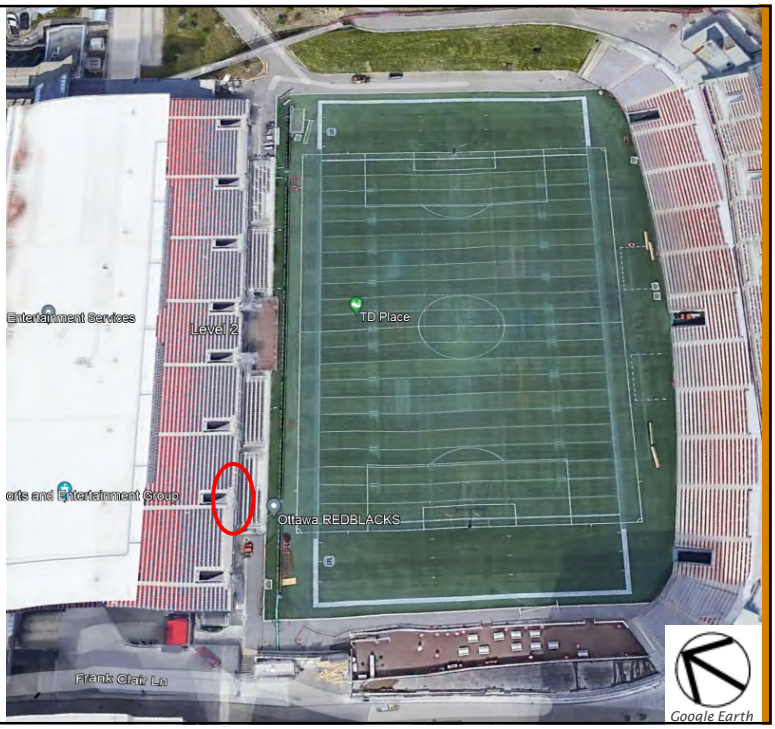
Lansdowne Park Guardrail Failure

- North Stands completed in 1967 (TD Place)
- "Panda" Football Game Oct. 17, 1987 Carleton University (Ravens) vs Ottawa University (Braves)
- Half-time – large number of people crowding railing with notions of climbing and jumping onto the field
- 26ft of guardrail gave way around 2pm and 14 people fell over, 36 taken to hospital in total
- No fatalities



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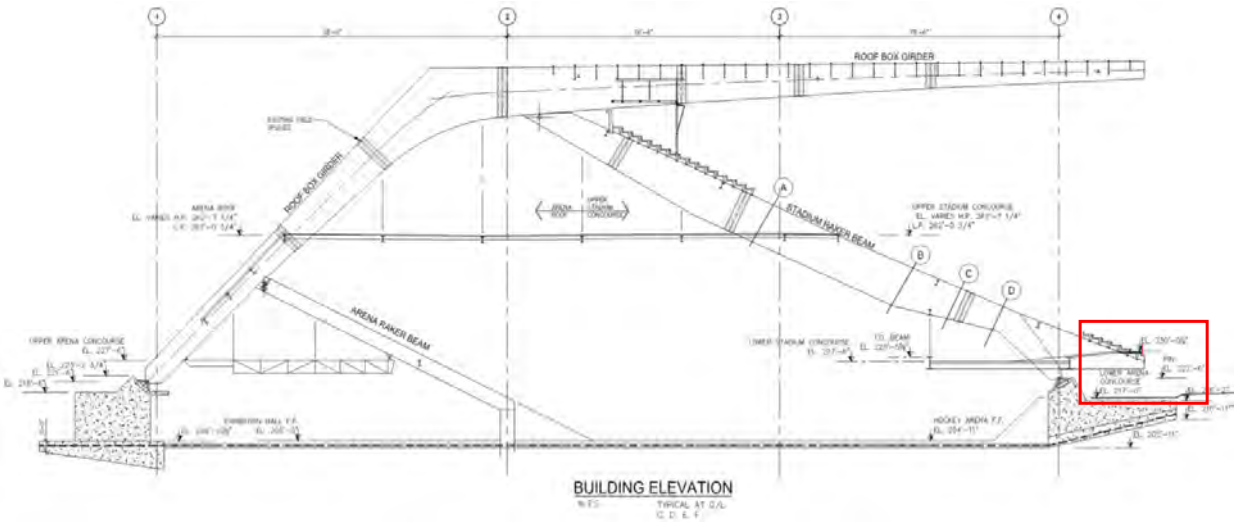
TD Place – North Stadium



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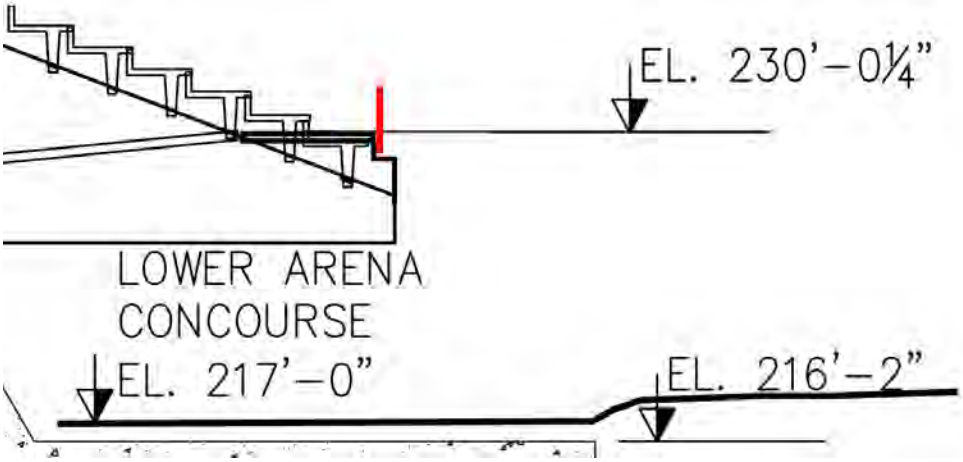

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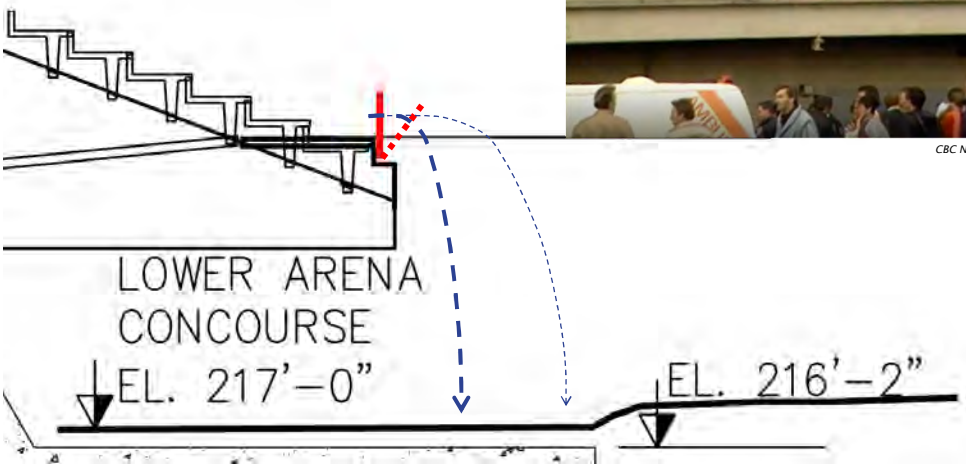
TD Place – North Stadium

