

PART VI
Appendix J

Working Stress Design Method for Reinforced Concrete Structures

J.1 Analysis and Design - General Consideration

J.1.1 Notation

A_s	=	Area of tension reinforcement
A'_s	=	Area of compression reinforcement
A_v	=	Area of shear reinforcement perpendicular to flexural tension reinforcement within a distance s , mm ²
A_{vh}	=	Area of shear reinforcement parallel to flexural tension reinforcement within a distance s_l , mm ²
E_c	=	Modulus of elasticity of concrete, N/mm ²
E_s	=	Modulus of elasticity of reinforcement, N/mm ²
H	=	Total lateral force acting in any storey
M	=	Moment at the section acting simultaneously with P
M_n	=	Flexural moment capacity
M_r	=	Resisting moment capacity based on f'_c
N	=	Axial load normal to cross section occurring simultaneously with V , to be taken as positive for compression, negative for tension and to include effects of tension due to creep and shrinkage
P	=	Working axial load at the section
R	=	Constant, $\frac{1}{2} f_c k j$
T	=	Torsional moment at section
T_c	=	Torsional moment strength provided by concrete
T_s	=	Torsional moment strength provided by torsion reinforcement
V	=	Shear at section
V_c	=	Shear strength provided by concrete
V_s	=	Shear strength provided by shear reinforcement
V_n	=	Shear strength
a	=	Shear span, distance between concentrated load and face of support, mm

b	=	Width of rectangular beam, or effective width of compression flange for T-beam
b_w	=	Web width, or diameter of circular section
d, d'	=	Distance of extreme compression fibre to centroid of compression reinforcement
d_c	=	Thickness of concrete cover measured from the extreme tension fibre to centre of bar or wire located closest thereto
f_c	=	Allowable stress in concrete
f'_c	=	Specified compressive strength of concrete, N/mm ²
f_s	=	Allowable/Permissible tensile stress in reinforcement, N/mm ²
f_y	=	Specified yield strength of reinforcement, N/mm ²
h	=	Overall thickness of members, mm.
j, k	=	Beam constants defined in Sec J.2.6.1
l	=	Effective span, mm
l_n	=	Clear span measured face-to-face of supports, mm
n	=	Modular ratio, E_s/E_c
r	=	Stress ratio, f_s/f_c
s	=	Spacing of shear or torsion reinforcement in direction parallel to longitudinal reinforcement, mm
s_1	=	Spacing of shear or torsion reinforcement in direction perpendicular to longitudinal reinforcement, mm
t	=	Thickness of compression flange of T-beams
v	=	Design shear stress, N/mm ²
v_c	=	Permissible shear stress carried by concrete, N/mm ²
z	=	lever arm used in Sec J.8.3
β_c	=	Ratio of long side to short side of concentrated load or reaction area.
Δ	=	Elastically computed first order lateral deflection due to H at the top of the storey relative to the bottom of the storey.
ρ	=	Ratio of tension reinforcement, $= A_s/bd$
ρ_w	=	$A_s/b_w d$

For all other symbols reference shall be made to Sec 6.1.1.

J.1.2 Design Methods

In the design of reinforced concrete structures using working stress design method, members shall be proportioned for adequate capacity in accordance with the provisions of this Chapter using working loads and permissible stresses. The working stress design method may be used as an alternative method with the requirement that provisions of Chapter 6, except Sec 6.1.5, shall apply to members designed by this method.

J.1.3 Design Assumptions

The design of reinforced concrete structures by the working stress design method is based on the following assumptions.

- J.1.3.1 At any cross section, plane sections before bending remain plane after bending; strains vary with the distance from the neutral axis.
- J.1.3.2 All tensile stresses are taken up by reinforcement and none by concrete, except otherwise specifically permitted.
- J.1.3.3 The stress-strain relation for concrete is a straight line under working loads within the allowable working stresses. Stresses vary linearly with the distance from the neutral axis except for deep beams.
- J.1.3.4 The tension reinforcement area is replaced in design computations with a concrete tension area equal to n times that of the reinforcement steel, where n is the modular ratio E_s/E_c .
- J.1.3.5 In doubly reinforced beams the compression reinforcement shall be transformed to an equivalent concrete area which is $2n$ times that of the reinforcement steel.
- J.1.3.6 The modular ratio $n = \frac{E_s}{E_c}$ may be taken as the nearest whole number, but not less than 6.
- J.1.3.7 The compressive stress developed in compression reinforcement of doubly reinforced beams shall not exceed the permissible tensile stress for such steel.

J.1.4 Loading

- J.1.4.1 Design provisions of this Chapter based on the assumption that structures shall be designed to resist all applicable loads.
- J.1.4.2 Service loads shall be in accordance with Chapter 2, Loads, with such live load reductions as are permitted therein.

- J.1.4.3 In the design for wind and earthquake loads, integral structural parts shall be designed to resist the total lateral loads.
- J.1.4.4 Consideration shall be given to effects of forces due to crane loads, vibration, impact, shrinkage, temperature changes, creep and unequal settlement of supports.
- J.1.4.5 When dead load reduces effects of other loads, members shall be designed for 85 percent of the dead load in combination with the other loads.

J.1.5 Stiffness

- J.1.5.1 Use of any consistent set of assumptions is permitted for computing relative flexural and torsional stiffness of columns, walls, floors, and roof systems.
- J.1.5.2 In computing the value of I for relative flexural stiffness of slabs, beams, girders, and columns, contribution of the reinforcement may be neglected. In T-shaped sections allowance shall be made for the effect of flange.
- J.1.5.3 If the total torsional stiffness in the plane of a continuous system at a joint does not exceed 20 percent of the flexural stiffness at the joint, the torsional stiffness need not be taken into consideration in the analysis.
- J.1.5.4 Effect of haunches shall be considered both in determining the moments and in the design of members.

J.1.6 Span Length

- J.1.6.1 Span length of members not built integrally with supports shall be considered as the clear span plus depth of member but need not to exceed distance between centres of supports.
- J.1.6.2 In determining moments in frames or continuous construction, span lengths shall be taken as the centre-to-centre distance of supports.
- J.1.6.3 For design of beams built integrally with supports, the use of moments at faces of support is permitted.
- J.1.6.4 Solid or ribbed slabs built integrally with supports, with clear span not more than 3.0 m, are permitted to be analysed as continuous slabs on knife edge supports, with spans equal to the clear spans of the slab, the width of beams being otherwise neglected.
- J.1.6.5 Effective span of cantilevered beams or slabs shall be taken as its span to the face of support plus half its effective depth, except where it is an overhang of a continuous beam, the length to the centre of the support shall be used.

J.1.7 Arrangement of Live Loads

For continuous beams and frames the arrangement of live load may be limited to the combination of:

- (a) Service dead load on all spans with full service live load on two adjacent spans, and
- (b) Service dead load on all spans with full service live load on alternate spans.

