

ENGINEERED MASONRY DESIGN COURSE

23-Supplemental Wall Analysis and Design Techniques



CANADA
MASONRY
DESIGN
CENTRE

Lecture Outline

- Solid Unreinforced Multi-Wythe Walls (10.3.1)
- Infill Shear Walls (10.4)
- Walls on Flexible Members (10.5)



Design of Solid Unreinforced Multi- Wythe Walls (pg. 654)

Also referred to as composite walls, or mass walls, they are a common type of historic masonry wall system

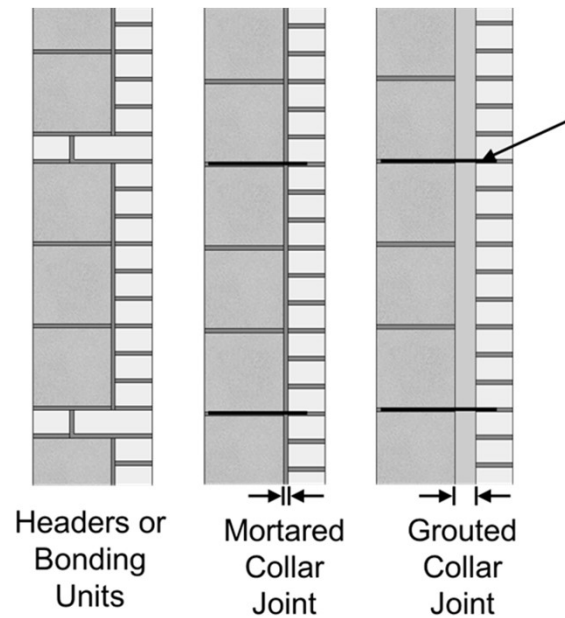
Terminology of CSA S304

Composite wall — masonry in which two or more parallel wythes are connected together by ties, collar joints, bonding units, or other mechanical means, or by a combination thereof, in such a way as to ensure shear transfer between wythes and composite action which may be partial or full. Depending upon the means by which composite action is achieved, the space between the wythes may consist of a cavity or a collar joint.

7.7.2 Composite and other multi-wythe solid walls

10.7.1 Composite and other multi-wythe solid walls

Terminology



- Composite Walls
 - *Solid* Unreinforced Multi-wythe
 - Historic walls would be unreinforced, more *recent construction* may have reinforcement present
 - *Solid masonry* may be constructed with hollow, cored, or semi-solid units
 - Cavity is filled solid, or no cavity is present

Terminology

- What is solid is not always solid
- NBC

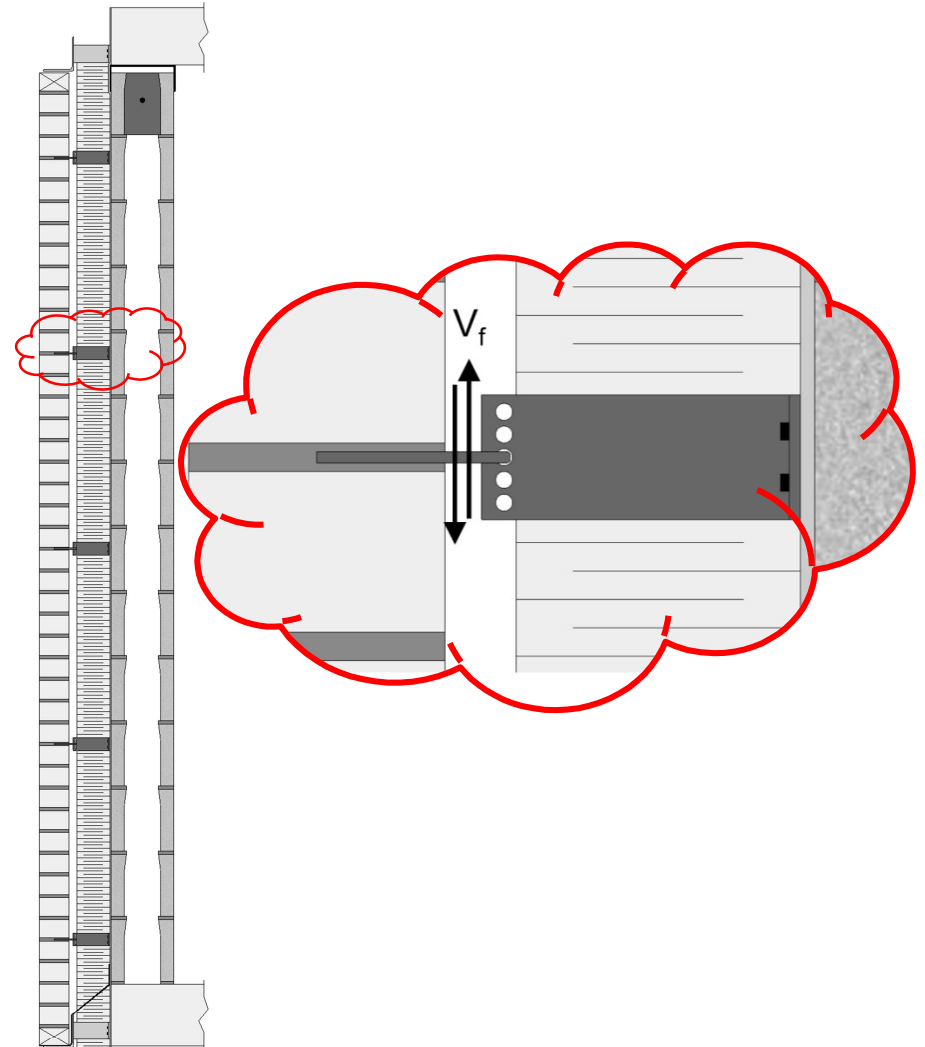
Solid masonry means a single wythe or multi-wythe construction made of *solid masonry units* or semi-solid, cored, or hollow masonry units, the cells of which may or may not be filled with mortar or grout. In multi-wythe masonry construction, the space between the wythes consists of a mortar-filled collar joint or grout-filled space and the wythes may or may not be constructed of the same masonry materials.