CBC News Archives



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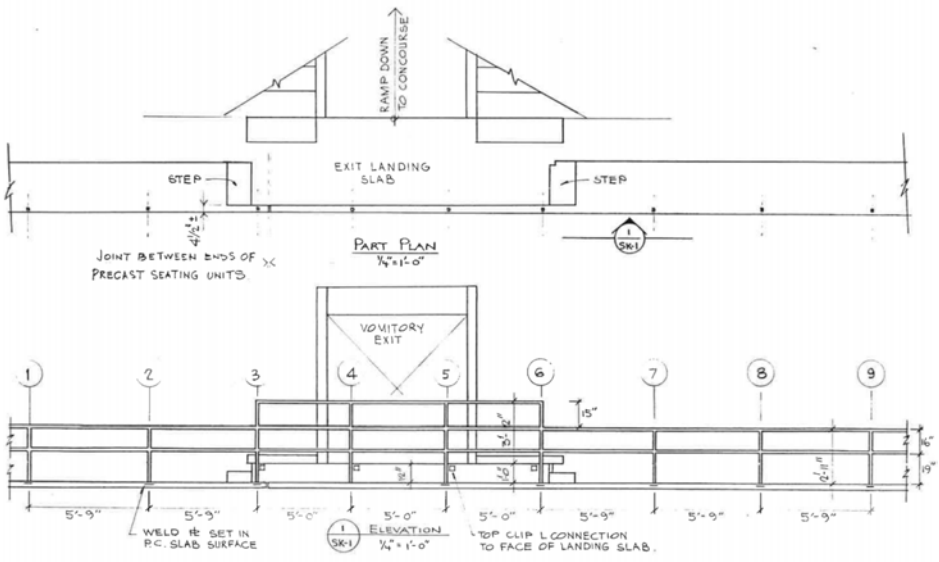

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TD Place – Guardrail Failure

- Typical Railings at Seating
  - 2'-11" tall
  - HSS 1 ½" x 1 ½" x 0.12" welded with fillet weld to steel plate embed in concrete
  - Weld plate set with 3 headed stud anchors
  - Welds were incomplete seal welds which allowed water/condensation inside of post led to corrosion of the steel at the base of the post
  - Water was also able to penetrate under the weld plate leading to corrosion of the headed stud anchors
  - Not easily seen by visual inspection

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Photos courtesy Adjeleian Allen Rubeli, Ltd.

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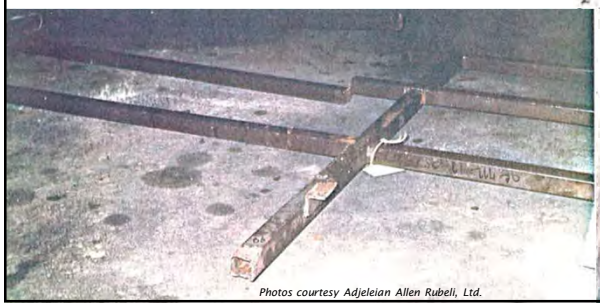
TD Place – Guardrail Failure

- Guards at Exit Landing
  - 3'-2" tall at landing
  - HSS 1 ½" x 1 ½" x 0.12" welded with fillet weld to steel plate embed in concrete
  - Additional clip angle near top of landing welded to steel embed
  - Rear fillet weld at base of post not easily constructible and point of highest tension



Photos courtesy Adjeleian Allen Rubeli, Ltd.

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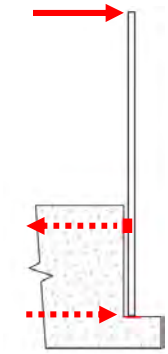
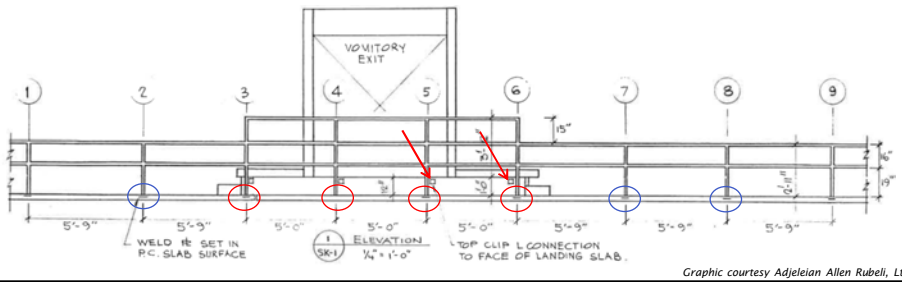
TD Place – Guardrail Failure – Summary

- Severe internal corrosion at base of 3, 4, 5 & 6
- Clip angle missing at 5 & 6
- Fracture of headed stud anchors at 2, 7 & 8 due to corrosion – reduced cross section at studs
- Locations 1 & 9 remained intact





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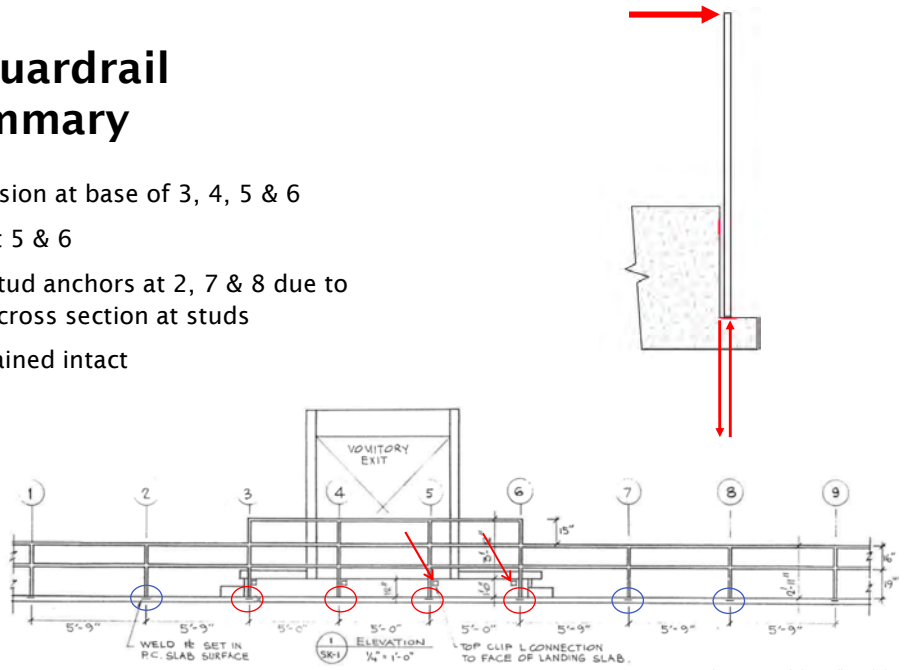

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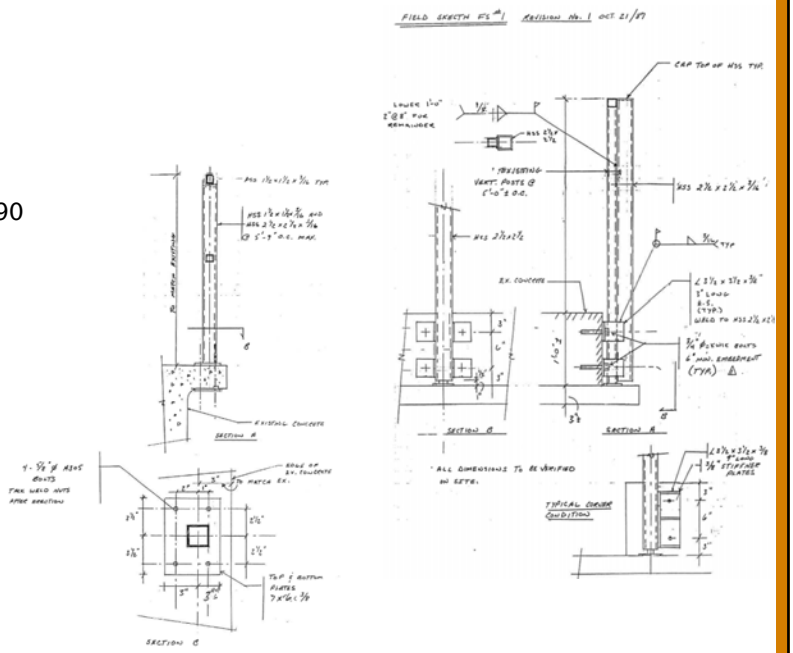
TD Place Guardrail Replacement

