Design of Beams

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Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

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Course Description

This session will review the allowable stress design of masonry beams and lintels, including an examination of whether arching action can be used to reduce the loads on these elements. Deflection calculations will be reviewed, along with code compliance requirements relating to reinforcement and grouting. Partial depth beams, deep beams, shear reinforcement long-span beam criteria, torsion, and other requirements will also be covered.

Learning Objectives

1. Introduce the design of masonry beams and lintels for bending moment and shear
2. Describe deflection calculations for beams and lintels
3. Review partial depth beams and partial grouting
4. Examine arching and discuss when it can be used

Determination of Loads, Shears, and Moments

- Arching
- Beam Depth
- Beam Span

5

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Arching

(State College, PA)

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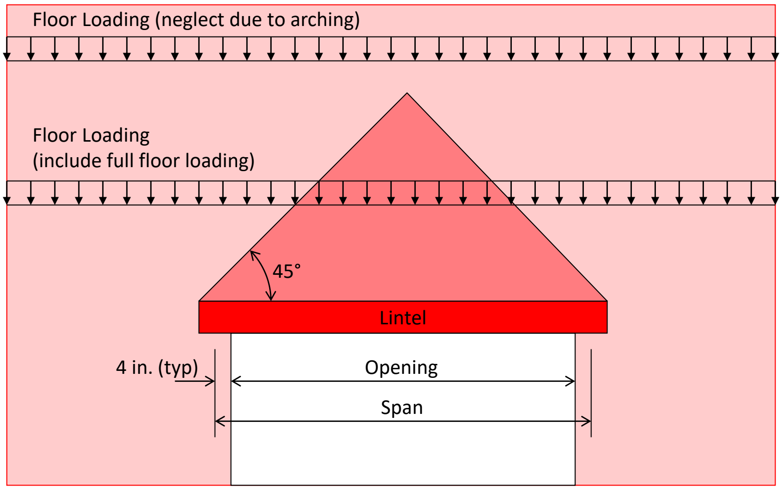
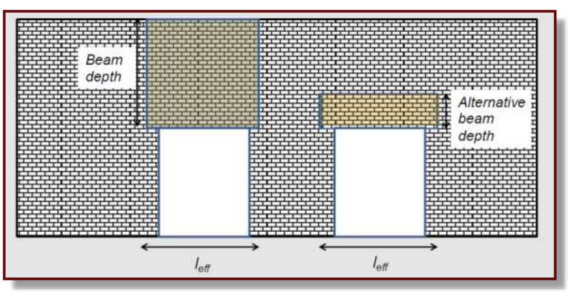
Arching



Beam Depth

TMS 402-16: 5.2 – Use either 5.2.1 or 5.2.2
2016 Masonry Designers' Guide: 7.5.3.5 and 7.5.3.7

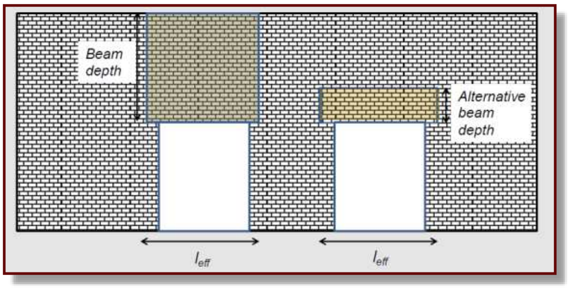


TMS 402 Figure CC-5.2-2

TMS Strength Design Guide Figure 6.3.1-3

Beam Depth

TMS 402-16: 5.2 – Use either 5.2.1 or 5.2.2
2016 Masonry Designers' Guide: 7.5.3.3



TMS 402 Figure CC-5.2-2

TMS 402 Section 2.2

- Beam: A member designed primarily to resist flexure and shear induced by loads perpendicular to its longitudinal axis.
- Deep Beam: A beam that has an effective span-to-depth ratio, l_{eff}/d_v, less than 3 for a continuous span and less than 2 for a simple span.
- ***Commentary for 5.2.2 Deep beams clarifies that 'depth of the beam need not be taken as the entire height of masonry above the opening.'***
- ***Design to control deflection***

Beam Span: Beams not built integrally with supports

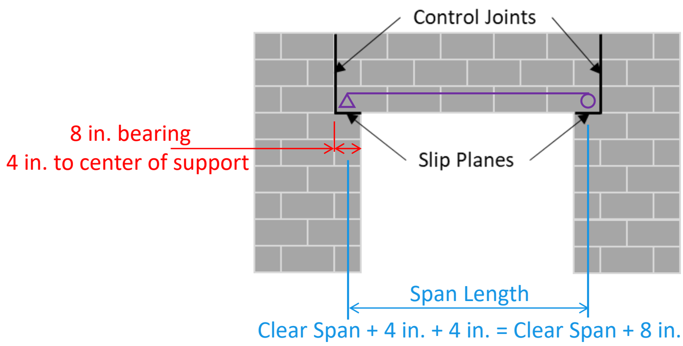
Poll: Who still designs beams as 'not built integrally with supports'?

