= 0.7 for compressive forces applied normal to the head face where the grout is continuous horizontally in the zone of compression

= 1.0 for compressive forces applied normal to the bed face

β_1 = 0.8 for masonry strengths f'_m up to and including 20 MPa

= 0.8 minus 0.1 for each 10 MPa of strength in excess of 20 MPa

c = the distance from the fibre of maximum strain to the neutral axis measured in a direction perpendicular to that axis, mm

Notes:

(1) *Grout is considered to be horizontally continuous where the grout in compression zone is not interrupted by webs.*

(2) *Splitter blocks should not be used in the construction of masonry beams, as the split void in the centre web of these units cannot be fully grouted and will result in a reduced capacity.*

(3) *Grout will be continuous in the compression zone of a beam when, for example, lintel or knockout blocks are used to form the compression zone of the beam or when the cavity between two wythes of solid brick masonry is filled with grout.*

(4) *Linear interpolation may be used to calculate β_1.*

11.2.2 Maximum reinforcement in flexural members

For flexural members having no axial load, the area of tension reinforcement shall be such that the following condition is satisfied for the section:

$$\frac{c}{d} \leq \frac{600}{600+f_y}$$

11.2.3 Minimum reinforcement of flexural members

11.2.3.1

At any section of a flexural member, except as provided in Clause 11.2.3.2, where reinforcement is required by analysis, the ratio, ρ, provided shall not be less than that given by

$$\rho_{min} = \frac{0.8}{f_y}$$

11.2.3.2

Alternatively, with reference to Clause 11.2.3.1, the area of reinforcement provided at every section shall be at least one-third greater than that required by analysis.

11.2.4 Effective cross-sectional area

The effective cross-sectional area, A_e, to be used in the design of masonry beams shall be based on the minimum cross-sectional area in a plane perpendicular to the span.

11.2.5 Distance between lateral supports of beams

11.2.5.1

Unless a stability analysis that includes the effects of torsional loading is carried out, beams shall comply with the limits specified in Clauses 11.2.5.2 to 11.2.5.4.

11.2.5.2

Effects of lateral eccentricity of load shall be taken into account in determining the spacing of lateral supports.

11.2.5.3

For a simply supported or continuous beam, the distance between points at which lateral support is provided shall not exceed the smaller of $30b$ or $120b^2/d$.

11.2.5.4
For a cantilever beam having lateral restraint at the support, the distance between the support and the end of the cantilever shall not exceed the smaller of $15b$ or $60b^2/d$.

11.2.6 Distribution of flexural reinforcement in beams

11.2.6.1 Crack control
To control cracking, flexural tension reinforcement shall be well distributed within the maximum flexural tension zone of the cross-section, as required by Clause 11.2.6.2.

11.2.6.2 Crack control parameter
Cross-sections of maximum positive and negative moments shall be so proportioned that the quantity z given by

$$z = f_s \sqrt[3]{d_c A} \times 10^{-3}$$

does not exceed 30 kN/mm for interior exposure and 25 kN/mm for exterior exposure. The calculated stress in reinforcement at specified load, f_s (MPa), shall be computed as the moment divided by the product of the steel area and the internal moment arm. In lieu of such computations, f_s may be taken as 60% of the specified yield strength, f_y .

Note: *These provisions will in some cases not be sufficient for structures subject to very aggressive exposure or designed for watertightness. For such structures, special investigations and precautions will be required.*

11.2.6.3 Intermediate reinforcement
Where the height of the beam exceeds 600 mm, additional intermediate longitudinal reinforcement shall be uniformly distributed over two-thirds of the height of the beam nearest the main tension reinforcement. The minimum amount of intermediate reinforcement shall consist of a single 15M bar for beams up to 240 mm wide, and a 15M bar on each side for wider beams and shall be provided at 400 mm vertical spacing except that the first layer of intermediate reinforcement shall be placed not more than 300 mm from the main tension reinforcement. Intermediate reinforcement shall be taken into account in determining the maximum reinforcement in accordance with Clause 11.2.2.

Note: *Intermediate reinforcement may be included in determining the flexural resistance of beams in accordance with Clause 11.1.1.*

11.2.6.4 Compression reinforcement
Where compression steel is required in beams, it shall be anchored by ties or stirrups not less than 6 mm in diameter, spaced not more than 16 bar diameters or 48 tie diameters apart, whichever is less. Such ties or stirrups shall be used throughout the length of the beam where compression steel is required.

