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Night School

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AISC
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Session Description

Session 5: Façade Fundamentals **July 16, 2018**

Attaching modern facades to buildings requires an understanding of how facade systems perform—from moisture and thermal performance to structural performance. Developing successful facade attachments requires consensus among a number of different parties about the objectives for the facade system. The project team needs to establish who is responsible for various portions of the design and also establish the criteria against which the system's performance will be compared. In this session, we will explore these issues in depth to set projects up for success.





Learning Objectives

- Identify issues to consider when creating design criteria for the loading and serviceability of façade systems.
- Describe the roles and responsibilities of project team members for the design and construction of façade attachments.
- Define thermal bridges and thermal breaks, and describe their importance to a building system.
- List the various accumulated tolerances that can affect the installation and performance of façade systems.



There's always a solution in steel.

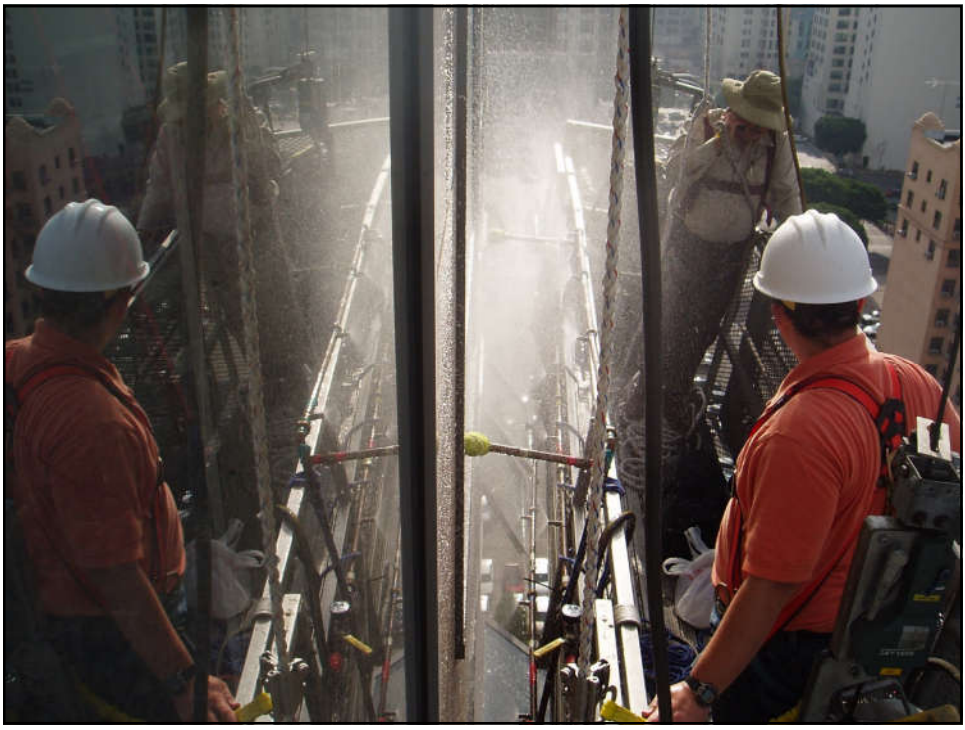
AISC Night School Behind the Façade: Guidance for Supporting Facades on Steel-Framed Buildings

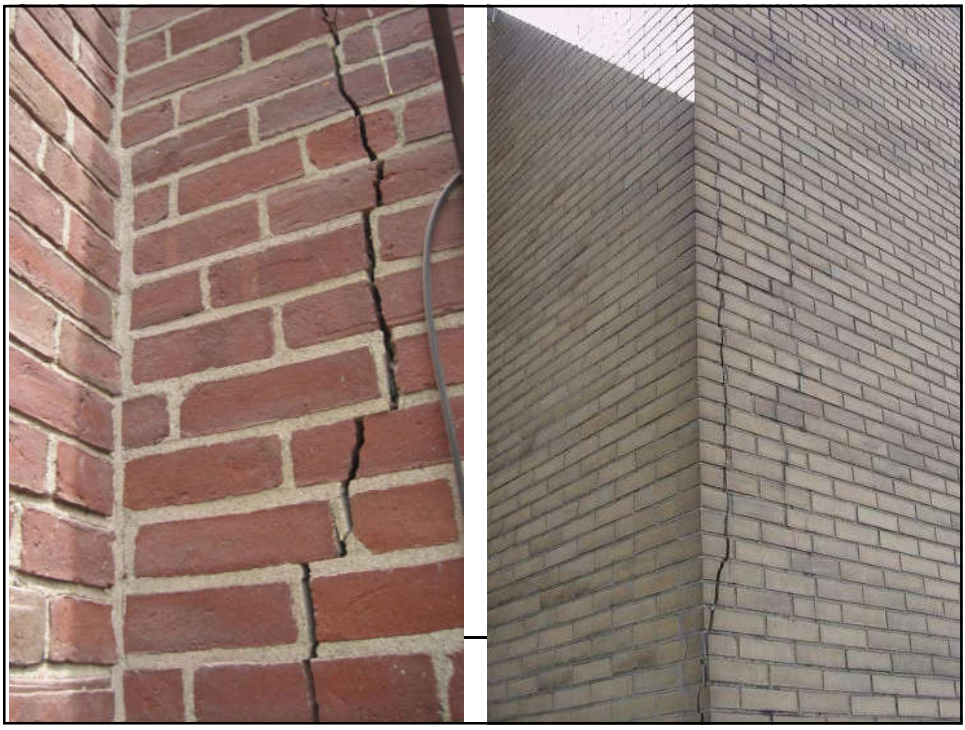


Alec Zimmer, P.E.
Senior Project Manager
Simpson Gumpertz & Heger Inc.
Waltham, MA











Attachments: What's the Problem?

- Design Coordination
- RFIs
- Delays in the shop drawing process
- Delays in erection
- Out-of-tolerance erection
- Failures
 - Envelope Performance
 - Structural



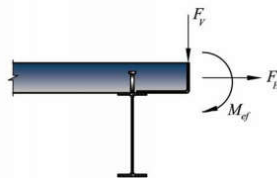
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AISC Design Guide 22



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Steel Design Guide

*Façade Attachments
to Steel-Framed Buildings*



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Design Guide Objective



- To assist the practicing structural engineer in achieving slab edge and spandrel beam details for steel frames that are:
 - Structurally sound
 - Durable
 - Economical
 - Accommodating of facade requirements



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Design Guide Scope



- Focus on attachment strategies and their effect on the design, fabrication, and erection of steel frames.
- Guidance for the structural engineer of record responsible for the design of the steel frame.
- Attachment concepts and performance characteristics – not “preferred” details.
- Not design of the facade systems, just attachments to the steel frame.



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Syllabus for Night School Sessions

- Session 1
 - Fundamentals of Facades
 - Design Criteria
- Session 2
 - Design and Execution Responsibilities
- Session 3
 - Thermal Bridging
 - Planning for Clearances
- Session 4
 - Accommodating Tolerances



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Syllabus for Night School Sessions

- Session 1
- **Session 2**
 - Traditional Masonry Cavity Walls
 - Panelized Façade Systems
 - Aluminum-Glass Curtain Walls
 - Sizing Joints for Vertical Movement
- Session 3
- Session 4



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Syllabus for Night School Sessions

- Session 1
- Session 2
- **Session 3**
 - Slab Edges
 - Spandrel Beams
 - Cladding Supports Away from Floors
- Session 4



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Syllabus for Night School Sessions

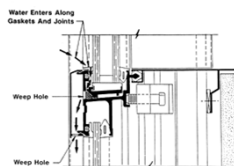
- Session 1
- Session 2
- Session 3
- Session 4
 - Accommodating Lateral Drifts
 - In-Plane Movements
 - Out-of-Plane Movements
 - Building Corners



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Fundamentals of Façade Performance

Fundamentals of Façade Performance



The building envelope encloses the building, controlling the transmission of air, water, heat, sound, and light both into and out of the building.




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Fundamentals of Façade Performance

The Façade and the Building Envelope


The diagram illustrates a cross-section of a building envelope. At the top, the 'roofing' is shown with blue arrows pointing down into the interior and red wavy arrows pointing up out of the exterior. The 'walls' are shown with blue arrows pointing inward and red wavy arrows pointing outward. 'windows' and 'doors' are also labeled with blue arrows pointing inward. 'all interfaces' is labeled with red wavy arrows pointing outward. At the bottom, the 'foundations' are shown with blue arrows pointing down into the ground and red wavy arrows pointing up out of the ground.

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Fundamentals of Façade Performance

Time Line


The timeline chart shows the evolution of building envelope types from 2000 B.C. to 2000 A.D. The x-axis is marked with 2000, 1000 B.C., 0, 1000 A.D., and 2000. Three horizontal bars represent different types of building envelopes: 'Load Bearing Masonry' (light blue bar from 2000 B.C. to 2000 A.D.), 'Transitional Masonry' (grey bar from approximately 1000 B.C. to 1000 A.D.), and 'Contemporary Curtain Walls' (grey bar from approximately 1000 A.D. to 2000 A.D.).