- CSA S304

Solid masonry — masonry of solid, semi-solid, cored, or hollow masonry units, of either single wythe or multi-wythe construction. The cells of semi-solid, cored, or hollow units need not be filled with mortar or grout. For multi-wythe construction, the space between the wythes consists of a mortar-filled collar joint, or grout-filled space. The wythes need not be constructed of the same masonry materials.

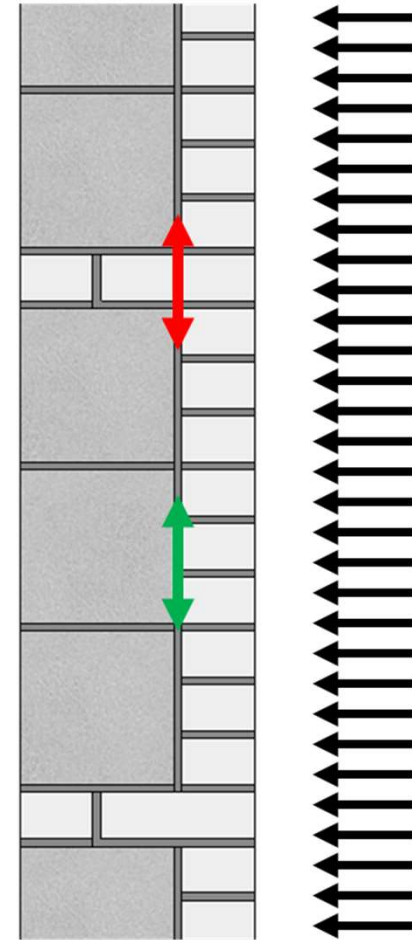
Terminology

- Composite Walls
 - Modern Masonry Backup-Veneer Walls
 - Engage in load shearing
 - Veneer ties (*shear ties*) span a typical modern cavity
- This is not *solid* masonry