Beam Span: Beams not built integrally with supports

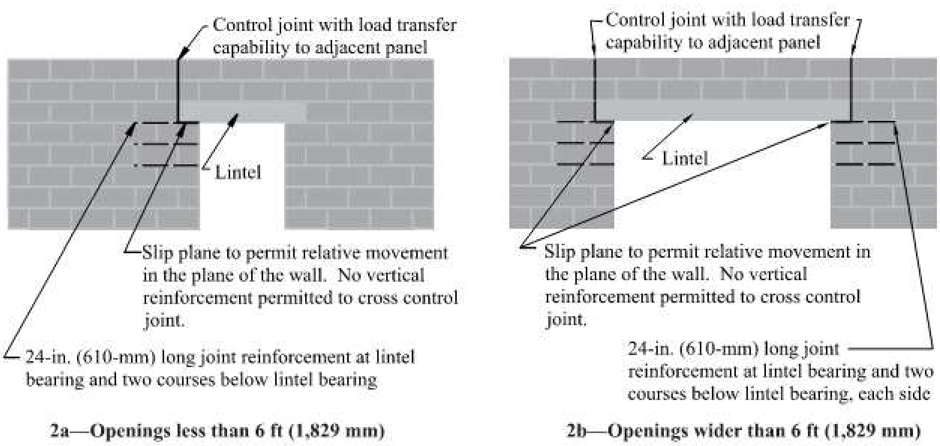
TMS 402-16: 5.2.1.1.1
2016 Masonry Designers' Guide: 7.5.3.2

Span is minimum of:

- Clear span + depth of beam
- Distance between centers of supports



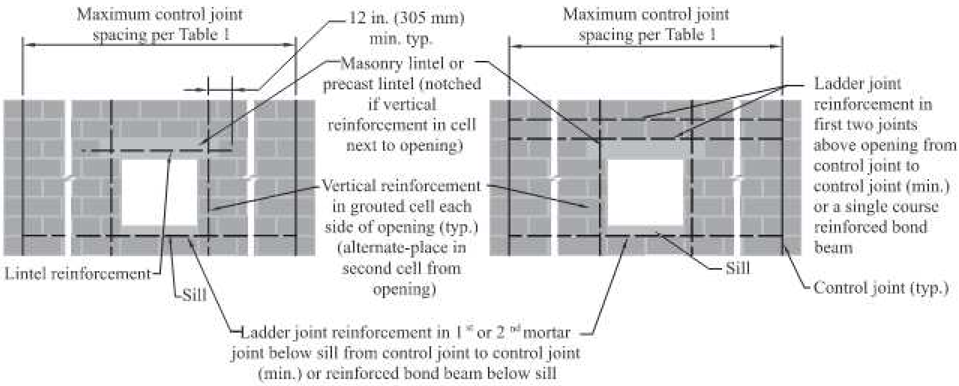
Beam Span: Beams not built integrally with supports



Control Joints at Openings in Walls With No Reinforcement in Adjacent Cells

NCMA TEK 10-2C – Figure 2

Beam Span: Beams built integrally with supports



2c—Preferred strengthening of opening with reinforcement—extending lintel reinforcement and joint reinforcement under the sill

2d—Opening strengthened with joint reinforcement (first two courses over opening and under sill)

Control Joints at Openings Wrapped with Reinforcement

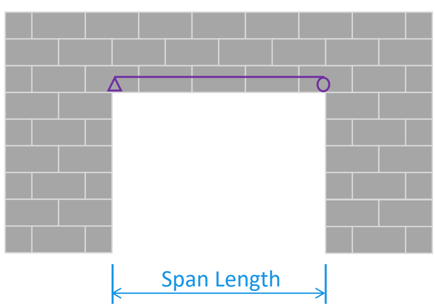
NCMA TEK 10-2C – Figure 2

Beam Span: Beams built integrally with supports

TMS 402: is silent
2016-Masonry Designers' Guide: is silent

Reasonable approximation: Clear span

- without significant negative moment reinforcement
- Lee et al (1983) showed end restraint reduced deflection from 20-45% of simply support

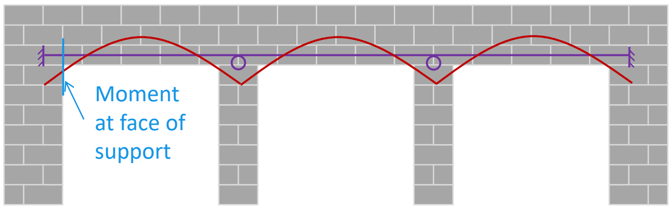


Beam Span: Continuous

TMS 402 5.2.1.1.2
Masonry Designers' Guide: 7.5.3.2

Requires negative moment reinforcement (otherwise built integrally with supports)

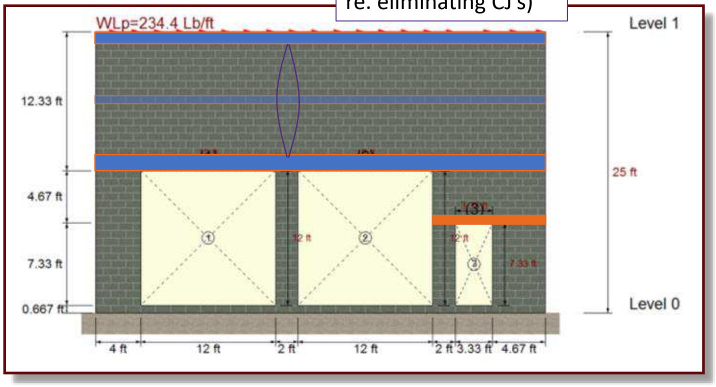
- Span length distance between centers of support for determining moments
- Reasonable approximation: Design for moment at face of supports

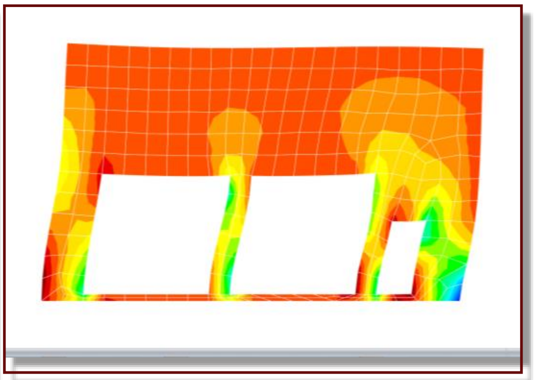


Beam Span: Continuous

Beam Span: Continuous

(See NCMA TEK 10-3 re. eliminating CJ's)