J.1.8 Floor Finish

J.1.8.1 A floor finish shall not be included as part of a structural member unless placed monolithically with the floor slab or designed in accordance with requirements of composite concrete flexural members.

J.1.8.2 It is allowed to consider all concrete floor finishes as part of required cover or total thickness for non-structural considerations.

J.1.9 Allowable Stresses in Concrete

Allowable stresses in concrete shall not exceed the following:

- (a) Flexure:

Extreme fibre stress in compression $0.45 f'_c$

- (b) Shear:

Beams, one-way slabs and footings :

Shear stress carried by concrete, v_c $0.091\sqrt{f'_c}$

Maximum shear stress carried by concrete plus shear reinforcement $0.457\sqrt{f'_c}$

Ribs: $0.10\sqrt{f'_c}$

Shear stress carried by concrete, v_c

Two-way slabs and footings : $(0.083 + 0.17/\beta_c)\sqrt{f'_c} \leq 0.17\sqrt{f'_c}$

Shear stress carried by concrete, v_c

- (c) Bearing stress on loaded area :

When the loaded area (area of column, pier or base plate) and the supporting area (area of the top of footing) are equal $0.3\sqrt{f'_c}$

When the supporting area is larger than the loaded area on all sides $0.3\sqrt{\left(\frac{A_1}{A_2}\right)}f'_c \leq 0.6f'_c$

Where,

A_1 = Area of the lower base of the largest frustum of a pyramid, cone, or tapered wedge contained wholly within the footing and having for its upper base, the area actually loaded, and having side slopes of 1 vertical to 2 horizontal, and

A_2 = Loaded area of the column base.

J.1.10 Allowable Stresses in Reinforcement

Allowable tensile stresses in reinforcement f_s , shall be those as specified below:

(a) Except as specified in (b) below, f_s shall be determined as follows :

(i) For $250\text{ N/mm}^2 \leq f_y < 275\text{ N/mm}^2$: $f_s = 125\text{ N/mm}^2$

(ii) For $275\text{ N/mm}^2 \leq f_y < 420\text{ N/mm}^2$: $f_s = 138\text{ N/mm}^2$

(iii) For $f_y \geq 420\text{ N/mm}^2$: $f_s = 165\text{ N/mm}^2$

(b) For flexural reinforcement, 100 mm or less in diameter in one-way slabs of not more than 3.5 m span: $f_s = 0.5f_y$ but not greater than 200 N/mm^2

J.1.11 Allowable Stresses for Wind and Earthquake Forces

Members subject to stresses produced by wind or earthquake forces combined with other loads may be proportioned for stresses 33 percent greater than those specified in Sections J.1.9 and J.1.10, provided that the section thus required is not less than that required for the combination of dead and live load.

J.1.12 Development and Splices of Reinforcement

J.1.12.1 Development and splices of reinforcement shall be in accordance with Chapter 8, Detailing of Reinforcement in Concrete Structures.

J.1.12.2 In satisfying requirements of Sec 8.2.8.3, M_n shall be taken as computed moment capacity assuming all positive moment tension reinforcement at the section to be stressed to the permissible tensile stress f_s and V_u shall be taken as unfactored shear force at the section.

J.2 Beams and One-Way Slabs

J.2.1 Notation

All the notation used this Section are provided in Sec. J.1.1

J.2.2 Span Length

Determination of span length shall be in accordance with Sec J.1.6.

J.2.3 Design Assumptions

Design assumptions shall be in accordance with Sec J.1.3.

J.2.4 General Principles and Requirements

- J.2.4.1 Design of cross section subject to flexural or combined flexure and axial loads shall be based on design assumptions of Sec J.1.3.
- J.2.4.2 Compression reinforcement in conjunction with additional tension reinforcement may be used to increase flexural strength of the members.
- J.2.4.3 The effective depth, d , of a beam or slab shall be taken as the distance from the centroid of its tensile reinforcement to its compression face.
- J.2.4.4 The effects of lateral eccentricity of load shall be taken into account in determining the spacing of lateral supports for a beam. The spacing shall never exceed 50 times the least width b of compression flange or face.
- J.2.4.5 Requirements of T-beams
 - (a) In T-beam construction the slab and beam shall be built integrally or otherwise effectively bonded together.
 - (b) The effective flange width to be used in the design of symmetrical T-beams shall not exceed one-fourth of the span length of the beam, and its overhanging width on either side of the web shall not exceed eight times the thickness of the slab nor one-half the clear distance to the next beam.
 - (c) Isolated beams in which the T-form is used only for the purpose of providing additional compression area, shall have a flange thickness not less than one-half the width of the web and a total flange width not more than four times the width of the web.
 - (d) For beams having a flange on one side only, the effective overhanging flange width shall not exceed $\frac{1}{12}$ th of the span length of the beam, nor six times the thickness of the slab, nor one-half the clear distance to the next web.

- (e) The overhanging portion of the flange of the beam shall not be considered effective in computing the shear and diagonal tension resistance of T-beams.
- (f) Provision shall be made for the compressive stress at the support in continuous T-beam construction.

J.2.5 Continuous Beams

Continuous beams shall be analysed in accordance with Sec J.2.5.2 and designed and detailed according to Sec J.2.6 and J.2.7 to resist moments and shear forces.

J.2.5.1 Arrangement of Live Loads: Arrangement of live loads shall be in accordance with Sec J.1.7.

J.2.5.2 Methods of analysis

- (a) All members of frames or continuous construction shall be designed for the maximum effects of working loads as determined by the theory of elastic analysis.
- (b) In lieu of exact analysis, the approximate moments and shears given in Sec 6.1.4.3 may be used for design of continuous beams and one way slabs (slab reinforced to resist flexural stresses in only one direction), provided that the quantity w_u in the expressions in Sec. 6.1.4.3 is replaced by the working load w .
- (c) No redistribution of negative moment shall be permitted for working stress design.

J.2.6 Design for Flexure

J.2.6.1 The following equations are applicable to singly and doubly reinforced rectangular beams :