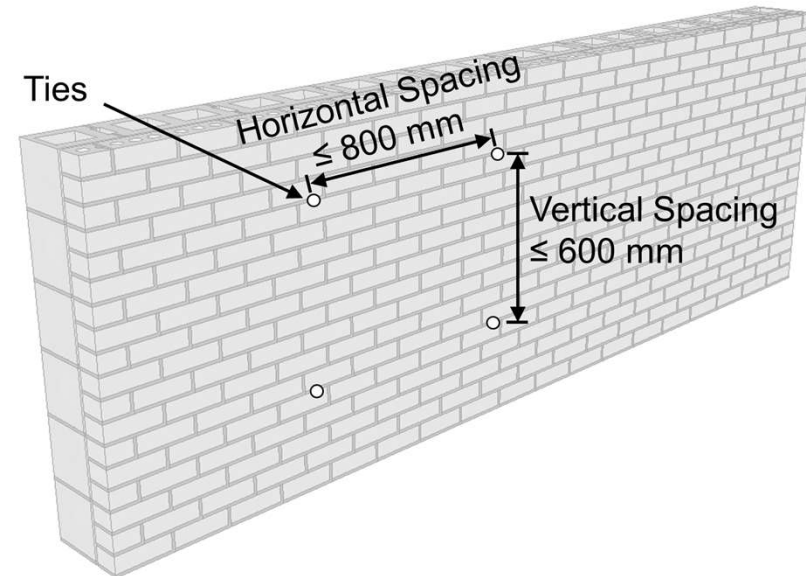
Shear Transfer

- Masonry Units
 - No code provision
 - Reasonable strength can be estimated as the square-root of the *unit* compressive strength
 - $\sqrt{f_{\text{unit}}}$
- Collar Joints
 - **Mortar (0.10 MPa)**
 - Up to 20 mm
 - **Grout (0.20 MPa)**
 - No Maximum



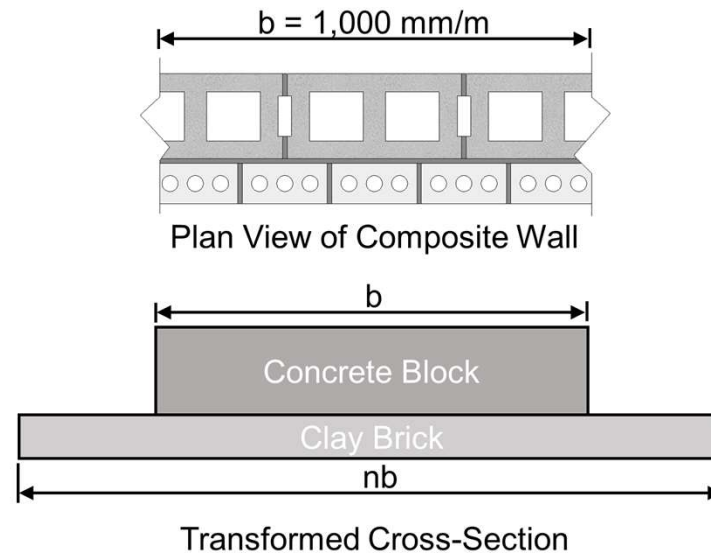
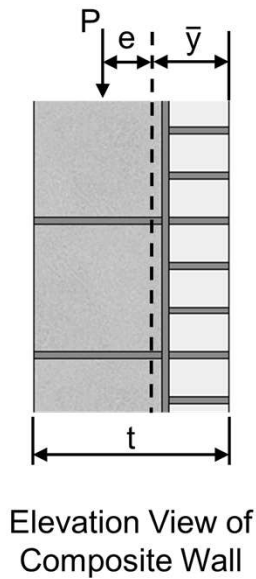
Common Concerns

- Historic
 - Multi-wythe brick
 - Similar materials
 - Face brick, interior brick, headers, fill
- Different Materials
 - Block and Brick Composite walls
 - Different material properties
 - Cracking due to differential movements
 - Use of ties required to resist shear flow



Analysis of Composite Walls

- Out-of-Plane wall design
 1. Transformed Section (mortar, grout, brick, block)



Analysis of Composite Walls

- Out-of-Plane wall design
 1. Transformed Section (mortar, grout, brick, block)
 2. Shear Flow (CSA S304-24)

