AISC Night School

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AISC Night School

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AISC Night School

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Session Description

Session 6: Façade Attachments, Part 1

July 23, 2018

Every type of facade system presents its own challenges for the design team. Where and how are the gravity and lateral loads supported? How much movement can the facade system accommodate? What is the jointing pattern? In this session, we will explore masonry cavity wall systems, aluminum-glass curtain wall systems and panelized systems such as precast concrete panels or prefabricated metal-framed panels with masonry or glass-fiber reinforced concrete facing to help answer these questions.

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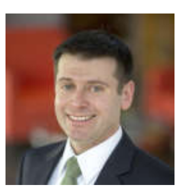
Learning Objectives

- List the issues to consider when locating joints in masonry cavity walls.
- Describe how panelized façade systems are best supported.
- Explain the importance of allowing for field adjustments of aluminum curtain walls.
- Name the sources of vertical movement in façade systems.

There's always a solution in steel.

Behind the Facade: Guidance for Supporting Facades on Steel-Framed Buildings

Session 6: Façade Attachments, Part 1
July 23, 2018



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

structural STEEL

Syllabus for Night School Sessions

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

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Syllabus for Night School Sessions

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

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Masonry Cavity Walls

Masonry Cavity Walls

The strategy for supporting masonry cavity walls starts with the decision for the location of the horizontal movement joints.

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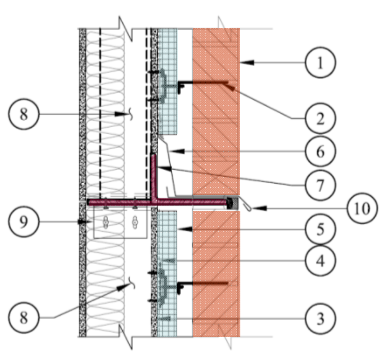
Masonry Cavity Walls

General Description



NOTES:

1. Veneer.
2. Veneer anchor.
3. Exterior sheathing, usually gypsum based.
4. Water barrier.
5. Insulation.
6. Through wall flashing.
7. Shelf angle.
8. Backup wall (metal stud shown).
9. Top of backup wall connection allows vertical movement between portion of wall above soft joint and portion below, plus allow in-plane movement.
10. Soft joint under shelf angle.

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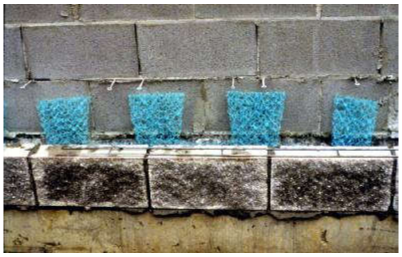
Masonry Cavity Walls

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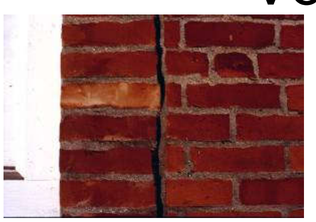
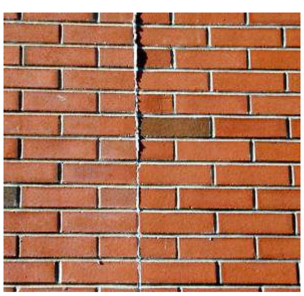
Masonry Cavity Walls

Volume Change

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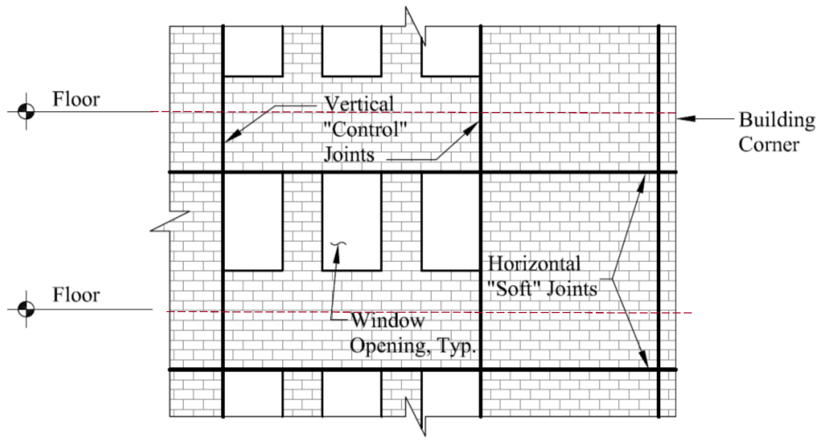
Masonry Cavity Walls

Movement Joints



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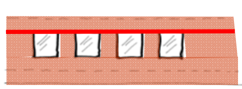
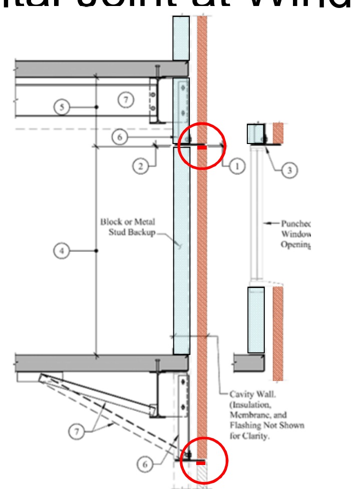
Masonry Cavity Walls

Punched Window Openings Horizontal Joint at Window Head



Elevation



NOTES:

1. Soft joint below shelf angle.
2. Movement joint between shelf angle assembly and backup wall below. The connection to underside of shelf angle assembly provides out-of-plane lateral support to the backup wall.
3. Movement joint between shelf angle assembly and window head. The window head connection provides out-of-plane support of the window.
4. Backup wall of block or metal studs below movement joint is supported on floor slab.
5. Backup wall above movement joint is supported on shelf angle assembly and anchored to underside of floor slab.
6. Hangers from plate brackets support the shelf angle assembly.
7. Roll beams or kickers can resist the twist of the spandrel beam.

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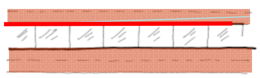
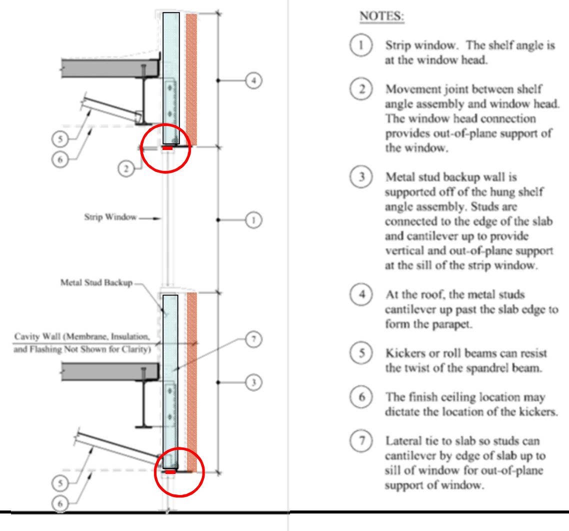
Masonry Cavity Walls

Strip Windows



Elevation



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Masonry Cavity Walls

Parameters Affecting Design

- Architecture Decisions
  - Fenestration
  - Horizontal Joint Patterns
  - Vertical Joint Patterns
- Dimensions
  - Story Heights
- Magnitude of Loads
- Field Adjustability
- Relative Movements
- Durability
- Thermal Performance

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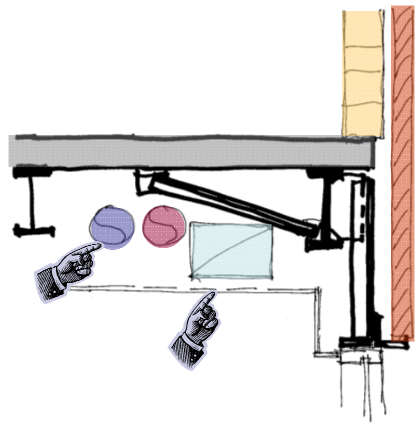
Masonry Cavity Walls

Architectural Decisions

Ceilings, MEP



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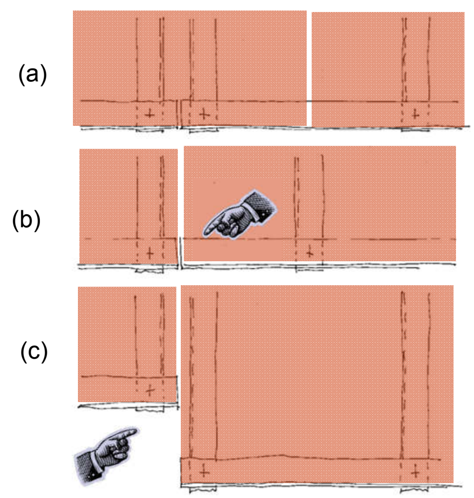
Masonry Cavity Walls

Architectural Decisions

Vertical Control Joints



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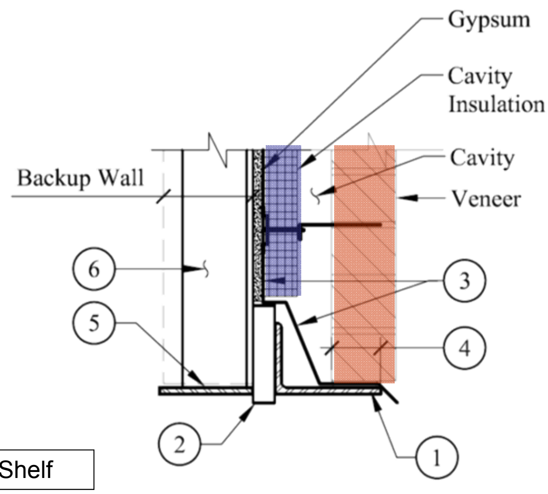
Masonry Cavity Walls

Dimensions

NOTES:

1. Shelf angle made from standard rolled angle shape.
2. Structural spacer may be required for projects with thick insulation requirements in the cavity or with thick veneer in order to keep standard rolled angle as shelf.
3. Line of membrane and flashing.
4. A minimum of 2/3 of the veneer should bear on the shelf angle.
5. Continuous plate to support backup wall above.
6. Structural hangers behind membrane and within the thickness of the backup wall.



Horizontal Leg of Shelf

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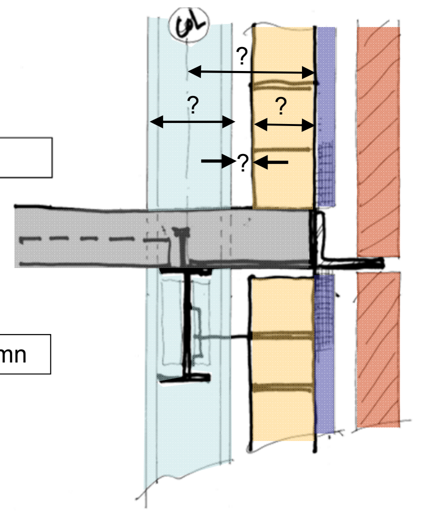
Masonry Cavity Walls

Dimensions



Thickness of Backup

Relative Location of Column

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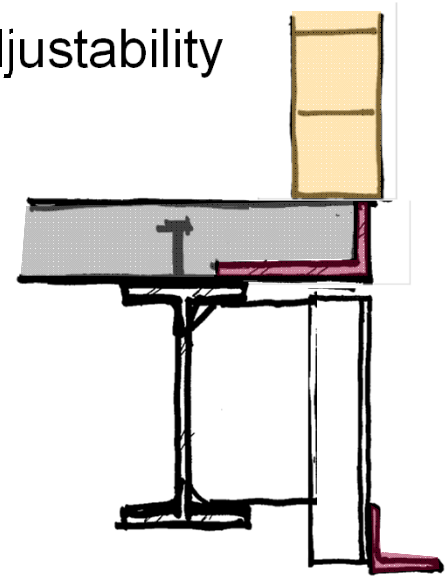
Masonry Cavity Walls

Field Adjustability

- Slab edge
- Backup wall
- Shelf angle



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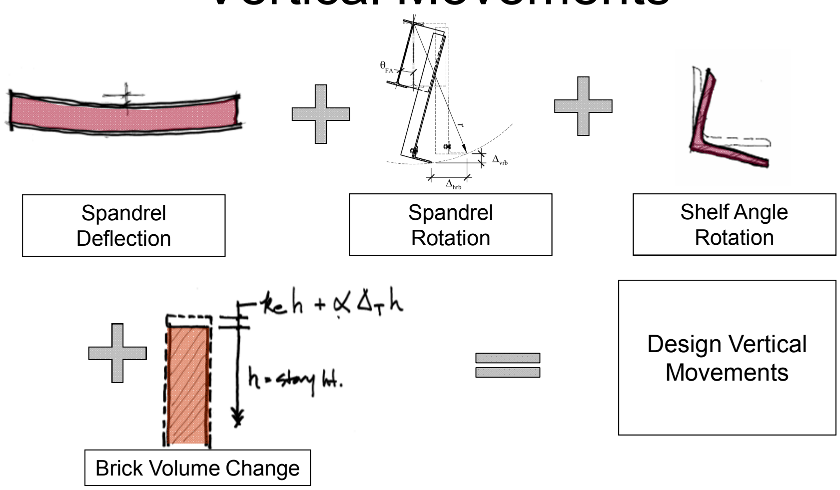
Masonry Cavity Walls

Vertical Movements



Note: Column shortening is important too for tall building's bottom story.