When, the stress ratio, r is known

$$k = \frac{n}{n + r} \quad (6.J.1)$$

When, steel ratio, ρ is known

$$k = \sqrt{2n\rho + (n\rho)^2} - n\rho \quad (6.J.2)$$

$$j = 1 - k / 3 \quad (6.J.3)$$

$$R = \frac{1}{2} f_c k j \quad (6.J.4)$$

$$M_r = R b d^2 \quad (6.J.5)$$

J.2.6.2 Formulae for Singly Reinforced Rectangular Beams: If external bending moment M is less than resisting moment M_r , the area of tensile reinforcement shall be calculated using the following formula :

$$A_s = \frac{M}{f_s j d} \quad (6.J.6)$$

J.2.6.3 Formulae for Doubly Reinforced Beams : If $M > M_r$ the beam shall be designed for tensile and compressive reinforcements using the following formulae :

$$A'_s = \frac{M - M_r}{f'_s (d - d')} \quad (6.J.7)$$

Where,

$$f'_s = \frac{2n-1}{n} \left(\frac{k - d'/d}{1-k} \right) f_s \leq f_s \quad (6.J.8)$$

$$A_s = \frac{M_r}{f_s j d} + \frac{(M - M_r)}{f_s (d - d')} \quad (6.J.9)$$

J.2.6.4 Design of T-beams: A T-beam, where the flange is on the compression side, shall be treated as a rectangular beam if $M \leq \frac{1}{2} f_c b t (d - t/3)$. Otherwise, the beam shall be considered as a T-beam, in which case the following formulae shall be applicable :

$$k = \frac{n\rho + \frac{1}{2}(t/d)^2}{n\rho + (t/d)} \quad (6.J.10)$$

Where,

$$\rho = A_s / b d$$

$$j = 1 - \left[\frac{3k - 2(t/d)}{2k - (t/d)} \right] (t/d) \quad (6.J.11)$$

$$A_s = \frac{M}{f_s j d} \quad (6.J.6)$$

Actual stress in concrete, f_{ca} can be obtained from the relation:

$$f_{ca} = \frac{M}{(1 - t/2kd) b t j d} \quad (6.J.12)$$

While using Eq. 6.J.10, if ρ is not known, it may be initially estimated as $\rho = M / [(d - t/2) b d f_s]$

J.2.7 Shear and Torsion

J.2.7.1 The design shear force V shall not exceed the sum of the shear strength provided by concrete, V_c and that provided by shear reinforcement, V_s .

$$V \leq V_c + V_s \quad (6.J.13)$$

J.2.7.2 When the reaction, in the direction of applied shear, introduces compression into the end regions of a member, sections located less than a distance d from face of support may be designed for the same shear force V as that computed at a distance d .

J.2.7.3 Shear strength provided by concrete

- (a) For members subject to shear and flexure, shear strength provided by concrete, V_c shall not exceed $0.091\sqrt{f'_c}b_wd$ unless a more detailed calculation is made in accordance with (d) below.
- (b) For members subject to shear and axial compression, shear strength provided by concrete V_c shall not exceed $0.091\sqrt{f'_c}b_wd$ unless a more detailed calculation is made in accordance with (e) below.
- (c) For members subject to significant axial tension, shear reinforcement shall be designed to carry total shear, unless a more detailed calculation is made using

$$V_c = 0.091 \left(1 + 0.58 \frac{N}{A_g} \right) \sqrt{f'_c} b_w d \quad (6.J.14)$$

Where, N is design axial load normal to cross-section occurring simultaneously with V and is negative for tension.

(d) For members subject to shear and flexure only, V_c may be computed by :

$$V_c = \left(0.083\sqrt{f'_c} + 9\rho_w \frac{Vd}{M} \right) b_w d \leq 0.16\sqrt{f'_c} b_w d \quad (6.J.15)$$

Quantity Vd/M shall not be taken greater than 1.0, where M is design moment occurring simultaneously with V at section considered, and $\rho_w = A_s / b_w d$.

(e) For members subject to axial compression, V_c may be computed by :

$$V_c = 0.091 \left(1 + 0.09 \frac{N}{A_g} \right) \sqrt{f'_c} b_w d \quad (6.J.16)$$

- (f) For members subjected to torsional moment T exceeding $(0.023\sqrt{f'_c})\sum x^2y$, V_c may be computed by

$$V_c = \frac{0.091\sqrt{f'_c}b_wd}{\sqrt{1+(2.5C_t T/V)^2}} \quad (6.J.17)$$

For calculation of $\sum x^2y$, the following conditions shall apply:

- (i) For members with rectangular or flanged sections, the sum $\sum x^2y$ shall be taken for the component rectangles of the section, but the overhanging flange-width used in design shall not exceed three times the flange thickness.
- (ii) A rectangular box section shall be taken as solid section provided the wall thickness t is at least $x/4$. A box section with wall thickness less than $x/4$ but greater than $x/10$ shall be taken as solid section except that $\sum x^2y$ shall be multiplied by $4h/x$. When t is less than $x/10$, the stiffness of the wall shall be considered. Fillets shall be provided at interior corners of box sections.
- (g) In determining shear strength provided by concrete V_c , whenever applicable, effects of axial tension due to creep and shrinkage in restrained members shall be considered and effects of inclined flexural compression in variable-depth members may be included.

J.2.7.4 Shear strength provided by shear reinforcement

- (a) Types of shear reinforcement

Shear reinforcement may consist of:

- (i) stirrups perpendicular to axis of member,
- (ii) bent up longitudinal reinforcement with bent portion making an angle of 30° or more with longitudinal tension reinforcement,
- (iii) combination of stirrups and bent longitudinal reinforcement,
- (iv) spirals.

- (b) Design yield strength of shear reinforcement shall not exceed 420 N/mm^2 .

- (c) Stirrups shall extend to a distance d from extreme compression fibre and shall be anchored at both ends in accordance with Sec 8.2.

(d) Spacing limits for shear reinforcement

- (i) Spacing of shear reinforcement perpendicular to member axis shall not exceed $d/2$, nor 600 mm.
- (ii) Bent longitudinal bars shall have a maximum spacing of $0.375d (1 + \cot \alpha)$, but not greater than 600 mm, where, α is the acute angle between the bent bar and the horizontal.
- (iii) When $(V - V_c)$ exceeds $0.17\sqrt{f'_c}b_wd$ maximum spacing given in (i) and (ii) above shall be reduced by one-half.

(e) Minimum shear reinforcement

- (i) A minimum area of shear reinforcement shall be provided in all reinforced concrete flexural members where design shear force V is greater than one-half the permissible shear strength V_c provided by concrete, except slabs, footings, ribbed construction and beams with total depth not exceeding the largest of 2.5 times thickness of flange, one-half the width of web, and 250 mm.
- (ii) Where shear reinforcement is required by (i) above or by analysis, minimum area of shear reinforcement shall be computed by

$$A_v = 0.35 \frac{b_w s}{f_y} \quad (6.J.18)$$

- (iii) Where torsional moment T exceeds $(0.023\sqrt{f'_c})\sum x^2y$ and where web reinforcement is required by (i) above or by analysis, the minimum area of closed stirrups shall be computed by

$$A_v + 2A_t = 0.35 \frac{b_w s}{f_y} \quad (6.J.19)$$

Where, A_t is the area of one leg of closed stirrup.