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Beam Requirements

- Chapter 5
- Chapter 8

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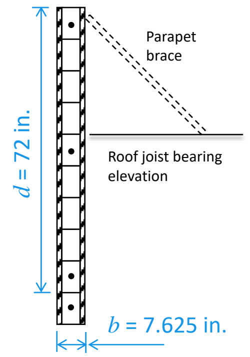
General Beam Design

TMS 402 5.2.1.2 and 5.2.1.3
Masonry Designers' Guide: 7.5.3.2 and 7.5.3.5

- Lateral support (TMS 402 5.2.1.2)
  - Minimum of:
    - $32b$
    - $120b^2/d$
- Bearing length (TMS 402 5.2.1.3)
  - Minimum of 4 in. in direction of span



$$32b = 32(7.625in.) = 244in.$$
$$120b^2/d = 120(7.625in.)^2/72in. = 96.9\ in.$$

Brace at every roof joist, which is 5 ft spacing
(If 12" CMU, then brace at 225 in.)

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Beams

TMS 402: 5.2
Masonry Designers' Guide: 7.5.3

Unlike Strength Design, Allowable Stress Design:

- **DOES NOT** place a limit on the axial stress in beams
- **DOES NOT** place a limit on the variation in longitudinal reinforcing bars in a beam.
- **DOES NOT** require beams to be fully grouted.

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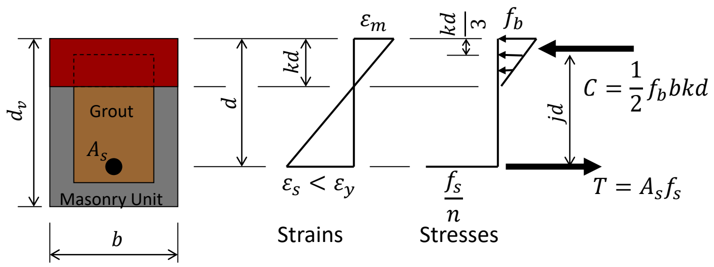
Flexural Design

- Moment Capacity
- Shear Capacity
- Beam Construction

Moment Capacity

TMS 402 8.3.2 (Design Assumptions)
Masonry Designers' Guide: 11.4.2 and 11.4.3



ε_{mu} = 0.0025 CMU
ε_{mu} = 0.0035 SCU (Clay)

$M = A_s f_s jd$ (Steel Controls)

$M = \frac{1}{2} f_b jkbd^2$ (Masonry Controls)

At 'Balanced Design' – Use F_s and F_b

Flexural Design

Masonry Designers' Guide 11.4.2

1. Determine material properties $(f_y,\ f'_m)$
2. Choose beam dimensions
   A. Thickness: typically, nominally, 8 in. or 12 in. – use actual dimensions
   B. Depth: if possible, choose so no shear reinforcement is required
3. Estimate force couple lever distance, jd, as 90% of d
4. Solve for $A_{s,reqd}$ using F_s $$A_{s,reqd} = \frac{M}{F_s jd} = \frac{M}{F_s(0.9)(d)}$$
5. Check and iterate if required

Flexural Design

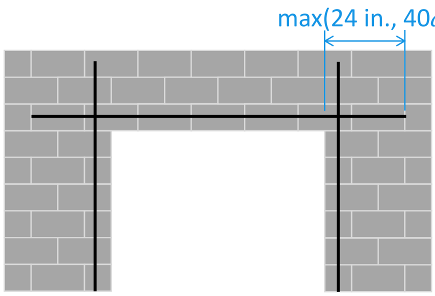
Masonry Designers' Guide 11.4.2

1. Assume that tension in reinforcement steel will control, determine $A_{s,reqd}$
2. Calculate modular ratio, n: $n = \frac{E_s}{E_m}$
3. Calculate the reinforcement ratio, ρ: $\rho = \frac{A_s}{bd}$
4. Solve k: $k = \sqrt{(n\rho)^2 + 2n\rho} - n\rho$
5. Solve j: $j = (1 - \frac{k}{3})$
6. Check masonry and steel stresses:

$$f_b = \frac{2M}{jkbd^2} \leq 0.45f'_m \qquad f_s = \frac{M}{A_s jd} \leq F_s$$

Beam Construction

- d = depth to centroid of tension reinforcement
- For one layer of reinforcement, $d \sim (d_v - 3in.)$
- ½" clear to reinforcement for course grout
- ¼" clear to reinforcement for fine grout



Seismic Requirements (TMS 402 7.3.2.3.1)

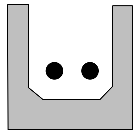
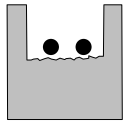
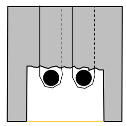
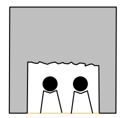


Figure courtesy of Wirebond





Wire to web



Support on chairs

Beam Construction

- The basics:
- Know your depth: 2.25" or 2.75" to bottom of bars?

Beam Construction

Beam Construction

Deflections

- When???
- Effective Moment of Inertia
- Deflection Requirements

Deflection Requirements

TMS 402 Section 5.2.1.4
Masonry Designers' Guide 7.5.3.6

- Deflection of beam or lintels supporting unreinforced masonry is limited to $L/600$ for Dead + Live Loads, where L is span length (TMS 402 5.2.1.4.1)
- Deflections of approximately $L/300$ needed to be visible.
- Deflections do not need to be checked when $L \leq 8d$ (TMS 402 5.2.1.4.3).

