J.B. SPEED SCHOOL OF ENGINEERING

Design of Shelf Angles for Masonry Veneers

W. Mark McGinley, Ph. D., PE
FASTM

MASONRY DAY
Indianapolis
March 3, 2016

Indiana/Kentucky Structural Masonry Coalition

1

Objectives

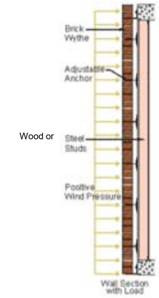
Present a Brief Overview of:

- Masonry Veneer Wall systems and their vertical supports.
- How these systems behave under vertical loads.
- How the vertical support systems can be designed.
- Present a few examples.

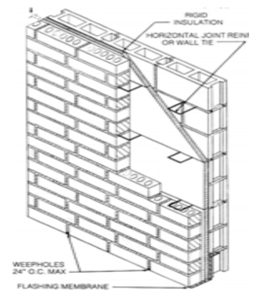
2

Masonry Veneer

Wood or Steel Stud Backed
From BIA TECH Note



CMU Backed
From Maconline

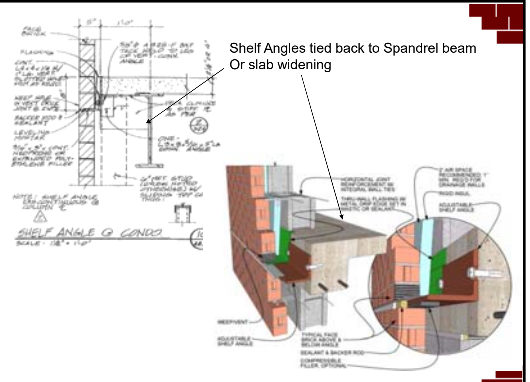


3

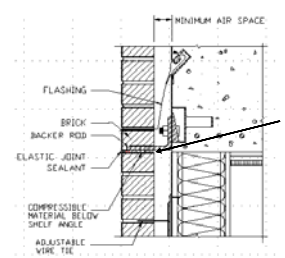
Introduction

In general, masonry veneer (stud backed) must be supported at very floor over 30 ft in height (except at gables). Also typically done for CMU backed veneers (differential movements).

This usually requires that shelf angles be placed at each floor above 30 ft. and designed to support the weight of veneer above.



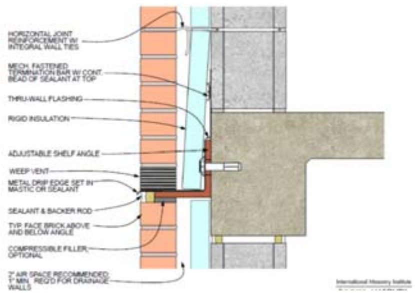
5



Movement joint below shelf angle must accommodate: Thermal and moisture expansion of brick and elastic and creep shorting of support elements.

What's wrong with this detail ?

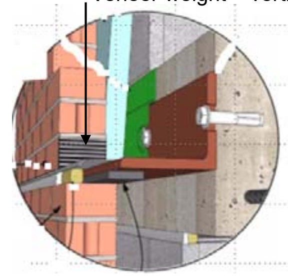
The angle is awful thin and where's the Continuous Insulation (CI)?



More “realistic detail” – Note the angle thickness and expansion joint height.

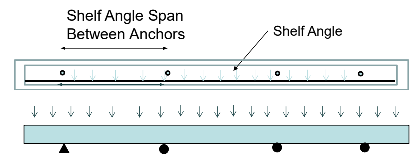
Design -typically ties spaced to resist out-of-plane loads

Veneer weight – vertical load



Shelf angle must be designed to resist vertical veneer weight load

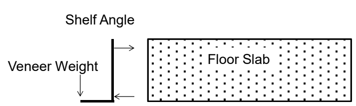
8



Common shelf angle design is to assume a uniform dead load from the veneer and design the angle to span as a beam between anchors OR

9

Shelf Angle Frame Design Model



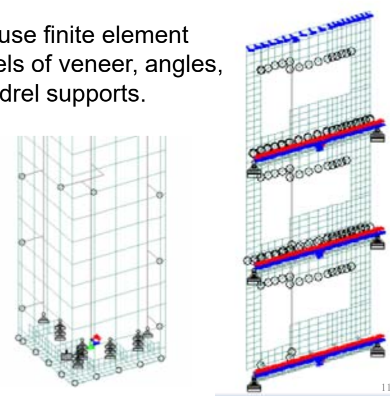
B) Anchored Frame Shelf Angle Model

Assuming the angle legs act as a bolted frame with a vertical dead load applied to the end of the horizontal leg

Question how much of the angle length is effective ?