(f) Design of Shear Reinforcement

- (i) Where design shear force V exceeds shear strength provided by concrete V_c , shear reinforcement shall be provided in accordance with (ii) to (viii) below.
- (ii) When shear reinforcement perpendicular to axis of member is used,

$$A_v = \frac{(V - V_c) s}{f_s d} \quad (6.J.20)$$

- (iii) When inclined stirrups are used as shear reinforcement,

$$A_v = \frac{(V - V_c) s}{f_s d (\sin \alpha + \cos \alpha)} \quad (6.J.21)$$

- (iv) When shear reinforcement consists of a single bar or a single group of parallel bars, all bent up at the same distance from the support,

$$A_v = \frac{(V - V_c) s}{f_s d \sin \alpha} \quad (6.J.22)$$

Where $(V - V_c)$ shall not exceed $0.133\sqrt{f'_c}b_w d$

- (v) When shear reinforcement consists of a series of parallel bent-up bars or groups of parallel bent-up bars at different distances from the support, required area shall be computed by Eq. 6.J.21.
- (vi) Only the centre three-quarters of the inclined portion of any longitudinal bent bar shall be considered effective for shear reinforcement.
- (vii) When more than one type of shear reinforcement is used to reinforce the same portion of member, required area shall be computed as the sum of the various types separately. In such computations, V_c shall be included only once.
- (viii) Value of $(V - V_c)$ shall not exceed $0.365\sqrt{f'_c}b_w d$

J.2.7.5 Combined shear and torsion

- (a) Torsion effects shall be included with shear and flexure where torsional moment T exceeds $(0.023\sqrt{f'_c})\sum x^2 y$. Otherwise, torsion may be neglected. For calculation of $\sum x^2 y$, see Sec J.2.7.3(f).
- (b) If torsional moment T in a member is required to maintain equilibrium, the member shall be designed to carry that torsional moment in accordance with (c) to (j) below.
- (c) In a statically indeterminate structure where reduction of torsional moment in a member can occur due to redistribution of internal forces, maximum torsional moment may be reduced to $(0.06\sqrt{f'_c})\sum x^2 y$.
- (i) In such case the corresponding adjusted moments and shears in adjoining members shall be used in design.
- (ii) In lieu of exact analysis, torsional loading from a slab shall be taken uniformly distributed along the member.
- (d) Sections located less than a distance d from face of support may be designed for the same torsional moment T as that computed at a distance d .
- (e) Torsional Moment Strength

Design of cross-section subject to torsion shall be based on

$$T = T_c + T_s \quad (6.J.23)$$

Where,

T = is torsional moment at section,

T_c = is torsional moment strength provided by concrete in accordance with (f) below,

T_s = is torsional moment strength provided by torsion reinforcement in accordance with (j) below.

(f) Torsional moment strength provided by concrete

(i) Torsional moment strength T_c shall be computed by

$$T_c = \frac{(0.036\sqrt{f'_c})\sum x^2y}{\sqrt{1 + \left(\frac{0.4V}{C_tT}\right)^2}} \quad (6.J.24)$$

(ii) For members subject to significant axial tension, torsion reinforcement shall be designed to carry the total torsional moment, unless a more detailed calculation is made, in which T_c given by Eq. 6.J.24 and V_c given by Eq. 6.J.17 shall be multiplied by $\left(1 + \frac{0.3N}{A_g}\right)$, where N is negative for tension.

(g) Torsion Reinforcement Requirements

- (i) Torsion reinforcement, where required, shall be provided in addition to reinforcement required to resist shear, flexure and axial forces.
- (ii) Reinforcement required for torsion shall be combined with that required for other forces, provided the area furnished is the sum of individually required areas and the most restrictive requirements for spacing and placement are met.
- (iii) Torsion reinforcement shall consist of closed stirrups, closed ties or spirals, combined with longitudinal bars.
- (iv) Design yield strength for torsion reinforcement shall not exceed 420 N/mm².
- (v) Stirrups used as torsion reinforcement shall extend to a distance d from extreme compression fibre and shall be anchored in accordance with Sec 8.2.
- (vi) Torsion reinforcement shall be provided at least a distance $(bt + d)$ beyond the point theoretically required.

(h) Design of Torsion Reinforcement

- (i) Where torsional moment T exceeds torsional moment strength T_c , torsion reinforcement shall be provided to satisfy Eq. 6.J.23, where torsional moment strength T_s shall be computed by

$$T_s = 0.55 \frac{A_t x_1 y_1 f_y}{s} \quad (6.J.25)$$

Where A_t is the area of one leg of closed stirrup resisting torsion within a distance s and $\alpha_t = (2 + y_1/x_1)/3$, but not more than 1.5. Longitudinal bars distributed around the perimeter of the closed stirrup A_t shall be provided in accordance with (iii) below.

- (ii) A minimum area of closed stirrup shall be provided in accordance with Sec J.2.7.4(e).
- (iii) Required area of longitudinal bar A_l distributed around the perimeter of the closed stirrup A_t shall be computed by :

$$A_l = 2A_t \left(\frac{x_1 + y_1}{s} \right) \quad (6.J.26)$$

$$\text{or,} \quad A_l = \left[\frac{2.8xs}{f_y} \left(\frac{T}{T + \frac{V}{3C_t}} \right) - 2A_t \right] \left(\frac{x_1 + y_1}{s} \right) \quad (6.J.27)$$

$$\text{or,} \quad A_l = \left[\frac{2.8xs}{f_y} \left(\frac{T}{T + \frac{V}{3C_t}} \right) - \frac{b_w s}{3f_y} \right] \left(\frac{x_1 + y_1}{s} \right) \quad (6.J.28)$$

Whichever is the greatest

- (iv) Torsional moment strength T_s shall not exceed $4T_c$

(i) Spacing Limits for Torsion Reinforcement

- (i) Spacing of closed stirrups shall not exceed the smaller of $\left(\frac{x_1 + y_1}{4} \right)$, or 300 mm.
- (ii) Spacing of longitudinal bars, not less than 10 mm diameter, distributed around the perimeter of the closed stirrup shall not exceed 300 mm. At least one longitudinal bar shall be placed in each corner of the closed stirrups.

J.2.8 Reinforcement

J.2.8.1 At any section of a beam or one-way slab, except as provided in Sec J.2.8.2 and J.2.8.3 below, where positive reinforcement is required by analysis, the ratio ρ provided shall not be less than that given by

$$\rho_{\min} = \frac{1.38}{f_y} \quad (6.J.29)$$

In flanged beams where the web is in tension, the ratio ρ shall be computed for this purpose using the width of web.

J.2.8.2 Alternatively, area of reinforcement provided at every section, positive or negative, shall be at least one-third greater than that required by analysis.

J.2.8.3 For structural slabs of uniform thickness, minimum area and maximum spacing of reinforcement in the direction of the span shall be as required for shrinkage and temperature according to Sec 8.1.11.

J.2.8.4 Where the principal reinforcement in a slab which is considered as the flange of a T-beam (not ribbed floor) is parallel to the beam, transverse reinforcement shall be provided in the top of the slab. This reinforcement shall be designed to carry the load on the portion of the slab assumed to act as the flange of the T-beam. For isolated beams, the full width of overhanging flange shall be considered. The flange shall be assumed to act as a cantilever. The spacing of the bars shall not exceed five times the thickness of the flange, nor 450 mm. This reinforcement need not be additive to any other reinforcements required.