11.2.7 Deep beams

11.2.7.1
Beams having span-to-depth ratios less than 3 for continuous spans or 2 for simple spans, or having a cantilever-to-depth ratio less than 1 for cantilevers shall be designed as deep beams having a reduced moment arm between the compression zone and the tensile reinforcement. For these members, the effective depth, d, may be taken as 0.67 of the section depth, but not greater than 0.35 times the span or 0.7 times the cantilever length.

11.2.7.2
Deep beams shall be designed taking into account nonlinear distribution of strain, lateral buckling, and the increased anchorage requirements for reinforcement in such members.

Note: *Special attention should be given to the anchorage of longitudinal reinforcement in deep beams.*

11.2.7.3
Minimum horizontal and vertical reinforcement in the side faces of deep beams shall satisfy the requirements of Clause 11.3.6.

11.3 Shear in beams

11.3.1 General principles and requirements: Design methods and design considerations

11.3.1.1
Beams shall be designed for shear, in accordance with Clauses 11.3.1 to 11.3.5.

11.3.1.2
For deep beams, the special provisions of Clause 11.3.6 shall apply.

11.3.1.3
In determining shear resistance, the effects of axial tension due to creep, shrinkage, and thermal effects in restrained members shall be considered wherever applicable.

11.3.1.4
For variable depth members, the components of flexural compression and tension in the direction of the applied shear shall be taken into account if their effect is unfavourable, and may be taken into account if their effect is favourable.

11.3.1.5
In determining shear resistance, V_r, the effect of any openings in members shall be considered.

11.3.2 Shear reinforcement details

11.3.2.1 Type of shear reinforcement
Transverse reinforcement provided for shear shall consist of stirrups placed perpendicular to the axis of the member.

11.3.2.2 Anchorage of shear reinforcement
Stirrups and other bars or wires used as shear reinforcement shall be anchored at both ends in accordance with Clause 12.4.11 to develop the design yield strength of the reinforcement.

11.3.2.3 Yield strength of shear reinforcement
The yield strength used in design calculations of shear transverse reinforcement shall not exceed 400 MPa.

11.3.3 Low and normal density concrete masonry units
Values of the modification factor, λ, to account for the type of concrete shall be
(a) 1.00 for concrete units with density over 2000 kg/m^3;
(b) 0.85 for concrete units with density not less than 1800 kg/m^3; and
(c) 0.75 for concrete units with density not less than 1700 kg/m^3.

11.3.4 Shear design

11.3.4.1 Factored shear resistance
The factored shear resistance shall be determined from

$$V_r = V_m + V_s$$

V_m shall be determined in accordance with Clause 11.3.4.3 for masonry constructed in accordance with Clause 11.1.3. V_s shall be determined in accordance with Clause 11.3.4.4 for stirrups detailed for adequate anchorage in accordance with Clause 12.4.11.2.

Note: *Where the conditions for determining V_m or V_s specified in the above clause are not met, V_m or V_s should be taken as zero.*

11.3.4.2 Calculation of V_f in regions near supports

Sections located less than d_v from the face of a support may be designed for the same V_f as that computed at distance d_v if the following conditions are satisfied:

(a) the support reaction, in the direction of the applied shear, produces compression in the end region of the member; and

(b) no concentrated load applied to the flexural compression face of the beam causing a shear force greater than 15% of the total shear force is applied within a distance d_v from the face of the support

where

h_b = overall height of the beam, mm

d_v = effective depth for shear calculations, taken as the greater of $0.9d$ or $0.72h_b$, mm

11.3.4.3 Calculation of V_m

The factored shear resistance of beams provided by the masonry, V_m , shall be calculated as follows:

$$V_m = \phi_m \lambda K_b \beta \sqrt{f'_m} b_w d_v$$

where

b_w = overall web width of the beam, mm

β = a value calculated in accordance Clause 11.3.4.5

K_b = 1.0 for reinforced grouted hollow and semi-solid concrete masonry and grouted hollow clay masonry (see Figure 4)

= 0.35 for reinforced grouted brick masonry of solid or cored units (see Figure 5)

= 0.175 for reinforced brick masonry of solid or cored units (see Figure 6)

11.3.4.4 Calculation of V_s

The factored shear resistance, V_s, of shear reinforcement perpendicular to the flexural reinforcement in the member shall be calculated as

$$V_s = \phi_s A_v f_y d_v \cot\theta_1 / s$$

but not greater than

$$0.36\phi_m \sqrt{f'_m} b_w d_v$$

where

s = spacing of shear reinforcement measured parallel to the longitudinal axis of the member, mm

θ_1 = angle of inclination of diagonal compressive stresses

11.3.4.5 Calculation of β and θ_1

The calculation of β and θ_1 shall be determined in accordance with either Clause 11.3.4.6 or Clause 11.3.4.7.

