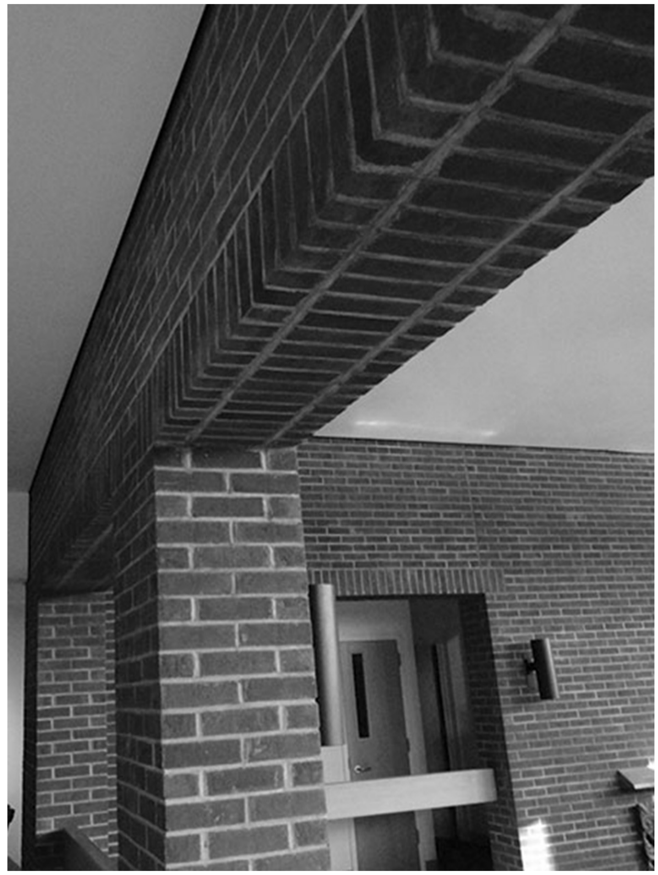
Architecture 504
Masonry Structures

Masonry Beams and Lintels

Definitions
Behavior under flexure
Reinforcement

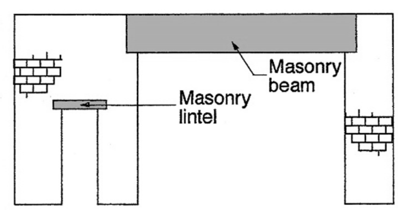


Siena College, NY
David T. Biggs, P.E.
1981

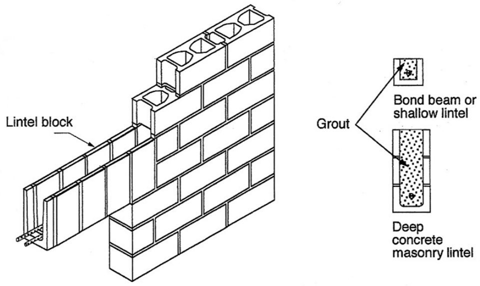
Types of Flexure in Masonry

Beams and Lintels

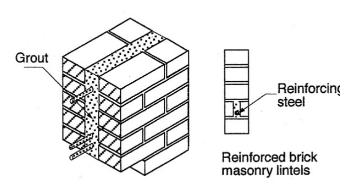
- single-wythe brickwork
- double-wythe brickwork + grout
- special lintel CMU
- bond beam CMU
- special knock-out CMU