J.2.9 Crack Control

J.2.9.1 This section prescribes rules for distribution of flexural reinforcement to control flexural cracking in beams and in one-way slabs (slabs reinforced to resist flexural stresses in only one direction).

J.2.9.2 Flexural tension reinforcement shall be well distributed within the maximum flexural tension zone of a member cross-section as required by Sec J.2.9.3 below.

J.2.9.3 When design yield strength f_y for tension reinforcement exceeds 275 N/mm², cross-section of maximum positive and negative moment shall be so proportioned that the quantity z given by

$$z = f_s (d_c A)^{1/3} \quad (6.J.30)$$

does not exceed 30 kN/mm for interior exposure and 25 kN/mm for exterior exposure. Calculated stress in reinforcement at working load, f_s , shall be computed as the moment divided by the product of steel area and internal moment arm. In lieu of such computations, it is permitted to take f_s as 60 percent of specified yield strength of f_y .

J.2.9.4 Provisions of Sec J.2.8.3 are not sufficient for structures subject to very aggressive exposure or designed to be watertight. For such structures, special investigation and precautions are required.

J.2.9.5 When flanges of T-beam construction are in tension, part of the flexural tension reinforcement shall be distributed over an effective flange width as defined in Sec J.2.4.5 or a width equal to $\frac{1}{10}$ the span, whichever is smaller. If the effective flange width exceeds $\frac{1}{10}$ the span, some longitudinal reinforcement shall be provided in the outer portion of the flange.

J.2.9.6 If the depth of the web exceeds 900 mm, longitudinal skin reinforcement shall be uniformly distributed along both side faces of the member for a distance $d/2$ from the nearest flexural tension reinforcement. The area of skin reinforcement A_{sk} on each side face shall be at least $(d - 750) \text{ mm}^2$ per metre height. The maximum spacing of the skin reinforcement shall not exceed the lesser of $d/6$ and 300 mm. Such reinforcement may be included in strength computation if a strain compatibility analysis is made to determine stresses in the individual bars. The total area of longitudinal skin reinforcement in both faces need not exceed one-half of the required flexural tensile reinforcement.

J.2.10 Deflection

J.2.10.1 Beams and one-way slabs shall be designed to have adequate stiffness to limit deflections or any deformations that affect strength or serviceability of a structure adversely at working load.

J.2.10.2 Minimum thickness stipulated in Table 6.2.5.1 of Chapter 6 shall apply for beams and one-way slabs not supporting or attached to partitions or other construction likely to be damaged by large deflections, unless computation of deflection indicates a lesser thickness can be used without adverse effects.

J.2.10.3 Deflections, when computed, shall be those which occur immediately on application of the load evaluated by the usual methods or formulae for elastic deflections, considering the effects of cracking and reinforcement on member stiffness.

J.2.10.4 Unless stiffness values are obtained by a more comprehensive analysis, immediate deflection shall be computed with the modulus of elasticity E_c for concrete as specified in Sec 6.1.7, and with the effective moment of inertia I_e computed by Eq (6.2.1) of Chapter 6, but not greater than I_g .

J.2.10.5 For continuous members, effective moment of inertia may be taken as the average of values obtained from Eq (6.2.1) for the critical positive and negative moment sections. For prismatic members, effective moment of inertia may be taken as the value obtained from Eq (6.2.1) at mid-span for simple and continuous spans, and at support for cantilevers.

J.2.10.6 Unless values are obtained by a more comprehensive analysis, additional long-term deflection resulting from creep and shrinkage of flexural members shall be determined by multiplying the immediate deflection caused by the sustained load considered, by the factor λ_{Δ} as determined from Eq (6.2.4) of Chapter 6.

J.2.10.7 Deflections computed in accordance with Sec J.2.10.3 through J.2.10.6 shall not exceed the limits stipulated in Table 6.2.5.2 of Chapter 6.

J.3 Columns

Sections J.3.1 to J.3.5 as detailed hereunder along with the Sec 6.3, except Sections 6.3.2.1 to 6.3.2.7, and 6.3.3, shall form part of this section. In case of any conflict, the provisions of this Appendix B shall prevail.

In using the provisions of Sec 6.3, the word factored shall be read as working or working load whichever is applicable.

J.3.1 Definitions and Notation

J.3.1.1 Notation

All the notation used this Section are provided in Sec. J.1.1. For other symbols used in this section but not provided in Sec J.1.1, the notation given in Sec 6.1.1 shall be applicable.

J.3.1.2 Definitions: The definitions given in Chapter 6 shall apply to this section. In applying the provision of Chapter 6, the terms P_u and Δ_u shall be replaced by their working load counterparts P and Δ respectively.

J.3.2 Design Assumptions

J.3.2.1 The design assumptions specified in Sec J.1.3 are valid for this section.

J.3.2.2 The provisions of Sec 6.3.8.2 and 6.3.8.3 shall apply to this section.

J.3.3 General Principles and Requirements

J.3.3.1 Design of cross-section subject to flexure, or to axial loads, or to combined flexure and axial loads shall be based on design assumptions of Sec J.1.3.

J.3.3.2 All compression members, with or without flexure, shall be proportioned using the ultimate strength design method.

J.3.3.3 Combined flexure and axial load capacity of compression members shall be taken as 40 percent of that computed in accordance with the provisions of Chapter 6 of this part.

J.3.3.4 Design axial load P of compression members shall not be taken greater than the following :

(a) For members with spiral reinforcement conforming to Sec 8.1.9.3 or composite compression member conforming to Sec 6.3.13 :

$$P_{\max} = 0.289f'_c A_g + (0.34f_y - 0.289f'_c) A_{st} \quad (6.J.31)$$

(b) For members with tie reinforcement conforming to Sec 8.1.9.4

$$P_{\max} = 0.272f'_c A_g + (0.32f_y - 0.272f'_c) A_{st} \quad (6.J.32)$$

J.3.3.5 Members subject to compressive axial load shall be designed for maximum moment that can accompany the axial load. The axial load P at given eccentricity shall not exceed that given in Sec J.3.3.4 above. The maximum moment M shall be magnified for slenderness effects in accordance with Sec J.3.4.

J.3.4 Slenderness Effects

J.3.4.1 Slenderness effects shall be included in accordance with the requirements of Sec. 6.3.10.

J.3.4.2 In applying the provisions of Sec. 6.3.10, the following convention and modification shall be used:

- (a) the term factored shall be replaced by working or working load as the context implies,
- (b) the value of strength reduction factor ϕ shall be taken as unity, and
- (c) the term P_u shall be replaced by 2.5 times the design axial working load P when gravity loads govern the design, and by 1.875 times P when gravity loads combined with wind or earthquake forces govern the design.

J.3.5 Reinforcement

Column reinforcements shall comply with the requirements of Sec 6.3.9.

J.4 Flat Plates, Flat Slabs and Edge-Supported Slabs

J.4.1 General

General requirements for the design of slabs by working stress design method shall be the same as those specified in Sec 6.5 of Chapter 6.