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Fundamentals of Façade Performance


1250 B.C.



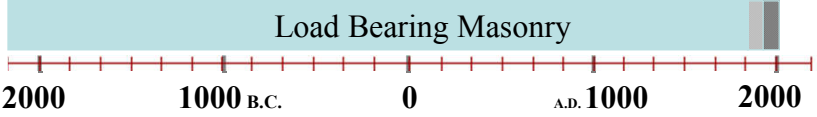
430 B.C.




A.D. 530




Load Bearing Masonry




A.D.
1220 to
1472



1713

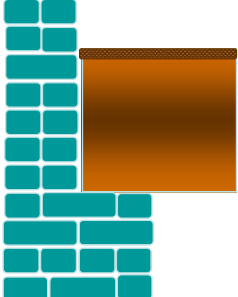


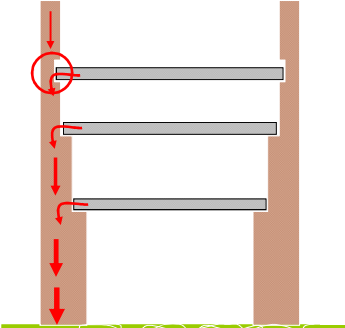

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Fundamentals of Façade Performance

Load Bearing Masonry

- Walls are thick
- Walls support all loads
- Floor “rides” with walls





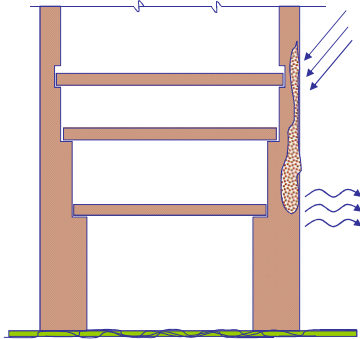

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Fundamentals of Façade Performance

Load Bearing Masonry

- Walls manage moisture as a reservoir

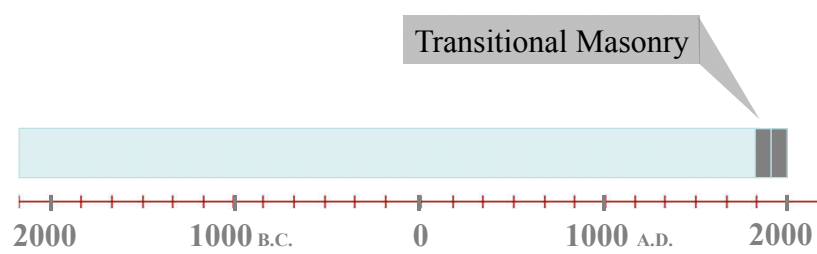


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Fundamentals of Façade Performance


Time Line




2000 1000 B.C. 0 1000 A.D. 2000

Transitional Masonry


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Fundamentals of Façade Performance



Transitional Masonry Buildings



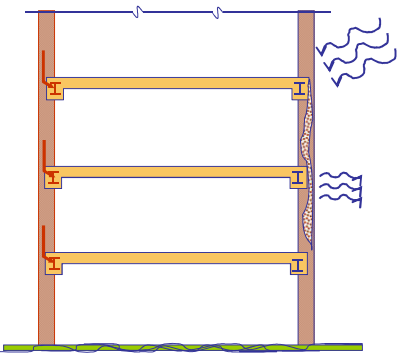



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Fundamentals of Façade Performance

Transitional Masonry Buildings

- Masonry walls still thick
- Floor & wall loads supported by steel or iron frame
- Wall still functions as a reservoir
- Masonry is tight against frame






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Fundamentals of Façade Performance

Transitional Masonry Buildings


(Ref. Good Practice in Construction, by Phillip G Knobloch, The Pencil Point Press, 1923.)


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Fundamentals of Façade Performance

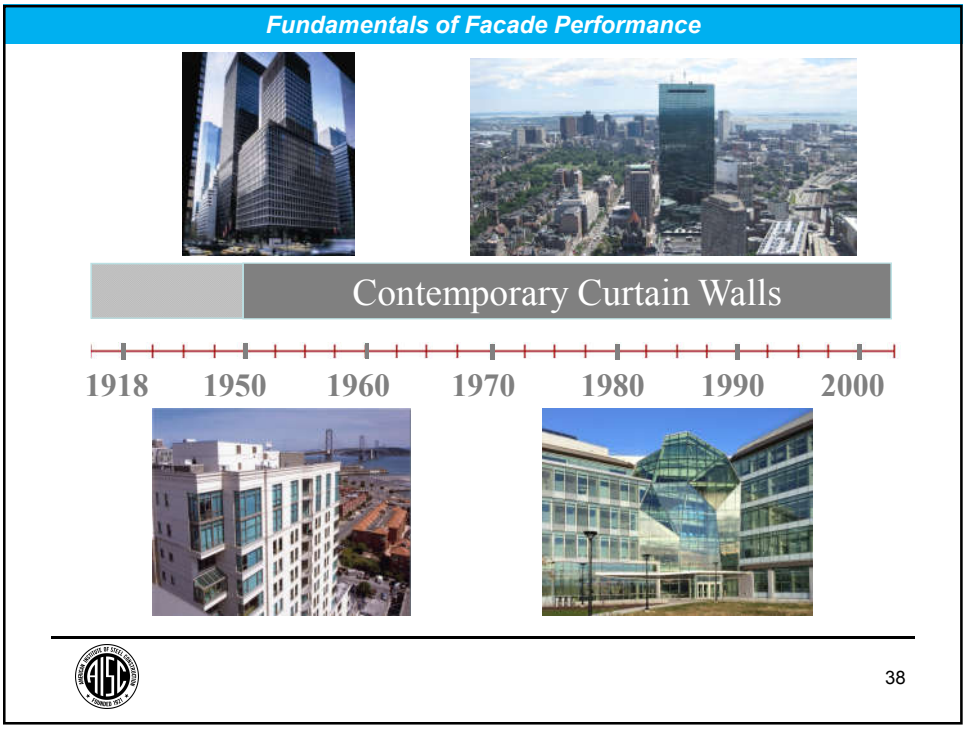
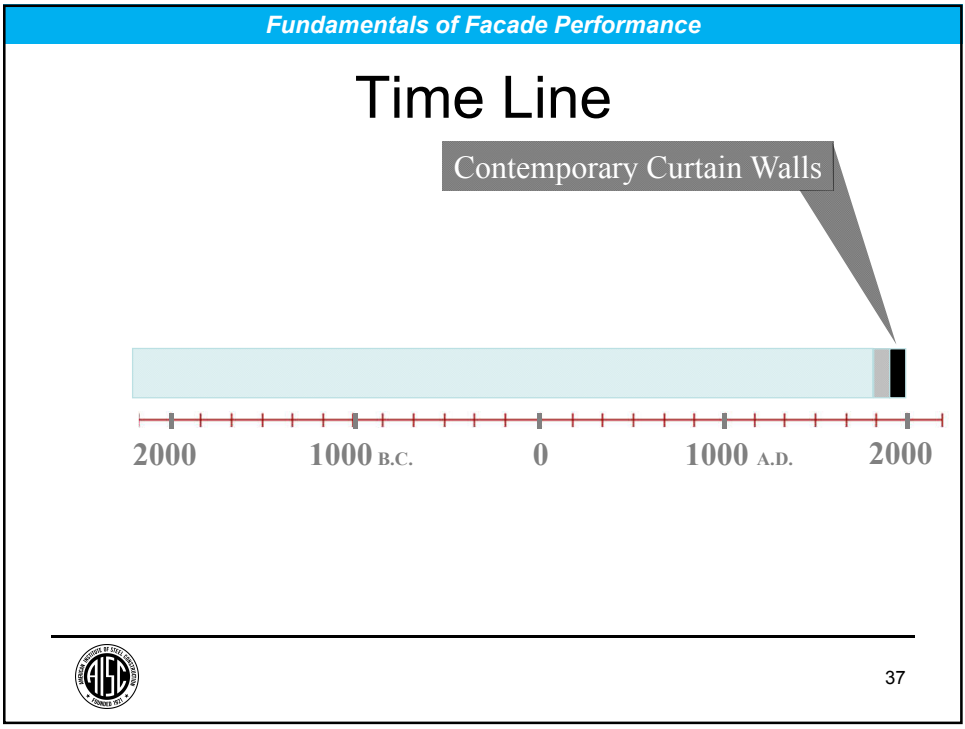
Transitional Masonry Buildings

(Ref. Good Practice in Construction, by Phillip G Knobloch, The Pencil Point Press, 1923.)