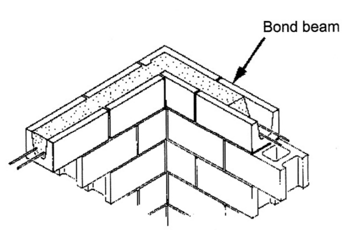
Beams and Lintels



Concrete Block Beams and Lintels

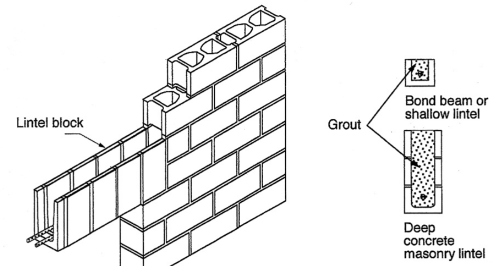


Brick Beams and Lintels



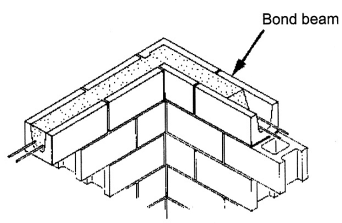
Typical masonry bond beams

Types of Flexure in Masonry



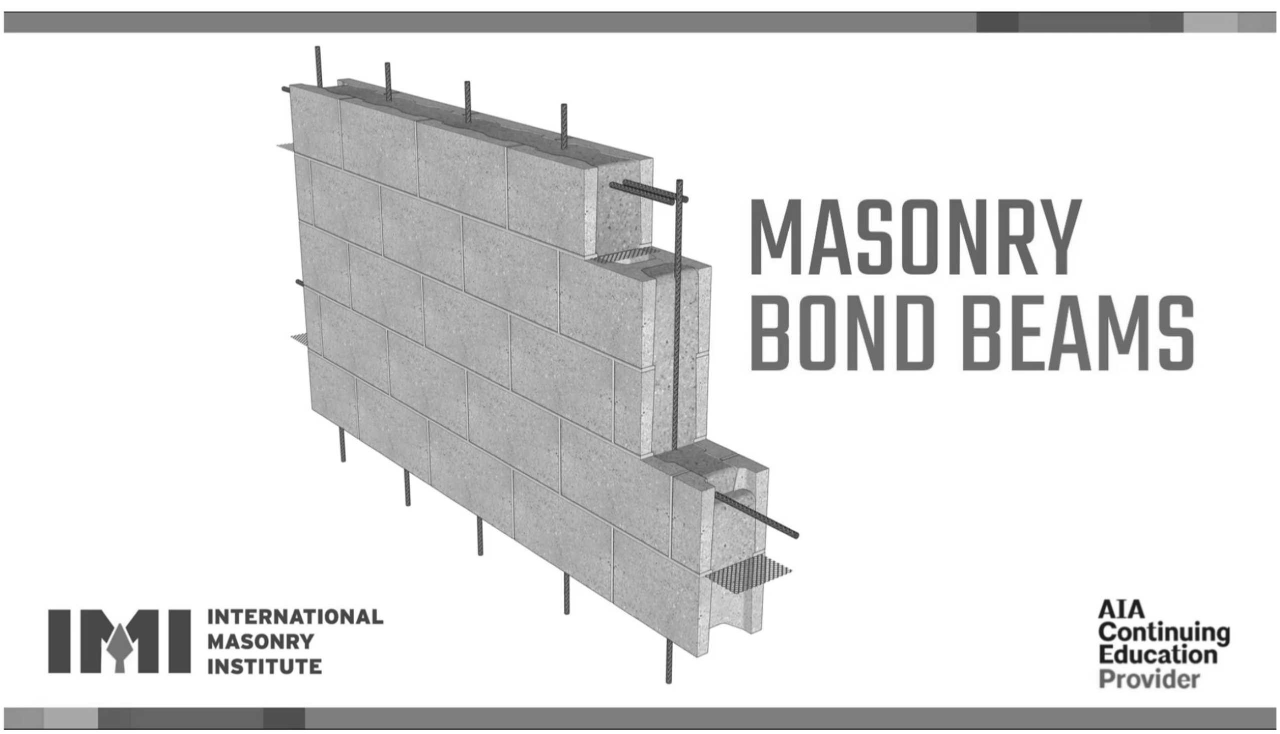
Concrete Block Beams and Lintels

Bond Beams
- within a wall
- horizontally reinforced and grouted
- resist out of plane bending
- resist in plane tension and shear
- typically at top of foundation and floor and roof levels
- distribute floor or roof loads
- bond beam CMU
- special knock-out CMU