The provisions of Sec 6.5 except those for nominal strength evaluation shall also be applicable along with the provisions of this section.

In using Sec 6.5, the word factored shall be read as working or working load whichever is applicable and the factor ϕ shall be taken as unity.

J.4.2 The shear strength of slabs in the vicinity of columns, concentrated loads or reactions is governed by the more severe of the following two conditions:

- (a) Beam action for slab, with critical section extending in a plane across the entire width and located at a distance d from the face of columns, concentrated loads or reaction. For this condition, the slab shall be designed in accordance with Sec J.2.7.1 through J.2.7.4.
- (b) Two way action for slab, with a critical section perpendicular to plane of slab and located so that its perimeter is a minimum, but need not approach closer than $d/2$ to:
 - (i) edges or corners of columns, concentrated loads or reaction areas or
 - (ii) change in slab thickness such as edges of capitals or drop panels.

For two way action, the slab shall be designed in accordance with Sec J.4.3 and J.4.4.

J.4.3 Design shear stress shall be computed by

$$v = \frac{V}{b_o d} \quad (6.J.33)$$

Where V and b_o shall be taken at the critical section defined in Sec J.4.2(b) above.

J.4.4 Design shear stress v shall not exceed v_c given by Eq. 6.J.34 unless shear reinforcement is provided.

$$v_c = 0.083 \left(1 + \frac{2}{\beta_c} \right) \sqrt{f'_c} \leq 0.17 \sqrt{f'_c} \quad (6.J.34)$$

Where β_c is the ratio of long side to short side of concentrated load or reaction area.

- J.4.5** If shear reinforcement consisting of bars or wires is used in accordance with Sec 6.4.3, v_c shall not exceed $0.083\sqrt{f'_c}$, and v shall not exceed $0.25\sqrt{f'_c}$.
- J.4.6** If shear reinforcement in the form of shear heads is used in accordance with Sec 6.4.10.4, v on the critical section, as defined in Sec J.4.2.(b) above, shall not exceed $0.29\sqrt{f'_c}$ and v on the critical section, as defined in Sec 6.4.10.4.7, shall not exceed $0.17\sqrt{f'_c}$. In using Equations 6.6.75 and 6.6.76, the quantity v_u shall be replaced by 2 times the design working shear force V .

J.5 Alternative Design of Two-Way Edge-Supported Slabs

- J.5.1** The provisions of this section may be used as alternative to those of Sec J.4 for two-way slabs supported on all four edges by walls, steel beams or monolithic concrete beams having a total depth not less than 3 times the slab thickness.
- J.5.2** The provisions of Sec 6.5.8 (except as may be superseded by the provisions of Appendix B), shall also form a part of this section. In using the provisions of Sec 6.5.8, the word factored shall be read as working or working load as the context implies, and the factor ϕ shall be taken as unity.

J.5.3 Analysis by the Coefficient Method

The slab may be analysed for the determination of negative moments and dead and live load positive moments in accordance with the provisions of Sec. 6.5.8.3.

J.5.4 Flexural Design of Slabs

The flexural design of slabs shall be performed in accordance with the provisions of Sec J.2.6.1.

J.5.5 Shear Strength of Slabs

The shear strength of slabs shall be provided in accordance with the requirements of Sec J.4.2 through J.4.6.

J.6 Ribbed and Hollow Slabs

General requirements for the design of ribbed and hollow slabs by the working stress design method shall be in accordance with Sec 6.5.9 Chapter 6. The provisions of Sec 6.5.9 except Sec 6.5.9.3 shall also form a part of this section.

J.6.1 In applying the provisions of Sec 6.5.9, the word factored shall be read as working or working load as the context implies, and the factor ϕ shall be taken as unity.

J.6.2 Ribbed and hollow slabs shall be designed for flexure in accordance with Sec J.2.6.

J.6.3 The shear strength of ribbed and hollow slabs shall be provided to satisfy the requirements of Sec J.4.2 through J.4.6, except as specified in Sec J.6.4 below.

J.6.4 For one-way ribbed and hollow slab construction, contribution of concrete to shear strength V_c is permitted to be 10 percent more than that specified in Sec J.2.7. It is allowed to increase shear strength using shear reinforcement or by widening the ends of ribs.

J.7 Framed Structures

J.7.1 Scope

The provisions of this section shall apply to rigidly jointed RC framed structures subject to lateral loads in addition to gravity loads.

J.7.2 Continuity

All intersections of members in a framed structure shall be continuous, with the steel reinforcements continued through the joints into the adjacent members to provide adequate development length. At construction joints, special care shall be taken to bond the new concrete to the old by carefully cleaning the latter, by extending the reinforcement through the joint and by other means.

J.7.3 Placement of Loads

All individual members and joints of the framed structure shall be designed for the worst combination of loads as provided in Sec 2. Gravity live loads in different bays and in different storeys of a framed structure shall be so arranged as to produce the maximum moment and shear at all critical sections.

J.7.4 Idealization

J.7.4.1 For the purpose of analysis, the members of the frame shall be represented by straight lines coincident with their centroidal axes. When the centroidal axes of the members meeting at a joint do not coincide at a single point, the effect of offset from the point representing the joint shall be taken into consideration.

J.7.4.2 Use of any set of reasonable assumptions is permitted for computing relative flexural and torsional stiffness of columns, walls, floors, and roof systems. The assumptions adopted shall be consistent throughout the analysis.

J.7.4.3 The moment of inertia of the frame members shall be based on the gross concrete cross-section.

J.7.4.4 Effect of haunches shall be considered both in determining moments and in the design of members.

J.7.4.5 Columns having their bases monolithically cast in a substantial foundation, which may be anchored to a solid rock mass or supported on piles with their tops encased in pile cap, or which is a continuous raft or mat, may be assumed to be fixed at their bases. Otherwise, the column bases shall be assumed to permit rotation. In either case, the foundation shall be designed to resist any moment that may be transferred to it from the structure in view of the assumptions made and the detailing used at the base.

J.7.5 Method of Analysis

J.7.5.1 Gravity Loads: For building frames with reasonably regular outline, not involving unusual asymmetry of loading or shape, moments due to gravity loads may be determined by dividing the entire frame into simpler sub-frames. Each sub-frame shall consist of one continuous beam, plus the top and bottom columns framing into that particular beam. The far ends of the columns, built integrally with the structure, shall be considered fixed. For the sub-frame at the bottom of the structure, the column end conditions at the base shall be dictated by the soil and foundation considerations in accordance with Sec J.7.4.5 above.

The arrangement of live load on the sub-frame may be limited to the combinations, (a) dead load on all spans with full live load on two adjacent spans, and (b) dead load on all spans with full live load on alternate spans.

For building frames not satisfying the requirements above, a full frame analysis using elastic method shall be carried out for gravity loads.

J.7.5.2 Lateral Loads: Any method of elastic analysis that satisfies equilibrium and compatibility requirements may be used for framed structures. Approximate methods that reduce the frame to a statically determinate structure by making simplifying assumptions shall not be used except for preliminary proportioning of sections for subsequent more accurate analysis.