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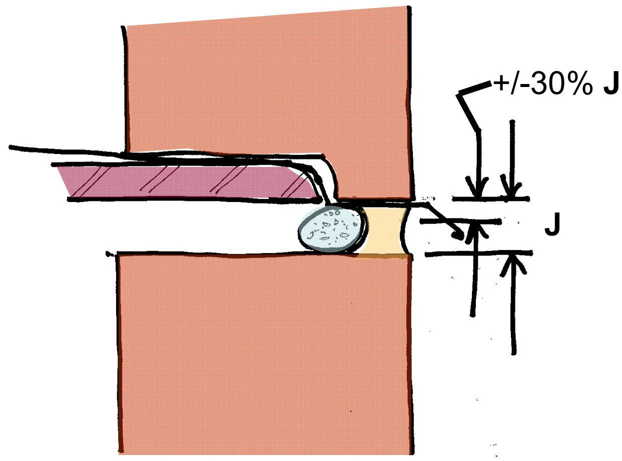
Masonry Cavity Walls

Joint Compressibility



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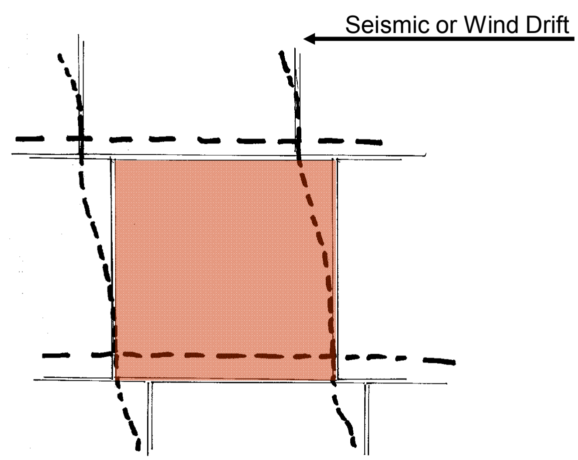
Masonry Cavity Walls

In-Plane Movements



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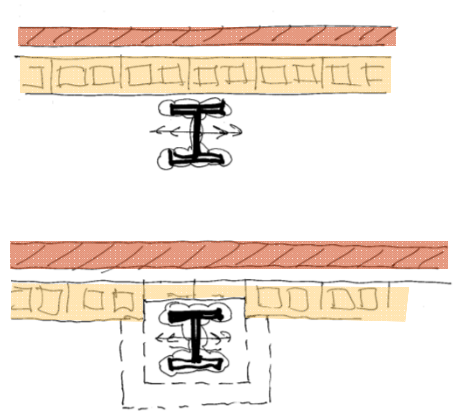
In-Plane Movements



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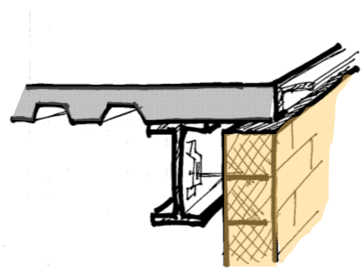
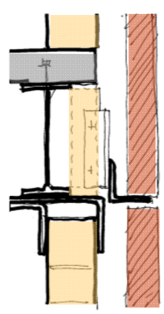
Masonry Cavity Walls

Top of Wall Connections



CMU Backup
Long Slab Overhang
Angle at Slab



CMU Backup
Short Slab Overhang
Hung Angle

Metal Stud Backup
Long Slab Overhang
Hung Angle

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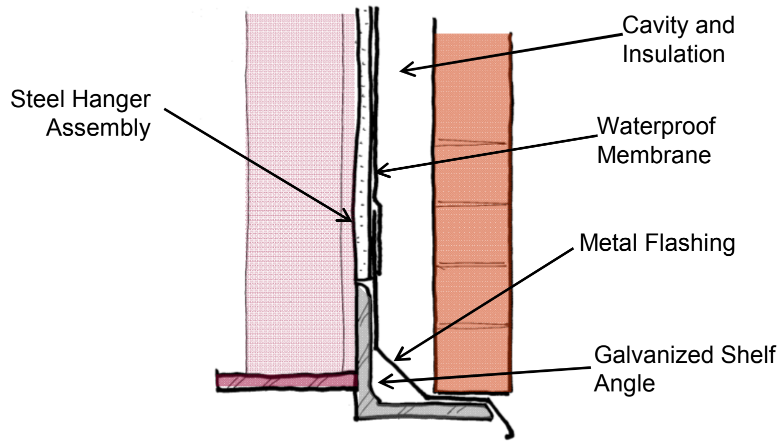
Masonry Cavity Walls

Durability



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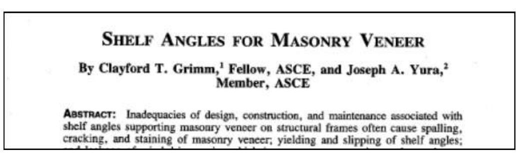
Masonry Cavity Walls

Design of Shelf Angles

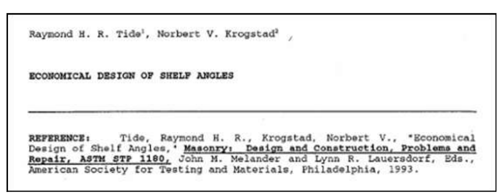
- Grimm and Yura (1989)
- Tide and Krogstad (1993)



SHELF ANGLES FOR MASONRY VENEER

By Clayford T. Grimm,[1] Fellow, ASCE, and Joseph A. Yura,[2] Member, ASCE

ABSTRACT: Inadequacies of design, construction, and maintenance associated with shelf angles supporting masonry veneer on structural frames often cause spalling, cracking, and staining of masonry veneer; yielding and slipping of shelf angles;



Raymond H. R. Tide[1], Norbert V. Krogstad[2]

ECONOMICAL DESIGN OF SHELF ANGLES

REFERENCE: Tide, Raymond H. R., Krogstad, Norbert V., "Economical Design of Shelf Angles," Masonry: Design and Construction, Problems and Repair, ASTM STP 1180, John M. Melander and Lynn R. Lauersdorf, Eds., American Society for Testing and Materials, Philadelphia, 1993.

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Masonry Cavity Walls

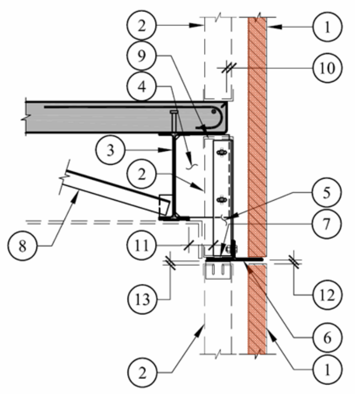
Shelf Angle Tables

Table 7-1. Vertical Deflection at Tip of Shelf Angle, in.
Supporting 10 Vertical Feet of Brick[1]

Angle	Thickness, in.	Spacing of Angle Attachment to Structure, in.								
		24	30	36	42	48	54	60	66	72
L5x5	5/16	0.0258	0.0329	0.0399	0.0467	0.0534	0.0651	0.0788	0.0949	0.114
	3/8	0.0151	0.0193	0.0234	0.0274	0.0316	0.0386	0.0468	0.0565	0.0679
	7/16[8]	0.00965	0.0123	0.0149	0.0175	0.0204	0.0250	0.0304	0.0368	0.0444
	1/2	0.00653	0.00834	0.0101	0.0119	0.0140	0.0171	0.0209	0.0254	0.0307
	5/8	0.00340	0.00435	0.00527	0.00618	0.00743	0.00917	0.0113	0.0138	0.0168
	3/4	0.00200	0.00256	0.00311	0.00365	0.00448	0.00557	0.00689	0.00851	0.0105
L6x4 (LLH)	5/16	0.0491	0.0624	0.0755	0.0883	0.1008	0.117	0.142	0.171	–
	3/8	0.0286	0.0364	0.0441	0.0516	0.0589	0.0694	0.0842	0.102	0.122
	7/16[8]	0.0182	0.0232	0.0281	0.0328	0.0375	0.0447	0.0544	0.0659	0.0793
	1/2	0.0123	0.0156	0.0189	0.0222	0.0253	0.0305	0.0373	0.0452	0.0547
	9/16[8]	0.00870	0.0111	0.0134	0.0157	0.0179	0.0219	0.0268	0.0327	0.0397
	5/8	0.00639	0.00813	0.00985	0.0115	0.0132	0.0163	0.0200	0.0245	0.0299
	3/4	0.00374	0.00477	0.00578	0.00676	0.00793	0.00985	0.0122	0.0151	0.0186

Masonry Cavity Walls

Hung Shelf Angle



(Note: Sheathing and Insulation Not Shown for Clarity, Typ.)

Masonry Cavity Walls

Hung Shelf Angle

(See preceding slide)

NOTES:

1. Veneer of cavity wall. Membrane, insulation, flashing, etc. not shown.
2. Block or metal stud backup wall.
3. Spandrel beam.
4. Full depth stiffener plates provide brackets that project from the spandrel beam to pick up the hanger.
5. Single angle hangers. Erection bolts in long horizontal slots in the angle and long vertical slots in the bracket plates allow for field adjustment prior to field welding.
6. Shelf angle. May be shop welded if hangers have sufficient adjustment. Can have erection bolts in slotted holes with field welding after final placement for additional adjustment.
7. Continuous plate to support backup wall above movement joint. Welded to hangers.
8. Kickers or roll beams restrain twist of spandrel.
9. Field application of light gage metal pour stop provides adjustment of slab edge location.
10. Nominal overhang of the backup allows for field adjustment of the face of backup relative to the slab edge.
11. Clearance is required between the inside edge of the hanger and the outside tips of the spandrel's flanges.
12. Horizontal soft joint in the veneer.
13. Backup connection to hanger assembly provides out-of-plane restraint only. Allows vertical and in-plane movement.

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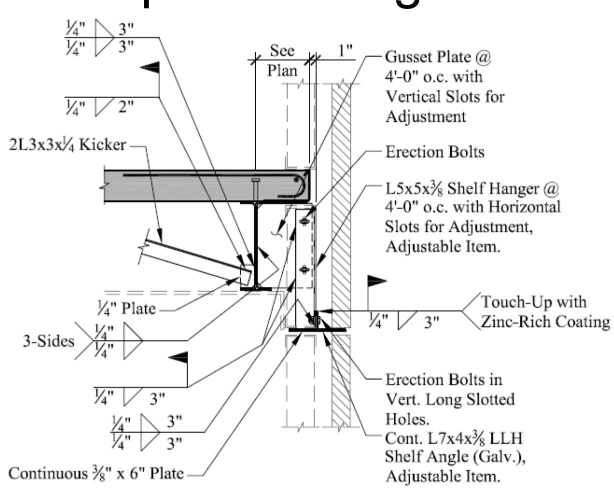
Masonry Cavity Walls

Example Drawing Detail



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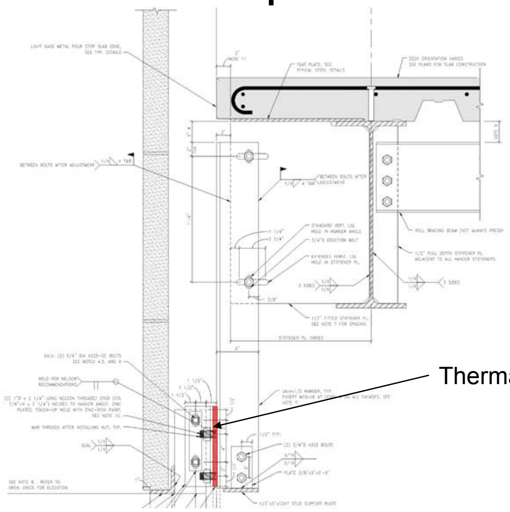
Masonry Cavity Walls

Example Drawing Detail



Thermal Isolation Pad

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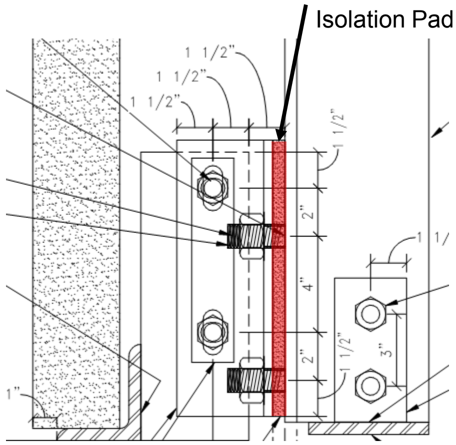
Masonry Cavity Walls

Example Drawing Detail

Thermal
Isolation Pad



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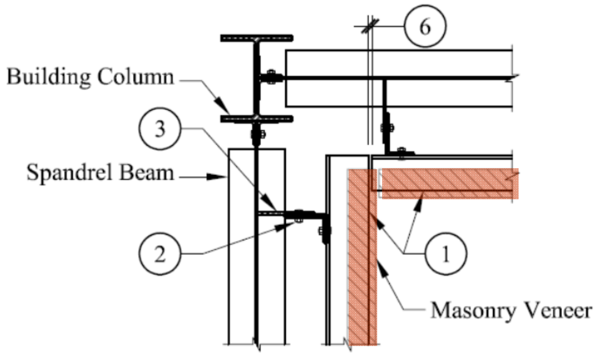
Masonry Cavity Walls

Plan Locations of Hangers



(b) Hung Shelf Angle at Re-Entrant Corner

NOTES:

1. Shelf angle.
2. Hangers.
3. Brackets from spandrel to hangers.
4. Allow clearance from last bracket hanger to column for column connection - 12 to 18 inches is usually sufficient.
5. Design shelf angle for cantilever past last hanger on spandrel. - 18 to 24 inches is not unusual.
6. Gap between shelf angles - ½ inch +/- ½ inch. Gaps in angles and vertical control joints need not align.
7. Field install adjustable brackets from column to support ends of shelf angles if cantilever from last bracket is too long.