Typical masonry bond beams

Types of Flexure in Masonry – Bond Beams

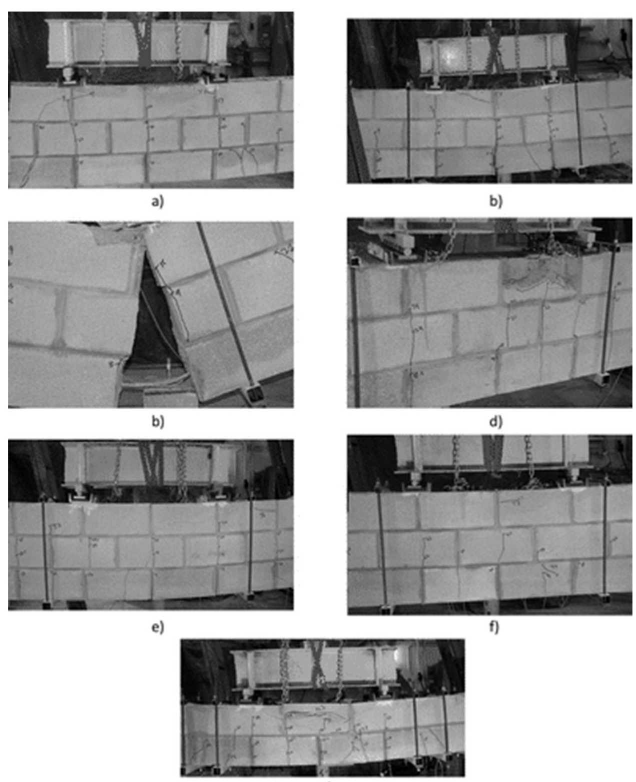


Types of Flexure in Masonry – Bond Beams

Design considerations

Strength and Stability
- flexure
- shear
- anchorage

Serviceability
- deflection
- cracking



Fundamental Assumptions

Elastic Analysis:

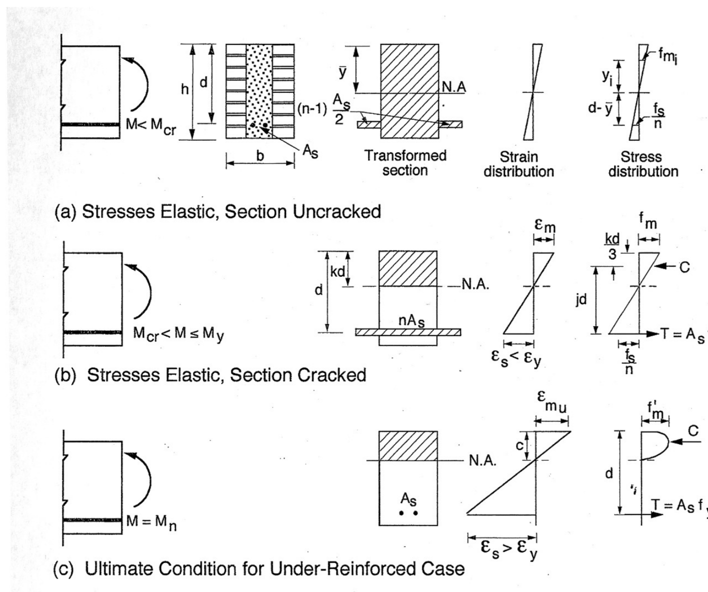
- internal forces at any section are in equilibrium with external loads
- plane sections before bending remain plane after bending
- after cracking tension in masonry is ignored. Tension is carried by steel.
- linearly elastic behavior exists for both steel and masonry within the service load range. N.A. at centroid of cracked section.
- complete bond exists between steel and grout