- Railing replacement started in 1990 after complete redesign
- All railings removed and replaced with heavier steel guards meeting Code requirements at that time
- Base of posts welded to steel base plates and through bolted to precast concrete or side bolted into thicker CIP.
- Many areas required concrete repairs



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Library Gardens – Berkley, CA

- 5-story wood-framed apartment building, completed in 2006
- June 16, 2015, at 12:40am – balcony gave way
- 6 fatalities, 7 students suffered serious injuries
- Cantilevered balcony framing (LVL)
- OSB sheathing with self-adhered membrane waterproofing and concrete topping (alum. balcony-form edge)

https://www.cslb.ca.gov/Resources/Reports/Investigative/cslb_berkeley_balcony_materials_packet.pdf

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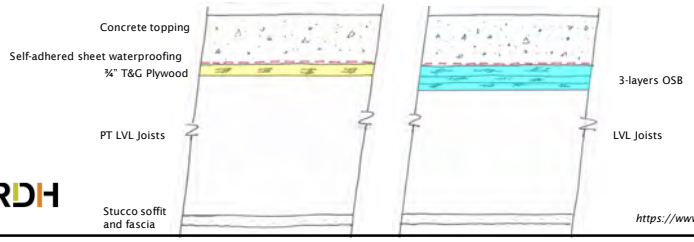
Library Gardens – Berkley, CA

- Some key deviations and field conditions
  - Original details called for ¾" T&G plywood
  - As-built 3 layers of OSB sheathing (1 ¾" layer and 2 5/8" layers)
  - No membrane pre-stripping under edge extrusion, back lapped deck to wall membrane
  - Balcony framing completed mid-Oct. 2005
  - Waterproofing completed by Aug. 2, 2006
  - 38.78" of rain recorded over that period

> 10-month exposure



Trapped construction moisture with no ability to dry exacerbated by other poor perimeter detailing

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Library Gardens – Berkley, CA – Outcomes

- California Building Code and Berkeley Municipal Code updated to include:
  - Section 1202.7 – Added vented space under balconies, decks, etc. (1/150th of area)
  - Sections 1404.13, 2304.11.1, and 2304.11.4.2 - Materials to be naturally durable or PT wood and corrosion resistant metal components
  - 601.4 Structural Maintenance
    - Essentially all elevated balconies, decks, stairs, landings, handrails and all parts of weather-exposed areas Group R-1 or R-2 to be inspected on 5-year interval.
- California Senate Bill 721 (2018)
  - **Apartments** (multi-family residential with 3 or more dwelling units)
  - Requires inspection of 15% of *Exterior Elevated Elements*
  - Review on 6-year intervals
- California Senate Bill 326 (2019)
  - **Condos**
  - Requires inspection of a "statistically significant sample" of *Exterior Elevated Elements,* for 95% confidence level, ± 5% margin of error
  - Review on 9-year intervals

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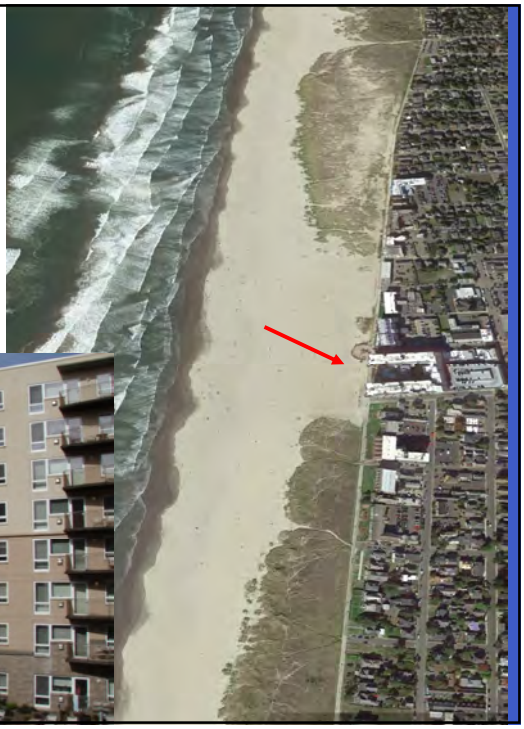
Building at the Beach Seaside, OR

- 8-story resort hotel
- Full exposure and salt-laden air
- Concrete balconies with pedestrian coating and SS guards
  - 304 stainless
  - Set in grout pockets
- Corrosion on guards
- Spalling concrete at post locations



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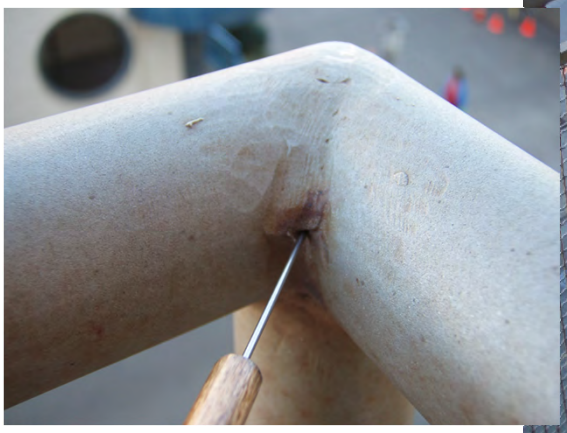
Building at the Beach Seaside, OR

→ Pinholes in welds allowed water into posts



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Building at the Beach Seaside, OR

→ Coating had insufficient upturn/adhesion at posts

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Building at the Beach Seaside, OR

- Grout pocket sleeves created additional pathway for water
- Water entering perimeter of post migrated to rebar and initiated corrosion

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Building at the Beach Seaside, OR

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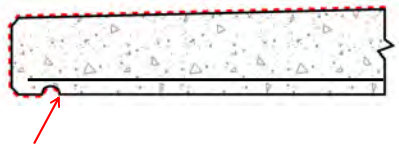
Building at the Beach Seaside, OR

- In marine exposure, choose high corrosion resistant materials
  - 316 stainless or greater
  - Consider Duplex 2205 series stainless
- Avoid grout pockets
- Maintain adequate cover to reinforcing
- Detail coatings carefully and wrap to back of drip reglet, due to reduced rebar cover



Key Components of Stainless Steels

	304	316	2205
Chromium	18%	16%	21%
Nickel	8%	10%	4.50%
Molybdenum		2%	2.50%

Mechanical Properties

	304	316	2205
Ult. Tensile (Mpa)	515	515	700

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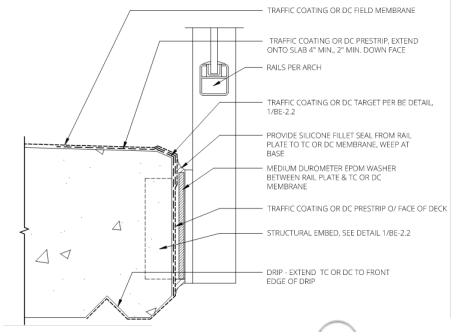
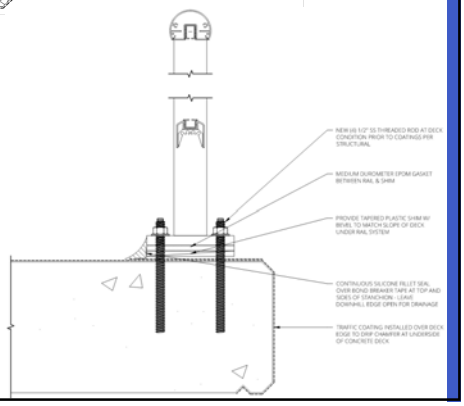
Some Design Approaches

- Coatings on concrete
  - Polyurethane membranes are very common – Typically require recoating every 5-8 years
  - Consider PMMA or PUMA – require recoating in the range of 10-15 years.
    - Higher install cost, lower life cycle cost
- Top or side mounted guards for concrete decks