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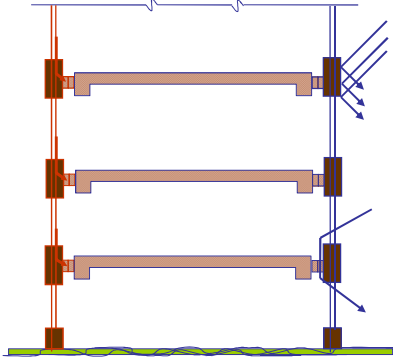





Fundamentals of Façade Performance

Contemporary Curtain Walls

- Floor loads carried by frame
- “Skin” transfers wind loads to the frame
- “Skin” typically employs a drainage plane and back-up waterproofing



The diagram illustrates a cross-section of a curtain wall system. It shows a vertical steel frame with horizontal mullions. The skin is attached to the mullions. A drainage plane is shown behind the skin, with arrows indicating water flow outwards. A back-up waterproofing layer is also shown behind the drainage plane. The system is supported by a concrete slab at the bottom.




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Exterior Wall System

Performance Requirements of the Exterior Wall System

- Accommodates loads and deformations
- Minimizes water and air flow (vapor movement)
- Controls heat gain and/or loss



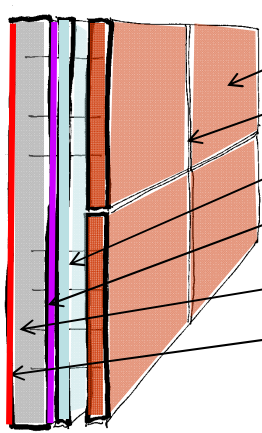
The photograph shows a modern building with a glass and metal exterior wall system. The building has a curved facade and large glass windows. The exterior wall system is made of metal panels and glass. The building is surrounded by a parking lot with several cars.



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Exterior Wall System

Functional Components of the Exterior Wall System



The diagram shows a cross-section of an exterior wall system with the following components labeled from left to right:


- Cladding
- Joints
- Insulation
- Water barriers and air barriers
- Back-up structure
- Interior finishes

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Exterior Wall System

Insulation and Thermal Performance

- Building codes demanding better performance
- Structural attachments can create thermal bridges
- Thermal and moisture modeling can assess consequences of bridges

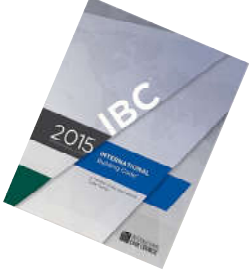



The photograph shows a construction site where a wall is being insulated. Blue insulation panels are visible, with a worker on a yellow scaffold. The panels have labels like 'CCW-705' and 'SIL-M20'.


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Exterior Wall System

Façade Design Criteria




- Structural Integrity
- Provisions for Movement
- Envelope Performance


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Attachment Criteria

Criteria for Façade Attachment

- Structural Integrity
- Accommodating Movement
- Durability
- Accounting for Tolerances and Clearances
- Constructability
- Economy




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Attachment Criteria

Structural Integrity

Redundancy Ductility


Strength

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Attachment Criteria

Conflicting Ideas

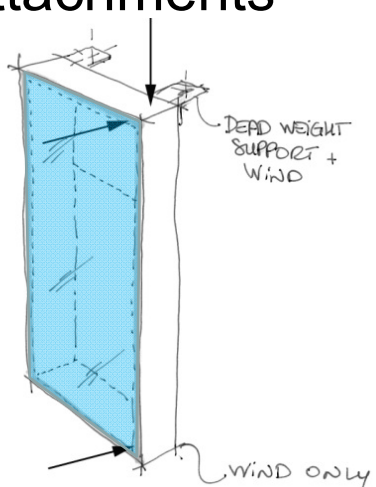
TWO SUPPORT POINTS REDUNDANCY


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Attachment Criteria

Loads on Attachments

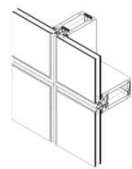
The role of the facade attachment is to provide a reliable **LOAD PATH** from the building enclosure to the building frame for each of the load types acting on the facade.




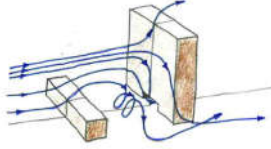
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Attachment Criteria

Loads on Attachments


- 

Dead Loads
Weight of the wall system
- 

Seismic Loads
Perpendicular OR parallel to the wall
- 

Wind Loads
Perpendicular OR parallel to the wall
- 

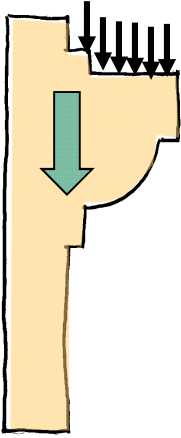
Thermal Loads
Facade expansion/contraction


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Attachment Criteria

Gravity Loads

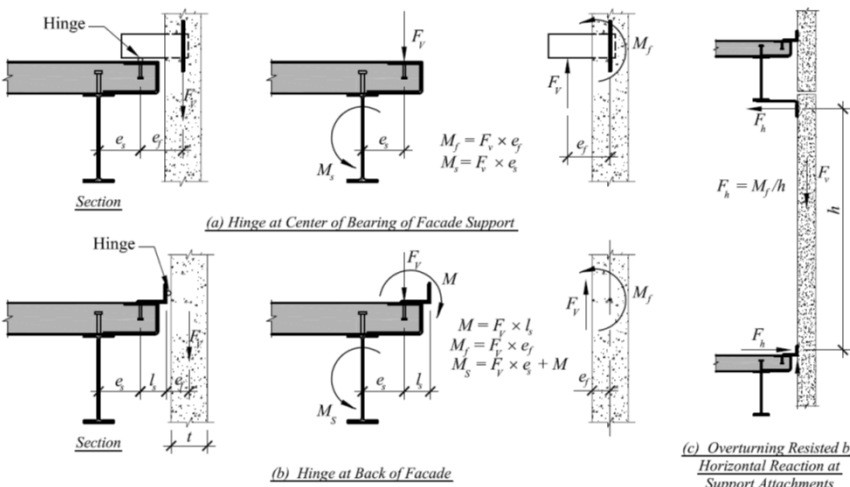
- Façade dead load
 - Need to understand materials and system
- Façade live loads
 - Horizontal projections
- SER usually needs to estimate before wall is designed
- Window washing activities




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Attachment Criteria

Gravity Load Eccentricities



(a) Hinge at Center of Bearing of Façade Support

Section: e_f , e_s

Equations: $M_f = F_v \times e_f$, $M_s = F_v \times e_s$

(b) Hinge at Back of Façade


Section: e_f , l , e_s , t

Equations: $M = F_v \times l$, $M_f = F_v \times e_f$, $M_s = F_v \times e_s + M$

(c) Overturning Resisted by Horizontal Reaction at Support Attachments

Section: F_h , F_v , h

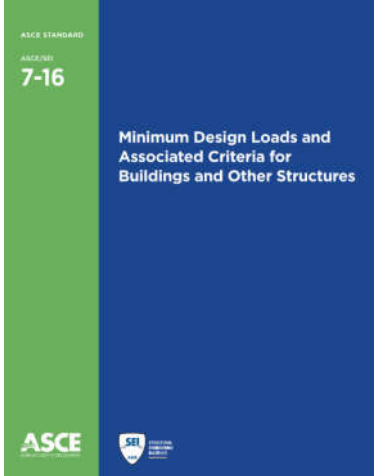
Equation: $F_h = M_f/h$


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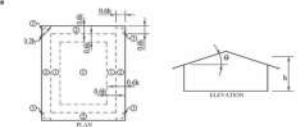


Attachment Criteria

Wind Loads

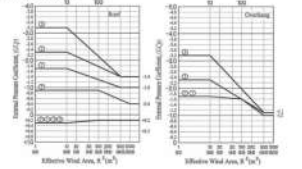


Diagrams




Notation
 H = Horizontal dimension of building measured normal to wind direction, in ft (m);
 B = Down height, shall be used for $H < 10'$;
 θ = Angle of slope of roof from horizontal, in degrees.

External Pressure Coefficients



Notes
 1. Vertical wind direction θ (Cpe) is the wind velocity.
 2. Horizontal wind direction effective wind area, in ft² (m²).
 3. The wind stress shall specify pressure acting inward and away from the surface, respectively.
 4. Each component shall be designed for the maximum positive and negative pressures.
 5. If a parapet equal to or higher than 1.0 ft (0.3 m) is provided around the perimeter of the roof with $H < 10'$, the negative values of C_{pe} (Cpe) shall be equal to those for the same roof profile shown in Fig. 10.3.1.
 6. Values of roof or wall overhang include pressure coefficients from both upper and lower surfaces.
 7. Windward walls, the base horizontal dimension of the building shall not include any overhang dimensions, but the edge distance, it shall be measured from the outside edge of the overhang.

FIGURE 10.3-2B Components and Cladding (a) - (d) External Pressure Coefficients, (Cpe), for Windward and Paralel Exposed Buildings—Case No. 1, 2, 3, 4, 5, 6, 7.