Effective Moment of Inertia

TMS 402 Section 5.2.1.4.2
Masonry Designers' Guide 7.5.3.6

$$I_{eff} = I_n \left(\frac{M_{cr}}{M_a}\right)^3 + I_{cr}\left[1 - \left(\frac{M_{cr}}{M_a}\right)^3\right]$$

$$I_{cr} = \frac{bk^3d^3}{3} + nA_s(d - kd)^2$$

I_{eff} = effective moment of inertia
I_n = net moment of inertia
I_{cr} = cracked moment of inertia
M_{cr} = cracking moment
M_a = Moment under allowable stress level loads

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Effective Moment of Inertia

TMS 402 Section 5.2.1.4
Masonry Designers' Guide 7.5.3.6

$$M_{cr} = \frac{f_r I_n}{y_t} = \frac{f_r}{S}$$

$$f_r = 2.5\ x\ Allowable\ Flexural\ Tensile\ Stress\ (TMS\ 402\ Table\ 8.2.4.2)$$

$$k = \sqrt{(n\rho)^2 + 2n\rho} - n\rho$$

$$\rho = \frac{A_s}{bd} \qquad n = \frac{E_s}{E_m}$$

M_{cr} = cracking moment
f_r = Modulus of rupture
n = modular ratio, E_s/E_m
k = multiplier for depth to neutral axis under allowable stress assumptions

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Shear

- Shear strength
- Stirrups
- Shear at $d/2$

Shear Strength

TMS 402 Section 8.3.5.1 and 8.3.5.2
Masonry Designers' Guide 11.4.4.2

$$f_v = \frac{V}{A_{nv}}$$

Assume $M/(V/d_v)$ = 1.0, Axial force = 0.0

$$F_v = (F_{vm} + F_{vs})\gamma_g$$

$$F_{vm} = \frac{1}{2}(2.25)\sqrt{f'_m}$$

$$F_{vs} = 0.5\left(\frac{A_v F_s d_v}{A_{nv} s}\right)$$

$$F_v \le (2\sqrt{f'_m})\gamma_g$$

Stirrups required if the calculated shear stress exceeds the allowable shear stress in the masonry

- d_v = actual depth of masonry
- A_{nv} = net shear area = bd_v
  - Many designers use d instead of d_v for beams; clarified in 2022 TMS 402
- γ_g = 1.0 for fully grouted beams

Stirrups

TMS 402 Section 8.3.5.2.1
Masonry Designers' Guide 11.4.4.2

Maximum spacing is $d/2$ or 48 in.

Unlike Strength Design, Allowable Stress Design:

a) **DOES NOT** specify single bar with 180-degree hook at each end

b) **DOES NOT** require hooking shear reinforcement around longitudinal reinforcement

c) **DOES NOT** specify a minimum area of shear reinforcement of $0.0007bd_v$

d) **DOES NOT** require the first stirrup within $d_v/4$

Shear at d/2

TMS 402 Section 8.3.5.4
Masonry Designers' Guide 11.4.4.2

If the following conditions are met, sections within $d/2$ from face of support can be designed for shear at $d/2$ (TMS 402 8.3.5.4): (moved to Chapter 5 in 2022 TMS 402)

A. Noncantilever beam
B. Reaction introduces compression into end region of member
C. No concentrated load between $d/2$ and face of support

For cantilever beams, use maximum shear

Design Example

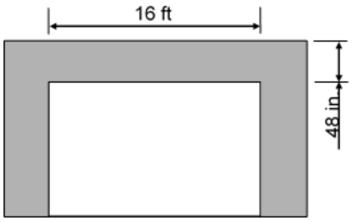
Beam Design

Design Example

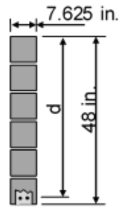
Masonry Designers' Guide Example 11.4-2

Given:

- superimposed dead load = 700 lb/ft
- live load = 300 lb/ft
- Grade 60 steel
- Type S PCL mortar
- 8 in. CMU
- f'_m = 2000 psi



ELEVATION



CROSS-SECTION

Design Example: Load

Masonry Designers' Guide Example 11.4-2

Span length: Assume not built integrally with support
Span length = 16 ft + 2(4 in.) = 16.67 ft

Beam Weight: Assume fully grouted, medium weight units; 81 psf
Weight = 81psf(4ft) = 324 lb/ft

Applied load, w

$$w = 1.0D + 1.0L = 1.0\left(700\frac{lb}{ft} + 324\frac{lb}{ft}\right) + 1.0\left(300\frac{lb}{ft}\right) = 1{,}324\frac{lb}{ft}$$

Max. Net Shear Area, A_{nv}

$$A_{nv} = bd_v = 7.625in\ x\ 47.625in = 363.1in^2 \text{ (maximum)}$$

Select beam design depth for avoiding stirrups, use 'd' rather than d_v

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Design Example: Beam Depth

Masonry Designers' Guide Example 11.4-2

Maximum Shear, V

$$\mathrm{V} = \frac{1{,}324\frac{lb}{ft}(16.67ft)}{2} = 11{,}040\ lb$$

(Could reduce shear by designing for shear at $\frac{d}{2}$)

Allowable Shear Stress, F_v

$$F_{vm} = \frac{1}{2}(2.25\sqrt{f'_m}) = \frac{1}{2}(2.25\sqrt{2000}) = 50.3 \text{ psi}$$

Calculate the minimum depth to avoid shear reinforcement:

$$d_{min} = \frac{V}{bF_{vm}} = \frac{11{,}040lb}{(7.625in)(50.3\ psi)} = 28.8in$$

- 32 in. deep beam, minimum, is needed using 8" nominal module for coursing
- Although not required, use the full 48" depth and grout entire height of beam
- Shear strength OK by inspection

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Design Example: Sharpen Pencil