$$V_r = \frac{\phi_m v_{bond} I \ell_w}{Q}$$

where

v_{bond} = 0.10 MPa for mortared collar joints

= 0.20 MPa for grouted collar joints

$$V_r = \frac{\phi_{co} \rho_{vc} f_y \ell_w I}{Q}$$

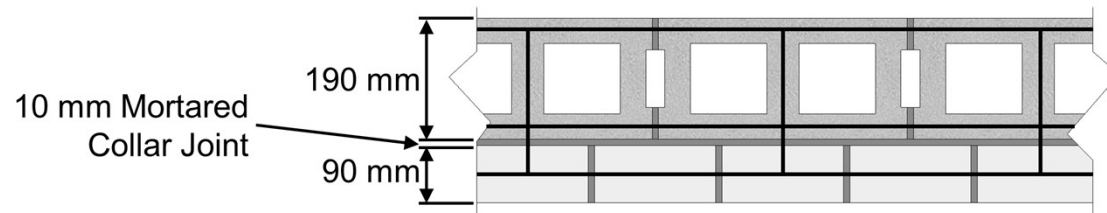
where

ϕ_{co} = 0.6 for connectors

ρ_{vc} = $A_{vc} / (s_v s_h)$

Design Example 10.3

1. Transformed Section
 - Area, Centroid, Moment of Inertia, Section Modulus
2. Bed Joint Wire
 - Longitudinal Wire – 485 MPa
 - Cross-Wires (butt welded) – $485 \div 2$ (CSA A370)
3. Asymmetric Cross-Section
 - Elastic design conditions
 - Varying values of f_t

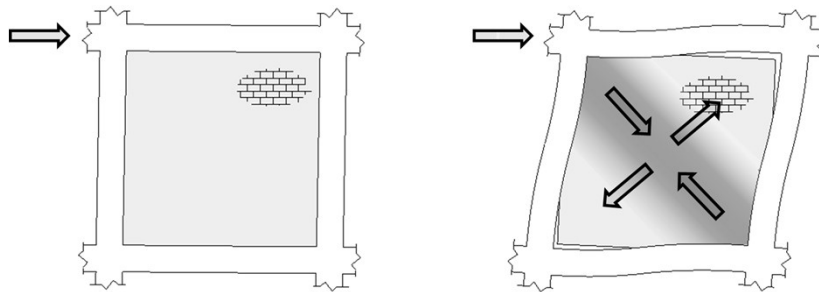


Infill Shear Walls (pg. 662)

Although an acceptable form of new construction infill walls are problematic when unintentionally detailed

Wall Types

- Partition Wall
 - Masonry wall typically built within a surrounding structure with gaps to ensure the masonry does not participate in in-plane load sharing
- Infill Shear Wall
 - Masonry wall built in tight along all 4 edges to engage in gravity and in-plane load sharing
 - Lateral loads resisted by formation of a compression strut

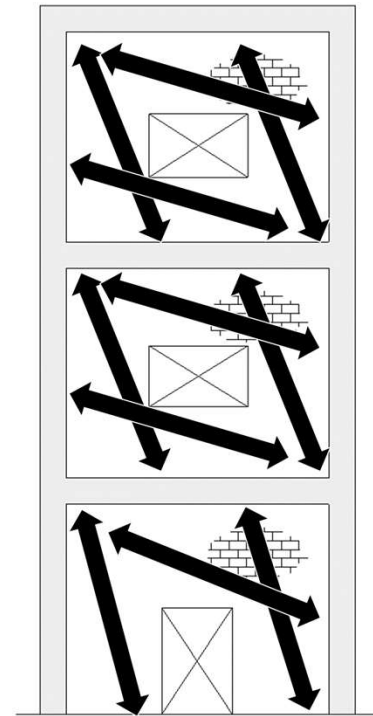


Wall Types

- Infill Shear Walls with Gaps or Openings
 - Infill wall behaviour may occur, but no S304 provisions are provided
 - Requires additional advanced analysis
- In-Plane Composite (Confined Masonry)
 - Where a masonry infill is tied or bonded to a structural frame to form a composite in-plane system
 - Not covered in CSA S304 or NBC

Infill Walls with Openings

- Unreinforced masonry
 - Modeling would require consideration of compression struts
 - Shear and sliding
 - Cracking



Infill Shear Walls

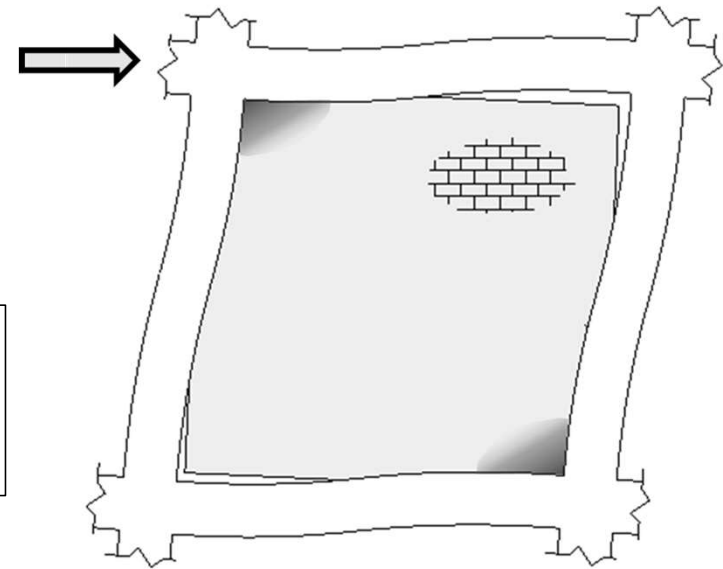
- An infill shear wall is a type of unreinforced masonry SFRS
- Resistance is based on the formation of a compression strut in the wall
- Design must ensure unintended failure modes do not occur
 - Capacity design principles
 - Out-of-plane instability
 - Infill walls would still need to be designed for out-of-plane loads and induced axial loads/bending within the compression strut
 - Damage to the frame
 - Crushing of strut