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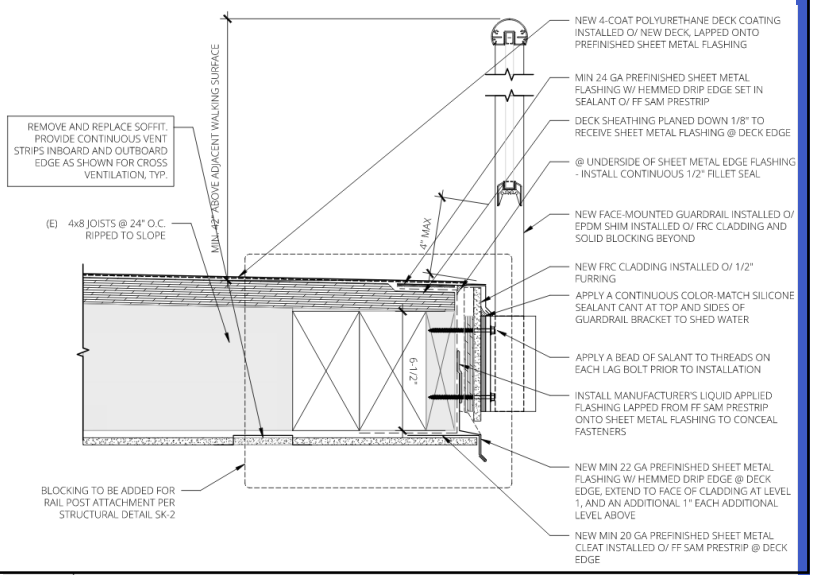
Some Design Approaches

- Side mounted guards in wood framed const. Avoid top mounted guards wherever possible



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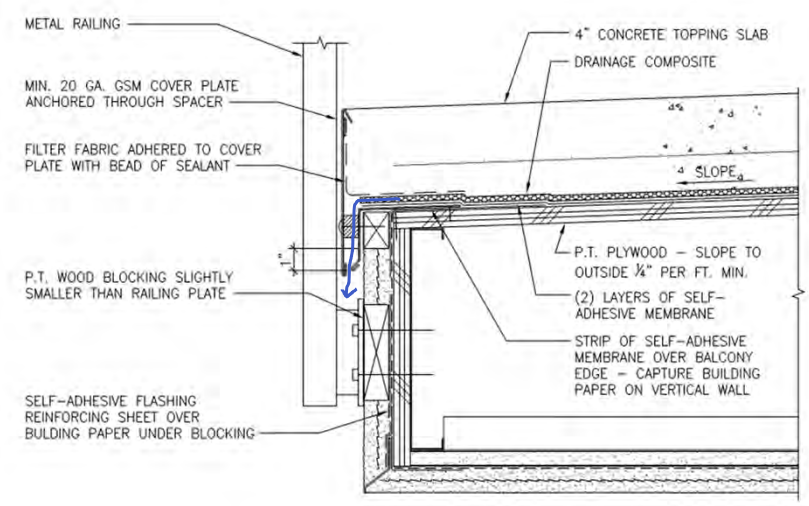

- Provide a clear means of drainage in concrete-topped wood-framed balconies (and rainscreen fascia)

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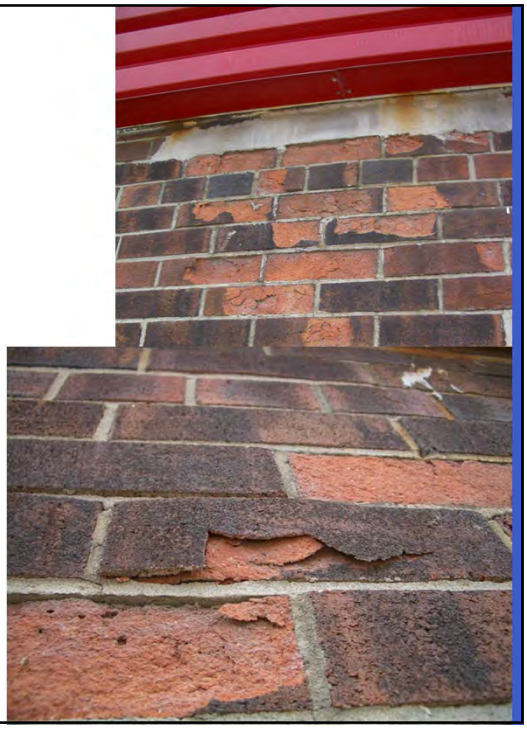
Freeze-Thaw Damage

- What is Freeze-thaw?
  - A porous material freezes then thaws out
  - Water within pores freezes and expands, leading to deterioration
  - Common in brick, stone, concrete, manufactured products (hardi cement board, cultured stone etc.)
- Thresholds
  - Area of material must be near saturation moisture level for freezing to cause damage (75% to 95% of free water saturation)
  - Pore size/air voids matter (ie air-entrained concrete)
  - Temperature for freezing of water is 0˚C, but F/T damage typically only occurs when freezing down below -5˚C
- Number of F/T cycles until damage & resistance varies



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Portland Condo – Balcony Guards

- Freeze/Thaw can also manifest in other ways
- Example of split railing – Photo taken in January 2009

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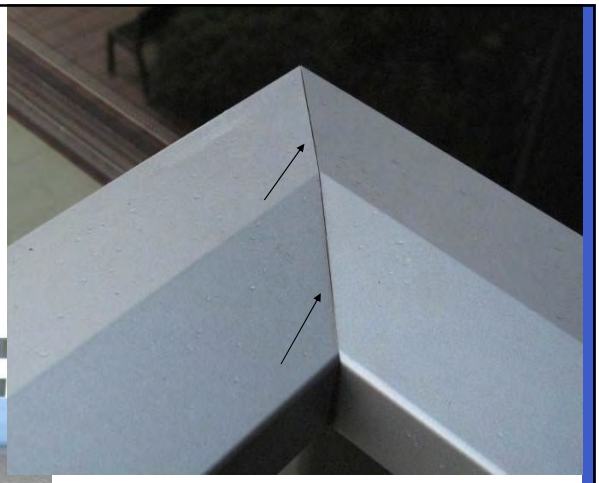
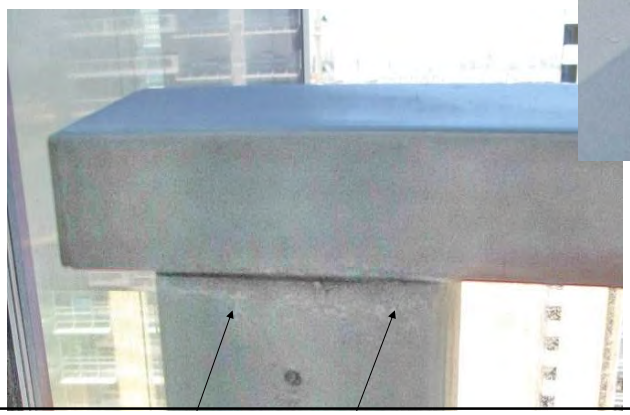
Portland Condo – Balcony Guards

- Joints in railing caps and post connections allowed water to enter aluminum railing system





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Portland Condo – Balcony Guards

- Example of bowed railing post – deformation as a result of frozen water and lack of drainage (photo taken August 2011).
- Condition observed at several balconies

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Portland Condo – Balcony Guards

- Damaged railing post cut and removed during January 2009 repair work
- Solid grout column at railing post location after removal during the repair work in 2009

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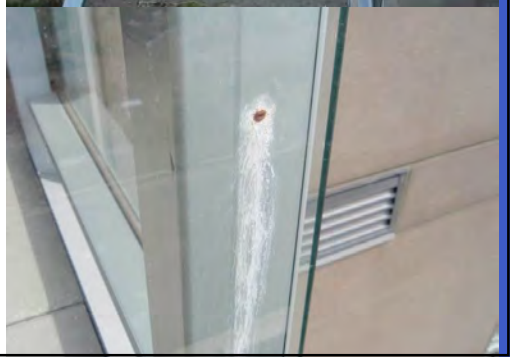
Portland Condo – Balcony Guards