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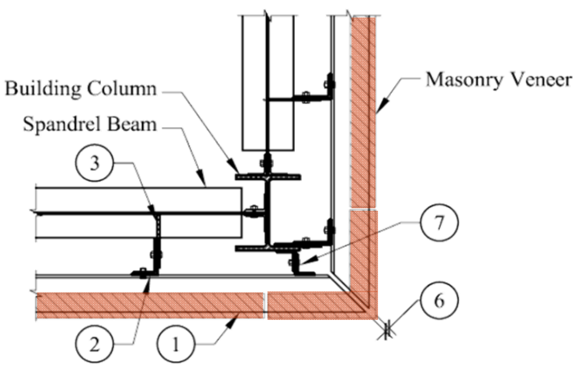
Masonry Cavity Walls

Plan Locations of Hangers



(c) Hung Shelf Angle at Building Corner

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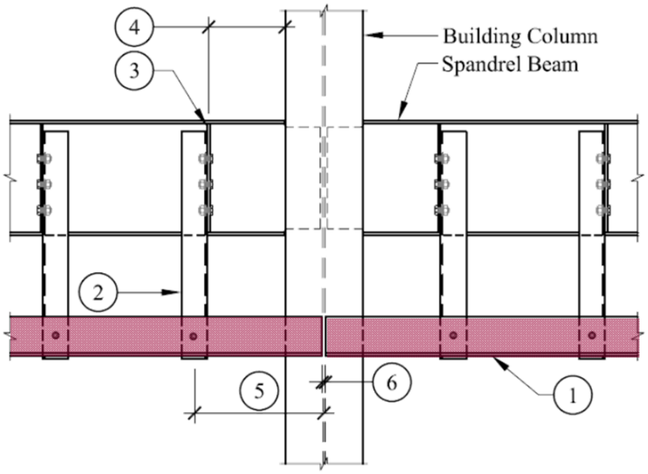
Masonry Cavity Walls

Plan Locations of Hangers



(a) Hung Shelf Angle at Column

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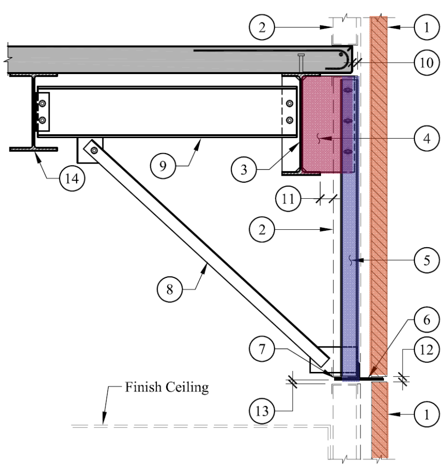
Masonry Cavity Walls

Long Hangers



(Note: Sheathing and Insulation Not Shown for Clarity, Typ.)

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Masonry Cavity Walls

Long Hangers

(See preceding slide)

NOTES:

1. Veneer of cavity wall. Membrane, insulation, flashing, etc. not shown.
2. Block or metal stud backup wall.
3. Spandrel beam.
4. Full depth fitted stiffener plates provide brackets that project from the spandrel beam to pick up the hanger.
5. Hangers. Erection bolts in long horizontal slots in the angle and long vertical slots in the bracket plates allow for field adjustment prior to field welding.
6. Shelf angle. May be shop welded if hangers have sufficient adjustment. Can have erection bolts in slotted holes with field welding after final placement for additional adjustment.
7. Continuous plate to support backup wall above movement joint. Welded to hangers.
8. Kickers. Field weld to connection plates after adjustment of hangers.
9. Roll beam to restrain twist on spandrel due to eccentricity of hanger. Can also help get horizontal force from kicker into slab.
10. Nominal overhang of the backup allows for field adjustment of the face of backup relative to the slab edge.
11. Clearance is required between the inside edge of the hanger and the outside tips of the spandrel's flanges.
12. Horizontal soft joint in the veneer.
13. Backup connection to hanger assembly provides out-of-plane restraint only. Allows vertical and in-plane movement.
14. Interior beam resists vertical force from kicker. Consider bottom flange may go into compression and be unbraced if there is net uplift.

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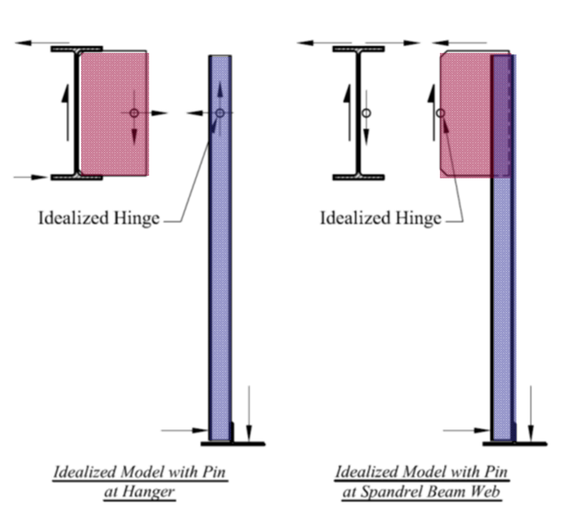
Masonry Cavity Walls

Long Hangers



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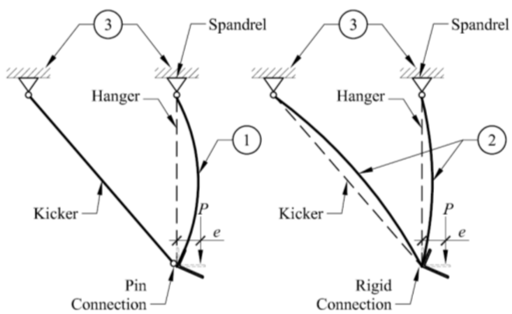
Masonry Cavity Walls

Additional Rotation in Long Hangers



NOTES:

1. If connection of the kicker to the hanger is a pin, only the hanger resists rotation of the shelf angle. Check stiffness and strength of hanger.
2. If connection of the kicker to the hanger is rigid, the hanger and kicker resist rotation of the shelf angle. Check stiffness and strength of both.
3. There can be differential deflection between supports which will impact shelf angle deflection.

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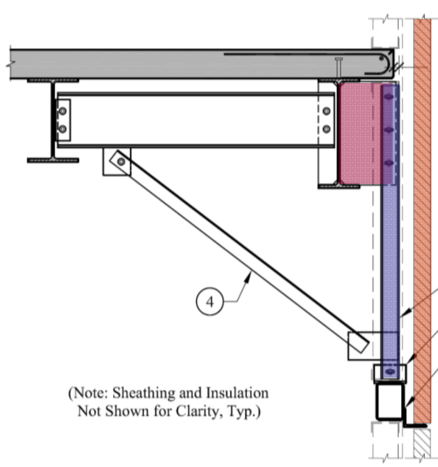
Masonry Cavity Walls

Other Concepts for Long Hangers



(Note: Sheathing and Insulation Not Shown for Clarity, Typ.)

NOTES:

1. Fewer, heavier hangers. Perhaps at 1/4 or 1/3 span of the spandrel beam. Double angles or channels may be appropriate.
2. HSS + shelf angle assembly spans between hangers. HSS takes torsion from eccentric shelf angle. Support HSS at columns to avoid heavy hangers adjacent to columns.
3. Design connection between HSS and hangers for vertical and horizontal field adjustment. Consider erection bolts in slotted holes and field welding.
4. Kicker.

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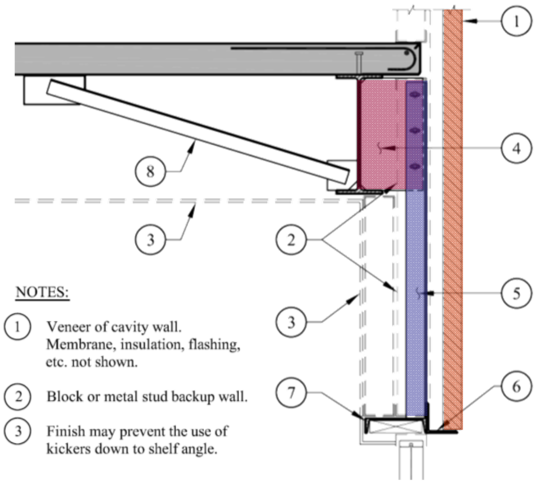
Masonry Cavity Walls

Other Concepts for Long Hangers



NOTES:

1. Veneer of cavity wall. Membrane, insulation, flashing, etc. not shown.
2. Block or metal stud backup wall.
3. Finish may prevent the use of kickers down to shelf angle.

NOTES:

4. Full depth stiffener plates provide brackets that project from the spandrel beam to pick up the hanger.
5. Hangers. Erection bolts in long horizontal slots in the angle and long vertical slots in the bracket plates allow for field adjustment prior to field welding.
6. Shelf angle. May be shop welded if hangers have sufficient adjustment. Can have erection bolts in slotted holes with field welding after final placement for additional adjustment.
7. Continuous girt spans between columns for out of plane wall loads and the horizontal force that results from eccentric load on hanger. Also supports the backup wall above movement joint. Welded to hangers for vertical support.
8. Kicker to resolve eccentric forces on spandrel beam.

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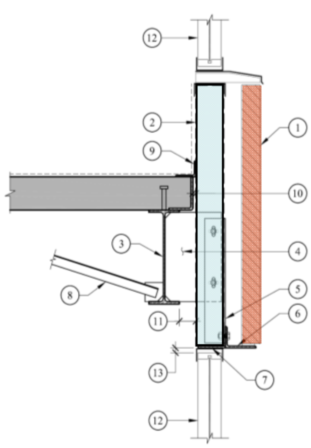
Masonry Cavity Walls

Hung Angle – Back Up Runs By Slab



(Note: Sheathing and Insulation Not Shown for Clarity, Typ.)

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Masonry Cavity Walls

Hung Angle – Back Up Runs By Slab

(See preceding slide)

NOTES:

1. Veneer of cavity wall. Membrane, insulation, flashing, etc. not shown.
2. Metal stud backup wall runs by edge of slab.
3. Spandrel beam.
4. Full depth stiffener plates provide brackets that project from the spandrel beam to pick up the hanger.
5. Hangers. Erection bolts in long horizontal slots in the angle and long vertical slots in the bracket plates allow for field adjustment prior to field welding.
6. Shelf angle. May be shop welded if hangers have sufficient adjustment. Can have erection bolts in slotted holes with field welding after final placement for additional adjustment.
7. Continuous plate to support backup wall above movement joint. Welded to hangers.
8. Kickers or roll beams to restrain twist on spandrel due to eccentricity of hanger.
9. Metal studs have lateral anchor by means of a continuous clip to top of slab, or individual clips for each stud to edge of slab.
10. Nominal gap by design between backup and slab edge allows for field adjustment of the face of backup relative to the slab edge.
11. Clearance is required between the inside edge of the hanger and the outside tips of the spandrel's flanges.
12. Windows can be strip windows in this detail as the studs sit on the hanger assembly and cantilever up by the edge of slab.
13. Window head connection to hanger assembly provides out-of-plane restraint only. Allows vertical and in-plane movement.

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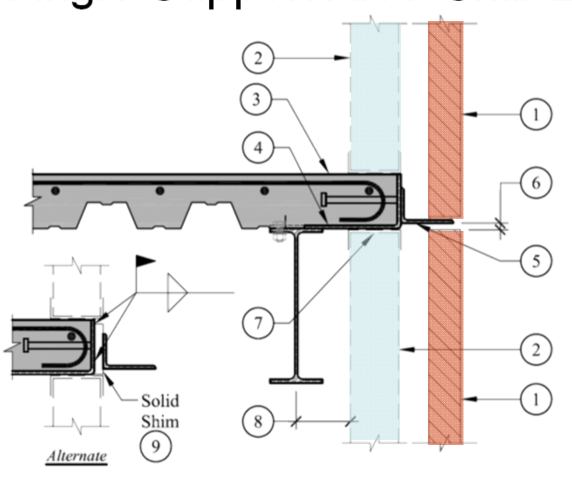
Masonry Cavity Walls

Shelf Angle Supported At Slab Edge



(Note: Sheathing and Insulation Not Shown for Clarity, Typ.)