For beams subjected to significant axial tension, the simplified method for determining β and θ_1 in accordance with Clause 11.3.4.6 shall not be used.

Note: *A modified compression field theory, similar to that applied to reinforced concrete, was used to develop the provisions in Clauses 11.3.4.6 and 11.3.4.7.*

11.3.4.6 Simplified method

In lieu of more accurate calculations in accordance with Clause 11.3.4.7, and provided that the specified yield strength of the longitudinal steel reinforcement does not exceed 400 MPa, θ_1 shall be taken as 42° and β shall be determined as:

(a) For beams with an area of stirrups equal to or greater than that specified in Clause 11.3.4.8.2, β shall be taken as 0.18;

(b) For beams with no stirrups or with an area of stirrups less than that specified in Clause 11.3.4.8.2, β shall be taken as; or

$$\beta = \left(\frac{230}{1000 + 1.4d_v}\right)$$

(c) If the beam has longitudinal crack control reinforcing bars placed along the height of the beam, β may be calculated using the above equation, replacing the parameter d_v with the vertical spacing between layers of such reinforcement, z_s, provided that each layer of reinforcement has an area of at least $0.002b_w z_s$.

11.3.4.7 General method

11.3.4.7.1 Calculation of β

The value of β in Clause 11.3.4.3 shall be determined as

$$\beta = \frac{0.40}{1 + 1500\varepsilon_\chi} \cdot \frac{1300}{1000 + z_e}$$

where

z_e = equivalent value of z_s that allows for the influence of aggregate size in the grout determined in accordance with Clause 11.3.4.7.2

ε_χ = a value determined in accordance with Clause 11.3.4.7.3.

11.3.4.7.2 Calculation of z_e

For sections containing an area of stirrups equal to or greater than that specified in Clause 11.3.4.8.2, z_e shall be 300. Otherwise, z_e shall be calculated as

$$z_e = g_a z_s$$

where

g_a = 1.4 for coarse grout and 1.7 for fine grout, in accordance with CSA A179

z_s = the lesser of d_v or the vertical spacing between layers of intermediate reinforcement, in accordance with Clause 11.3.4.6(c)

11.3.4.7.3 Calculation of ε_χ

In lieu of more accurate calculations, the longitudinal strain, ε_χ, at mid-height of the beam cross-section shall be computed as

$$\varepsilon_\chi = \frac{M_f / d_v + V_f + 0.5N_f - A_{p1}f_{po}}{2\left(E_s A_s + E_p A_p\right)}$$

In evaluating ε_χ, the following conditions shall apply:

(a) V_f and M_f shall be taken as positive quantities, and M_f shall not be taken as less than $V_f d_v$. N_f shall be positive for tension, negative for compression.

(b) A_s and A_{p1} shall be taken as the areas of nonprestressed tensile reinforcement and prestressed tensile reinforcement, respectively, located within $0.5h_b$ from the tension face of the beam.

(c) In calculating A_s, the area of bars that are terminated less than their development length from the section under consideration shall be reduced in proportion to their lack of full development.

(d) If ε_χ is calculated to be less than zero, it shall be taken as zero.
(e) For sections located within distance d_v from the face of the support, the value of ε_χ calculated at d_v from the face of the support may be used in evaluating β.
(f) If axial tension is large enough to crack the flexural compression face of the section, the resulting increase in ε_χ shall be taken into account. In lieu of more accurate calculations, the value calculated above shall be doubled.

11.3.4.7.4 Calculation of θ_1

The angle of inclination of diagonal compressive stresses, θ_1, shall be calculated as

$$\theta_1 = 29 + 7000\varepsilon_\chi$$

11.3.4.8 Minimum shear reinforcement

11.3.4.8.1

A minimum area of shear reinforcement shall be provided in all regions of beams where the factored shear force, V_f , exceeds V_m for beams with h_b not greater than 800 mm and where V_f exceeds $0.5V_m$ for beams with h_b greater than 800 mm.