$$f_{m_i} = My_i/I_{tr}$$

$$f_s = n(My_s/I_{tr})$$

$$n = \frac{E_s}{E_m}$$

E_s = modulus of elasticity of steel
E_m = modulus of elasticity of masonry



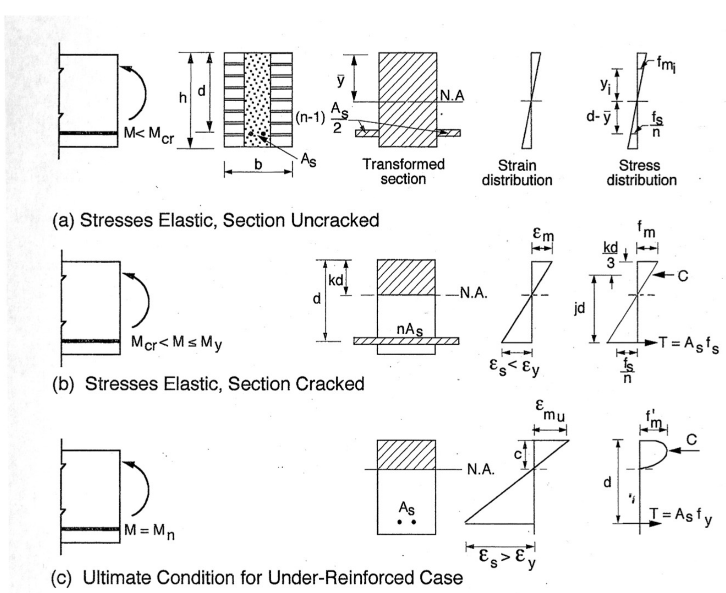
Fundamental Assumptions - uncracked

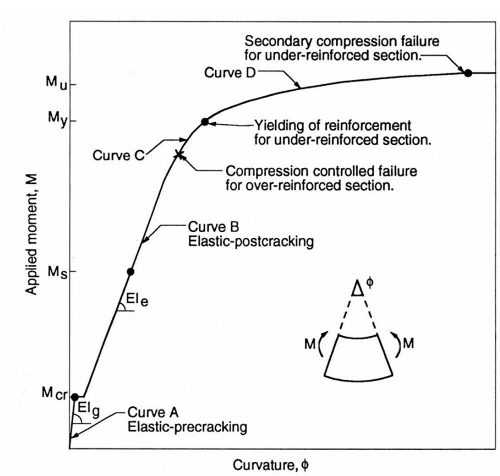
$$f_{m_i} = My_i/I_{tr}$$

$$f_s = n(My_s/I_{tr})$$

$$n = \frac{E_s}{E_m}$$

E_s = modulus of elasticity of steel
E_m = modulus of elasticity of masonry





Fundamental Assumptions - cracked

$$\rho_b = \frac{nF_b}{2F_s\,(n + F_s/F_b)}$$

$$C = f_m kbd/2$$

$$T = A_s f_s = \rho bdf_s$$

$$jd = d - kd/3$$

$$j = 1 - k/3$$

$$n = \frac{E_s}{E_m}$$

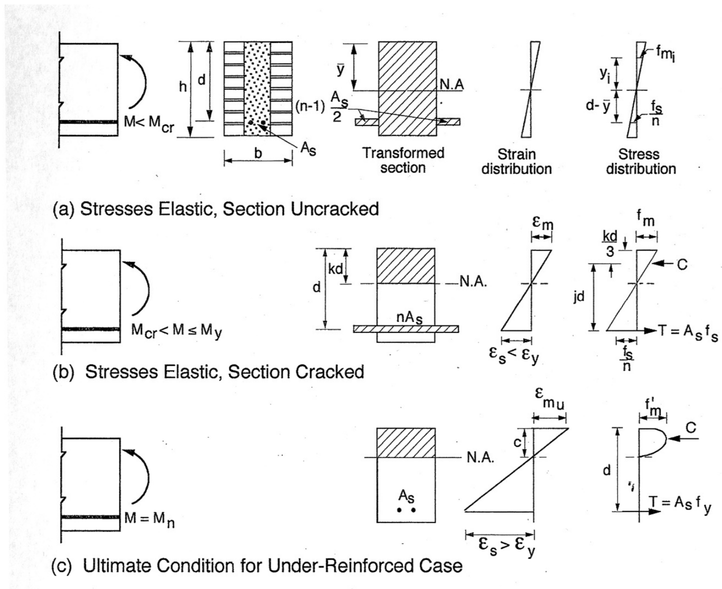
E_s = modulus of elasticity of steel
E_m = modulus of elasticity of masonry