J.7.6 Design

The frame members shall be designed for the shear, moment, torsion and axial force obtained from the elastic analysis. All members of frames shall be designed for the maximum effects of working loads using allowable working load stresses. The critical section for design for negative moment in beams may be assumed to be at the face of the support.

J.8 Deep Beams

J.8.1 Notation

All the notation used this Section are provided in Sec. J.1.1.

J.8.2 General

J.8.2.1 Flexural members with overall depth to clear span ratio greater than 0.4 for continuous spans, or 0.5 for simple spans, shall be designed as deep beams taking into account nonlinear distribution of strain and lateral buckling (See also Sec 8.2.7.6).

J.8.2.2 Shear strength of deep beams shall be provided in accordance with Sec J.8.4 below.

J.8.2.3 Minimum flexural tension reinforcement shall conform to Sec J.2.8.

J.8.2.4 Minimum horizontal and vertical reinforcement in the side faces of deep beams shall satisfy the requirements of Sec J.8.4.8, J.8.4.9 and J.8.4.10 below, but the reinforcement shall not be less than that required for walls in Sec 6.6.3.2 and 6.6.3.3.

J.8.3 Flexure

Deep flexural members shall be designed as beams. The lever arm, z , shall be computed in compatibility with Sec. 6.3.7, 6.4.6, and Appendix I.

J.8.4 Shear

J.8.4.1 The provisions of this section shall apply to members with $\frac{l_n}{d}$ less than 5 that are loaded on one face and supported on the opposite face so that compression stress can develop between the loads and the supports.

J.8.4.2 The design of simply supported deep beams for shear shall be based on Sec J.2.7.1. The shear strength provided by concrete, V_c , shall be computed in accordance with Sec J.8.4.6 or J.8.4.7 and that provided by steel, V_s , in accordance with Sec J.8.4.8.

J.8.4.3 The design of continuous deep beams for shear shall be based on Sections J.2.7.1 to J.2.7.5 or on any method satisfying equilibrium, compatibility and strength requirements. In either case the design shall also satisfy Sec J.8.4.4, J.8.4.9 and J.8.4.10 below.

J.8.4.4 Shear strength V_n for deep beams shall not be taken greater than $0.37\sqrt{f'_c}b_wd$ when $\frac{l_n}{d}$ is less than 2. When $\frac{l_n}{d}$ lies between 2 and 5,

$$V_n = 0.31 \left(10 + \frac{l_n}{d} \right) \sqrt{f'_c} b_w d \quad (6.J.35)$$

J.8.4.5 Critical section for shear shall be taken at a distance of $0.15 \ell_n$ for uniformly loaded beams and $0.50a$ for beams with concentrated loads, measured from the face of support, but in either case not greater than d .

J.8.4.6 Unless a more detailed calculation is made in accordance with Sec J.8.4.7, V_c shall be taken as

$$V_c = 0.091\sqrt{f'_c}b_wd \quad (6.J.36)$$

J.8.4.7 Shear strength V_c may be computed more accurately by

$$V_c = \left(1.93 - 1.38 \frac{M}{Vd} \right) \left(0.16\sqrt{f'_c} + 17.2\rho_w \frac{Vd}{M} \right) b_w d \quad (6.J.37)$$

Except that the term $\left(1.93 - 1.38 \frac{M}{Vd} \right)$ shall not exceed 1.38 and V_c shall not to be taken greater than $0.275\sqrt{f'_c}b_wd$.

J.8.4.8 Where shear force V exceeds shear strength V_c , shear reinforcement shall be provided to satisfy the requirement of Sec J.2.7.1. The shear strength, V_s , contributed by shear reinforcement shall be computed by

$$V_s = \left[\frac{A_v}{s} \left(\frac{1 + \frac{l_n}{d}}{12} \right) + \frac{A_{vh}}{s_1} \left(\frac{11 - \frac{l_n}{d}}{12} \right) \right] f_s d \quad (6.J.38)$$

Where A_v is the area of shear reinforcement perpendicular to flexural tension reinforcement within a distance s , and A_{vh} is the area of shear reinforcement parallel to flexural reinforcement within a distance s_1 .

J.8.4.9 Area of shear reinforcement A_v shall not be less than $0.0015 b_w s$, and s shall not exceed $d/5$, nor 450 mm.

J.8.4.10 The area of horizontal shear reinforcement A_{vh} shall not be less than $0.0025 b_w s_1$ and s_1 shall not exceed $d/3$, nor 450 mm.

J.8.4.11 Shear reinforcement required at the critical section defined in Sec J.8.4.5 shall be used throughout the span.

J.9 Reinforced Concrete Walls

J.9.1 General requirements for and analysis of reinforced concrete walls for design by the working stress design method shall be the same as those specified in Sec. 6.4.8 and Sec 6.6.

In applying the provision of Sec. 6.4.8 and Sec 6.6, the word factored shall be read as working or working load as the context implies.

J.9.2 Walls shall be designed in accordance with Sec 6.6 with flexural and axial load capacities taken as 40 percent of that computed using Sec 6.6. Strength reduction factor ϕ shall be taken equal to 1.0.

J.9.3 In computing the effect of slenderness, the quantity P_u shall be taken as $2.5P$ when gravity loads govern the design and as $1.875P$ when lateral loads combined with gravity loads govern the design, where P is the design working axial load in the wall.

J.9.4 Design of walls for shear shall be in accordance with the provisions of Sec 6.4.8 except the following :

J.9.4.1 Shear strengths provided by concrete and the limiting maximum strengths for shear shall be taken as 55 percent of the values given in Sec 6.4.8.

J.9.4.2 In Sec 6.4.8.6, N_u shall be replaced by 2 times the design axial load for tension and 1.2 times the design axial load for compression.

J.9.4.3 The terms V_u and M_u shall be replaced by their working load values V and M respectively.

J.10 Footings

J.10.1 General requirements for the design of footings by the working stress design method shall be the same as those specified in Sec 6.4.10 and 6.8.

J.10.2 In using the provisions of Sec 6.4.10 and 6.8, the word factored shall be read as working or working load as the context implies, and the value of strength reduction factor ϕ shall be taken as 1.0.

J.10.3 Footings (combined or isolated), mats or pile caps shall be designed to resist the service loads and induced reactions in accordance with the appropriate design requirements of this chapter.

J.10.4 For flexural design of footings, the provisions of Sec 6.8.4 shall be applicable.

J.10.5 Development of reinforcement shall be provided in accordance with Sec 6.8.6.

J.10.6 The requirements of Sec 6.8.8 for transfer of force at base shall be applicable except the following:

J.10.6.1 The limiting bearing stress in Sec 6.8.8.1.1 and 6.3.14.1 shall be $0.3f'_c$ instead of $0.85\phi f'_c$.