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Attachment Criteria

Wind Tunnel Testing

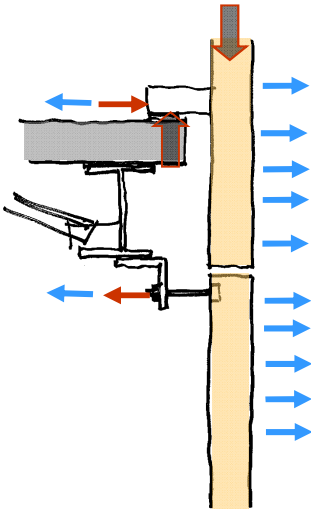




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Attachment Criteria

Wind Loads

- Negative pressures combined with gravity eccentricities often control.
- For the base building components, the SER can often be simple and conservative when planning for attachments without undue cost.




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Attachment Criteria

Seismic Requirements

- Seismic Forces
- Relative Displacements
- Ductility



Christchurch, New Zealand, February 2011
Photo: Ronald Mayes / SGH


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Attachment Criteria

Seismic Design Category

- ASCE 7-16: “A classification assigned to a structure based on its *Risk Category* and the severity of the design earthquake ground motion at the site...”


A	Least restrictive design category, not common
B	Common in low seismic areas
C	Common for higher risk buildings in eastern US and lower risk building in CA
D	Common design category for California and other high seismic areas; highly restrictive design
E	Special category for mapped spectral response acceleration parameters (S_1) greater than 0.75
F	Special category for Risk Category IV structures in Seismic Design Category E


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Attachment Criteria

Seismic Design Applicability

Seismic Design Category	Seismic Design Applicability per ASCE 7-16, Section 13.1.4
A and B	All architectural components with $I_p = 1.0$ are exempt except: <ul style="list-style-type: none"> Parapets Storage cabinets
C, D, E, F	Architectural components are not exempt
ALL	Temporary or moveable equipment


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Attachment Criteria

Seismic Loads

$$F_p = \frac{0.4a_p S_{DS} W_p}{\left(\frac{R_p}{I_p}\right)} \left(1 + 2\frac{z}{h}\right)$$

Table 13.5-1 Coefficients for Architectural Components

Architectural Component	a_p^a	R_p	Ω_0^b
Exterior nonstructural wall elements and connections ^b			
Wall element	1	2½	NA
Body of wall panel connections	1	2½	NA
Fasteners of the connecting system	¼	1	1
Veneer			
Limited deformability elements and attachments	1	2½	2
Low-deformability elements and attachments	1	1½	2



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Attachment Criteria

Seismic Loads

13.3.2 Seismic Relative Displacements. The effects of seismic relative displacements shall be considered in combination with displacements caused by other loads as appropriate. Seismic relative displacements, D_{pI} , shall be determined in accordance with Eq. (13.3-6):

$$D_{pI} = D_p I_e \quad (13.3-6)$$


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Attachment Criteria

Limit States for Design

- Attachments must safely accommodate forces.
- Joints must prevent hazardous damage; falling hazards.



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Attachment Criteria

Limit States for Design

- Serviceability checks may allow lower forces and drifts; for example joint sealant movements.
- ASCE 7-16 Commentary suggests:

$$D + 0.5L + W_a$$



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Attachment Criteria

Wind Deflections (IBC 2015)

CONSTRUCTION	L	S or W ^f	D + L ^g
Roof members: ¹			
Supporting plaster or stucco ceiling	l/360	l/360	l/240
Supporting nonplaster ceiling	l/240	l/240	l/180
Not supporting ceiling	l/180	l/180	l/120
Floor members	l/360	---	l/240
Exterior walls:			
With plaster or stucco finishes	---	l/360	---
With other brittle finishes	---	l/240	---
With flexible finishes	---	l/120	---
Interior partitions: ²			
With plaster or stucco finishes	l/360	---	---
With other brittle finishes	l/240	---	---
With flexible finishes	l/120	---	---
Farm buildings	---	---	l/180
Greenhouses	---	---	l/120

Footnote f:
The wind load is permitted to be taken as 0.42 times the “component and cladding” loads for the purpose of determining deflection limits herein. Where members support glass in accordance with Section 2403 using the deflection limit therein, the wind load shall be no less than 0.6 times the “component and cladding” loads for the purpose of determining deflection.

For SI: 1 foot = 304.8 mm.

a. For structural roofing and siding made of formed metal sheets, the total load deflection shall not exceed l/90. For secondary roof structural members supporting formed metal roofing, the live load deflection shall not exceed l/150. For secondary wall members supporting formed metal siding, the design wind load deflection shall not exceed l/90. For roofs, this exception only applies when the metal sheets have no roof covering.

b. Flexible, folding and portable partitions are not governed by the provisions of this section. The deflection criterion for interior partitions is based on the horizontal load defined in Section 1607.14.

c. See Section 2403 for glass supports.

d. The deflection limit for the D+L load combination only applies to the deflection due to the creep component of long-term dead load deflection plus the short-term live load deflection. For wood structural members that are dry at time of installation and used under dry conditions in accordance with the ANSI/AWC NDS, the creep component of the long-term deflection shall be permitted to be estimated as the immediate dead load deflection resulting from 0.5D. For wood structural members at all other moisture conditions, the creep component of the long-term deflection is permitted to be estimated as the immediate dead load deflection resulting from D. The value of 0.5D shall not be used in combination with ANSI/AWC NDS provisions for long-term loading.

e. The above deflections do not ensure against ponding. Roofs that do not have sufficient slope or camber to ensure adequate drainage shall be investigated for ponding. See Section 1611 for rain and ponding requirements and Section 1503.4 for roof drainage requirements.

f. The wind load is permitted to be taken as 0.42 times the “component and cladding” loads for the purpose of determining deflection limits herein. Where members support glass in accordance with Section 2403 using the deflection limit therein, the wind load shall be no less than 0.6 times the “component and cladding” loads for the purpose of determining deflection.

g. For steel structural members, the dead load shall be taken as zero.

h. For aluminum structural members or aluminum panels used in skylights and sloped glazing framing, roofs or walls of sunroom additions or patio covers not supporting edge of glass or aluminum sandwich panels, the total load deflection shall not exceed l/60. For continuous aluminum structural members supporting edge of glass, the total load deflection shall not exceed l/175 for each glass lite or l/60 for the entire length of the member, whichever is more stringent. For aluminum sandwich panels used in roofs or walls of sunroom additions or patio covers, the total load deflection shall not exceed l/120.

i. For cantilever members, l shall be taken as twice the length of the cantilever.

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Attachment Criteria

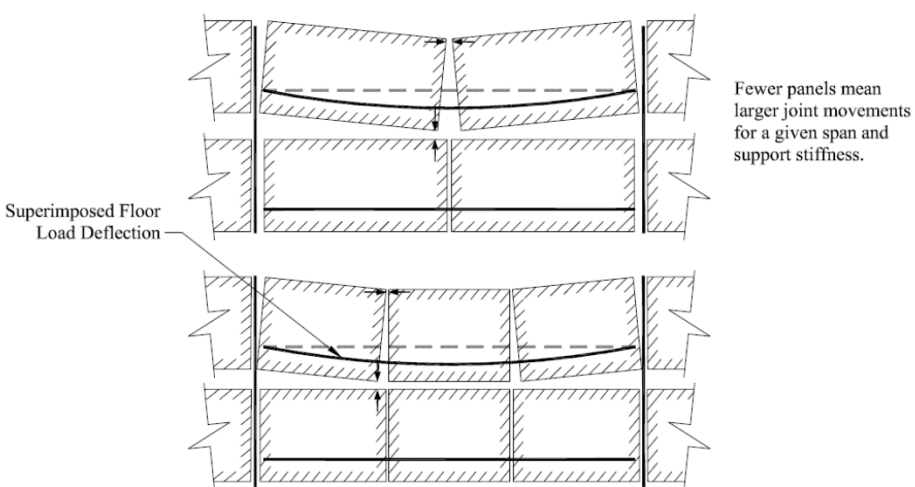
Accommodating Relative Movement

- Spandrel deflections, rotations, column shortening, bracket deflections.

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Attachment Criteria

Accommodating Relative Movement



Fewer panels mean larger joint movements for a given span and support stiffness.

Superimposed Floor Load Deflection





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Attachment Criteria

Accommodating Relative Movement

- Rules of thumb and code provisions for flexural stiffness to limit facade material cracking.
 - $L/360$?
 - $L/600$?
 - $L/720$?
 - 0.31 in.?
 - 3/4 in.?




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Attachment Criteria

Accommodating Relative Movement

- Joint sealant compression or extension may control the design of spandrel beams
- **Example:** Limiting compression of a sealant joint to 1/4 in. for a 30 ft long beam is $L/1440$


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Attachment Criteria

Accommodating Relative Movement

Inter-Story Drift from Lateral Loads

- Common drift limits:
 - Wind
 - $H/400$ (0.0025H) to $H/500$ (0.002H)
 - Inelastic Seismic Drift
 - $0.025 H$ (10 times wind!)
- For a 12 ft story height:
 - Wind – 0.36 inches
 - Seismic – 3.6 inches

ASCE 7-16 13.5.3.1 Requires that panel connections and joints accommodate at least 1/2 in. interstory movement.