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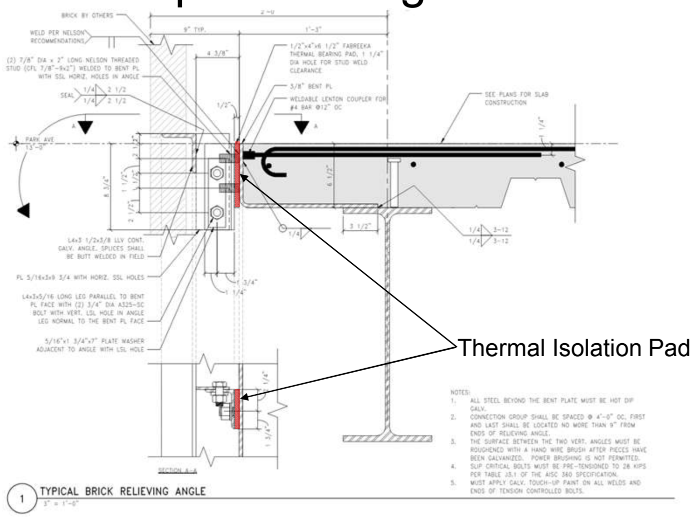
Masonry Cavity Walls

Example Drawing Detail



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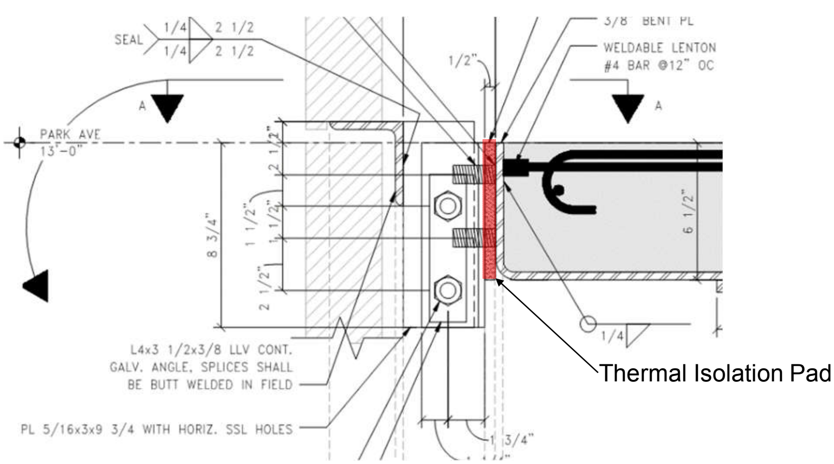
Masonry Cavity Walls

Example Drawing Detail



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Masonry Cavity Walls

Shelf Angle Supported At Slab Edge

(See preceding slide)

NOTES:

1. Veneer of cavity wall. Membrane, insulation, flashing, etc. not shown.
2. Metal stud or block backup wall.
3. Design the slab with adequate shear and flexure to overhang the spandrel and support the wall.
4. Provide a steel angle or bent plate as a pour stop and as a means to connect the shelf angle to the slab edge with headed studs or deformed bar anchors. Design ample in-out field adjustment of this bent plate. For additional adjustment detail for single, solid shim between angle and slab edge.
5. Field weld the shelf angle to the bent plate. If alternate shim detail is used, weld shim to bent plate and angle to shim.
6. Soft joint in veneer.
7. Anchorage of backup to slab. This connection needs to transfer out-of-plane forces from the wall to the slab but allow vertical movement between the slab and the lower backup wall, and in-plane movement of the wall relative to the slab for story drift of the frame.
8. Provide clearance between the backup wall and the outside tips of the spandrel beam flanges to allow the backup wall to be connected to the underside of the bent plate at the slab overhang.
9. Solid shims of varying thicknesses provide additional field in-plane/out-of-plane adjustment.

Masonry Cavity Walls

Potential Problems

- Inadequate provisions for the shelf angle adjustment:
  - Too little masonry bearing on shelf angle
  - Cavity too wide for specified masonry ties
- Flashing design does not accommodate projection of bolts or fasteners into the cavity at the shelf angle.

Masonry Cavity Walls

Potential Problems

- Inadequate sealant joint size
  - Thermal movement and brick growth
  - Spandrel beam deflections movements
- Support details at corners and atypical conditions are not clearly documented in the design.

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Panelized Facade Systems

Panelized Facade Systems

The most important strategy for support of panelized facade systems is to support the weight of each panel on no more than two points.

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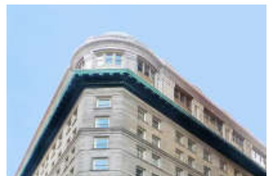
Panelized Facade Systems

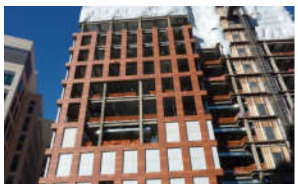
Types of Panelized Facade Systems

EIFS Panels

Thin Stone Veneer



GFRC Panels



Panelized Brick on Studs

Precast Panels

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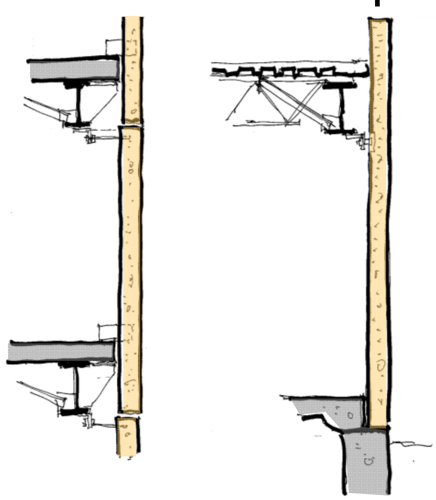
Panelized Facade Systems

General Description



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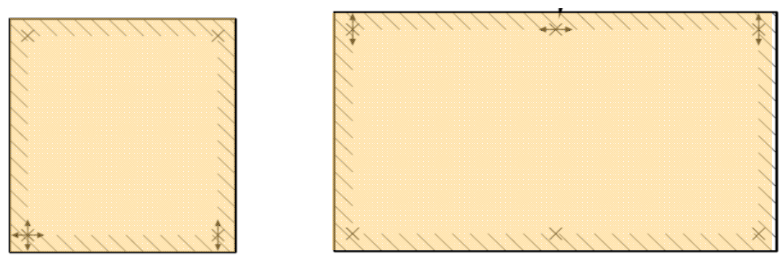
Panelized Facade Systems

Strategies for Support



KEY:
↕ Indicates direction of in-plane load resistance.
× Indicates out-of-plane load resistance.

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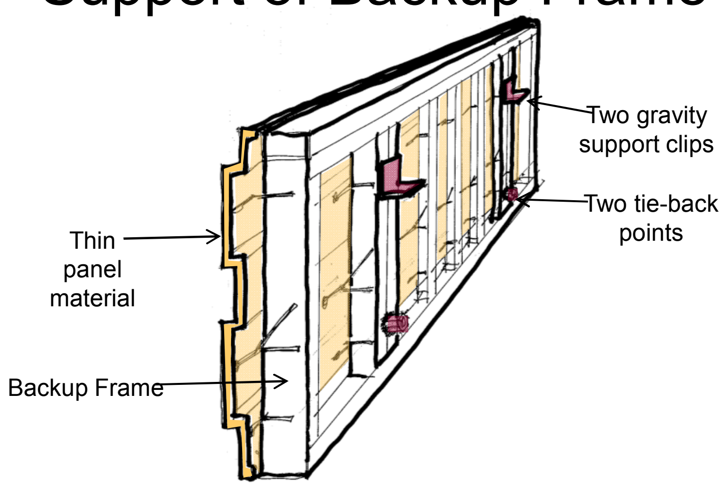
Panelized Facade Systems

Support of Backup Frame



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Panelized Facade Systems

Parameters Affecting Design

- Architectural Layout
- Relative Movements
- Magnitude of Lateral Loads
- Field Adjustability
- Durability

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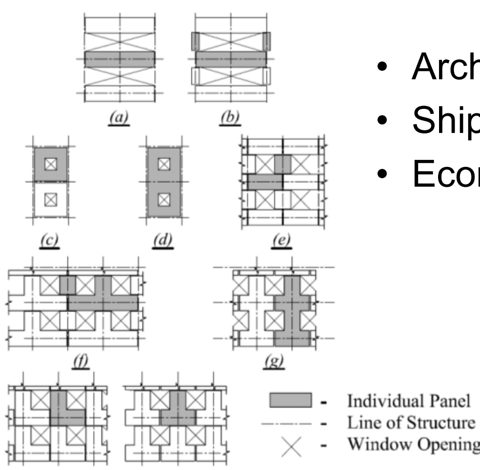
Panelized Facade Systems

Layout of Panels



- Architectural
- Shipping and erection
- Economics

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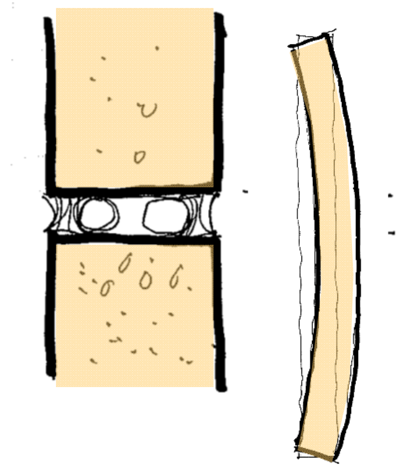
Panelized Facade Systems

Movement



- Vertical
  - Horizontal soft joints
- Lateral
  - Volume change
- In-plane story drift
- Out-of-plane
  - Wind, seismic
  - Bowing

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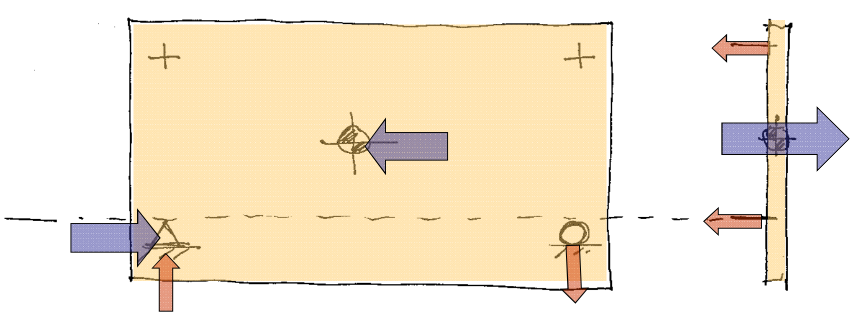
Panelized Facade Systems

Lateral Forces



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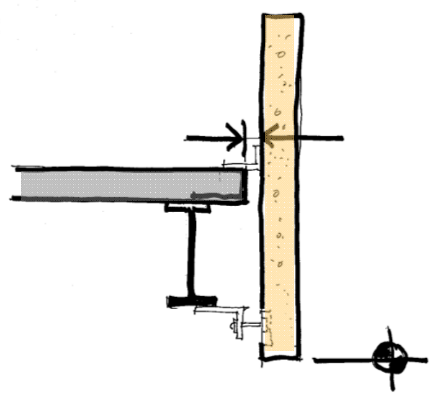
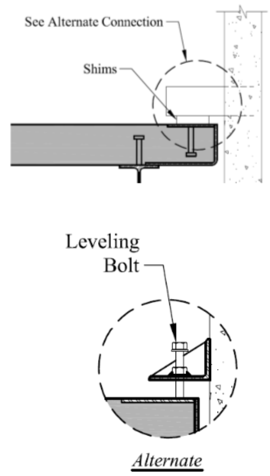
Panelized Facade Systems

Field Adjustability





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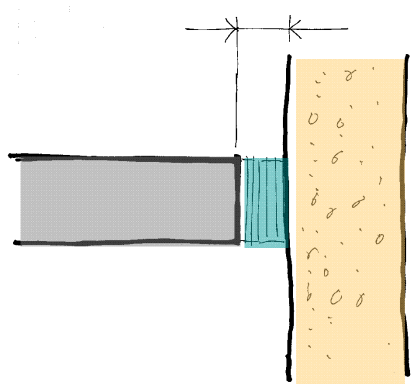
Panelized Facade Systems

Fire Safing

- Approved materials
- Securely installed
- Prevents passage of flame and hot gases



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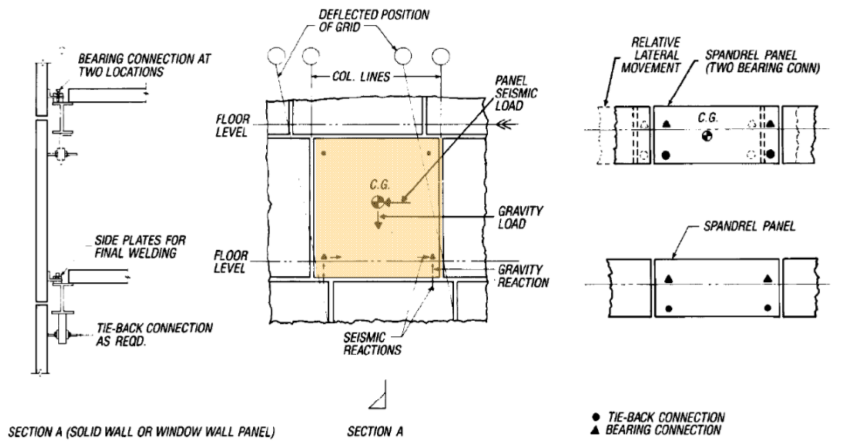
Panelized Facade Systems

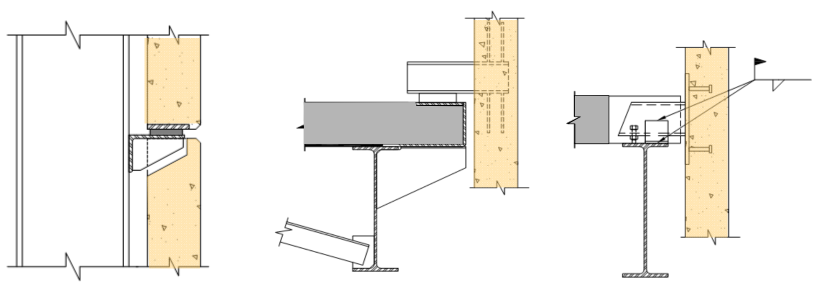
Connection Types



(Taken from reference Architectural Precast Concrete, Second Edition, PCI. Used with permission Precast/Prestressed Concrete Institute in Design Guide 22)

Panelized Facade Systems

Connection Types

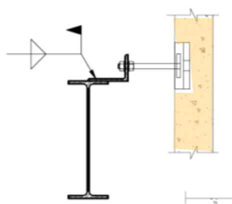


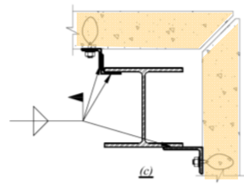
Bearing Connections

(Adapted from reference Architectural Precast Concrete, Second Edition, PCI. Used with permission Precast/Prestressed Concrete Institute in Design Guide 22.)