$$\rho = A_s/bd$$

$$\rho f_s bd = f_m kbd/2$$

$$k = 2\rho f_s/f_m$$

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



Compression

$$M = Cjd = f_m kjbd^2/2$$

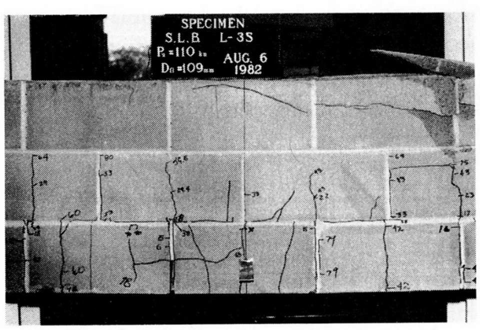
$$f_m = 2M/kjbd^2$$

Tension

$$M = Tjd = \rho f_s jbd^2$$

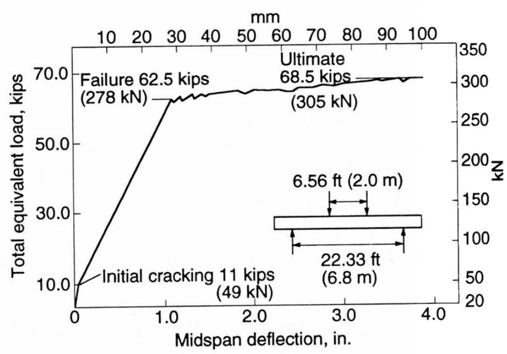
$$f_s = M/\rho jbd^2$$

Fundamental Assumptions – cracked + under reinforced

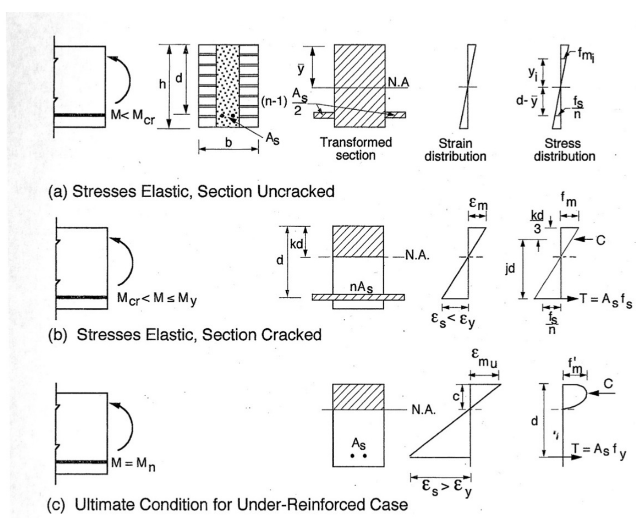


(a) Failure of Under-reinforced Beam (*Courtesy of V.V. Neis*)

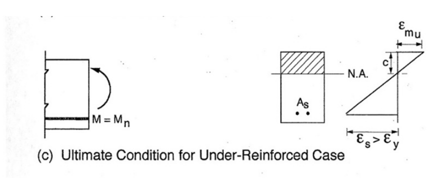
$$\rho_b = \frac{nF_b}{2F_s\,(n + F_s/F_b)}$$

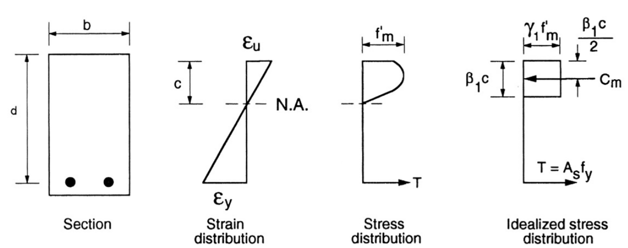


(b) Load-deflection Curve



Fundamental Assumptions – cracked + under reinforced





$$T = A_s f_y$$

$$C = \gamma_1 f'_m \beta_1 c b$$

$$c = \frac{A_s f_y}{\gamma_1 f'_m \beta_1 b}$$

$$M_n = T\left(d - \frac{\beta_1 c}{2}\right)$$

$$M_n = A_s f_y \left(d - \frac{A_s f_y}{2\gamma_1 f'_m b}\right)$$

$$\omega = \rho \frac{f_y}{f'_m}$$

$$M_n = bd^2 f'_m \omega \left(1 - \frac{\omega}{2\gamma_1}\right)$$

$$M_n = bd^2 f'_m \omega (1 - 0.59\omega)$$

$$\rho_b = \beta_1 \gamma_1 (f'_m / f_y)\left(\frac{\varepsilon_u}{\varepsilon_u + \varepsilon_y}\right)$$

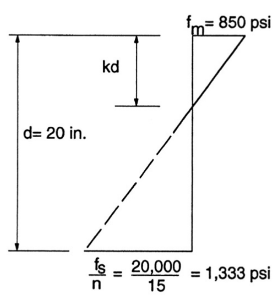
$$M_u \le \Phi\, M_n$$

$$M_u \le \Phi\, bd^2 f'_m \omega (1 - 0.59\omega)$$

Grouted Concrete Block – example ASD

Given:

- 3 blocks high
- 7 5/8 in. wide
- As = 1 x #8 = 0.79 in^2
- d = 20 in.
- modular ratio n = 15
- Fb = 850 psi
- Fs = 20 ksi