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Attachment Criteria

Accommodating Relative Movement

(a) Rotation at Attachments (b) Flexure of Façade Element (c) Increased Rotations at Façade Sub-Element Such as a Window

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Attachment Criteria

Forces from Restraint

- Best to avoid restraint altogether
- Predicting restraint forces inexact
 - Cracking
 - Creep
 - Attachment stiffness
- Watch out for inadvertent restraint

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Attachment Criteria

Durability of the Attachment

- Attachments are usually hard to inspect.
- Consider what happens if the wall leaks.
- Consider how likely the wall is to leak over time.
- Special attention to thin steel parts or steel fasteners.



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Attachment Criteria

Galvanized or Stainless?

- HDG Advantages:
 - Less expensive
 - More readily available
 - Field welding uses more common procedures
- HDG Disadvantages:
 - Zinc coating defects may allow rust product to stain facade
 - Zinc coating is sacrificial and has a defined life
 - Field-welds require touch-up after welding




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Attachment Criteria

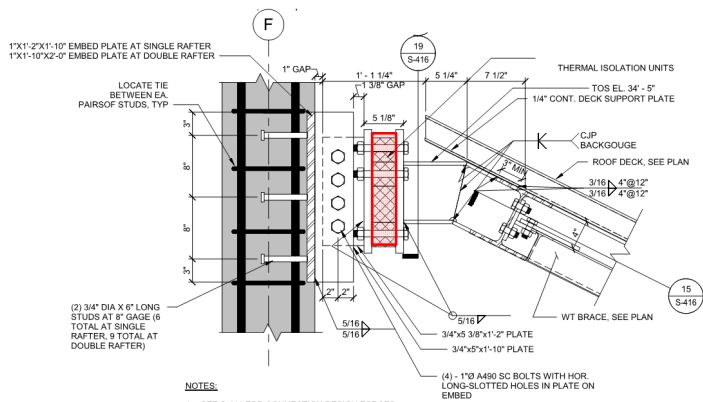
Problems Associated with Support and Anchorage

- Anchors contributing to poor drainage
- Anchors not stiff enough to prevent differential movement that tears barriers
- Damage to barriers during erection and installation
- Constructability
- Coordination of trades



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Attachment Criteria

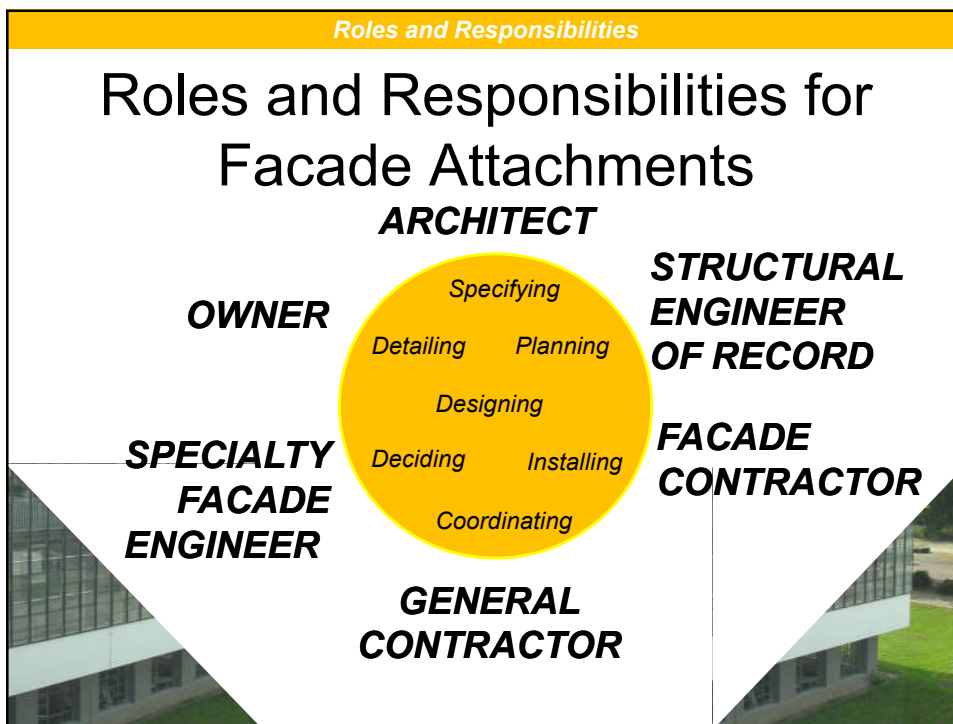
Constructability and Economy



13 SECTION: RAFTER TO CONC COLUMN CONNECTION
 1 1/2" = 1'-0"


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Roles and Responsibilities

Owner

- Contributes to facade requirements
 - Performance, aesthetics, budget
- Controls contractual relationships
- Maintenance
- Periodic inspections per local regulations



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Roles and Responsibilities

Architect (or PDP)

- Selects the system that can meet the project's requirements
- Fundamental building design decisions that effect facade attachments (materials, jointing patterns, thermal performance, etc.)
- Selects and defines attachment strategy in consultation with others
 - Structural engineer of record, facade engineer(s) and facade consultants, manufacturers, facade specialty contractors.



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Roles and Responsibilities

Structural Engineer of Record

- Must understand the facade system and the **strategy** for attachment to design the primary structure
- Provides anticipated structural movements
- Designs frame and slab edge consistent with attachment strategy



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Roles and Responsibilities

Structural Engineer of Record

- Delineates the structural steel elements from the attachment items by the SSE
- Indicates the assumptions/limitations of the facade attachments
- Indicates the tolerances of the steel frame
- Provides sufficient adjustability in structural frame details



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Roles and Responsibilities

Contractors

- General Contractor/Construction Manager
 - Coordinates trades and submittals
 - Reviews for conformance with project specifications
- Façade Contractor
 - Coordinates with the manufacturer of facade elements
 - Usually hires Specialty Structural Engineer
 - Responsible for fabrication and erection



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Roles and Responsibilities

Specialty Structural Engineer

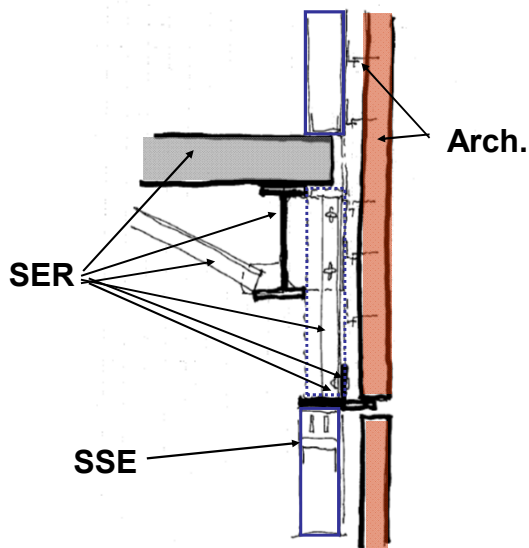
- Design professional responsible for the design of the facade and its attachments
 - Usually under contract to the contractor
- There may be one SSE for the facade elements itself and another SSE for the attachments.
- May be responsible for inspection during construction as delegated by the PDP or SER