- Weep holes provided after 2009 event. Staining and residue from drainage at weep hole. Condition observed at most balconies and deck guards during August 2011
- Example of water released from weep hole after removal of a build-up of residue that blocked the weep hole. Observed at numerous locations.
- Solution – provide adequate means of drainage



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General Design Loads for Guards

- **Canada**
  - Viewing Stands (Stadia) – 205plf (3kN/m) horiz. outward
  - Access ways to equipment platforms – 225lb (1kN) horiz. outward
  - All others – 50plf (0.75kN/m) horiz. Outward
  - Minimum inward – 50% of above loading
  - UDL – 100plf (1.5kN/m) applied vertically, or
  - Point Load – 1.0kN applied vertically
  - Components – 100lb (0.5kN) horiz. over 12" x12" areas
  - Consult CSA A500-16 – Building Guards when designing railings, particularly glass guards (Doesn't include Assembly occupancies)
- **US**
  - No special provision for Viewing Stands
  - All top rails – 50plf (0.73kN/m) – applied in any direction
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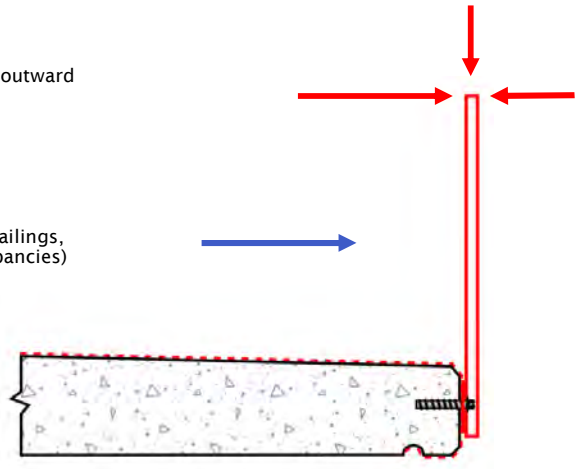

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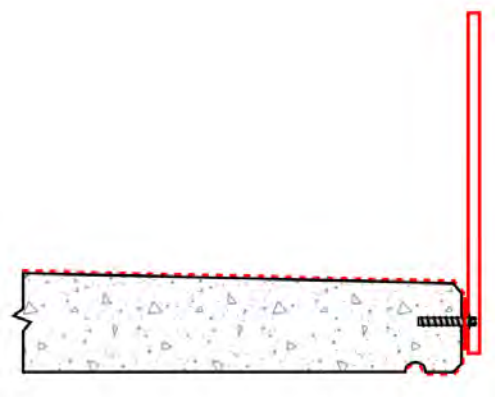

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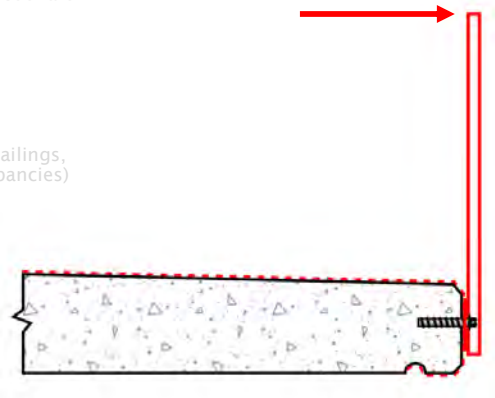

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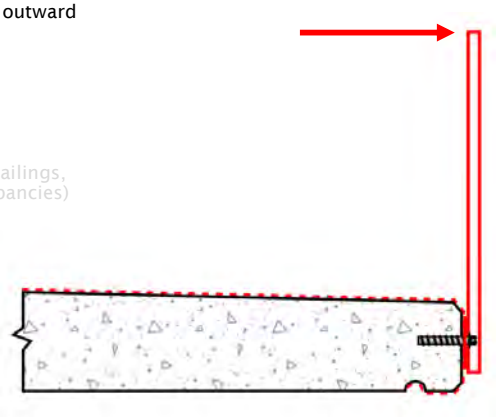

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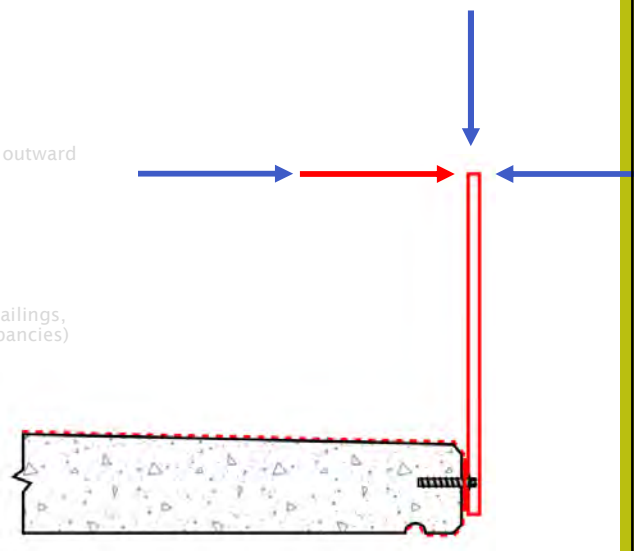

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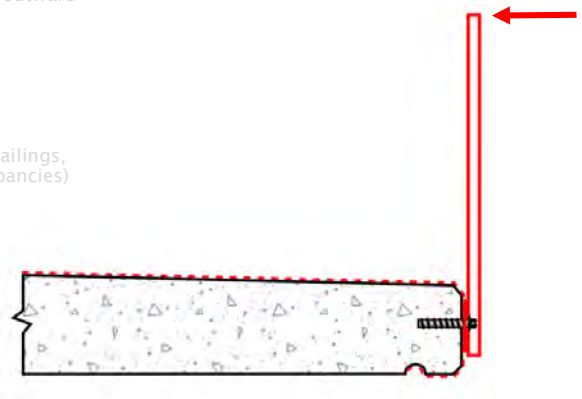

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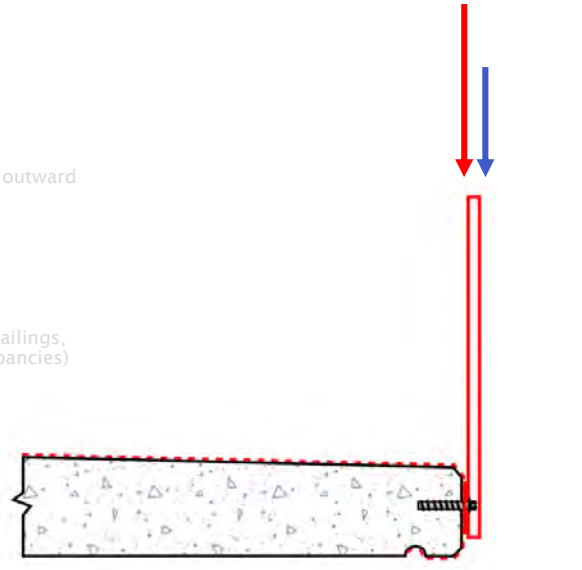
  - Components – 50lb (0.22kN) horiz. over 12" x12" areas



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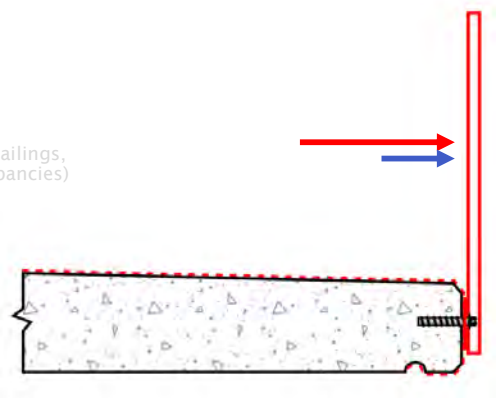
General Design Loads for Guards