Panelized Facade Systems

Connection Types





Tie-back connections

(Adapted from reference Architectural Precast Concrete, Second Edition, PCI. Used with permission Precast/Prestressed Concrete Institute in Design Guide 22.)

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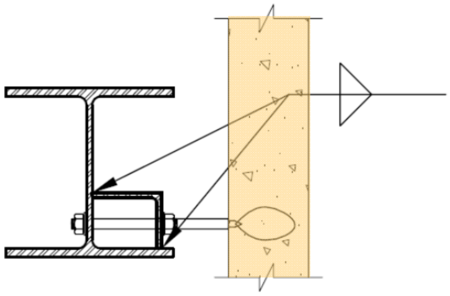
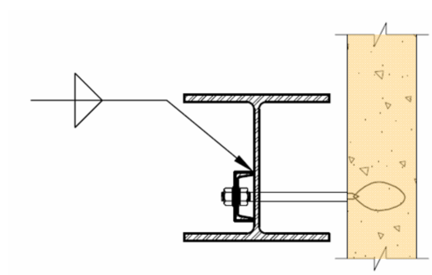
Panelized Facade Systems

Connection Types





Tie-back connections for limited access.

(Adapted from reference Architectural Precast Concrete, Second Edition, PCI. Used with permission Precast/Prestressed Concrete Institute in Design Guide 22.)

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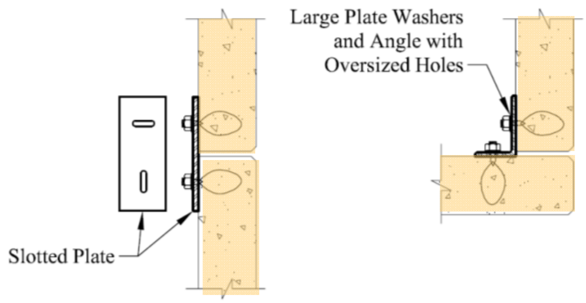
Panelized Facade Systems

Connection Types



Alignment Connections

(Adapted from reference Architectural Precast Concrete, Second Edition, PCI. Used with permission Precast/Prestressed Concrete Institute in Design Guide 22.)

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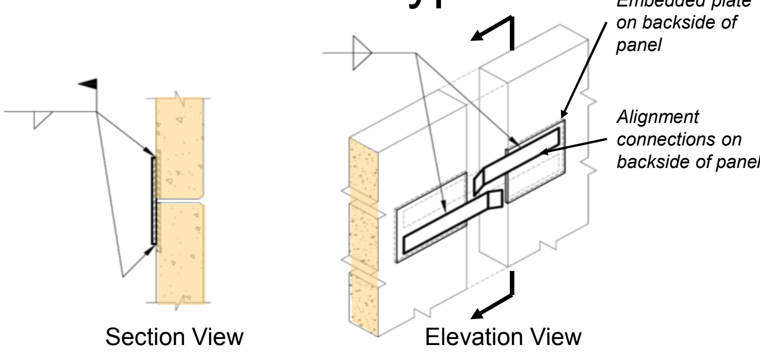
Panelized Facade Systems

Connection Types



Alignment Connections

(Adapted from reference Architectural Precast Concrete, Second Edition, PCI. Used with permission Precast/Prestressed Concrete Institute in Design Guide 22.)

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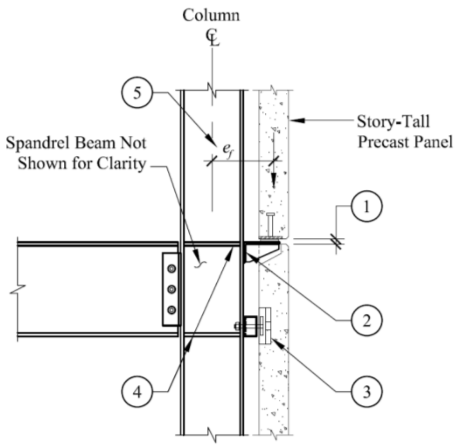
Panelized Facade Systems

Column-Supported Story-Tall Panels



NOTES:

1. Shim stack (or leveling bolt) bearing support at panel joint. Joint to allow differential vertical movement.
2. Steel bracket bearing connection. Typically designed by the SSE.
3. Tie-back connection at top of lower panel to allow vertical and horizontal relative movement.
4. Stiffener plates (as required). Consider impact of stiffeners on the out-of-plane spandrel beam connection.
5. Maximum allowable eccentricity (e_f) specified by the Structural Engineer of Record.

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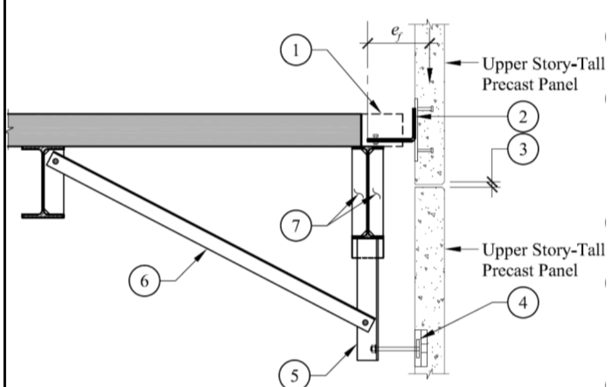
Panelized Facade Systems

Spandrel-Supported Panels



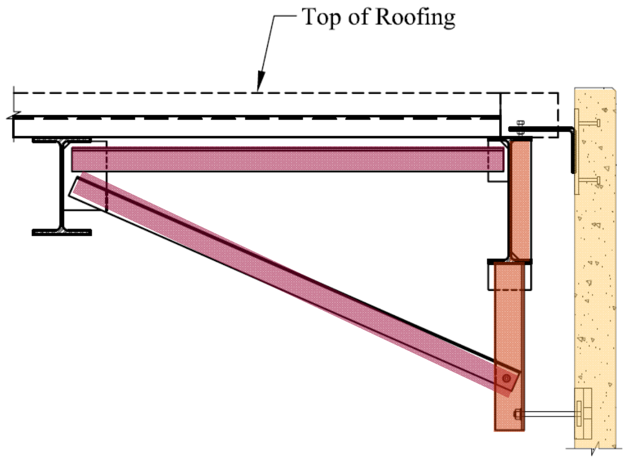
Detail at Composite Deck Floor Slab

NOTES:

1. Blockout in slab for bearing connection.
2. Bearing clip and connection to precast is typically specified by the SSE. Connection to panel is designed for moment to resolve eccentricity (e_f).
3. Panel joint allows relative movement between panels.
4. Slotted (or threaded) insert tie-back connection allows vertical and in-plane relative movement.
5. Steel shape hanger from spandrel to receive tie-back connection.
6. Steel shape kicker to resist tie-back alone and avoid torsion on spandrel.
7. Stiffener plates, if required, for local flange bending for bearing clip on hanger.

Panelized Facade Systems

Spandrel-Supported Panels



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Panelized Facade Systems

Potential Problems

- Erection sequence may be complex when coordinating brackets, blockouts or recesses, and embedment plates.
- Cantilever brackets on panels without sufficient stiffness may deflect or rotate significantly during erection.
- Division of responsibilities for designing and providing attachment and support components may be unclear.

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Panelized Facade Systems

Potential Problems

- Joints in architectural elevations are not coordinated with the points of load application to the primary structure as anticipated by the SER.
- Inadequate coordination and accommodation for adjustability results in greater eccentricities than anticipated by the SER, SSE, or both.

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Panelized Facade Systems

Potential Problems

- Attachments designed by the SSE may inadvertently:
  - Deliver moments or otherwise load the primary structure with eccentric loads not anticipated by the SER designing the primary structure.
  - Resolve horizontal and vertical kicker loads to lightweight roof elements that are not designed for the kicker loads.
  - Apply loads to the bottom flange of the spandrel.

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Aluminum Curtain Wall Systems

Aluminum Curtain Walls



Often the most important part of the aluminum curtain wall design is anchorage adjustability to the base building structure.

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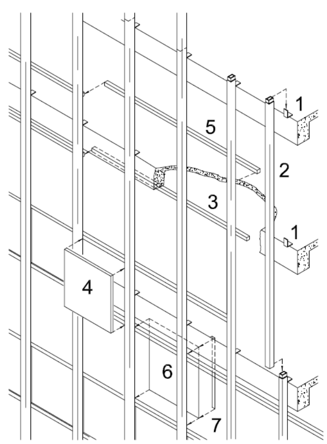
Aluminum Curtain Wall Systems

General Description

"STICK BUILT"



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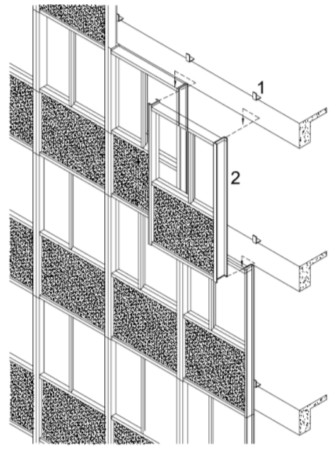
Aluminum Curtain Wall Systems

General Description

"UNITIZED"



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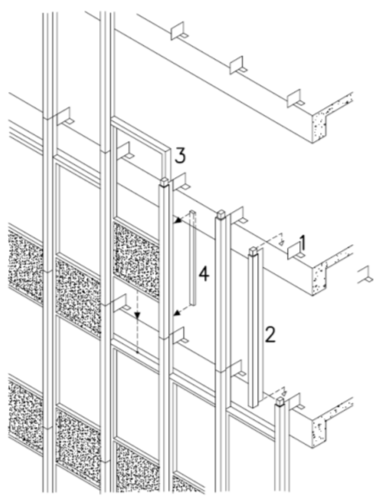
Aluminum Curtain Wall Systems

General Description

"UNIT AND MULLION"



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Aluminum Curtain Wall Systems

Strategies for Support

- Easily accessible attachments
- Adjustability
- Limit eccentricity
- Block-outs of fire proofing
- Factory drilled bolt holes in curtain wall
- Field-welded connections

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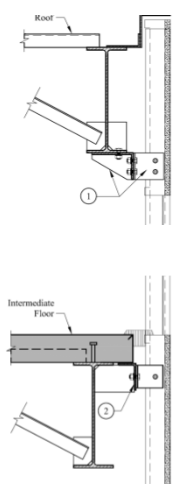
Aluminum Curtain Wall Systems

Strategies for Support

Dead + Lateral Attachment

Lateral Attachment



NOTES:

1) Dead load attachment. Curtain wall hangs from roof structure in this example. Attachment detail needs to provide vertical and horizontal adjustments.

2) Wind load attachment. Detail provides out-of-plane support of mullion and allows vertical movement relative to structure.

