WHY DOES TMS 402 STANDARD HAVE A DESIGN CHECK FOR WEB SHEAR STRESSES?

Historically, the shear stresses in the webs connecting the face shells of a concrete masonry unit were not explicitly checked as part of routine design practice. Instead, ASTM C90, *Standard Specification for Loadbearing Concrete Masonry Units* [1], prescriptively required a minimum amount of web such that this design check was unnecessary. In 2011, however, ASTM C90 was modified to allow concrete masonry units with alternative web configurations (such as single or double-open-ended units); thus prompting the new design check – but only for unreinforced/ungrouted masonry assemblies. Once grout is added to the cells of a unit, the presence of the grout more than compensates for any reduction in the web area. The design check discussed herein was first introduced into TMS 402 in the 2013 version [2]. This FAQ discusses this check in relation to the 2022 version of TMS 402 [3].

DESIGN CHECKS

Both the allowable stress and strength design provisions (Chapters 8 and 9, respectively of TMS 402 -22 require a check on web shear stress for unreinforced masonry construction.

For allowable stress design, the shear stresses in the webs of a concrete masonry assembly are calculated in accordance with Section 8.2.6.1 as follows:

$$f_v = \frac{VQ}{I_n b}$$

Where:

f_v = calculated shear stress in masonry, lb/in.^{2} (MPa)
I_n = moment of inertia of net cross-sectional area of a member, in.^{4} (mm^4)
Q = first moment about the centroid of an area between the extreme fiber and the plane at which the shear stress is being calculated, in.^{3} (mm^3)
V = shear force, lb. (N)
b = width of section for which shear stresses are being calculated (e.g., web thickness), in. (mm)

TMS 402 further stipulates that the calculated shear stresses in the webs cannot exceed the following and some other conditions stipulated in TMS 402 section 8.2.6.2:

$$F_v = 1.5\sqrt{f'_m}$$

Where:

F_v = allowable shear stress, lb/in.^{2} (MPa)
f'_m = specified compressive strength of the masonry, lb/in.^{2} (MPa)

Similarly, Section 9.2.6.2 contains the following limits for web shear stresses in assemblies designed using the strength design provisions:

$$\phi V_n = \frac{\phi 3.8\sqrt{f'_m}I_n b}{Q}$$

Where:

ϕ = strength-reduction factor taken equal to 0.80
A_{nv} = net shear area, in.^{2} (mm^2)
V_n = nominal shear strength, lb (N)

SAMPLE CALCULATIONS

Consider, for example, a standard 8 in. (203 mm) wide concrete masonry assembly measuring 18 feet (5.48 m) in height with a specified compressive strength of 2,000 lb/in.^{2} (13.8 MPa). If this wall were subjected to a 25 lb/ft^2 (1197 Pa) out-of-plane design pressure, the resulting maximum shear would be 225 lb/ft (3,283 N/m). Correspondingly, the critical shear carried by the webs of individual units within the assembly would be:

$$V_{web} = \frac{Design\ Shear * Nominal\ Unit\ Length}{(12\ in.)} = \frac{(225)(16)}{(12)}$$

$$= 300\ lb$$

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While the actual unit configuration may vary, if we assume this assembly was constructed using double-open-ended units (H-block) similar to that below, then the resulting cross-sectional properties for this unit would be (assuming standard 3/8 in. (10 mm) mortar joints are used):
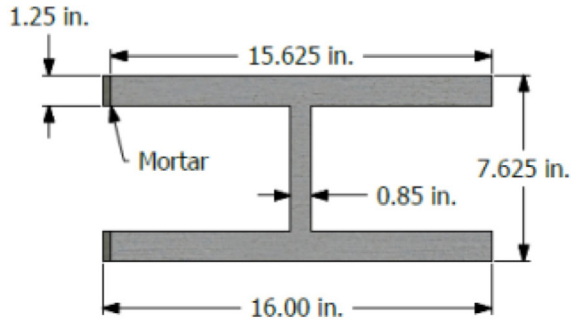
$$I_n = \left(\frac{1}{12}\right)(16)(7.625)^3 - \left(\frac{1}{12}\right)(7.575)(5.125)^3(2)$$
$$= 421.1 \; in.^4$$

$$Q = (1.25)(16)(3.188) + (0.85)(2.563)(1.281)$$
$$= 66.6 \; in.^3$$

These section properties are determined about the centroid of the unit cross-section, which also corresponds to the location where the shear stresses across the web will be the largest. Using the allowable stress design provisions, the resulting critical shear stress is:

$$f_v = \frac{(300)(66.6)}{(421.1)(0.85)} = 55.8 \; lb/in^2$$

We then compare the shear stresses across the unit with the allowable shear stresses. In reality one could argue that the compressive strength of the unit should be used as it is solely the web material that is resisting the shear stresses; however, for simplicity we'll conservatively apply the specified assembly compressive strength.