Masonry Designers' Guide Example 11.4-2

Try 24 in. deep beam, d = 21 in. Check V at $d/2$ from face of support

$d/2$ from face of support

$$\left(4in + \frac{21in}{2}\right)\frac{1ft}{12in} = 1.21ft$$

Applied shear, V

$$V = 11{,}040\ lb\frac{8.33ft - 1.21ft}{8.33ft} = 9{,}435\ lb$$

$$d_{min} = \frac{V}{bF_{vm}} = \frac{9{,}435lb}{(7.625in)50.3\ psi} = 24.6\ in$$

- A 24 in. deep beam will not quite work, but a 32" deep beam would – use 32" deep beam for efficiency… or minimize steel with full depth
- In this example, most engineers would still fully grout the beam

Design Example: Flexure

Masonry Designers' Guide Example 11.4-2

Using 48" overall depth $with\ d = 47.6in. - 2in. = 45.6\ in.$

Applied moment, M_u

$$M = \frac{wL^2}{8} = \frac{1{,}324\frac{lb}{ft}(16.67ft)^2}{8}\frac{12in}{ft} = 551{,}200 in \cdot lb$$

Estimate required steel, $A_{s,reqd}$

$$A_{s,reqd} = \frac{M}{F_s jd} = \frac{M}{F_s 0.9d} = \frac{551{,}200 in{\cdot}lb}{(32{,}000psi)(0.9)(45.6in)} = 0.42in^2$$

With 48" overall depth: $d = 45.6\ in$ – use (1) #6 bar

Design Example: Flexure

Masonry Designers' Guide Example 11.4-2

With 48" overall depth and $d = 45.6\ in.$ – final checks:

Determine n $\quad n = \frac{E_s}{E_m} = \frac{29{,}000{,}000\ psi}{900(2{,}000\ psi)} = 16.11$

Determine ρ $\quad \rho = \frac{A_s}{bd} = \frac{0.44 in^2}{7.625 in(45.6 in)} = 0.00126$

Determine nρ $\quad n\rho = 16.11(0.00126) = 0.0204$

Determine k $\quad k = \sqrt{(n\rho)^2 + 2n\rho} - n\rho = \sqrt{(0.0204)^2 + 2(0.0204)} - 0.0204 = 0.1825$

Determine j $\quad j = \left(1 - \frac{k}{3}\right) = \left(1 - \frac{0.1825}{3}\right) = 0.939$

$$f_b = \frac{2M}{jkbd^2} = \frac{2(551{,}200 in \cdot lb)}{0.939(0.1825)(7.625 in)(45.6 in)^2} = 405.2\ psi \leq 0.45(2{,}000 psi) = 900 psi$$ **OK**

$$f_s = \frac{M}{A_s jd} = \frac{551{,}200 in \cdot lb}{0.44 in^2(0.939)(45.6 in)} = 29{,}240\ psi \leq 32{,}000 psi$$ **OK**

Design Example: Bracing

Masonry Designers' Guide Example 11.4-2

$32b = 32(7.625 in.) = 20.3 ft$

$120b^2/d = 120\,(7.625 in.)^2/45.6 in. = 153 in. = 12.7 ft$

- If top of beam were the roof, that would provide continuous lateral support
- It top of beam were a parapet, provide bracing at midspan and ends

Design Example: Deflections

Masonry Designers' Guide Example 11.4-2

- Beam is not supporting unreinforced masonry, so deflections do not need to be checked
- As a quick check: $L/d = 16.67ft\left(12\frac{in.}{ft}\right)/45.6in. = 4.4 \leq 8$ **OK**
- Deflection check will be illustrated in next example

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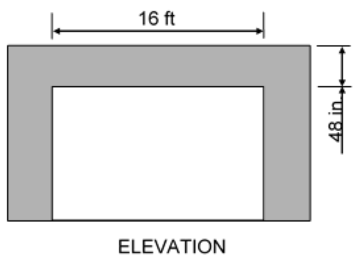
Design Example

Masonry Designers' Guide Example 11.4-2



Given: Modify load

- superimposed dead load = 2,000 lb/ft
- live load = 700 lb/ft

Applied load, w

$$w = 1.0D + 1.0L = 1.0\left(2{,}000\frac{lb}{ft} + 324\frac{lb}{ft}\right) + 1.0\left(700\frac{lb}{ft}\right) = 3{,}024\frac{lb}{ft}$$

Flexural reinforcement is 4 – No. 4

2 bars in each of bottom two courses

$d = 40.0in$

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Design Example: Shear

Masonry Designers' Guide Example 11.4-2

Maximum shear, V	$V = 3{,}024\frac{lb}{ft}\left(\frac{16ft}{2} - 40in(\frac{1ft}{12in})/2\right) = 19{,}150lb$
Shear area, A_{nv}	$A_{nv} = 7.625in(40in) = 305in^2$
Shear Stress, f_v	$f_v = \frac{V}{A_{nv}} = \frac{19{,}150\text{lb}}{305in^2} = 62.8psi$
Maximum Shear Stress, F_v	$F_v \leq \left(2\sqrt{f'_m}\right)\gamma_g = \left(2\sqrt{2{,}000psi}\right)1.0 = 89.4psi$ **OK**
Maximum Masonry Shear Stress, F_v	$F_{vm} = \frac{1}{2}(2.25)\sqrt{f'_m} = \frac{1}{2}(2.25)\sqrt{2{,}000psi} = 50.3psi$ **stirrups required**

Design Example: Shear

Masonry Designers' Guide Example 11.4-2

Required Steel Stress, f_{vs}	$f_{vs} = f_v - F_{vm} = 62.8psi - 50.3psi = 12.5psi$

Determine spacing for #3 double-leg stirrups, use required f_{vs}, and use d rather than d_v:

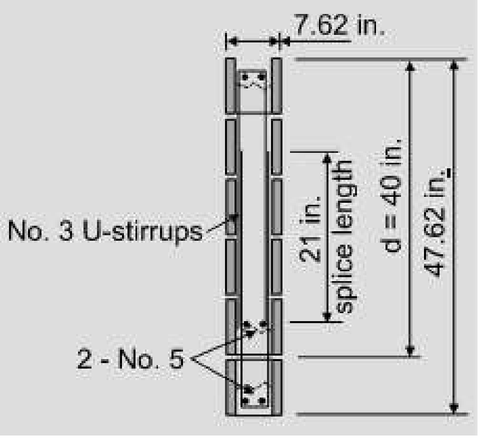
$$F_{vs} = 0.5\left(\frac{A_vF_sd_v}{A_{nv}s}\right) \rightarrow s = 0.5\left(\frac{0.5A_vF_sd}{F_{vs}A_{nv}}\right) = 0.5\left(\frac{(0.22in^W)(32{,}000psi)(40.0in)}{12.5psi(305in^2)}\right) = 36.9in$$

TMS 402 Section 8.3.5.2.1 requires spacing less than or equal to $\frac{d}{2}$ or 48in

Use $s = \frac{40.0in}{2} = 20in$ → Use a spacing of 16" for every other cell, could consider #3 single-leg stirrups at that spacing…. Deformed wire could, also, be used.

Design Example: Shear Details

Masonry Designers' Guide Example 11.4-2



Parameter	Width
Face shell; 1.25 in. each	2.50 in.
Block taper; assume to be 0.25 in. each side	0.50 in.
Thickness of coarse grout between reinforcement and masonry; 0.50 in. each side, (TMS 402 6.1.3.5)	1.00 in.
Stirrup diameter: 2 at 0.375 in.	0.75 in.
Longitudinal reinforcement diameter; 2 at 0.625 in.	1.25 in.
Space between bars; 1.00 in. (TMS 402 6.1.3.1)	1.00 in.
TOTAL	7.00 in.

≤ 7.625 in. OK

Design Example: Deflections

TMS Strength Design Guide Example 6.3.1.9 **Not Required - For Illustration Only**

Modulus ratio $$n = \frac{E_s}{E_m} = \frac{29000ksi}{900f'_m} = \frac{29000ksi}{900(2ksi)} = 16.11$$

Reinforcement ratio $$\rho = \frac{A_s}{bd} = \frac{4(0.20in^2)}{7.625in(40in)} = 0.002623 \qquad n\rho = 0.04225$$

Find k $$k = \sqrt{(n\rho)^2 + 2n\rho} - n\rho = \sqrt{(0.04225)^2 + 2(0.04225)} - 0.04225 = 0.252$$ $$kd = 0.252(40in) = 10.06in$$

Net moment of inertia, I_n $$I_n = \frac{bd_v^3}{12} = \frac{7.625in(48in)^3}{12} = 70{,}270in^4$$

Cracked moment of inertia, I_{cr} $$I_{cr} = \frac{bk^3d^3}{3} + nA_s(d-kd)^2 = \frac{7.625in(10.06in)^3}{3} + 16.11(0.80in^2)(40in - 10.06in)^2 = 14{,}140in^4$$

Design Example: Deflections

Strength Design Guide Example 6.3.1.9 Not Required - For Illustration Only

ASD load $w = D + L = \left(2{,}000\frac{lb}{ft} + 324\frac{lb}{ft}\right) + 700\frac{lb}{ft} = 3{,}020\frac{lb}{ft}$

ASD Moment, M_a $M_a = \frac{wL^2}{8} = \frac{3{,}020\frac{lb}{ft}(16.67ft)^2}{8}\frac{12in.}{ft} = 1{,}259{,}000in.\cdot lb$

Cracking Moment, M_{cr} $M_{cr} = f_r S_n = f_r\frac{bh^2}{6} = 267psi\frac{7.625in.(48in.)^2}{6} = 782{,}000in.\cdot lb$

Effective Moment of Inertia, I_{eff}

$$I_{eff} = I_n\left(\frac{M_{cr}}{M_a}\right)^3 + I_{cr}\left[1 - \left(\frac{M_{cr}}{M_a}\right)^3\right]$$

$$70{,}270in.^4\left(\frac{782in\cdot k}{1{,}259in\cdot k}\right)^3 + 14{,}140in^4\left[1 - \left(\frac{782in\cdot k}{1{,}259in\cdot k}\right)^3\right] = 27{,}590in^4$$

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Design Example: Deflections

Strength Design Guide Example 6.3.1.9 Not Required - For Illustration Only

Deflection, δ $\delta = \frac{5wL^4}{384EI} = \frac{5\left(3{,}020\frac{lb}{ft}\right)(16.67ft)^4}{384(1{,}800{,}000psi)(27{,}590in.^4)}\frac{1728in.^3}{1ft^3} = 0.106in.$

Allowable δ $\frac{L}{600} = \frac{16.67ft}{600}\frac{12in.}{ft} = 0.333in.$ OK

Quick check using cracked moment of inertia, δ = 0.206 in.