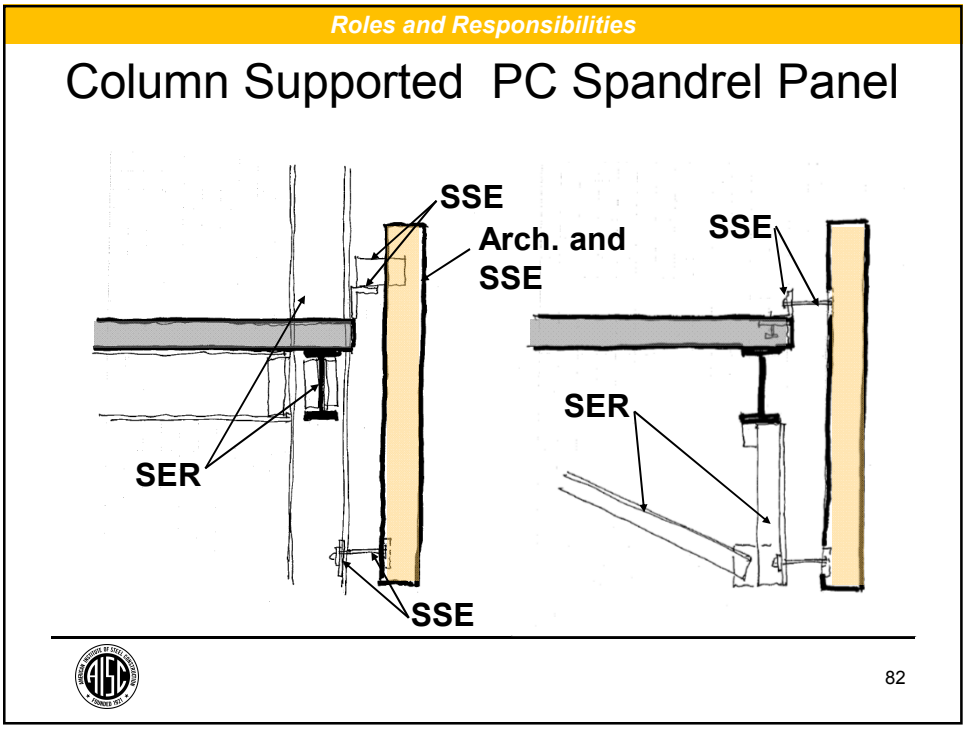
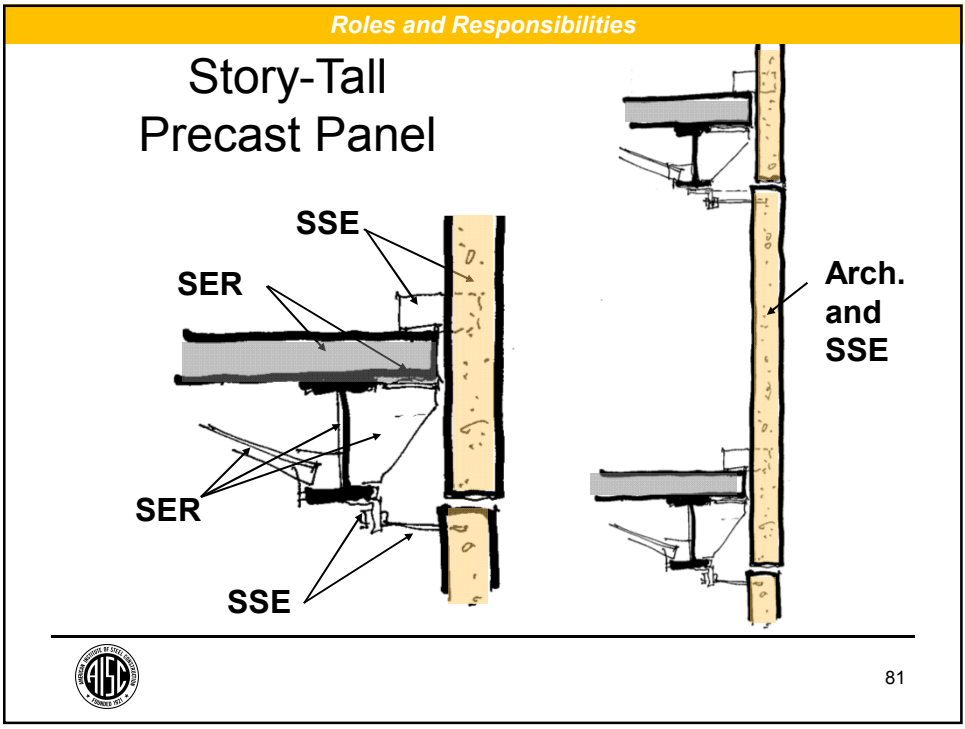
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Roles and Responsibilities

Masonry Veneer



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Roles and Responsibilities

Aluminum/Glass Curtain Wall

The diagram illustrates the structural connections for an Aluminum/Glass Curtain Wall. It shows two levels: 'Roof' and 'Intermediate Floor'. At each level, a vertical steel member is connected to a horizontal member. The connections are labeled 'SER' (Structural Edge Restraint) and 'ARCH; SSE' (Architectural/Structural Steel End). The diagram shows how the wall is supported and restrained at these levels.

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Roles and Responsibilities

Case Study: Dormitory Project

The diagram shows a cross-section of a dormitory building facade. A red shaded area highlights a specific section of the facade. Labels indicate the types of restraints provided: 'Gravity, In-Plane Lateral, and Out-of-Plane Lateral Restraint' for the upper part and 'Out-of-Plane Lateral Restraint Only' for the lower part. The diagram also shows window units (WZ0) and structural details like 'PRIVATE INTERIOR CONNECTION' and 'FLOOR 2 30'-10"'. Dimensions and other structural markers are also present.

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Roles and Responsibilities

Summary

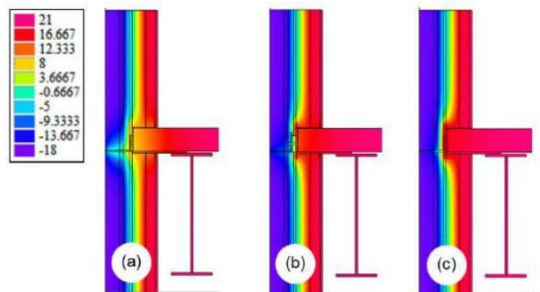
- Communicate!
- Façade attachments are difficult because every member of the design team has a significant role in the planning, designing and coordination.



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Thermal Bridges and Breaks

Thermal Bridges and Breaks



Peterman et al, "Thermal Break Strategies for Cladding Systems in Building Structures" (2017)

As the state of building design evolves to improve thermal efficiency, the need to accommodate thermal breaks in facade attachments continues to develop.



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Thermal Bridges and Breaks

Two Good Resources

**Thermal Bridging Solutions:
Minimizing Structural Steel's Impact
on Building Envelope Energy Transfer**

This document is the product of the joint Structural Engineering Institute (SEI)/American Institute of Steel Construction (AISC) Thermal Steel Bridging Task Committee, in conjunction with the SEI's Sustainability Committee's Thermal Bridging Working Group. More information on the work of the committee and on the topic in general can be found at www.seisustainability.org and www.aisc.org/sustainability respectively.

SEI / AISC Thermal Steel Bridging Task Committee Members

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Sabina Siroc	
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Northeastern University Department of Civil and Environmental Engineering

THERMAL BREAK STRATEGIES FOR CLADDING SYSTEMS IN BUILDING STRUCTURES

Report to the Charles Pankow Foundation

CHARLES PANKOW
FOUNDATION
Building Innovation through Research

Kara D. Peterman, Justin Kordas, Julieta Miranda, Kyle Coleman, and Jerome F. Hajjar,
Department of Civil and Environmental Engineering, Northeastern University
James A. D'Aloisio, Klippert Hahn & Hyatt
Mark D. Webster, Jason Der Ananian, Simpson Gumpertz & Heger, Inc.

May 2017

https://www.aisc.org/globalassets/modern-steel/archives/2012/03/2012v03_thermal_bridging.pdf

<http://www1.coe.neu.edu/~jhajjar/home/Peterman,%20Webster,%20D%27Aloisio,%20Hajjar%20et%20al.%20-%20Thermal%20Break%20Strategies%20-%20CPEF%20Final%20Report%20-%20May%202017.pdf>

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Thermal Bridges and Breaks

Risks of Thermal Bridges

- Energy loss
- Occupant comfort
- Condensation
 - Corrosion
 - Mold growth

The diagram shows a cross-section of a window or door frame assembly. It includes a vertical frame member, a horizontal sill, and a vertical mullion. Various components are numbered from 1 to 13, indicating different parts of the assembly and potential thermal bridge locations. The diagram is a detailed technical drawing showing the interaction between different materials and components.

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Thermal Bridges and Breaks

Alignment of Thermal Break

TRIM POUR STOP FLUSH WITH TOP OF SLAB AT WINDOW OPENINGS

$\frac{3}{4}$ " ϕ 6" LONG HEADED STUDS @ 1'-6" OC TYP., @ 1'-0" OC LEVEL 4 EXCEPT LINES J AND 10

HORIZONTAL LONG-SLOTTED HOLE IN PLATE

#4x3'-6" @ 6" AT BRICK PIERS; @ 12" ELSEWHERE

3'-0"

DECK ORIENTATION VARIES

$\frac{3}{4}$ " ϕ A325 ERECTION BOLT

SPANDREL BEAM

GRID

SHEATHING

AIR BARRIER/WATER BARRIER

INSULATION CAVITY

L7x4 (GALV.) WITH LONG VERTICAL SLOTTED HOLE IN VERTICAL LEG. MASK AREAS TO BE WELDED. SEE NOTE 1. SEE TABLE FOR THICKNESS.

(2) $\frac{3}{4}$ " ϕ A325 ERECTION BOLTS MIN. PER RELIEVING ANGLE SEGMENT

BENT PLATE $\frac{3}{8}$ "x7 $\frac{3}{8}$ "x0'-8 $\frac{1}{2}$ "x CONT. POUR STOP. MITER AT CORNERS.