Failure Modes

- Corner Crushing of Masonry
 - Normal to Head Face
 - Slenderness Effects may limit axial strength
 - Consider out-of-plane effects

7.13.3.4.3 Compression resistance of the diagonal strut

The compressive strength of the diagonal strut shall be calculated in accordance with [Clause 7.2.2](#) using compressive strength of masonry normal to the head face times the effective cross-sectional area of the diagonal strut. The effective cross-sectional area of the diagonal strut shall be the lesser of the effective cross-sectional areas parallel or normal to the bed-joints. Slenderness effects shall be included in accordance with [Clause 7.7](#).

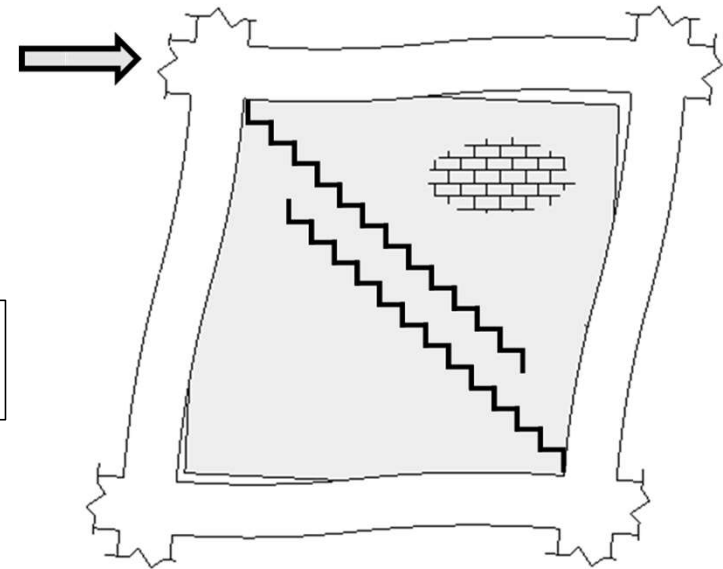


Failure Modes

- In-Plane Shear
 - No axial load contribution
 - Based on unreinforced masonry

7.13.3.1 In-plane shear

Infill shear walls shall be designed to resist the in-plane shear loads in accordance with [Clause 7.10.2](#), except that P_d shall be set to zero.



Failure Modes

- Sliding Shear
 - Compression strut acts as compressive failure
 - Consider loads on frame

7.13.3.2 In-plane sliding shear

Infill shear walls shall be designed to resist all applied in-plane shear loads in accordance with [Clause 7.10.4](#), except that P_d shall be replaced by P_{strut}