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Deep Beams

- Internal Lever Arm
- Miscellaneous Requirements
- Example

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Internal Lever Arm

TMS 402 Section 5.2.2.1, 5.2.2.2
Masonry Designers' Guide 7.5.3.7

Definition (TMS 402 2.2)

$$\frac{l_{eff}}{d_v} \leq \begin{cases} 3 & \text{continuous span} \\ 2 & \text{simple span} \end{cases}$$

Effective span length, l_{eff}, smaller of:

- center-to-center distance between supports
- 1.15 multiplied by the clear span

z – internal lever arm	
Simple spans	Continuous spans
$1 \leq \frac{l_{eff}}{d_v} < 2 \quad z = 0.2(l_{eff} + 2d_v)$	$1 \leq \frac{l_{eff}}{d_v} < 3 \quad z = 0.2(l_{eff} + 1.5d_v)$
$\frac{l_{eff}}{d_v} < 1 \quad z = 0.6l_{eff}$	$\frac{l_{eff}}{d_v} < 1 \quad z = 0.5l_{eff}$

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Miscellaneous Requirements

TMS 402 Section 5.2.2.3, 5.2.2.4, 5.2.2.5
Masonry Designers' Guide 7.5.3.7

- Flexural reinforcement
  - distributed flexural reinforcement for half beam depth
  - maximum spacing of one-fifth d_v or 16 in.
  - joint reinforcement can be used as flexural reinforcement
  - horizontal reinforcement anchored to develop yield strength at face of supports
- Shear reinforcement (when required)
  - minimum area of vertical reinforcement is $0.0007bd_v$
  - horizontal shear reinforcement area ≥ half vertical shear reinforcement
  - maximum spacing of shear reinforcement one-fifth d_v or 16 in.
- Total reinforcement: sum of horizontal and vertical reinforcement at least $0.001bd_v$.

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Design Example

TMS Strength Design Guide Example 6.3.1.7 **as a basis, using ASD**

Given:

- 10 ft opening
- 6 ft deep beam
- superimposed dead load = 3.0 kip/ft
- live load = 2.0 kip/ft
- Grade 60 steel
- Type S masonry cement mortar
- 8 in. CMU
- f'_m = 2000 psi

C/C between supports = 10 ft + 2(4 in.) = 10.67 ft

1.15(clear span) = 1.15(10 ft) = 11.5 ft

Effective span length, l_{eff} = min(10.67, 11.5) = 10.67 ft

Span ratio, l_{eff}/d_v $$\frac{l_{eff}}{d_v} = \frac{10.67ft}{6ft} = 1.78 \leq 2$$

Therefore, this is a deep beam

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Design Example: Flexure

TMS Strength Design Guide Example 6.3.1.7 **as a basis, using ASD**

Beam Weight: Assume fully grouted, medium weight units; 81 psf

Weight = 81psf(6ft) = 0.486 k/ft

Applied load, w

$$w = 1.0D + 1.0L = 1.0\left(3.0\frac{k}{ft} + 0.486\frac{k}{ft}\right) + 1.0\left(2.0\frac{k}{ft}\right) = 5.486\frac{k}{ft}$$

Factored moment, M_u

$$M_u = \frac{5.49\frac{k}{ft}(10.67ft)^2}{8} = 78.1k \cdot ft$$

Internal lever arm, z

$$z = 0.2\left(l_{eff} + 2d_v\right) = 0.2\left(10.67ft + 2(6ft)\right) = 4.53ft$$

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Design Example: Flexure

TMS Strength Design Guide Example 6.3.1.7 **as a basis, using ASD**

Use z in place of jd:

Req'd A_s

$$A_{s,reqd} = \frac{M}{zF_s} = \frac{78.1k \cdot ft}{4.53ft(32ksi)} = 0.539in.^2 \qquad \left(f_s = \frac{M}{A_s jd} \le F_s\right)$$

Using standard beam theory would have $A_{s,reqd}$ underestimated by 14%.

Although 1-#7 could be used, use 2-#5, one in each of bottom two courses

- reduces development length and extension of bars beyond face of support
- helps with requirement of distributed reinforcement

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Design Example: Reinforcement

TMS Strength Design Guide Example 6.3.1.7 **as a basis, using ASD**

$d = 72in. - 8in. = 64in.$ distance to centroid of reinforcement

ρ_{max} $\rho = \frac{A_s}{bd} = \frac{2(0.31in.^2)}{7.625in.(64in.)} = 0.00127 \leq 0.00952$ **OK – but not req'd for ASD**

ρ_{min} $A_s = 0.62in.^2 \geq \frac{4}{3}A_{s,reqd} = \frac{4}{3}(0.43in.^2) = 0.57in.^2$ **OK – but not req'd for ASD**

Distributed reinforcement: required over bottom half of beam at a spacing of $1/5d_v$ = 1/5(72in.) = 14.4in., but not greater than 16 in.

Use W1.7 (9 gage) joint reinforcement every 8 in. in bottom five bed joints.

Design Example: Development

TMS Strength Design Guide Example 6.3.1.7 **as a basis, using ASD**

Development length, l_{de}

$$l_{de} = \frac{0.13 d_b^2 f_y \gamma}{K\sqrt{f'_m}} = \frac{0.13(0.625in.)^2(60{,}000psi)(1.0)}{\min\{9(0.625in.), 3.81in. - 0.625in./2\}\sqrt{2{,}000psi}} = 19.5in.$$

- Extend bars 20 in. beyond face of support
- Details of development length will be covered in Session 6

Design Example: Shear

TMS Strength Design Guide Example 6.3.1.7 as a basis, using ASD

Maximum shear, V	$V = 5.49\frac{k}{ft}(\frac{10.67ft}{2}) = 29.3k$
Shear area, A_{nv}	$A_{nv} = 7.625in.(72in.) = 549in.^2$
Shear stress, f_v	$f_v = \frac{V}{A_{nv}} = \frac{29.3k}{549in.^2} = 53.4psi$
Maximum Masonry Shear Stress, F_v	$F_{vm} = \frac{1}{2}(2.25)\sqrt{f'_m} = \frac{1}{2}(2.25)\sqrt{2{,}000psi} = 50.3psi$

stirrups required (not required when using SD…)

Suggest: Avoid using Deep Beams, or if you do… for this case use f'm ≥ 2,300 psi and not stirrups…

Or, repeat the calculation from earlier example with Deep Beam parameters and provide:
Vertical shear reinforcement $\geq 0.0007bd_v$
Horizontal shear reinforcement ≥ one-half of the vertical shear reinforcement..