$$F_v = 1.5\sqrt{2000} = 67 \; {}^{lb}/_{in.^2}$$

While TMS 402 is not clear when applying the new web shear design checks on assemblies containing non-structural materials, such as insulation, when the material does not contribute to the strength of the assembly, the calculation would proceed exactly as above simply neglecting the presence of the non-structural material. If, however, the assembly contained both grout and insulation, then the section properties of the unit would need to be adjusted to account for the presence of the grout. Further, in cases where the insulation interrupts the bond between the face shell and the grout, as illustrated in the assembly configuration below, the web shear stresses

should be checked, regardless of whether the assembly was reinforced or not.
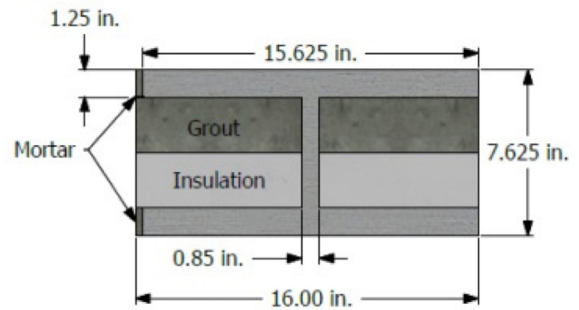

Assuming the grout and insulation each fill one-half of each cell in the assembly, we first determine the new centroid of the cross-section:

	Area, A (in.²)	Area Centroid Depth, y (in.)	(A)(y)(in.³)
Face Shell 1	20.00	7.03	140.50
Grout Area 1	19.41	5.09	98.87
Grout Area 2	19.41	5.09	98.87
Web	4.36	3.81	16.61
Face Shell 2	20.00	0.63	12.50
Total	83.18		367.36

Therefore, the resulting location of the new centroid of the cross-section, C, is:

$$C = \frac{367.36 \; in^3}{83.18 \; in^2} = 4.42 \; in.$$

Using conventional parallel axis theorem, the resulting moment of inertia of the composite unit/grout cross section is then:
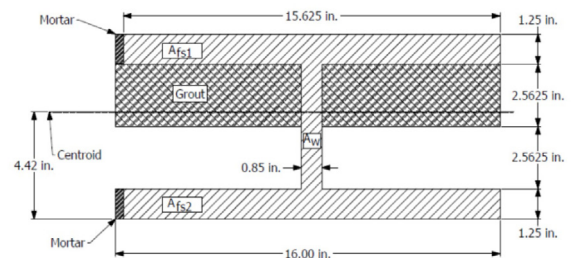
	Moment of Inertia, I (in.⁴)	Area, A (in.²)	Centroid Offset, d (in.)	$(A)(d^2)$ (in.⁴)	Composite Moment of Inertia, I_c (in.⁴)
Face Shell 1	2.60	20.00	2.58	133.49	136.09
Grout Area 1	10.62	19.41	0.68	8.90	19.52
Grout Area 2	10.62	19.41	0.68	8.90	19.52
Web	9.53	4.36	-0.60	1.59	11.12
Face Shell 2	2.60	20.00	3.79	287.51	290.12
Total					476.38

Next we'll need to determine Q for the location where the shear stresses are the largest. In this example it will be nearest to the center of the cross section of the unit where the web of the unit is the thinnest as follows:

$$Q = (1.25\ in. +2.5625\ in.)(16\ in.)$$
$$\left(7.625\ in. -4.42\ in. -\frac{1.25\ in. +2.5625\ in.}{2}\right)$$
$$= 79.2\ in.^3$$

The resulting critical shear stress is:

$$f_v = \frac{(300\ lb)(79.2\ in^3)}{(476.38\ in^4)(0.85\ in)} = 58.7\ lb/in^2$$

Which is still less than the allowable shear stress of 67 lb/in.² (0.46 MPa).

While this example illustrates the application of the web shear check using the allowable stress design provisions, the strength design shear check proceeds similarly using the nominal shear strength of the assembly.

In reality one could generally assess by inspection that if the assembly without grout was able to safely resist the resulting web shear stresses then the introduction of grout into the assembly would not weaken the assembly's ability to transfer shear stresses; thus considerably simplifying the design. In cases where the grout-to-face shell bond is uninterrupted by insulation or other non-structural materials located within the cells of the concrete masonry assembly, the provisions of TMS 402 would not require web shear stresses to be checked, as the presence of the grout compensates for any reduction in the web area connecting the face shells.

REFERENCES

1. ASTM C90, 2022, *Standard Specification for Loadbearing Concrete Masonry Units*, ASTM International, West Conshohocken, PA, 2022.

2. *Building Code Requirements for Masonry Structures*, TMS 402/ACI 530/ASCE 5-2013, The Masonry Society, Longmont, CO, 2013

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