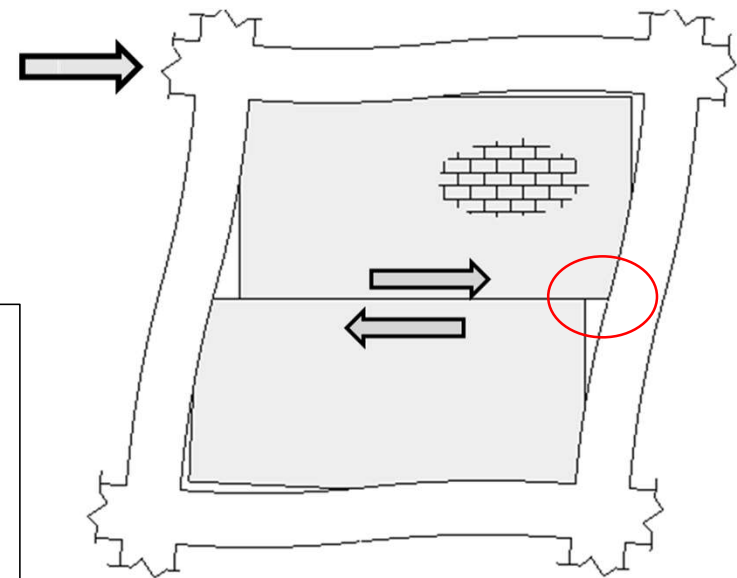
where

P_{strut} = compressive force in the unreinforced masonry acting normal to the sliding plane, normally taken as P_d plus 90% of the factored vertical component of the compressive forces resulting from the diagonal strut action found in infill shear walls, N

Shear forces are not transferred through the interface between the frame members and the infill shear wall except by direct bearing of the diagonal strut.

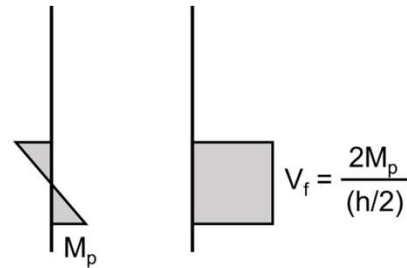
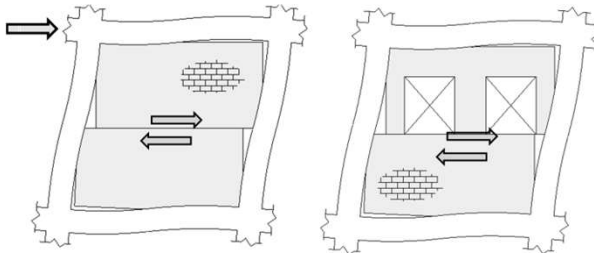
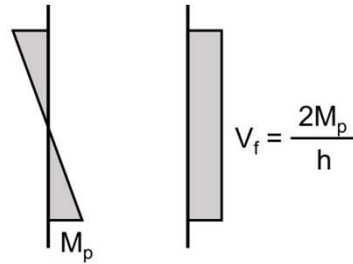
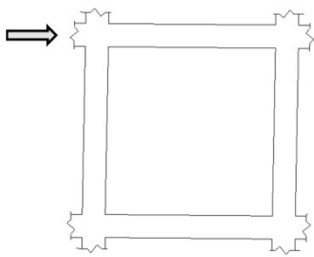
Notes:

- (1) Special attention should be given to the sliding shear resistance, since a sliding shear failure of the infill shear wall can lead to a knee-braced condition, potentially leading to a premature failure of the column in the surrounding frame.
- (2) The vertical component of the strut force is considered in the sliding shear resistance of the panel.
- (3) Frame members and their connections should be designed to resist the additional shear forces introduced by the diagonal strut action.



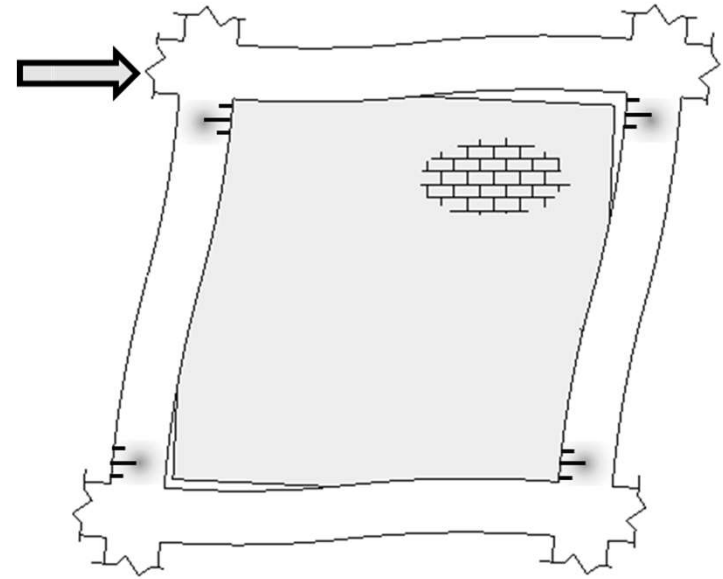
Knee Brace Failure

- Failure that can occur in the frame must be avoided
 - Design must consider changes to moment and shear profiles
 - Increased shear
 - New moment