- **Canada**
  - Viewing Stands (Stadia) – 205plf (3kN/m) horiz. outward
  - Access ways to equipment platforms – 225lb (1kN) horiz. outward
  - All others – 50plf (0.75kN/m) horiz. outward
  - Minimum inward – 50% of above loading
  - UDL – 100plf (1.5kN/m) applied vertically, or
  - Point Load – 1.0kN applied vertically
  - Components – 100lb (0.5kN) horiz. over 12" x12" areas
  - Consult CSA A500-16 – Building Guards when designing railings, particularly glass guards (Doesn't include Assembly occupancies)
- **US**
  - No special provision for Viewing Stands
  - All top rails – 50plf (0.73kN/m) – applied in any direction
  - All top rails – 200lb (0.89kN) – applied in any direction UDL and Point load not applied concurrently
  - Components – 50lb (0.22kN) horiz. over 12" x12" areas



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General Design Loads for Guards

- **Canada**
  - Viewing Stands (Stadia) – 205plf (3kN/m) horiz. outward
  - Access ways to equipment platforms – 225lb (1kN) horiz. outward
  - All others – 50plf (0.75kN/m) horiz. outward
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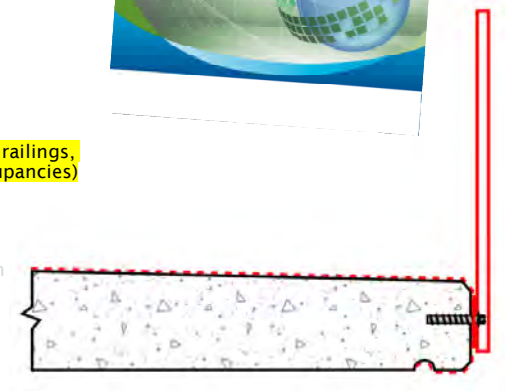

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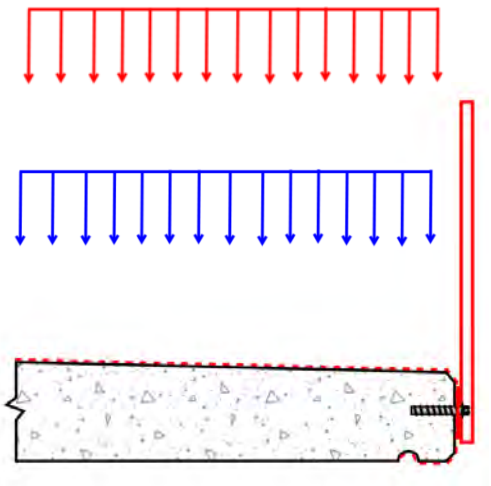
General Design Loads for Balcony Surface

- **Canada**
  - 100psf (4.8kPa)
- **US**
  - 1.5 x area served ≤ 100psf (4.8kPa)
  - Residential balconies = 40psf x 1.5 = 60psf (2.9kPa)



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Don't forget Snow

- Sometimes snow controls!

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Don't forget Snow

- 3-story townhome style condos on Mt. Hood
- Elev. 3,800ft
- High snow load area
- Top mounted guards to wood framed drip through balconies

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Thinking Outside the Box

- Strengthen Guards and Balconies to handle sliding snow???
- Shed snow away from balconies
- New cantilevered roof
- New side-mounted guards with decorative fascia

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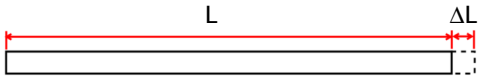
Thermal Expansion and Contraction of Materials

- Materials expand and contract with changes in temperature
- Important for the design of structural and enclosure components, as well as aluminum guards
- $\Delta L = \alpha \cdot L \cdot \Delta T$
  - Where ΔL = material length change, L is initial length, α is thermal expansion/contraction coefficient, ΔT is change in temperature



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Material Properties (SI)

- Steel, 12x 10^{-6}
- Concrete, 12x 10^{-6}
- Aluminum, 24x 10^{-6}
- Lead, 30x 10^{-6}

Table 13.1: Properties needed to assess change in dimension of materials

	Material	Coefficient of Thermal Expansion and Contraction (α) / °C x 10^{-6}	Coefficient of Expansion and Contraction Due to Moisture Change (μ) %	Irreversible Moisture Movement (+) Expansion (-) Shrinkage %	Modulus of Elasticity (E) kN/mm²
Natural Stone	Granite	8-10			20-60
	Limestone	3-4	0.01		10-80
	Marble	4-6			35
	Sandstone	7-12	0.07		3-60
	Slate	9-11			10-35
Cement-Based Composite (Concrete values for plain concrete)	Mortar and Fine Concrete	10-13	0.02-0.06	0.04-0.10(-)	20-35
	Dense Aggregate Concrete				
	Gravel Aggregate	12-14	0.02-0.06	0.03-0.08(-)	15-36
	Crushed Rock (Except Limestone)	10-13	0.03-0.10	0.03-0.08(-)	15-36
	Limestone	7-8	0.02-0.03	0.03-0.04(-)	20-36
	Steel-Fiber-Reinforced Concrete	5-14	0.02-0.06	0.03-0.05(-)	20-41
	Aerated Concrete	8	0.02-0.03	0.07-0.09(-)	1.4-3.2
	Lightweight Aggregate Concrete				
	Medium Lightweight	8-12	0.03-0.06	0.03-0.09 (-)	6
	Ultra Lightweight (Perlite)	6-8	0.10-0.20	0.20-0.40(-)	80
	Asbestos-Cement	8-12	0.10-0.25	0.06(-)	14-26
	Glass-Reinforced Cement	7-12	0.15-0.25	0.07(-)	20-34
CA-SO4 Based Composite	Asbestos Wallboard	5-12	0.14-0.27		8-10
	Asbestos Insulation Wallboard	2.5-7.2	0.16-0.25		2.5-3.6
Gypsum Based Composite	Dense Plaster; Plasterboard	18-21	(gypsum materials are highly susceptible to moisture damage. Moisture changes are not reversible)		16
	Sanded Plasters	12-15			8.5-16
	Lightweight Plasters	16-18			1.5-4
	Glass-Reinforces Gypsum	17-20			16-20
Brickwork, Blockwork, and Tiling	Concrete Brickwork and Blockwork				
	Dense Aggregate	8-12	0.02-0.04	0.02-0.06(-)	10-25
	Lightweight Aggregate (Autoclave)	8-12	0.03-0.06	0.02-0.08(-)	4-16
	Aerated (Autoclave)	8	0.02-0.03	0.05-0.08(-)	5-8
	Calcium Silicate Brickwork	8-14	0.01-0.05	0.01-0.04(-)	14-18
	Clay or Shale Brickwork or Blockwork	5-8	0.02	0.02-0.07(-)	4-26
	Clay Tiling	4-8	[illegible]	[illegible]	[illegible]
Metals	Cast Iron	10	(While not subject to expansion or contraction due to moisture changes, some metals can be adversely affected by changes in moisture resulting in corrosion. Most metals will exhibit some change in appearance upon exposure to moisture changes.)		80-120
	Plain Carbon Steel	12			210
	Stainless Steel				
	Austenitic	16			200
	Ferritic	10			200
	Aluminum and Alloys	24			70
	Copper	17			95-130
	Bronze	20			100
	Aluminum Bronze	18			120
	Brass	21			100
	Zinc				
	Parallel to Rolling	33			140
	Perpendicular to Rolling	23			220
	Lead	30			14