11.3.4.8.2

Where shear reinforcement is required by Clause 11.3.4.8.1 or by calculation, the minimum area of shear reinforcement shall be calculated as

$$A_v = \frac{0.35 b_w s}{f_y}$$

11.3.4.9 Spacing limits for shear reinforcement

The maximum spacing of shear reinforcement placed perpendicular to the member shall be the lesser of $d/2$ or 600 mm. Where the effective depth, d, is equal to or greater than 300 mm, the maximum spacing of shear reinforcement need not be less than 200 mm.

11.3.5 Special shear requirements for prestressed beams

11.3.5.1

The shear resistance, V_r, of a prestressed masonry beam shall be the average of the following two values:
(a) the value determined in Clause 11.3.4 including the effects of f_{po}; and
(b) the value determined in Clause 11.3.4 with f_{po} set equal to zero.

11.3.5.2

The component of the prestressing force in the direction of applied shear, V_p, multiplied by ϕ_p, may be added to V_r .

11.3.6 Special shear requirements for beams with deep shear spans

11.3.6.1 Application

The requirements of Clause 11.3.6 shall apply to regions of beams in which the effective depth, d_v , exceeds 400 mm, and the distance from the point of zero shear to the face of the support is less than $2d_v$.

11.3.6.2 General

Shear design of beams with deep shear spans shall be carried out using one of the two following methods:
(a) the shear provisions outlined in Clauses 11.3.1, 11.3.2, 11.3.3, and 11.3.4; or
(b) a recognized method that accounts for additional shear strength due to the formation of compressive struts and tension ties. Crack control reinforcement in accordance with Clause 11.3.6.3 shall be provided.

Notes:
(1) *Special attention should be given to the anchorage of longitudinal reinforcement in deep beams.*
(2) *An example of a recognized design method is the strut and tie model sometimes used for reinforced concrete beams.*

11.3.6.3 Crack control reinforcement

Regions of members designed in accordance with Clause 11.3.6.2(b) shall contain an orthogonal grid of reinforcing bars. The ratio of reinforcement area to gross area shall not be less than 0.002 in each direction. Spacing of this reinforcement shall not exceed 400 mm and shall meet the requirements of Clause 11.3.4.9.

11.4 Service load deflection of beams

11.4.1 General

Service load deflections of beams shall be checked when the clear span exceeds 10*d*.

11.4.2 Immediate deflection

Immediate deflections shall be computed using the modulus of elasticity, E_m, for masonry specified in Clause 6.5 and the effective moment of inertia specified in Clause 11.4.3.

11.4.3 Effective moment of inertia for deflection calculations at service loads

11.4.3.1

The effective moment of inertia, I_{eff}, to be used in service load deflection calculations for beams shall be calculated in accordance with Clauses 11.4.3.2 and 11.4.3.3.

11.4.3.2

Unless stiffness values are obtained by a more comprehensive analysis, the effective moment of inertia, I_{eff}, shall be determined as follows:

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

but not greater than I_o

where

M_a = maximum moment due to service loads, N•mm

$$M_{cr} = \frac{(f_t + f_{cs}) I_o}{y_t}$$

where

f_t = the appropriate flexural tensile strength value from Table 5, MPa

f_{cs} = axial compressive stress, using A_e, due to unfactored axial loads, including prestressing force, MPa

Note: f_{cs} *is positive for compression and negative for tension.*

11.4.3.3

For prismatic members, I_{eff} may be taken as the value obtained from Clause 11.4.3.2 at midspan for simple spans and at the support for cantilevers. For prismatic continuous spans, I_{eff} may be taken as the weighted average of the values from Clause 11.4.3.2 for the critical positive and negative moment sections calculated as