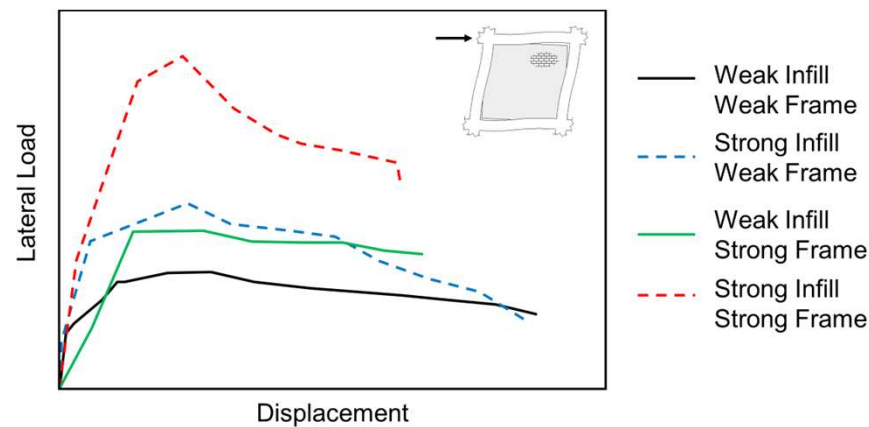
Failure Modes

- Failure in the Structural Frame
 - Can be due to complexity in frame interaction
 - Deformation of infill
 - Design of frame material should consider this



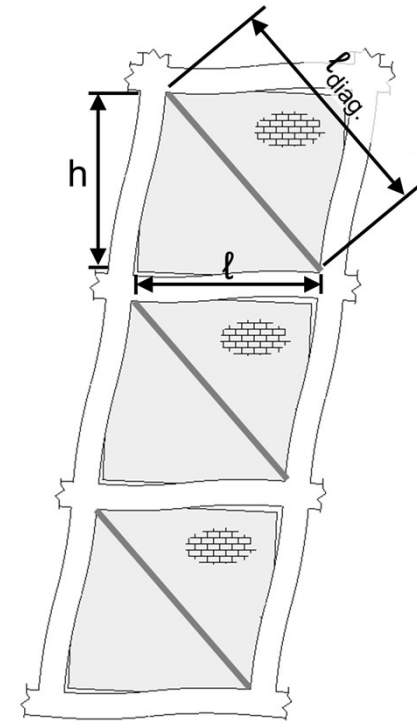
Infill Behaviour

- When intentionally designed
 - Can add significant stiffness and strength
 - Doubles up partition wall functionality with structural elements
- Why not just design structure as loadbearing masonry?



Compression Strut Properties

- Stiffness and Strength of the compression strut are required for lateral loads analysis
 - Infill walls will change the period and drift of buildings
 - Depending on their location they will alter the load distribution to other members and may impact torsion
 - Historic failures from unintentional infills have shown that they may have a catastrophic impact to buildings under seismic loads
 - Separate your partition walls