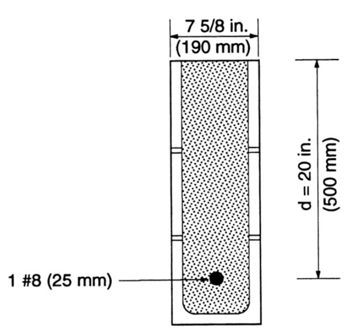
$$\rho = \frac{A_s}{bd} = \frac{0.79}{7.625 \times 20} = 0.0052$$

$$k = \sqrt{2n\rho + (n\rho)^2} - n\rho$$
$$= 0.324$$

$$j = 1 - k/3 = 0.892$$

Find:

- allowable bending moment M



Compression:

$$M = Cjd = \frac{1}{2} F_b kjbd^2$$
$$= \frac{850(0.324)(0.892)(7.625)(20)^2}{2(1000)(12)} = 31.1 \text{ ft-kip.}$$

Tension:

$$M = Tjd = \rho F_s jbd^2$$
$$= \frac{0.0052(20000)(0.892)(7.625)(20)^2}{1000(12)} = 23.6 \text{ ft-kip}$$

tension controls

Grouted Concrete Block – example ASD

Given:

- 3 blocks high
- 7 5/8 in. wide
- As = 1 x #8 = 0.79 in^2
- d = 20 in.
- modular ratio n = 15
- Fb = 850 psi
- Fs = 20 ksi

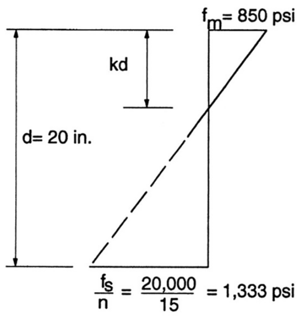
Find:
- Find balanced condition and As-bal

$$k = \frac{kd}{d} = \frac{850}{850 + 1333} = 0.389$$

$$kd = 0.389(20) = 7.78 \text{ in. from the top}$$
$$j = 1 - k/3 = 0.87$$

$$C = \frac{1}{2} f_m kbd = \frac{1}{2}(850)(0.389)(7.625)(20)(10)^{-3}$$
$$C = 25.21 \text{ kips}$$

$$C = T = A_s f_s$$
$$A_s = \frac{25{,}210}{20{,}000} = 1.26 \text{ in.}^2$$



$$\rho_b = \frac{nF_b}{2F_s(n + F_s/F_b)} = \frac{15(850)}{2(20000)(15 + 20000/850)} = 0.0083$$

$$A_s = \rho_b bd = 0.0083(7.625)(20) = 1.26 \text{ in.}^2$$

ρ_{max} = 0.5 ρ_b = 0.5(0.0083) = 0.00415 > 0.0052 NG!

2-Wythe Brick Beam - example

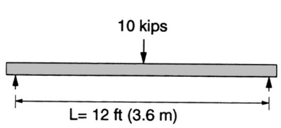
Given:
- Grouted beam
- L = 12 ft.
- P @ C.L. = 10 kips
- selfweight w_0 = 273 lb/ft
- f'_m = 3000 psi
- F_b = 0.33(f'_m)= 1000 psi
- F_s = 20 ksi
- d = 28 in.

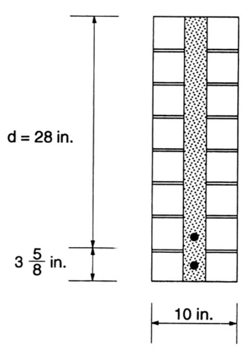
Find:
- Required reinforcement, A_s

$$M = \frac{Pl}{4} + \frac{w_0 l^2}{8}$$
$$= \frac{10 \times 12}{4} + \frac{0.273 \times (12)^2}{8} = 30 + 4.9 = 34.9 \text{ ft-kips}$$

$$M = Tjd = A_s f_s jd$$

$$A_s = \frac{M}{f_s jd} = \frac{34.9(12)(1000)}{20000(0.90)(28)} = 0.83 \text{ in.}^2$$





Try two No. 6 bars, giving A_s = 0.88 in.^{2}
check the stresses.