(a) for two ends continuous: $I_{eff} = 0.7I_{effm} + 0.15(I_{eff1} + I_{eff2})$; and
(b) for one end continuous: $I_{eff} = 0.85I_{effm} + 0.15I_{effc}$

where

I_{eff} = effective moment of inertia, mm^4

I_{effm} = effective moment of inertia at the midspan of a beam, mm^4

I_{eff1} = effective moment of inertia at end one of a continuous beam, mm^4

I_{eff2} = effective moment of inertia at end two of a continuous beam, mm^4

I_{effc} = effective moment of inertia at continuous end of a beam, mm^4

11.4.4 Long-term deflection

Unless values are obtained by a more comprehensive analysis, the long-term deflection for beams shall be obtained by multiplying the immediate deflection caused by the sustained load by the factor calculated as

$$\frac{S_1}{1+50\rho'}$$

where

S_1 = the time-dependent factor

= 1.0 for a sustained load of 5 years or more

= 0.7 for a sustained load of 12 months

= 0.6 for a sustained load of 6 months

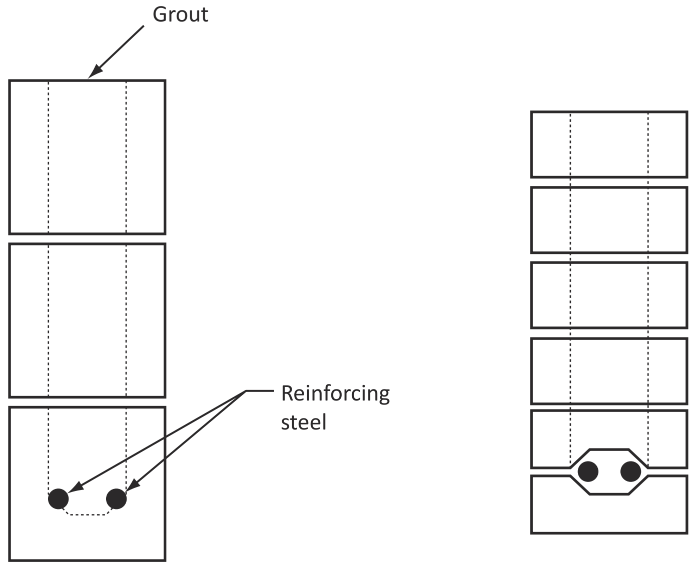
= 0.5 for a sustained load of 3 months

ρ' = the compression steel ratio, A'_s/bd, at midspan for simple and continuous spans, and at the support for cantilevers

11.4.5 Allowable deflection

Total live load plus long-term deflection of beams shall not exceed span/480.

Figure 4
Reinforced grouted masonry of hollow or semi-solid masonry units
(See Clauses 11.1.3 and 11.3.4.3.)



a) Reinforced grouted masonry of hollow or semi-solid concrete block units

b) Reinforced grouted masonry of hollow clay brick units

Figure 5
Reinforced grouted brick masonry of solid units
(See Clauses 11.1.3 and 11.3.4.3.)

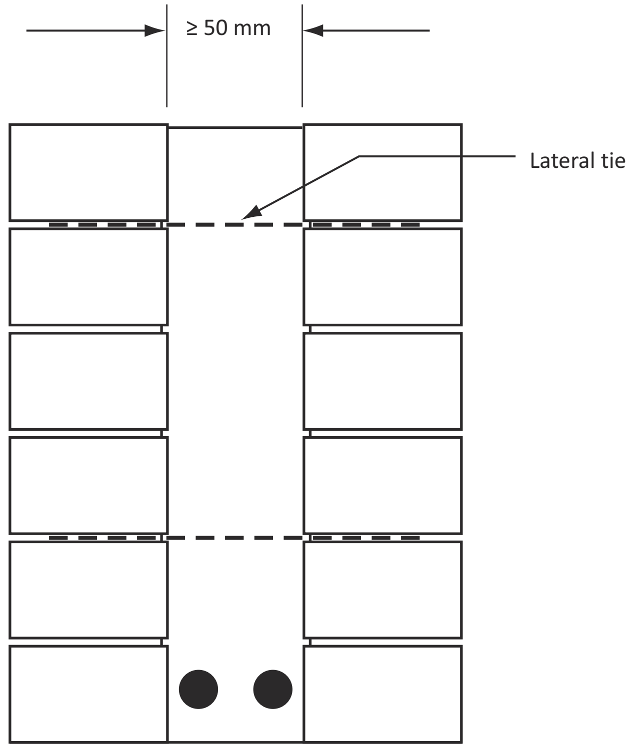


Figure 6
Reinforced brick masonry of solid units
(See Clauses 11.1.3 and 11.3.4.3.)