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Aluminum Curtain Wall Systems

Architectural Parameters

- Location of mullions
- Joints
- System type
- Story height
- Acceptable mullion size
- Direction of span

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Aluminum Curtain Wall Systems

Accommodating Thermal Movements

- Critical to performance
- Aluminum: $\alpha_{Al} \approx 13x10^{-6}$ in/in/˚F
- Steel: $\alpha_{S} \approx 6.5x10^{-6}$ in/in/˚F
- Concrete: $\alpha_{C} \approx 5.4x10^{-6}$ in/in/˚F
- Facade temperatures may be 4 times the interior temperature

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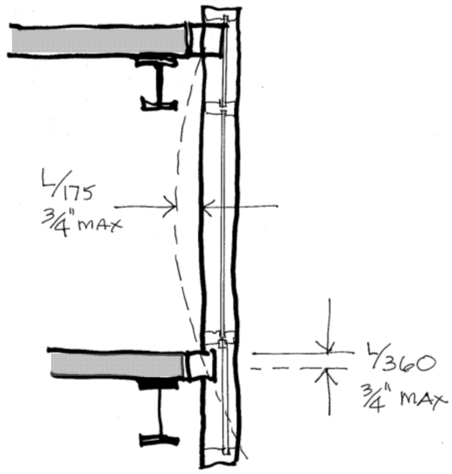
Aluminum Curtain Wall Systems

Accommodating Structural Movements



- Out-of-Plane:
  - L/175 for curtain wall
  - L/360 for members also supporting brittle finishes
  - Max. of 3/4 in.
- In-Plane:
  - L/360 common but may vary

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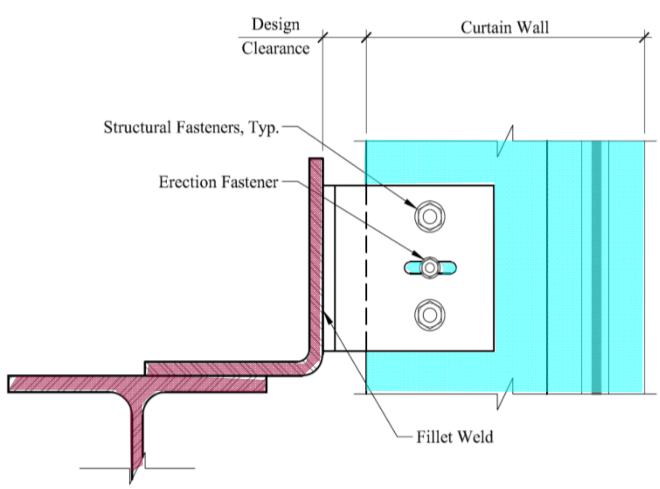
Aluminum Curtain Wall Systems

Field Adjustability – Gravity Anchor



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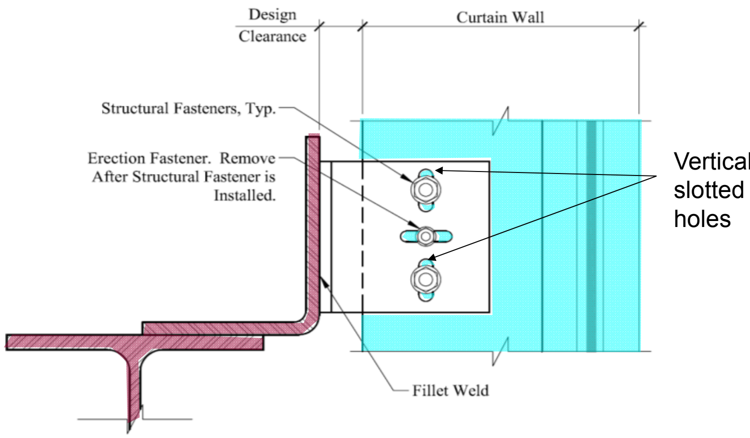
Aluminum Curtain Wall Systems

Field Adjustability – Lateral Anchor



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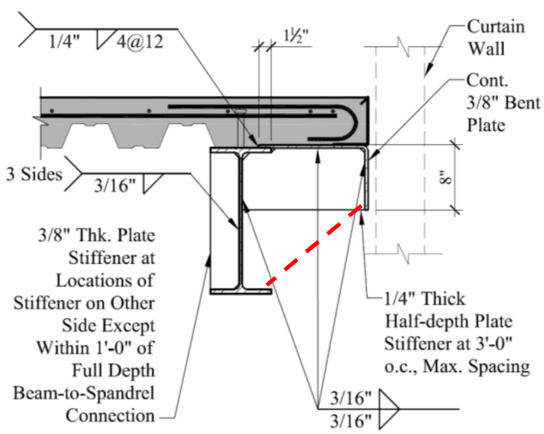
Aluminum Curtain Wall Systems

Attachment to Spandrel Beam



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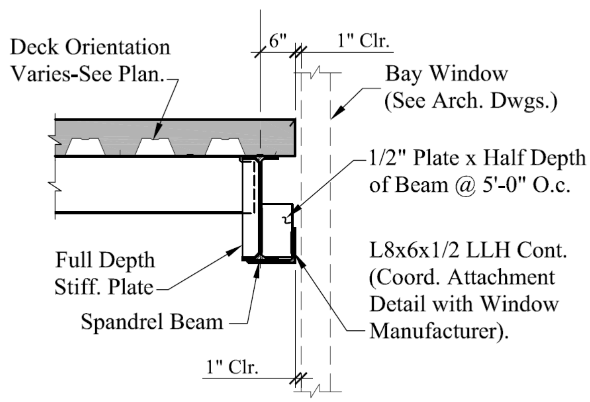
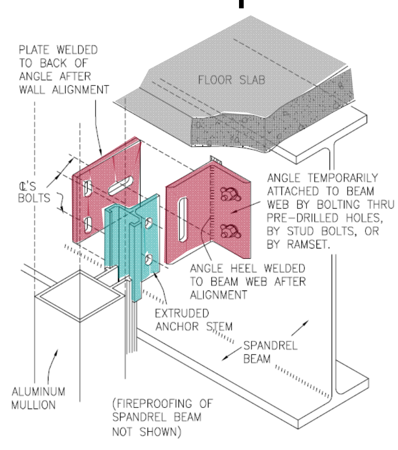
Aluminum Curtain Wall Systems

Attachment to Spandrel Beam



Aluminum Curtain Wall Systems

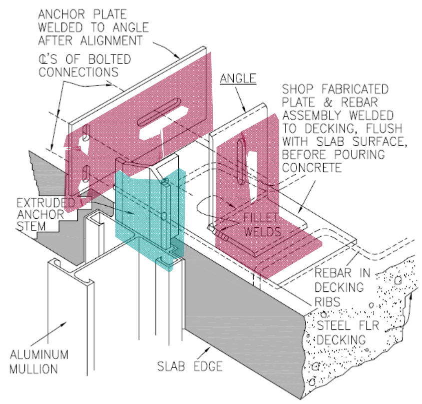
Attachment to Spandrel Beam



Movable anchor attached to face of spandrel beam

Aluminum Curtain Wall Systems

Attachment to Top of Slab



Movable anchor located on top of floor slab

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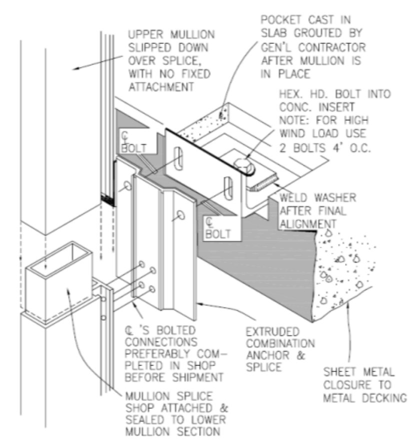
Aluminum Curtain Wall Systems

Attachment to Top of Slab



Fixed anchor for top of mullion, movable anchor for bottom of mullion above, located in pocket cast in top of floor slab

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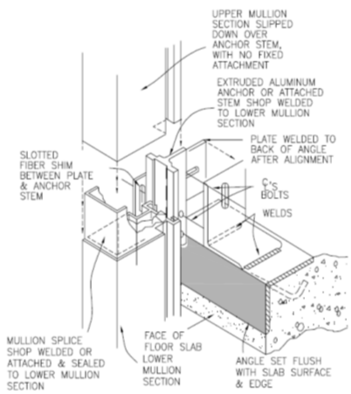
Aluminum Curtain Wall Systems

Attachment to Top of Slab



Fixed anchor for top of mullion, movable anchor for bottom of mullion above, located on top of floor slab

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Aluminum Curtain Wall Systems

Potential Problems

- Large gaps between the anchors and the primary building structure can result in excessive bending stresses.
- Coordination of locations for adjustment.
- Slotted holes must be long enough to accommodate adjustment.

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Aluminum Curtain Wall Systems

Potential Problems

- Coordination of bolted attachments to the primary building structure.
- Mullion splices should properly account for volume changes and movement of the primary building structure.

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Sizing Joints for Vertical Movement

Sizing Joints for Vertical Movement

Facade joints are building components just like mechanical or structural components and need to be explicitly **designed**.

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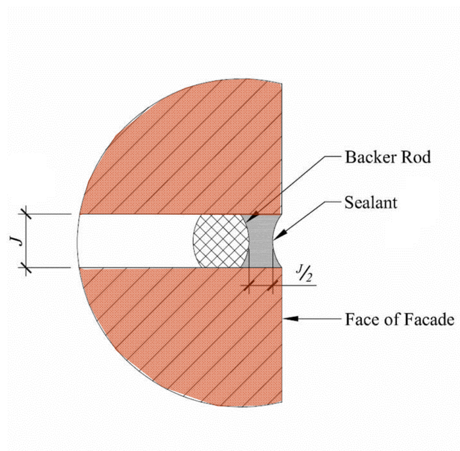
Sizing Joints for Vertical Movement

Joint Fundamentals

- Joints are necessary in facades.
- Joints accommodate movement and tolerances.
- Joints control air and water - especially in barrier systems.



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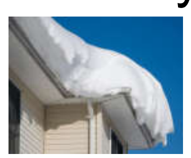
Sizing Joints for Vertical Movement

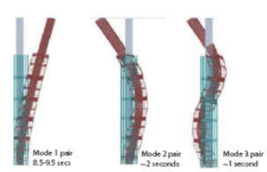
Movement Types



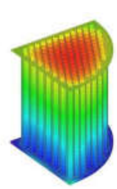
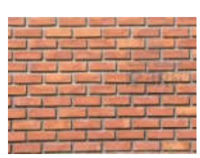


- Dead (Self) Load
- Superimposed Dead Load
- Live Load
- Snow/Rain Load

- Wind Load Drifts
- Seismic (Earthquake) Drifts





- Long-Term Shrinkage
- Differential Settlement
- Thermal Movements
- Moisture Movements

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Sizing Joints for Vertical Movement

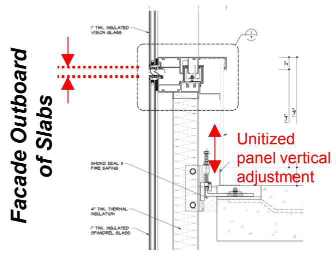
Joint Movements

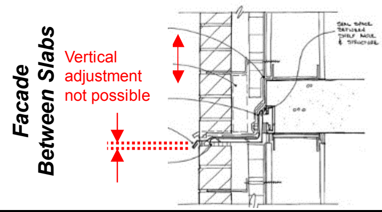
- Dead Load (Self-Weight) Deflections
- Superimposed Dead Load Deflections

Pre-Service Superstructure Movements → **DO NOT*** need to be considered in the facade joint design.

- Facade Weight Deflections

Superstructure Movements during Facade Installation → **MIGHT** need to be considered in the facade joint design, depending on the facade type and its ability to be adjusted after installation.





Sizing Joints for Vertical Movement

Joint Movements

- Live Load Deflections
- Snow/Rain Load Deflections
- Wind Load Deflections/Drift
- Seismic Deflections/Drift
- Long-Term Shrinkage
- Differential Settlement

In-Service Superstructure Movements → **MUST** be considered in the facade joint design.

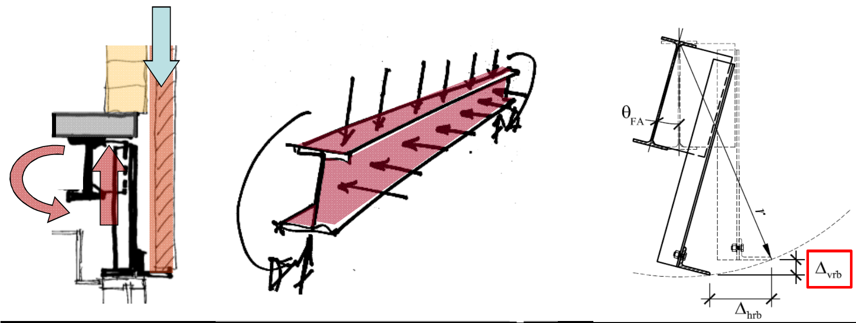
- Thermal Movements
- Moisture Movements

In-Service Facade Movements → **MUST** be considered in the facade joint design.