1'-4"

7 $\frac{3}{8}$ "

1/4"

4" ϕ 12"

4" ϕ 12"


1/4"

2" ϕ 16"

2" ϕ 16"

1/4"

1/4"


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Thermal Bridges and Breaks


Prefabricated Assemblies



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Thermal Bridges and Breaks

Built-Up Assemblies

- Thermal Isolation Pads
- Thermal Isolation Bushings
- Thermal Isolation Washers or Stainless Washers
- Stainless Steel Bolts

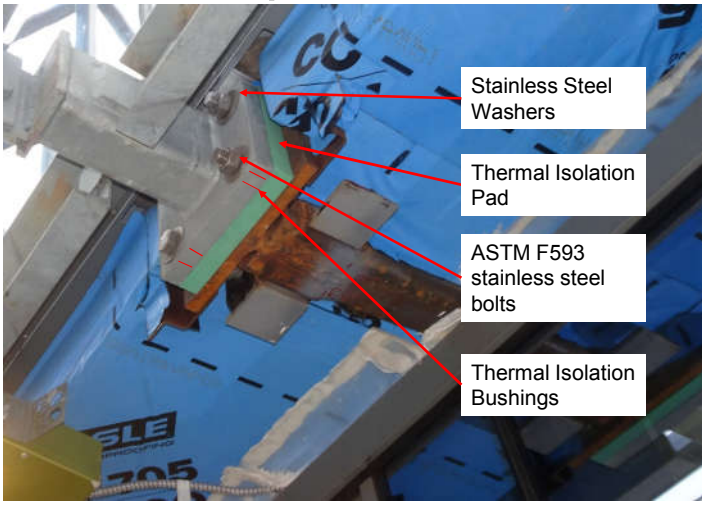





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Thermal Bridges and Breaks

Built-Up Assemblies



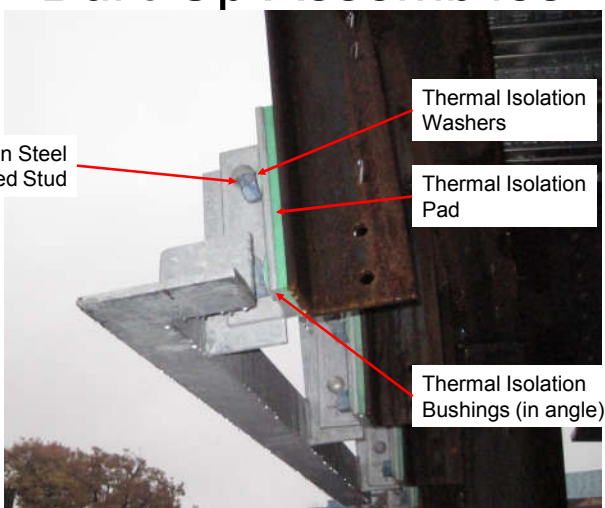
- Stainless Steel Washers
- Thermal Isolation Pad
- ASTM F593 stainless steel bolts
- Thermal Isolation Bushings



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Thermal Bridges and Breaks

Built-Up Assemblies




Carbon Steel Welded Stud

Thermal Isolation Washers

Thermal Isolation Pad

Thermal Isolation Bushings (in angle)



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Thermal Bridges and Breaks

Thermal Insulating Coatings



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Thermal Bridges and Breaks

Local Insulation Blankets

Local Insulation Blanket

Roofing Insulation


W12
W14 AT GENERATOR WELL

EMBED PLATE. SEE PLAN.
SEE BASE PLATE DETAILS FOR
COLUMN BASE DETAILS.

1/4" WIDE x CONT. CONCRETE RECESS
AROUND EDGE OF EMBED PLATE. FILL
WITH GROUT AFTER COMPLETION OF
FIELD WELD.

PENTHOUSE
84' - 5"


4" MIN.
8"
1' - 0"

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Thermal Bridges and Breaks

Additional Deflection and Rotation in the Connection

- Unlike a conventional steel-to-steel connection, a thermally-broken connection will include additional deflection and rotation due to:
 - Oversize in the bolt holes
 - Bending and compression in the thermal break material
 - Bolt flexural deformation
 - Bolt shear deformation

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Thermal Bridges and Breaks

Bending in Bolts / Studs

- Borrowing approach from AISC Design Guide 1, Second Edition, Example 4.11:

$$\phi F'_{nt} = \phi \left[1.3F_{nt} - \frac{F_{nt}}{\phi F_{nv}} f_{rv} \right] \leq \phi F_{nt} \quad \text{AISC 360-16 (J-3.3a)}$$

$$f_t = f_{ta} + f_{tb}$$

$$f_{ta} = \frac{2M_u}{d \times n \times A} + \frac{T_u}{n \times A}$$

$$f_{tb} = \frac{V_u \times l}{n \times Z}$$

$$Z = \frac{d^3}{6}$$

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Thermal Bridges and Breaks

Northeastern University Study Conclusions

- Using non-conductive shims is a thermally effective means of mitigating thermal bridges. This strategy is especially effective for continuous thermal bridges...
- FRP structural members are very effective at thermal bridge mitigation, in continuous and discrete cladding details.
- Stainless steel bolts offer significant improvement in thermal transmittance...
- Recommendation to cap compressive stress in FRP isolation pads to 0.3 to 0.35 of ultimate stress

Northeastern University Department of Civil and Environmental Engineering

THERMAL BREAK STRATEGIES FOR CLADDING SYSTEMS IN BUILDING STRUCTURES

Report to the Charles Pankow Foundation

CHARLES PANKOW FOUNDATION
Building Innovation Through Research

Kare D. Pittman, Anis Kordis, Aditya Mondal, Kyle Coleman, and Irem F. Rajic
 Department of Civil and Environmental Engineering, Northeastern University
 James A. O'Shea, Kasper Holten & Høist
 Mark D. Webster, James Diez Anagnostis, Stephen Compton & Edgar Jui

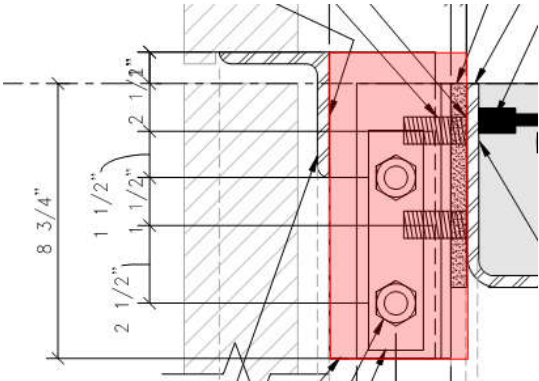
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Thermal Bridges and Breaks

Future Studies: Stainless Steel Thermal Performance

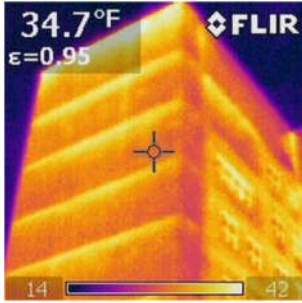



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Thermal Bridges and Breaks

Future Studies: Fire Ratings and Thermal Breaks

- Influence of temperature on polymers used as thermal separators has not been studied thoroughly
- Strength and stiffness of polymers is compromised at elevated temperatures



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Thermal Bridges and Breaks

Cost-Benefit Analysis

- Do the benefits to the owner justify the potential detailing challenges and construction costs?



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Accommodating Tolerances and Clearances

Accommodating Construction Tolerances and Clearances



University of Southern Indiana



Adjustability must be provided between the structural details and facade attachment details to achieve a facade erected within acceptable tolerances relative to the theoretical plane.



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Accommodating Tolerances and Clearances

Tolerances and Clearances

- Tolerances:
 - Permissible amount of deviation from a specified criterion: dimension, shape, location.



- Clearances:
 - Space purposely provided between two parts to allow for movement, accommodate tolerances and provide access.

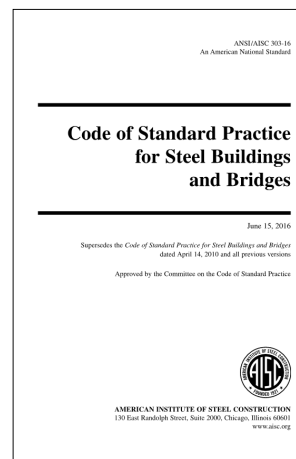


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Accommodating Tolerances and Clearances

Specifying Frame Tolerances

- Unreasonable for designers to disregard the realities of construction practice
- Note adjustable items on construction documents



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Accommodating Tolerances and Clearances

Types of Tolerances

- Material Production Tolerances
- Fabrication and Assembly Tolerances
- Erection and Installation Tolerances
- Accumulated Tolerances

Design Guide 22 includes summaries of major facade materials and components.



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Accommodating Tolerances and Clearances

Accumulated Tolerances

- Unlikely that all tolerances will vary to the maximum allowed and all occur in the same direction.
- However, no statistical data is usually available to the designer about the distribution of variation.

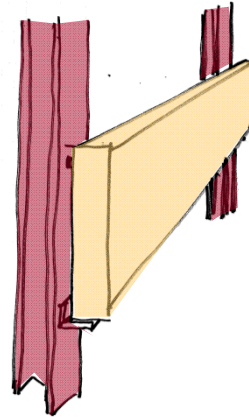


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Accommodating Tolerances and Clearances

Accumulated Tolerances

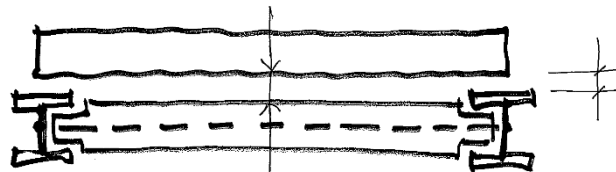
- Example:
 - PC panel supported on columns at 10th story
 - 40 ft span
 - Column plumbness:
 - -2 in. inward; +1 in. outward
 - Steel beam sweep:
 - +/- 1/2 in.
 - PC plan location at each end:
 - +/- 1/2 in.
 - PC bow: $L/360 = +/- 1.33$ in.