10

Can use finite element models of veneer, angles, spandrel supports.



11

Harbor Courts Complex Baltimore

Office/Condominium

8-Story Hotel

Parking D

Lots of shelf angles

Investigation of Problems

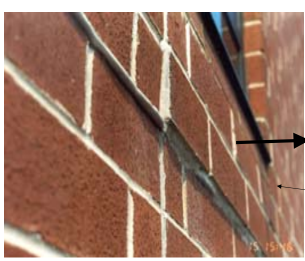

Localized Cracking and Distress of Brick

Mortar Blockage in Horizontal Expansion Joints Below Shelf Angle

Inadequate Bearing of Brick on Shelf Angle


Horizontal Expansion Joints

Problems

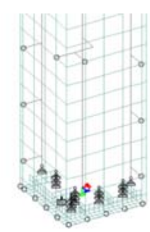
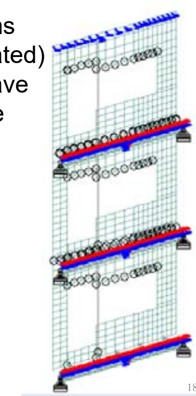


Popped out – no ties

Cracked away

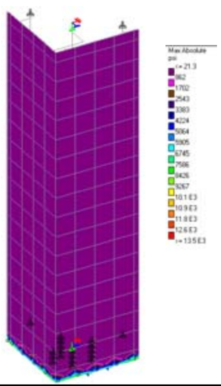
16


To solve these problems (mostly shelf angle related) you get to use FE to save money and lawyers are paying.

These analysis showed that the stiff brick (vertically) spans between the less flexible sections of the angle with little stress in the brick

(Dead load)



Based on finite element analyses and field testing, a number of observations about the shelf angle veneer interaction can be made:

1. The veneer is very stiff relative to its supports.
2. Shelf angles are poor in torsion and do not really act as beams between anchors.

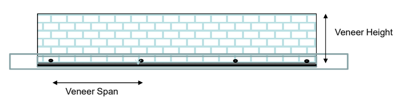
Based on finite element analyses and field testing, a number of observations about the shelf angle veneer interaction can be made:

3. The angle rotates away from veneer and provides little support to the veneer away from anchor.
4. The brick can span a significant distance.

Suggested Design Method Based on Observed Behavior:

1. Assume that the veneer will act as a beam spanning in-plane horizontally between anchors.
2. Design brick to ensure that the brick flexural stresses are low enough to be resisted by the veneer.
3. Determine the vertical veneer reactions at assumed support spacing.
4. Design shelf angle to transfer support reaction to slab or spandrel beams.

Veneer Span Design:



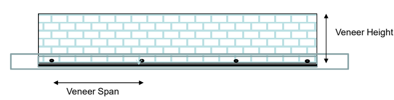
Limit Net flexural Tensile Stress

TMS 402 ASD Procedures for URM – Table 8.2.4.2 - F_t limits

But does not really have limits that apply to this type of loading You could may an argument that Stress are parallel to the Bed joints. For this loading and solid units the Ft varies from 40 to 106 psi.

For Normal to Bed joints (OOP) – F_t varies from 20 to 53 psi

Veneer Span Design:



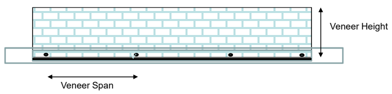
Limit Net flexural Tensile Stress
Assuming even as little as 20 psi as a limit to the allowable stress, simple supports and uniform loading, the following table of maximum spans for various veneer heights can be developed.