Straube & Burnett

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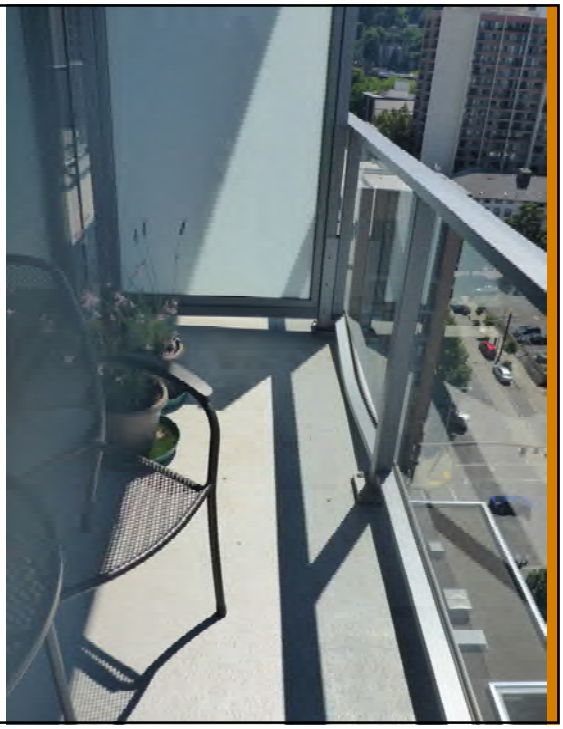
Hot Weather Guard Buckling

- Portland temperatures in June 2021 were hottest on record
- Received a call from condo board that railings were buckling
- Rushed to the scene (in shorts)



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Hot Weather Guard Buckling

- June PDX temps were hottest on record
- Call from condo that railings were buckling
- Rushed to the scene (in shorts)

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Hot Weather Guard Buckling

- June PDX temps were hottest on record
- Call from condo that railings were buckling
- Rushed to the scene (in shorts)
- 2 3/8" vertical displacement
- Inelastic buckling

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Hot Weather Guard Buckling

- Some bottom rails only experienced elastic deflection and did not buckle
- Other bottom rails were not affected

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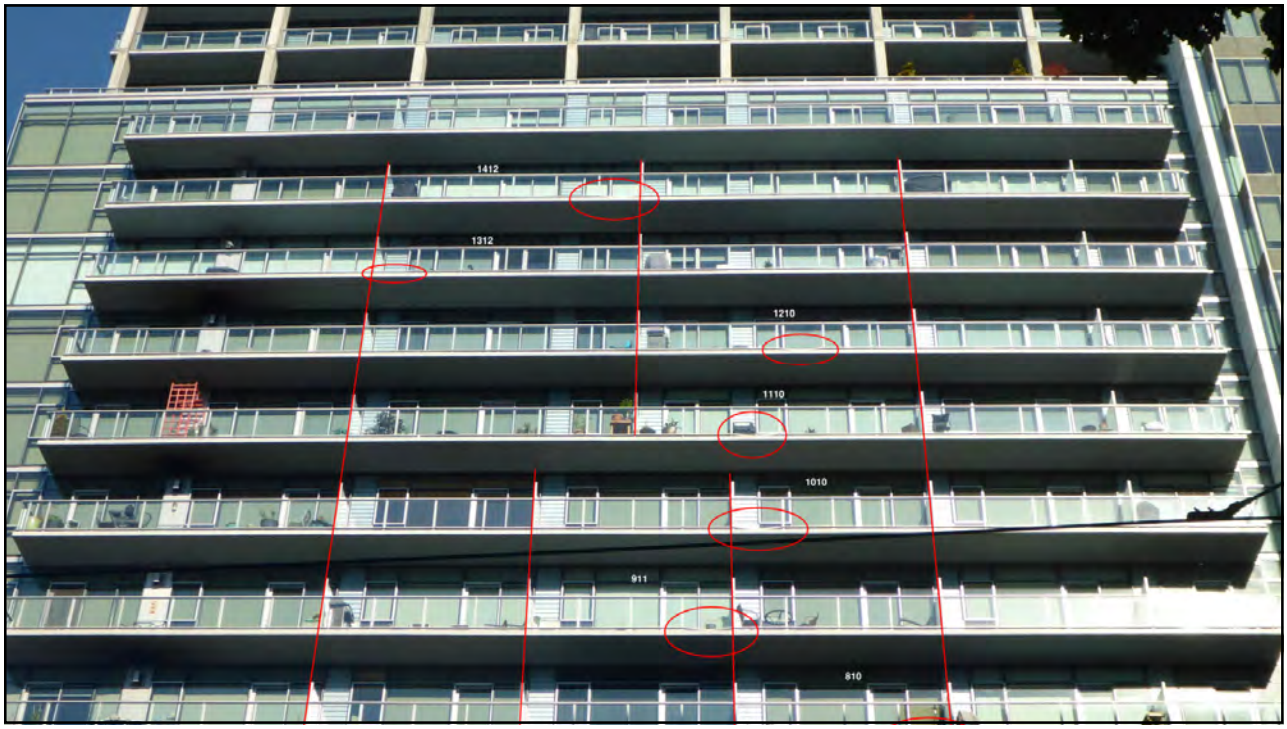

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Hot Weather Guard Buckling

- Continuous Aluminum top rail on west elevation
- Top rails did not buckle
- Generally random locations of inelastic buckling of bottom rails, but mostly within center 1/3rd of elevation
- Typically, one inelastic buckling location per floor
- Several bottom rails deflected elastically (returned after cooling)

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Portland Design Climate

- ASHRAE Fundamentals – 2017 (IP)
- PDX International Airport

Extreme Annual WS				Extreme Annual Temperature				n-Year Return Period Values of Extreme Temperature							
				Mean		Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years	
1%	2.5%	5%		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
23.7	19.7	17.4	DB	20.8	99.0	5.2	3.3	17.1	101.4	14.0	103.3	11.0	105.1	7.2	107.5
			WB	19.1	72.8	5.2	1.8	15.3	74.1	12.3	75.2	9.3	76.2	5.5	77.6

- High Temp on June 28, 2021 – 116˚F at 3:53pm
- 109˚F at time of review – 2:51pm
- High Temp > 8˚F above 50-year return period extreme

WMO#	World Meteorological Organization number	Lat	Latitude, °	Long	Longitude, °		
Elev	Elevation, m	StdP	Standard pressure at station elevation, kPa				
DB	Dry bulb temperature, °C	DP	Dew point temperature, °C	WB	Wet bulb temperature, °C		
WS	Wind speed, m/s	Enth	Enthalpy, kJ/kg	HR	Humidity ratio, grams of moisture per kilogram of dry air		
MCDB	Mean coincident dry bulb temperature, °C	MCWB	Mean coincident wet bulb temperature, °C	MCWS	Mean coincident wind speed, m/s		
PCWD	Prevailing coincident wind direction, °, 0 = North, 90 = East						

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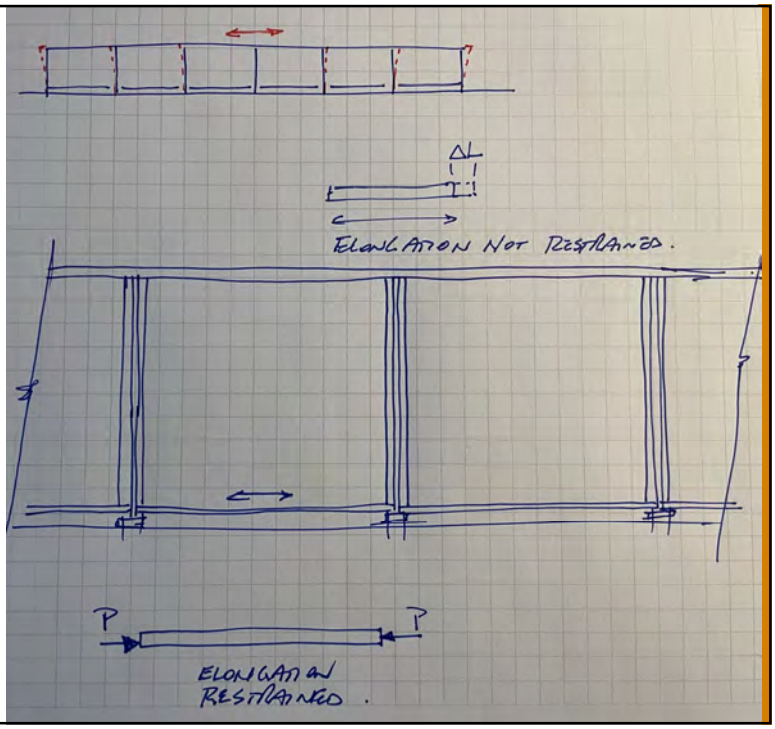
Why Just Bottom?