Design Example: Total Reinforcement

TMS Strength Design Guide Example 6.3.1.7 as a basis, using ASD

Total Reinforcement	$0.001bd_v = 0.001(7.625in.)(72\ in.) = 0.55in.^2$

2 - #5 (considering only flexural steel)meets total reinforcement by inspection.

Beam Boundaries?

What can masonry beams do for you?

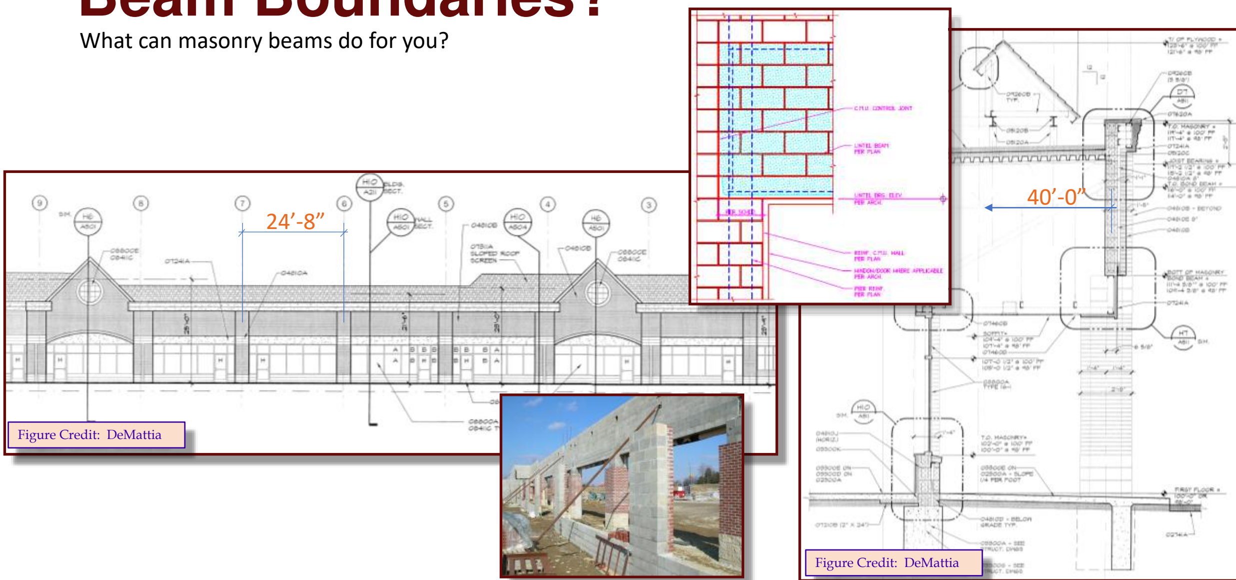

Figure Credit: DeMattia

Figure Credit: DeMattia

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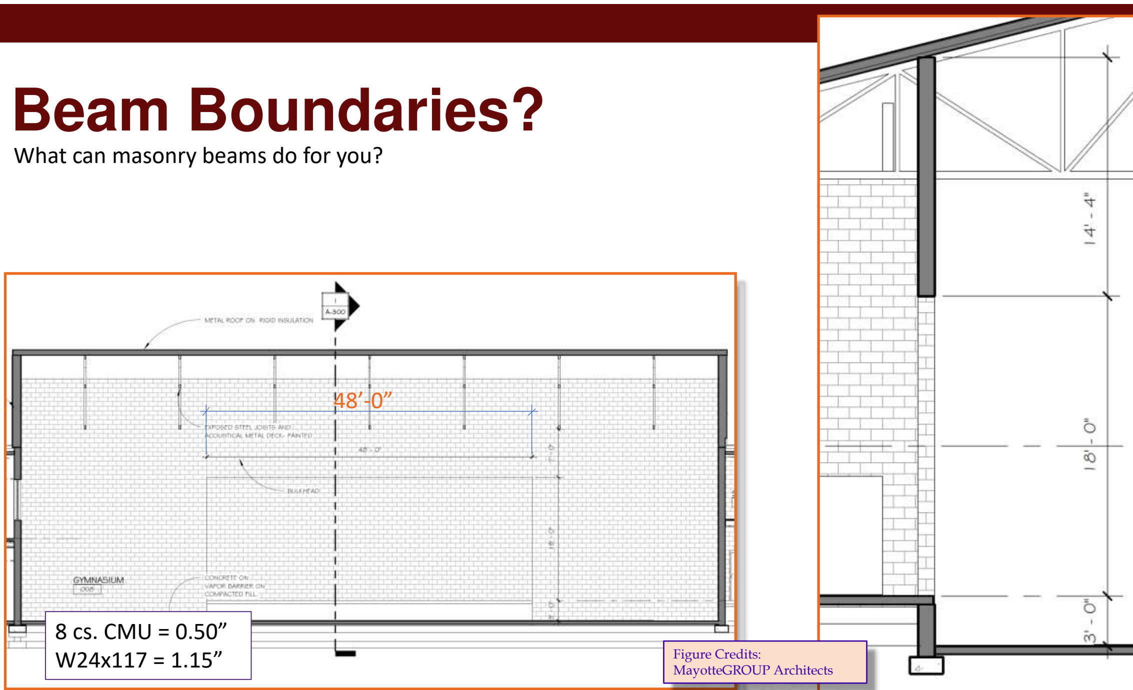
Beam Boundaries?

What can masonry beams do for you?



8 cs. CMU = 0.50”
W24x117 = 1.15”

Figure Credits:
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This concludes The American Institute of Architects Continuing Education Systems Course

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The Masonry Society