Table 1 Maximum Veneer Spans for Select Heights and Ft

Veneer Thickness (in)	Ft (psi)	Veneer Height (ft)	Span (ft)	Weight (psf)
3.625	20	1	5.38	40
3.625	20	2	7.61	40
3.625	20	4	10.77	40
3.625	20	6	13.19	40
3.625	20	8	15.23	40
3.625	20	10	17.03	40
3.625	20	12	18.65	40

Angle Design: Example 1

Support a 10 ft height of 4” clay brick veneer



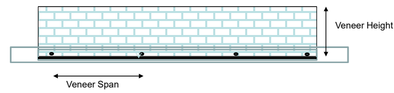
Previous Table would suggest the brick could span at least 17 ft. and as little as 1 ft height of veneer could span at least 5.4 ft.

Shear OK

The brick capacity will not often govern anchor spacing.

Try an anchor spacing of 6 ft. – The Veneer can span this distance for heights over 1.5 ft (Table 1)

Angle Design: Example 1



The anchor shear reaction would then be (assuming trib. width distribution):

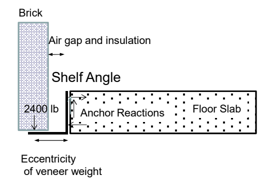
Reaction from brick = 40 psf x 10’ x 6’ = 2400 lb.

Adding an additional 10 lb/ft for the angle weight would produce a total vertical reaction of

R total = 2460 lb.

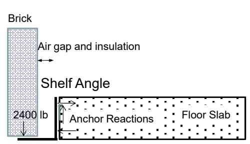
Angle Design: Example 1

At limit the brick reaction will be applied at the toe of the angle - However it is unlikely that the reaction will ever be applied at this location as the deflection of angle will actually move the reaction back from the toe.



Angle Design: Example 1

Thus a reasonable design condition is to assume that the Vertical Brick load is applied at the center of the veneer. If there is a 1” air gap, 1” of insulation and a 1/2 in. angle thickness the eccentricity to the center of the angle thickness can be determined (see next slide):



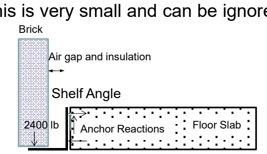
Angle Design: Example 1

Eccentricity of veneer weight
= 1 + 1 + ¼+ 3.625/2 = 4.06 in

The moment at the base of the angle toe =

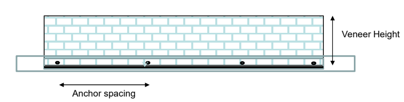
= 4.06 x 2400 =9750 lb.in

Note there is also a moment due to the angle self weight but this is very small and can be ignored.



Angle Design: Example 1

The moment at the base of the angle toe =9750 lb.in



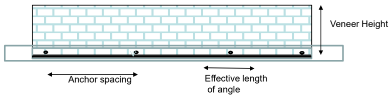
How much of the angle is resisting this moment?

At the limit, ½ the length of the angle on each side of anchor will resist the moment, however analysis shows the angle rotation will reduce the amount of angle effective in resisting the moment for longer anchor spacing.

How much angle resist the load depends on thickness of the angle, veneer stiffness and anchor spacing.

Angle Design: Example 1
10 ft height of 4" clay brick veneer

The moment at the base of the angle toe =9750 lb.in



In the past, the effective length of masonry wall resisting a concentrated load was 4x masonry wall thickness.

The range of analyses showed that
this could be used as a conservative rule of thumb
For the effective length of the angle
Use 4 x veneer thickness ≤ anchor spacing

31

Angle Design: Example 1
10 ft height of 4" clay brick veneer

Thus for the angle in question-
4 x 4 = 16 inches note that this can be quite conservative and is less than the 72 inch anchor spacing.

Using AISC LRFD provisions and a ϕM_y limit assuming F_y = 36 ksi. Limit deformation.

$S_{x\ required} = \frac{9750\ (1.2)}{0.9\ (36{,}000\ psi)} = 0.361\ in^3$

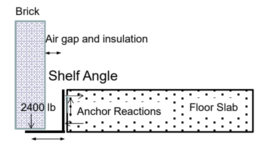
A 3/8" angle with 16 in. width - S = 0.375 in^3 ($S = bd^2/6$)

You could also make an argument to use $\phi M_p = \phi\ Z_x F_y$
And $Z_x = bd^2/6$

Angle Design: Example 1
10 ft height of 4" clay brick veneer

Both the vertical leg and the horizontal leg must resist the moment.
In addition the vertical leg must resist the tension of 2460 lb.