- Top rail not restrained
- Bottom rail tightly restrained
- $\Delta L = \alpha \cdot L \cdot \Delta T$
- $\Delta L = \frac{(P \cdot L)}{(A \cdot E)}$
  - Where ΔL = material length change, L is initial length, A is cross-sectional area, E is modulus of elasticity



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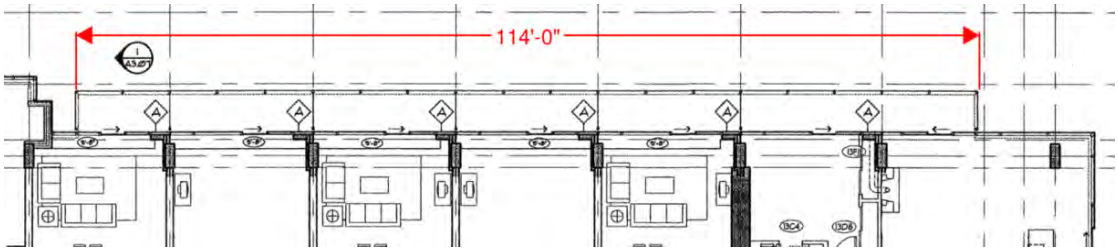
Top Rail Movement



- $\Delta L = \alpha \cdot L \cdot \Delta T \approx 1.8$" total
  - L = 114ft = 1368in
  - $\alpha = 13 \times 10^{-6}$ in/in˚F
  - Assumed install temp approx. ≈ 65˚F
  - Sol-Air Temp approx. ≈ 50˚F
  - ΔT = (116˚F – 65˚F + 50˚F) ≈ 101˚F

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Bottom Rail

- Constrained by posts bolted directly to concrete
- Concrete $\alpha = 7.8 \times 10^{-6}$ in/in°F
- Aluminum $\alpha = 13 \times 10^{-6}$ in/in°F (almost double α concrete)
- $\Delta L = \alpha \cdot L \cdot \Delta T \approx 1/16$ in total
  - L ≈ 52in
  - $\alpha = 13 \times 10^{-6}$ in/in˚F
  - Assumed install temp approx. ≈ 65˚F
  - Sol-Air Temp approx. ≈ 50F
  - $\Delta T = (116\,^{\circ}F - 65\,^{\circ}F + 50\,^{\circ}F) \approx 101\,^{\circ}F$
- Need to allow for movement!

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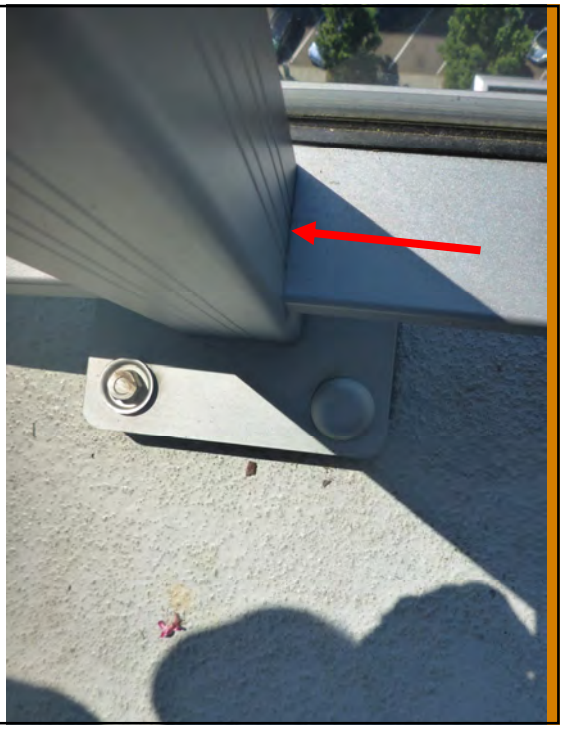

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Summary

- Design for long-term durability
- Consider constructability (avoid impossible welds, etc.)
- Protect weld plates, embeds, and materials susceptible to corrosion
- Protect moisture susceptible materials during construction
- Choose materials and assemblies appropriate for the climate, exposure, and application
- Detail to deflect, drain, and dry moisture away from guards, connections and adjacent surfaces
- Avoid grout pockets!
- Design in tolerance for the extremes
- Field review is always important

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Discussion + Questions

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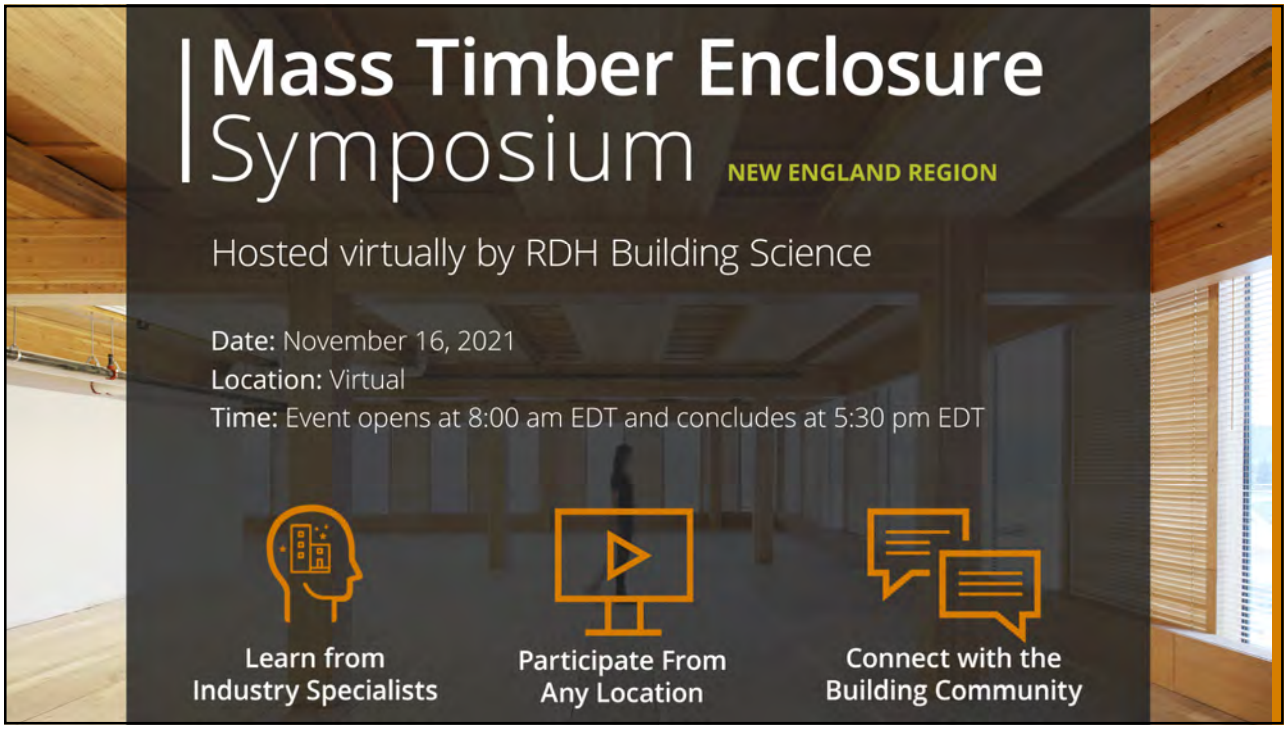

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