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Accommodating Tolerances and Clearances

Accumulated Tolerances



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Accommodating Tolerances and Clearances

Accumulated Tolerances

- Maximum change in planned gaps if using all tolerance maximums:
 - At columns:
 - Open: $2 + .5 = 2.5$ in.
 - Close: $1 + .5 = 1.5$ in.
 - At mid span:
 - Open: $2 + .5 + .5 + 1.33 = 4.33$ in.
 - Close: $1 + .5 + .5 + 1.33 = 3.33$ in.



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Accommodating Tolerances and Clearances

Accumulated Tolerances


- If you started with a theoretical 2 in. gap at the columns:
 - Largest gap = $2 + 2.5 = 4.5$ in.
 - Smallest gap = $2 - 1.5 = 0.5$ in.
- If you started with a theoretical 4 in. gap at the midspan:
 - Largest gap = $4 + 4.33 = 8.33$ in.
 - Smallest gap = $4 - 3.33 = 0.67$ in.



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Accommodating Tolerances and Clearances

Accumulated Tolerances



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Accommodating Tolerances and Clearances

SRSS Values

- Change in gap at column line
 - $-\sqrt{(1^2+0.5^2)}$ to $+\sqrt{(2^2+0.5^2)} = -1.1$ in. to $+2.1$ in.
- Change in gap at middle of panel
 - $-\sqrt{(1^2+0.5^2+0.5^2+1.33^2)}$ to $+\sqrt{(2^2+0.5^2+0.5^2+1.33^2)}$
 - $= -1.8$ in. to $+2.5$ in.

For change in gap at middle of panel:
 For uncorrelated case, 3% is below -1.8 in. and 6% is above +2.5 in. (total of about 9%)
 For correlated case, 5% is below -1.8 in. and 9% is above +2.5 in. (total of about 14%)


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Accommodating Tolerances and Clearances

Recommendations for Accumulated Tolerances

- Understand the sources of variability
 - Steel frame sources, facade sources
- Understand the consequence of exceeding the tolerance provisions in the details
- Understand the costs associated with providing means to accommodate the variability



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Accommodating Tolerances and Clearances

Recommendations for Accumulated Tolerances

- For each project, the team should develop a design criteria for addressing facade accumulated tolerances. For example:
 - Decide the target amount of adjustability
 - SRSS
 - AISC steel frame erection tolerances
 - Qualitative/quantitative probability analysis
 - Experience and judgment
 - Decide what elements will be adjustable and by how much.



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Accommodating Tolerances and Clearances

Sizing Joints



Designation: C1472 - 16

Standard Guide for Calculating Movement and Other Effects When Establishing Sealant Joint Width¹

This standard is issued under the fixed designation C1472; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

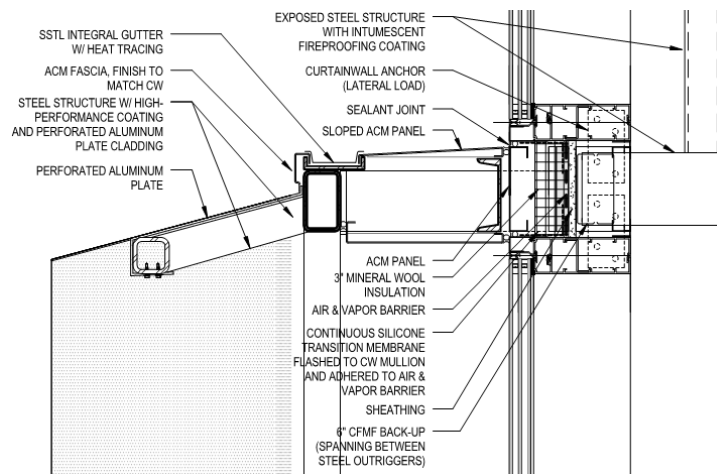
7.7.2 Negative Tolerance—A negative tolerance is one that has a tendency to cause a joint opening to become smaller. This has serious technical concerns in that, if not considered, a joint becomes too small to accommodate anticipated movements within the movement capacity of the sealant. The sealant in these circumstances can become stressed beyond its manufacturer's rating and subject to failure.



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Accommodating Tolerances and Clearances

Case Study: Sunshade



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Accommodating Tolerances and Clearances

Case Study: Sunshade

The drawing shows a detailed cross-section of a sunshade assembly. Key components include:

- HSS5x3x3/8**: Main vertical member.
- WT7x34x0'-7" long**: Top horizontal member.
- HSS6X4**: Secondary horizontal member.
- 1"x7"x8" PLATE WITH STANDARD HOLES**: Connection plate at the top.
- 1/4"xCONT. BENT PLATE**: Continuation bent plate.
- BENT PLATE TO HSS**: Plate connecting to the main member.
- L3x3x5/16x0'-3"**: L-shaped stiffener.
- HSS5x3**: Intermediate member.
- 3 SIDES TO HSS**: Connections on three sides.
- 3 SIDES, TYP.**: Typical connections on three sides.
- 1/4"**: Thickness of various plates.
- 1'-4"**, **2"**, **5"**: Dimensions and offsets.
- TOS EL. 1066'-4"**: Top of steel elevation.
- 3 Ø12**: Three 12mm diameter holes.
- ALL STEEL TO EXTERIOR OF THERMAL ISOLATION PAD IS GALV.**: Note on galvanneal coating.
- TC-U4A BOT., TYP.**: Typical bottom connection detail.
- R=1/4"**, **α=45°**: Fillet weld radius and angle.
- C6 SEE PLAN FOR EXTENTS**: Reference to another view.
- 1/4"**, **2"**, **2"**: Weld sizes and dimensions.
- T&B**: Top and bottom welds.

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Accommodating Tolerances and Clearances

Case Study: Sunshade

The photograph shows the physical installation of the sunshade connection. It illustrates the alignment of the steel members (HSS and WT) and the presence of thermal isolation pads between the steel and the building structure. The blue and white insulation is clearly visible, demonstrating the practical application of the design details shown in the drawing above.

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Key “Take-Aways”



1. The design team needs to develop a **strategy**, or strategies, for supporting the facade elements from the primary frame.
2. Given this **strategy**, the team needs to communicate responsibilities and scope.
 - Architect, SER, SSE, Contractor(s)
3. The SER needs to know the facade attachment **strategy** and needs enough information from the facade designer to anticipate the impact on the primary frame.
4. The SER needs to communicate the relevant frame performance characteristics (principally deformations).



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Key “Take-Aways”



5. The SER should strive to develop slab edge and spandrel beam designs that are consistent with the facade attachment **strategy**.
6. Tolerances, facade movements and frame movements need to be considered in total. Strategy and responsibility need to be clearly communicated and accepted.
7. The SER’s documents for the primary structure should indicate pertinent assumptions about facade attachment loads.
8. The Project Documents should indicate who is responsible for facade design and attachment and all performance requirements.



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Key “Take-Aways”



9. Consider that the steel frame will often be fabricated ahead of final facade attachment design, and detail the primary frame accordingly.
10. The steel frame detailers and fabricators are NOT the coordinators of the facade attachment details. The design team needs to develop and coordinate the strategy for the facade and its attachments so that shop drawings for the frame can be completed, sometimes ahead of deferred facade engineering by others.



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There's always a solution in steel.

Question time



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NS 14 8-Session Package-Night School 14 - Fundamentals of Stability	6/5/2017 7:00:00 PM

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NS13 - Economic Considerations	2/6/2017 7:00:00 PM	Handouts	Available 02/08/2017 5pm EST	Available 02/08/2017 5pm EST	Pending
NS13 - Lateral Load Systems and Details	2/13/2017 7:00:00 PM	Handouts	Available 02/15/2017 5pm EST	Available 02/15/2017 5pm EST	Pending
NS13 - Preliminary Design Procedures	2/27/2017 7:00:00 PM	Handouts	Available 03/01/2017 5pm EST	Available 03/01/2017 5pm EST	Pending
NS13 - Crane Girder Design and Frame Analysis	3/6/2017 7:00:00 PM	Handouts	Available 03/08/2017 5pm EST	Available 03/08/2017 5pm EST	Pending
NS13 - Frame Member and Connection Design	3/13/2017 7:00:00 PM	Handouts	Available 03/15/2017 5pm EST	Available 03/15/2017 5pm EST	Pending
NS13 - Transfer Crane Girder & Longitudinal Brag Bracing Dan	3/27/2017 7:00:00 PM	Handouts	Available 03/29/2017 5pm EST	Available 03/29/2017 5pm EST	Pending
NS13 - Building Envelope and Bracing Design	4/3/2017 7:00:00 PM	Handouts	Available 04/05/2017 5pm EST	Available 04/05/2017 5pm EST	Pending
NS13 - Final Exam	4/10/2017 7:00:00 PM			Available 04/12/2017 5pm EST	



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