This produces an axial tension stress of = $\frac{2460}{\frac{3}{8} x\ 16}$ = 410 psi less then 2% of yield and by inspection the combined loading OK .

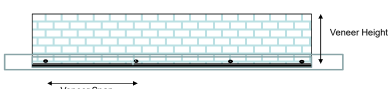


Use a 3/8 x 5 x 5 angle
– Size anchors to resist combined shear and tension loading not the weight is a little higher
But not significant.

Angle Design: Example 2 – 5 inch Cavity

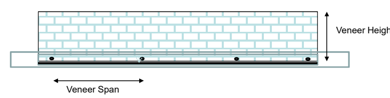
10 ft height of 4" clay brick veneer

But now assume that there is 4" of backing wall (cavity) insulation.



Try an anchor spacing of 4 ft. – The veneer can span this distance for heights over 3 courses.

Angle Design: Example 2 – 5 inch Cavity



The anchor shear reaction would then be (assuming trib. width distribution):

Reaction from brick = 40 psf x 10' x 4' = 1600 lb.

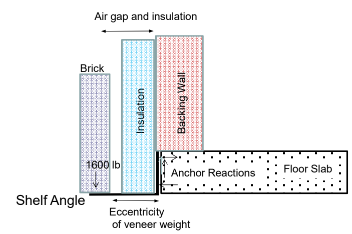
Adding an additional 15 lb/ft for the angle weight results in would produce a total vertical reaction of

R total = 1640 lb.

35

Angle Design: Example 2 – 5 inch cavity

The distance between the interface of the veneer and support wall is 1 + 4 = 5 in.



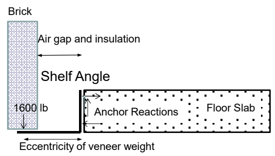
Note ties must be rationally designed as tie length exceeds prescriptive code limits.

36

Angle Design: Example 2 – 5 inch Cavity

Assume that the vertical brick load is applied at the center of the veneer. Assume a ½ in. angle thickness.

Eccentricity
of veneer weight = 5+ ¼+ 3.625/2 = 7.06 in

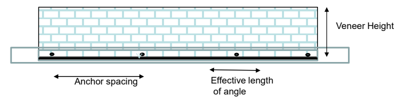


The moment at the base of the angle toe = 7.06 x 1600 =11,296 lb.in
Note there is also a moment due to the angle self weight but this is very small and can be ignored.

37

Angle Design: Example 2 – 5 inch cavity
10 ft. height of 4 in. clay brick veneer

The moment at the base of the angle toe =11,296 lb.in



Effective length of angle
Use 4 x veneer thickness ≤ anchor spacing

16 inches is less than 48 so use effective length of angle = 16 inches again.

38

Angle Design: Example 2

Using AISC LRFD provisions and a ϕM_y limit assuming F_y = 36 ksi. Limit deformation.

$S_{x\ required} = \frac{11,296\ (1.2)}{0.9\ (36,000\ psi)} = 0.418\ in^3$

The angle will have to be 8 inches to pick up the brick minimum thickness of this angle size is 7/16 in.

A 7/16 in. angle with 16 in. width - S = 0.510 in^3

Again you could make an argument to use ϕM_p

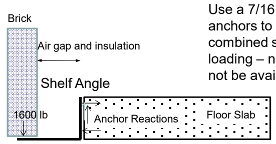
Angle Design: Example 2

Both the vertical leg and the horizontal leg must resist the moment.
In addition the vertical leg must resist the tension of 1640 lb.

This produces an axial tension stress of = $\frac{1640}{\frac{7}{16} x\ 16}$ = 234 psi

less then 1% of yield and by inspection the combined loading OK .

Use a 7/16 x 8 x 6 angle – Size anchors to resist combined shear and tension loading – note 7/16 x 6 x 8 may not be available everywhere



40

Summary

- Presented a brief overview of Masonry Veneer Wall systems and their vertical supports
- Discussed how these systems behave
- Presented a method how they can be designed
- Presented few examples for design

41

J.B. SPEED SCHOOL OF ENGINEERING

THANK YOU !

QUESTIONS?

42