2-Wythe Brick Beam - example

Given:
- Grouted beam
- L = 12 ft.
- P @ C.L. = 10 kips
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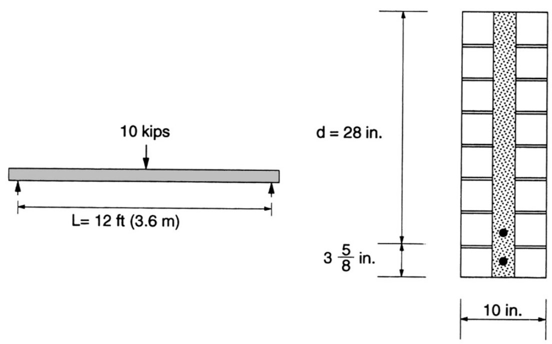
- Required reinforcement, A_s



$$\rho = \frac{A_s}{bd} = \frac{0.88}{10 \times 28} = 0.00314$$

$$n = \frac{E_s}{E_m} = \frac{29{,}000{,}000}{3000 \times 750} = 12.9$$

$$k = \sqrt{2n\rho + (n\rho)^2} - n\rho = 0.247$$

$$j = 1 - k/3 = 0.918$$

$$M = \frac{1}{2} f_m kjbd^2$$

$$f_m = \frac{2(34.9)(12)(1000)}{0.247(0.918)(10)(28)^2} = 471 \text{ psi}$$

f_m = 471psi < F_m =1000 ok

$$\rho_{\min} = \frac{80}{f_y} = \frac{80}{40{,}000} = 0.0020$$

$$\rho > \rho_{\min}$$

use two No. 6 bars

2-Wythe Brick Beam - example

Given:
- Grouted beam
- L = 12 ft.
- P @ C.L. = 10 kips
- selfweight w_0 = 273 lb/ft
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Find:
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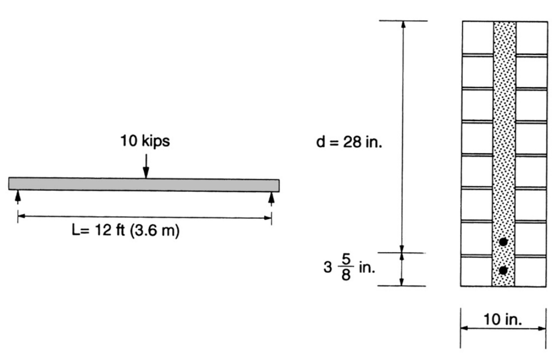

$$\rho = \frac{A_s}{bd} = \frac{0.88}{10 \times 28} = 0.00314$$

$$\rho_{\min} = \frac{80}{f_y} = \frac{80}{40{,}000} = 0.0020$$

$$\rho > \rho_{\min}$$

use two No. 6 bars

$$\rho_b = (0.85)(0.85)\left(\frac{3}{40}\right)\left(\frac{0.003}{0.003 + \frac{40}{29{,}000}}\right) = 0.037$$

$\rho_{max} = 0.5\, \rho_b = 0.5(0.037) = 0.0185$

0.00314 < 0.0185 ok

Mortar Types

Types M, S, N, O

The following mortar designations took effect in the mid–1950's:

M a **S** o **N** w **O** r **K**

strongest — weakest

Table 2-3. Guide to the Selection of Mortar Type*

Location	Building segment	Mortar type: Recommended	Mortar type: Alternative
Exterior, above grade	Load-bearing walls Non-load-bearing walls Parapet walls	N O** N	S or M N or S S
Exterior, at or below grade	Foundation walls, retaining walls, manholes, sewers, pavements, walks, and patios	S†	M or N†
Interior	Load-bearing walls Non-load-bearing partitions	N O	S or M N

*Adapted from ASTM C270. This table does not provide for specialized mortar uses, such as chimney, reinforced masonry, and acid-resistant mortars.
**Type O mortar is recommended for use where the masonry is unlikely to be frozen when saturated or unlikely to be subjected to high winds or other significant lateral loads. Type N or S mortar should be used in other cases.
†Masonry exposed to weather in a nominally horizontal surface is extremely vulnerable to weathering. Mortar for such masonry should be selected with due caution.

Note: For tuckpointing mortar, see "Tuckpointing," Chapter 9.

Portland cement – lime mortars

Relative Parts by Volume

mortar type	Portland cement	lime	sand
M	1	$\frac{1}{4}$	$3\frac{1}{2}$
S	1	$\frac{1}{2}$	$4\frac{1}{2}$
N	1	1	6
O	1	2	9

sum should equal 1/3 of sand volume
(assuming that sand has void ratio of 1 in 3)