Sizing Joints for Vertical Movement

Vertical Joint Movements
Facade Loads

- Weight of facade causes spandrel beam to deflect vertically
- Spandrel beam may twist under weight of facade at slab edge
- Twisting motion translates to additional facade joint closure



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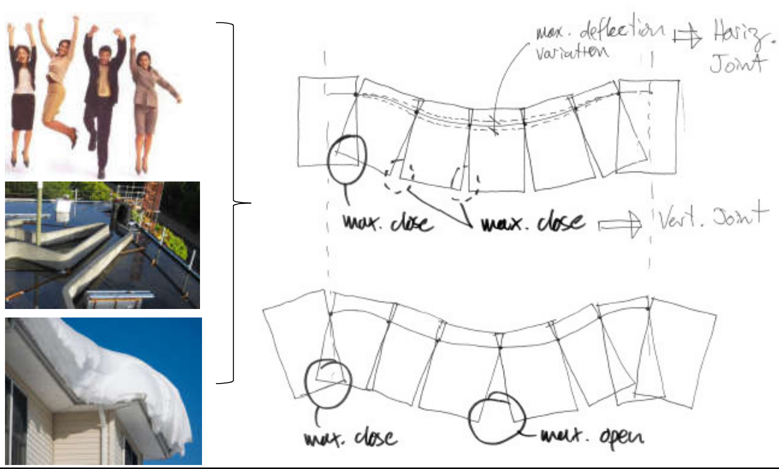
Sizing Joints for Vertical Movement

Vertical Joint Movements
Live, Snow, and Rain Loads



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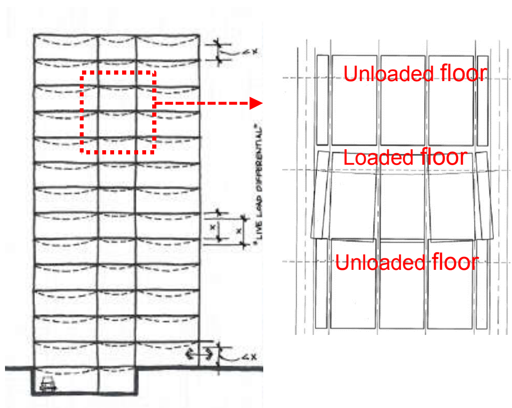
Sizing Joints for Vertical Movement

Vertical Joint Movements
Live, Snow, and Rain Loads



Potential "**pinch points**" include:

– Floors with different design live loads
– Unloaded floor beneath loaded floor
– Floor level immediately below the roof
– First level above foundation wall/base of facade

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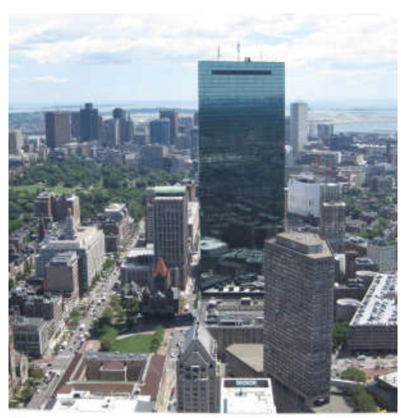
Sizing Joints for Vertical Movement

Vertical Joint Movement
Creep and Column Shortening

- Creep deformations over time in concrete buildings
- Column shortening in tall buildings, particularly at lower floors



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Sizing Joints for Vertical Movement

Vertical Joint Movement
Differential Settlement

- Anticipated building foundation differential settlement (if any) must be accounted for in design of facade joints

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Sizing Joints for Vertical Movement

Facade Movements
Thermal Changes

- Building superstructure typically is fully enclosed within building thermal envelope
- Facade elements must be designed to accommodate thermal movements:
  - –Morning to Night
  - –Winter to Summer

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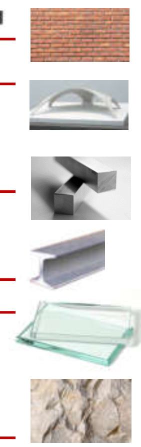
Sizing Joints for Vertical Movement

Facade Movements
Thermal Changes

- Coefficient of Linear Thermal Expansion of Common Building Materials

Construction Material	in/in/°F × 10⁻⁶
CLAY MASONRY	
Brick, Clay or Shale	3.6
Brick, Fire Clay	3.1
Tile, Clay or Shale	3.3
Tile, Fire Clay	2.5
CONCRETE	
Gravel Aggregate	6.0
Lightweight Structural	4.5
CONCRETE MASONRY	
Cinder Aggregate	3.1
Dense Aggregate	5.2
Expanded-Shale Aggregate	4.3
Expanded-Slag Aggregate	4.6
Volcanic Pumice and Aggregate	4.1
EXTERIOR INSULATION FINISH SYSTEMS	
EIFS - Light Colored	7.5
EIFS - Dark Colored	10.0
METALS	
Aluminum (6005 Alloy)	13.2
Brass, Red 230	10.0
Bronze, Arch. 385	10.4
Copper, 110	11.6
Iron	
Cast Gray	9.8
Wrought	5.9
Lead, Common	7.4
Monel	16.3
Stainless Steel	7.8
Type 302	9.6
Type 304	9.6
Structural Steel	6.7
Zinc	19.3
GLASS	
Plate	5.1
PLASTER	
Gypsum Aggregate	7.6
Perlite	5.2
Vermiculite Aggregate	5.9
PLASTICS	
Acrylics	40-50
Lexan	37.5
Phenolics	25-66
Plexiglas	39
Polyesters, Glass Reinforced	10-14
PVC	33
Vinyls	24-40
STONE	
Granite	6.2
Limestone	3.5
Marble	7.3



$$M = \Delta T * L * \alpha$$

- M: Thermal movement
- ΔT: Max Temperature Range
- L: Length
- α: Coefficient of Linear Thermal Expansion

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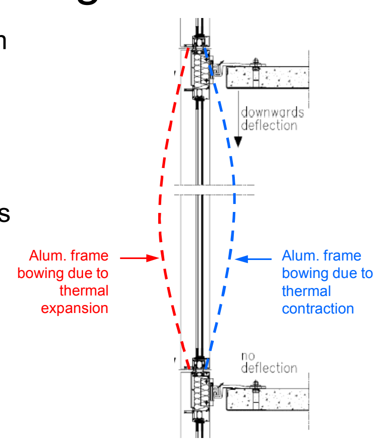
Sizing Joints for Vertical Movement

Facade Movements
Thermal Changes

- Thermally-broken curtainwall system will exhibit some differential thermal stresses.
- Slight bowing of the frame (dependent upon the thermal break's ability to transfer shear forces)
- For facade joint sizing, conservatively assume NO thermal break within curtainwall system.



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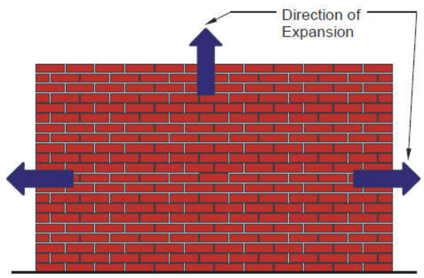
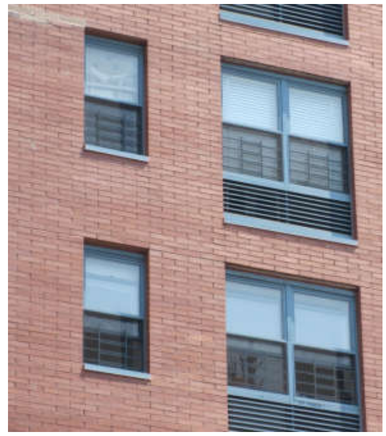
Sizing Joints for Vertical Movement

Facade Movements
Moisture Changes

- Most relevant for masonry and stone
- Brick masonry expands irreversibly due to water absorption by 0.02 – 0.07%.





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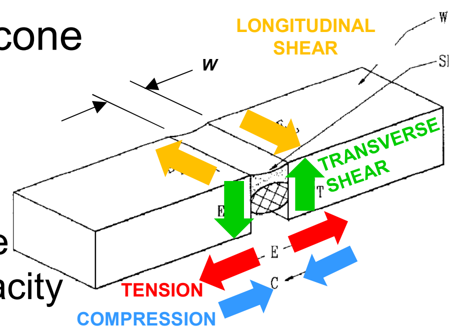
Sizing Joints for Vertical Movement

Joint Types: Sealant

- Medium Modulus Silicone Sealant
  - +50% / -50% typical movement capacity
  - Not all sealant has the same movement capacity
  - Need to confirm with manufacturer's product data



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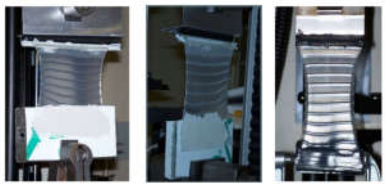
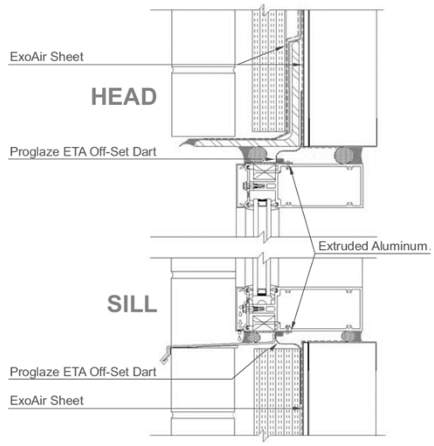
Sizing Joints for Vertical Movement

Joint Types: Extruded Silicone Sheet

- Typical Capacities
- +200% capacity
- -75% capacity





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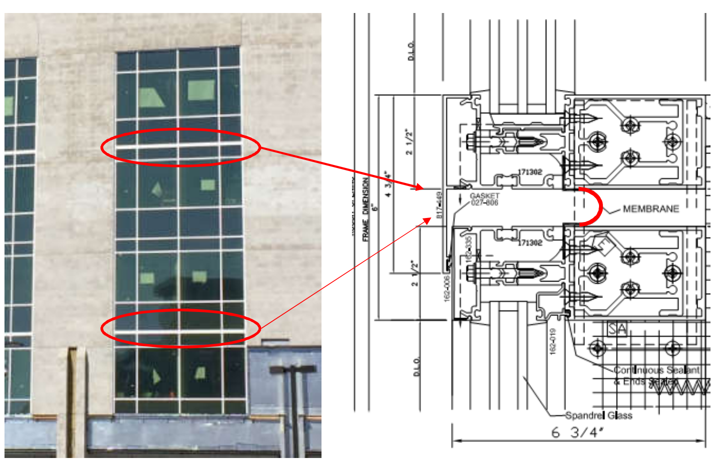
Sizing Joints for Vertical Movement

Joint Types: Extruded Silicone Sheet



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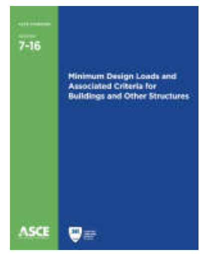
Sizing Joints for Vertical Movement

Load Combinations for Joint Design

- The building code provides some guidance on load combinations, but no specific requirements.
- 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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Sizing Joints for Vertical Movement

Sizing Horizontal Facade Joints

$$J' = \frac{\alpha \Delta_T h + k_e h + \delta_{sil}}{M} + Tol + \delta_{ps}$$

- α = coeff. thermal exp.
- k_e = coeff. Moisture exp.
- Δ_T = design temp. change
- h = vertical spacing between joints
- δ_{sil} = deflection after sealant is installed
- M = compressibility of sealant material
- Tol = allowance for tolerance
- δ_{ps} = deflection prior to sealant installation

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Sizing Joints for Vertical Movement

Example 7.1: Determination of Deflections for Structures Supporting Brick Veneers

For the clay brick veneer on a building supported at each floor level by a shelf angle, determine the amount by which the brick will expand and the amount by which the spandrel beam can deflect before compressing the joint filler material to its maximum allowable compressibility.

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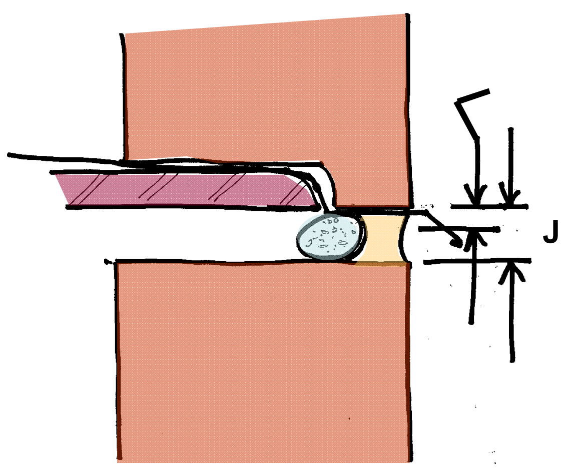
Sizing Joints for Vertical Movement

Example 7.1



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Sizing Joints for Vertical Movement

Example 7.1

Given:

The brick height between the shelf angles, h = 14 ft. The vertical as-built construction tolerance of the building, $Tol = 1/8$ in. The shelf angle deflection under the weight of the brick with respect to the floor below, $\delta_a = 1/16$ in.

The brick veneer is installed at an ambient temperature of 40 °F. The exterior wall of the building may experience a change in temperature, $\Delta_T = 100$ °F. The brick coefficient of thermal expansion, $\alpha = 4 \times 10^{-6}$ in./in./°F, and the brick coefficient of moisture expansion, $k_e = 3 \times 10^{-4}$ in./in.

The largest design gap width before sealant installation, $J' = 7/8$ in. The joint filler material is a high-performance sealant and the compressibility of the sealant material, $M = 50\%$.

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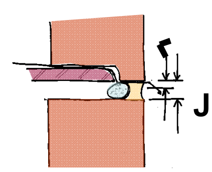
Sizing Joints for Vertical Movement

Example 7.1

Step 1: Determine the amount by which the brick will expand.

Width of sealant joint	$J = 0.875$ in.
Compressibility of sealant material	$M = 50\%$
Anticipated construction vertical tolerance	$Tol = 0.125$ in.
Shelf angle deflection	$\delta_a = 0.0625$ in.
Brick coefficient of thermal expansion	$\alpha = 4(10^{-6})$ in. / in.°F
Brick coefficient of moisture expansion	$k_e = 3(10^{-4})$ in./in.
Height of brick between shelf angles	$h = 14$ ft
Change in temperature	$\Delta_T = 100°F$



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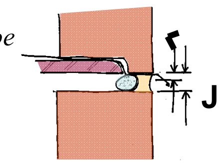
Sizing Joints for Vertical Movement

Example 7.1

The design gap before sealant is installed with may be expressed by the following equation:



$$J' = J + Tol + \delta_{ps}$$

$$J' = \frac{\alpha \cdot \Delta_T \cdot h + k_e \cdot h + \delta_{sil}}{M} + Tol + \delta_{ps}$$

$$\delta_{sil} + M\delta_{ps} = M\left(J' - Tol\right) - \left(\alpha\Delta_T h + k_e h\right)$$

$$\delta_s = \delta_{sil} + M\delta_{ps}$$

$$\delta_{vb} = k_e h + \alpha\Delta_T h$$

Note that the shelf angle deflection includes deflection of the horizontal leg of the angle as well as the deflection of the shelf angle between attachments to the building structure.