Compression Struts

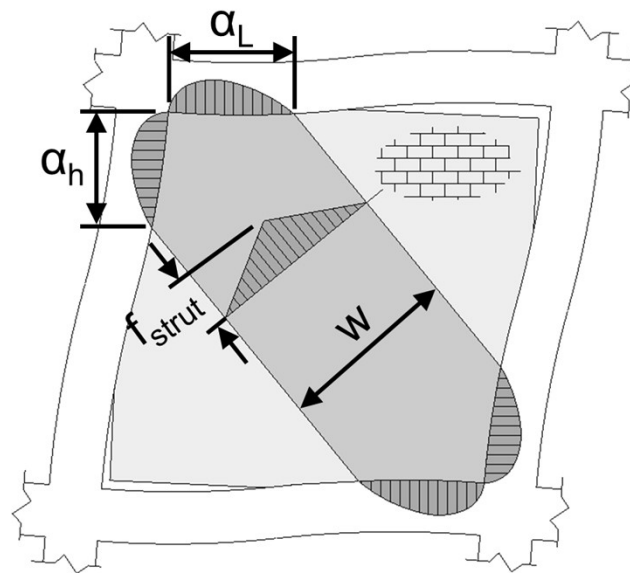
- Contact Length

$$\alpha_h = \frac{\pi}{2} \sqrt[4]{\frac{4E_f I_c h}{E_m t_e \sin 2\theta}}$$

$$\alpha_L = \pi \sqrt[4]{\frac{4E_f I_b \ell}{E_m t_e \sin 2\theta}}$$

- Strut Width

$$w = \sqrt{\alpha_h^2 + \alpha_L^2}$$



Design for Lateral Loads

- Design can consider the infill as a compression strut

- Forces based on

$$f_{strut} = \phi_m \chi (0.85 f'_m) w_{eff} t_e$$

- Stiffness of

$$k_{strut} = \frac{\phi_{st} w_{eff} t_e E_m}{\ell_s}$$

- $\chi = 0.5$ and $\phi_{st} = 0.5$

- Infill walls are considered to be unreinforced masonry

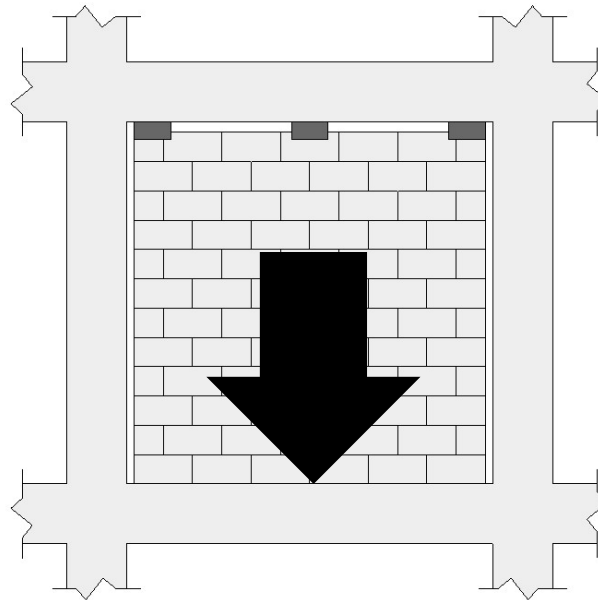
- $R_d = 1.0$, $R_o = 1.0$

Walls Supported on Flexible Beams (pg. 674)

Alterations to an existing masonry structure where the floor system does not have adequate stiffness

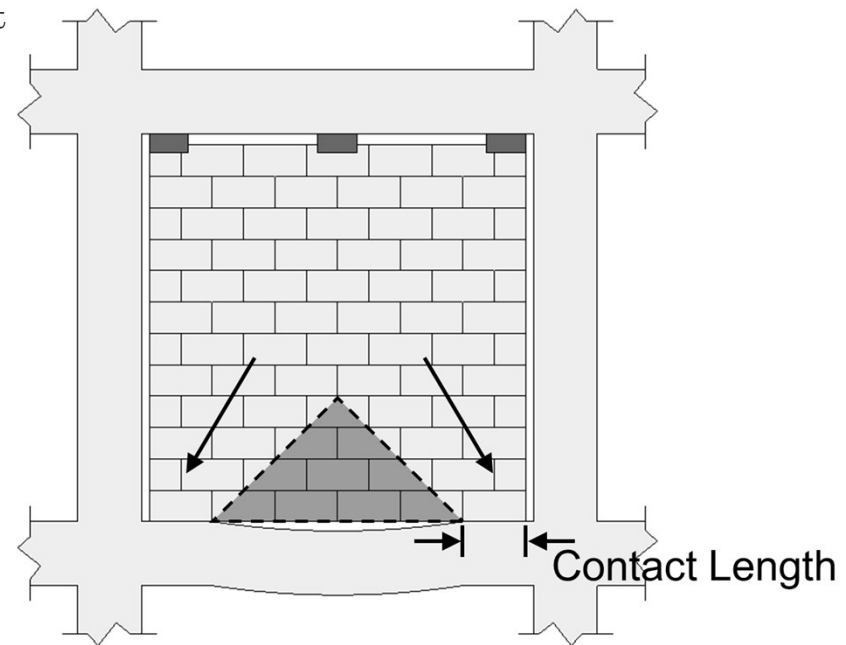
Typical Scenario

- Existing masonry walls adjacent to a new axial load
 - Heavy machinery, or storage, etc. is added to a building in a location close to an existing masonry partition wall



Analysis of Masonry

- Arching of self-weight can be considered
 - Contact length would need to be defined
 - Equilibrium between masonry and support



Advanced Modelling Techniques

- There is nothing in CSA S304 related to this
 - Would require engineering from first principles and likely some level of computer simulation
- Stability and arching of the wall facilitated by horizontal reinforcement