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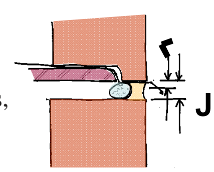
Sizing Joints for Vertical Movement

Example 7.1



The volume change of the brick between the shelf angles is,

$$\begin{aligned}\delta_{vb} &= k_e h + \alpha\Delta_T h \\ &= (3 \times 10^{-4}\text{ in./in.})(14\text{ ft})(12\text{ in./ft}) \\ &\quad + (4 \times 10^{-6}\text{ in./in./°F})(100\text{ °F})(14\text{ ft})(12\text{ in./ft}) \\ &= 0.118\text{ in.}\end{aligned}$$

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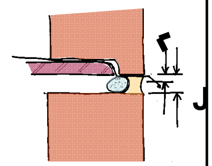
Sizing Joints for Vertical Movement

Example 7.1



The amount of movement that the joint can accommodate is,

$$\delta_{jm} = M\left(J' - Tol\right)$$
$$= 0.50\left(\tfrac{7}{8}\text{ in.} - \tfrac{1}{8}\text{ in.}\right)$$
$$= 0.375\text{ in.}$$

Thus, the permissible structural deflection, including the deflection due to the loads applied prior to installation of the sealant joint is,

$$\delta_s = \delta_{jm} - \delta_{vb}$$
$$= 0.375\text{ in.} - 0.118\text{ in.}$$
$$= 0.257\text{ in.}$$

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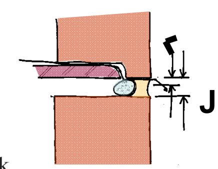
Sizing Joints for Vertical Movement

Example 7.1



The total structural deflection is $\delta_{sil} + M\delta_{ps}$, where

$$\delta_{ps} = \delta'_{sb} + \delta_a$$

The deflection of the spandrel beam, δ'_{sb}, due to the brick load and δ_a is the total deflection of the shelf angle due to the brick load. Substituting this quantity back into the equation for the total structural deflection, and limiting the total to not exceed δ_s,

$$\delta_{sil} + M\delta'_{sb} + M\delta_a \le \delta_s$$

The deflection of the spandrel beam is proportional to the load on it. Knowing that the uniformly distributed load due to the brick on the spandrel is w_{sb} and the superimposed load is w_{sil}, the deflection of the spandrel beam due to the uniformly distributed load due to the brick is,

$$\delta'_{sb} = \delta_{sil}\frac{w_{sb}}{w_{sil}}$$

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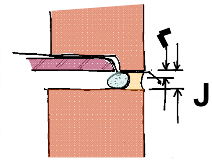
Sizing Joints for Vertical Movement

Example 7.1



This ratio assumes that the interior beams are parallel to the spandrel beam and do not frame into the spandrel beam. The assumption may still be a reasonable approximation when floor beams frame to the spandrel beam. Substituting this relationship back into the equation for δ_s above gives,

$$\delta_{sil} + M\left(\delta_{sil}\frac{w_{sb}}{w_{sil}}\right) + M\delta_a \le \delta_s$$

Rearranging this for δ_{sil}, the amount the spandrel beam can deflect is,

$$\delta_{sil} \le \frac{\delta_s - M\delta_a}{1 + M\left(\frac{w_{sb}}{w_{sil}}\right)}$$

$$\le \frac{0.257 \text{ in.} - 0.50\left(\frac{1}{16} \text{ in.}\right)}{1 + 0.50(1)}$$

$$\le 0.151 \text{ in.}$$

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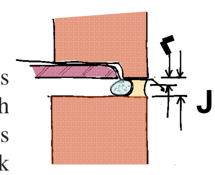
Sizing Joints for Vertical Movement

Example 7.1



This calculation requires the designer to make assumptions about the brick and superimposed loads on the beam, which may be difficult during preliminary design. In practice, it is conservative and often easier to use the total of the brick deflection and the superimposed load deflection such that:

$$\delta_s = \delta_{ps} + \delta_{sil}$$

Note that at the first elevated floor level where the brick below the shelf angle is supported on a foundation wall, δ_{ps} may be significant. At upper floor levels, however, where the spandrel beam on the floor below the shelf angle may deflect approximately as much as the spandrel beam supporting the shelf angle in question, δ_{ps} may be small. Thus, one can often conservatively select a beam for which the total deflection associated with cladding loads, superimposed dead loads, and live loads is less than δ_s.

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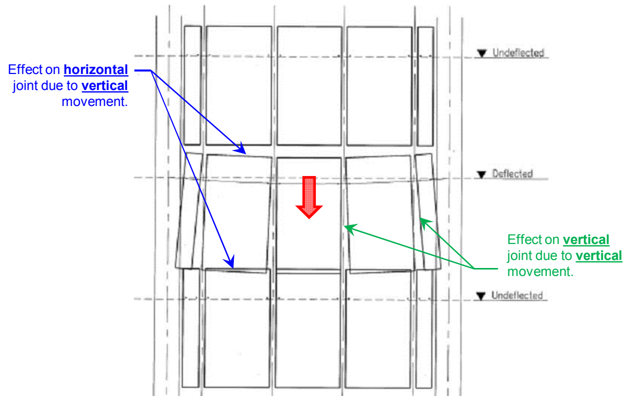
Sizing Joints for Vertical Movement

Effects of Vertical Movements on Vertical Joints

Vertical Movements



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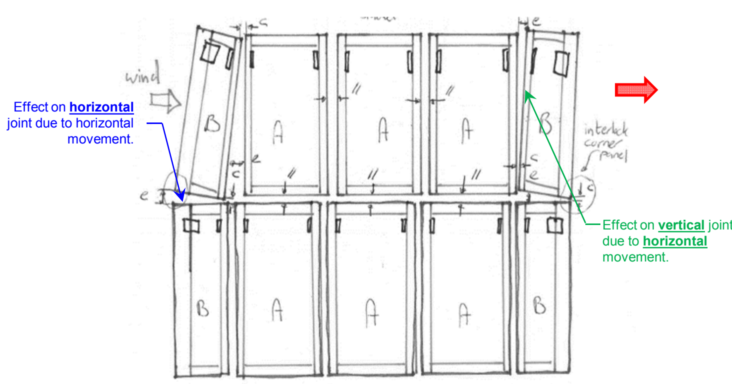
Sizing Joints for Vertical Movement

Effects of Horizontal Movements on Vertical Joints

Horizontal Movements



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Question time

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Individual Webinar Registrants

CEU/PDH Certificates

Within 2 business days…

- You will receive an email on how to report attendance from: registration@aisc.org.
- Be on the lookout: Check your spam filter! Check your junk folder!
- Completely fill out online form. Don't forget to check the boxes next to each attendee's name!

Individual Webinar Registrants

CEU/PDH Certificates

Within 2 business days…

- New reporting site (URL will be provided in the forthcoming email).
- Username: Same as AISC website username.
- Password: Same as AISC website password.

8-Session and 4-Session Registrants

CEU/PDH Certificates

One certificate will be issued at the conclusion of the full Night School course.

8-Session and 4-Session Registrants

Access to the quiz: Information for accessing the quiz will be emailed to you by Wednesday. It will contain a link to access the quiz. EMAIL COMES FROM NIGHTSCHOOL@AISC.ORG

Quiz and Attendance records: Posted Tuesday mornings. www.aisc.org/nightschool - click on Current Course Details.

Reasons for quiz:

- EEU – must take all quizzes and final to receive EEU (8-Session registrants only)
- CEUs/PDHS – If you watch a recorded session you must take quiz for CEUs/PDHs.
- REINFORCEMENT – Reinforce what you learned tonight. Get more out of the course.

NOTE: If you attend the live presentation, you do not have to take the quizzes to receive CEUs/PDHs.

8-Session and 4-Session Registrants

Access to the recording: Information for accessing the recording will be emailed to you by this Wednesday. The recording will be available for three weeks. For 8-session registrants only. EMAIL COMES FROM NIGHTSCHOOL@AISC.ORG.

CEUs/PDHS – If you watch a recorded session you must take AND PASS the quiz for CEUs/PDHs.

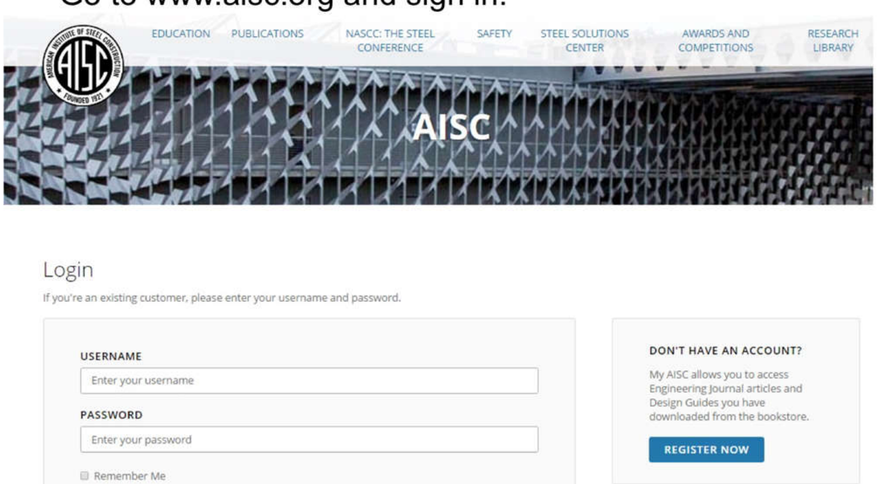
(Note that 4-Session registrants will not have access to the first four sessions)

8-Session and 4-Session Registrants

Find all your handouts, quizzes and quiz scores, recording access, and attendance information all in one place!

8-Session and 4-Session Registrants

Go to www.aisc.org and sign in.



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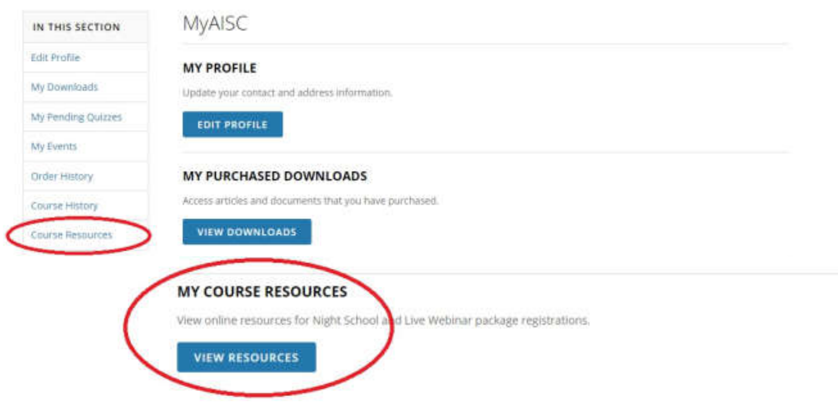
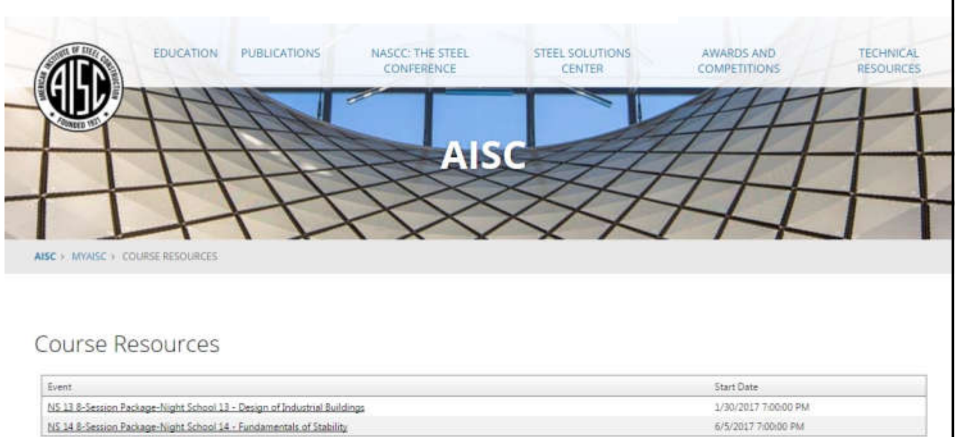


8-Session and 4-Session Registrants



8-Session and 4-Session Registrants

Night School 13: Design of Industrial Buildings

8-SESSION PACKAGE RESOURCES

Event	Date	Handouts	Video	Quiz	Attendance
NS13 - Design Criteria	1/30/2017 7:00:00 PM	Handouts	View Passcode: NS13DSN	Pass Score: 80	Pending
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 Bldg Bracing Dsn	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	

8-Session and 4-Session Registrants

- Weekly “quiz and recording” email.
- Weekly updates of the master Quiz and Attendance record found at www.aisc.org/nightschool. Scroll down to Quiz and Attendance records.
    - Updated on Tuesday mornings.

8-Session and 4-Session Registrants

- Webinar connection information:
  - Found in your registration confirmation/receipt.
  - Reminder email sent out Monday mornings.
- Link to handouts also found here.

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Thank You

Please give us your feedback!
Survey at conclusion of webinar.

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