J.10.6.2 When supporting surface is wider on all sides than the loaded area, the limiting bearing stress in Sec 6.8.8.1.1 and 6.3.14.1 shall be $0.3f'_c\sqrt{A_2/A_1}$ instead of $0.85\phi f'_c\sqrt{A_2/A_1}$. Where, the root of the area ratio is not to be taken larger than 2.

J.10.7 The provisions of Sec 6.8.9 for sloped or stepped footings and Sec 6.8.10 for combined footings and mats shall be applicable.

J.10.8 Shear in Footings

J.10.8.1 Shear capacity of footings in the vicinity of concentrated loads or reactions is governed by the more severe of the following two conditions :

- (a) Beam action for footing, with a critical section extending in a plane across the entire width and located at a distance d from face of concentrated load or reaction area. For this condition, the footing shall be designed in accordance with Sec J.2.7.1 through J.2.7.4.
- (b) Two-way action for footing, with a critical section perpendicular to plane of footing and located so that its perimeter is a minimum, but the critical section need not approach closer than $d/2$ to perimeter of concentrated load or reaction area. For this condition, the footing shall be designed in accordance with Sec J.10.2.2 and J.10.2.3.

J.10.8.2 Design shear stress v shall be computed by

$$v = \frac{V}{b_o d} \quad (6.J.39)$$

Where V and b_o shall be taken at the critical section defined in J.10.8.1(b) above.

J.10.8.3 Design shear stress v shall not exceed v_c given by Eq. 6.J.40 unless shear reinforcement is provided

$$v_c = \left(0.083 + \frac{0.17}{\beta_c} \right) \sqrt{f'_c} \leq 0.17 \sqrt{f'_c} \quad (6.J.40)$$

Where β_c is the ratio of long side to short side for concentrated load or reaction area.

J.10.8.4 If shear reinforcement consisting of bars or wires is provided in the footings, v_c shall not exceed $0.083\sqrt{f'_c}$, and v shall not exceed $0.25\sqrt{f'_c}$. The required area of shear reinforcement A_v shall be calculated in accordance with Sec J.2.7.4 and anchored in accordance with Sec 8.2.

J.10.9 Pile Caps

J.10.9.1 Pile caps shall be designed either by bending theory or by truss analogy.

J.10.9.2 Truss analogy method

- (a) When truss method is used, the truss shall be of triangulated form, with a node at the centre of loaded area. The lower nodes of the truss shall lie at the intersections of the centre lines of the piles with the tensile reinforcement.
- (b) Where the truss method is used with widely spaced piles (spacing exceeding three times the pile diameter), only the reinforcement within a band width of 1.5 times the pile diameter from the centre of a pile shall be considered to constitute a tension member of the truss.

J.10.9.3 Beam shear in pile cap shall be checked at critical sections extending across the full width of the cap. Critical sections shall be assumed to be located at 20% of the diameter of the pile inside the face of the pile. The total force from all the piles with centres lying outside this line shall be considered to constitute the shear force on this section.

The shear force V on the critical section shall not exceed V_c , where

$$V_c = 0.4\sqrt{f'_c}bd(2d/a_v) \quad (6.J.41)$$

in which $2d/a_v$ shall be greater than or equal to 1.0, a_v is the distance from the face of the column to the critical section as defined above, and b shall be taken as the full width of the critical section if the spacing of the piles is less than or equal to 3 times the pile diameter d_p , otherwise b shall be equal to 3 times the pile diameter.

J.10.9.4 Punching Shear: A check shall be made to ensure that the shear stress calculated at the perimeter of the column for the working loads does not exceed $0.4\sqrt{f'_c}$ or 2.5 N/mm^2 , whichever is the smaller. In addition, if the spacing of the piles is greater than 3 times the pile diameter, punching shear shall be checked on the perimeter defined in Sec. J.10.9.3, in accordance with Sec 6.4.10.

J.10.9.5 Anchorage: The tension reinforcement shall be provided with full anchorage in accordance with Sec 8.2.

J.11 Stairs

Requirements for the design of stairs by the working stress design method shall be in accordance with Sec 6.7 except the following:

- (a) Staircases shall be designed to support design working loads in accordance with the provisions of Sec J.1.4.
- (b) The provisions for beams and one-way slabs given in Sec J.2 shall apply for the design of stairs.

J.12 Shells and Folded Plates

Requirements for the design of shells and folded plates by the working stress design method shall be in accordance with Sec 6.9 Chapter 6 except the following:

- (a) All provisions of Sections J.1 and J.2 shall apply to thin-shell structures.
- (b) A portion of the shell equal to the flange width specified in Sec J.2.4.5 may be assumed to act with the auxiliary member. In such portions of the shell, the reinforcement perpendicular to the auxiliary member shall be at least equal to that required for the flange of a T-beam by Sec J.2.8.4.
- (c) Reinforcement required to resist shell membrane forces shall be provided so that the design strength in every direction shall be at least equal to the component of the principal membrane forces in the shell in the same direction due to working loads.
- (d) Where the principal membrane tensile stress on the gross concrete area due to working loads exceeds $0.17\sqrt{f'_c}$ reinforcement shall not be spaced farther apart than three times the shell thickness.
- (e) Design for flexure shall be in accordance with Sec J.2.6.

J.13 Precast and Composite Construction

Requirements for the design of precast and composite construction by the working stress design method shall be in accordance with Sections 6.10, 6.2.5.4, 6.3.13, and 6.12 except the following:

J.13.1 For design of composite concrete flexural members, allowable horizontal shear strength V_h shall not exceed 55 percent of the horizontal shear strengths V_{nh} given in Sec 6.12.5.3.

J.13.2 When an entire composite member is assumed to resist vertical shear, design shall be in accordance with requirements of Sec J.2.7 as for a monolithically cast member of the same cross-sectional shape.

J.13.3 Design for flexure shall be in accordance with Sec J.2.6.

J.13.4 Shear-friction provision of Sec 6.4.5 shall be applied with limiting maximum stress for shear taken as 55 percent of that given. Allowable stress in shear friction reinforcement shall be that given in Sec J.1.10.

PART VI
Appendix K
Anchoring to Concrete

K.1 Definitions

ANCHOR	A steel element used to transmit applied loads either by casting into concrete or post-installed into a hardened concrete member. An anchor includes headed bolts, hooked bolts (J- or L-bolt), headed studs, expansion anchors, or undercut anchors.
ANCHOR GROUP	Anchor group is formed by a number of anchors of approximately equal effective embedment depth with each anchor spaced at less than $3h_{ef}$ from one or more adjacent anchors when subjected to tension, or $3c_{a1}$ from one or more adjacent anchors when subjected to shear. Only those anchors susceptible to the particular failure mode under investigation shall be included in the group.
CLARIFICATION FOR ANCHOR GROUP	Only those anchors susceptible to a particular failure mode out of all potential modes (steel, concrete breakout, pullout, side-face blowout, and pryout) should be considered when evaluating the strength associated with that failure mode.
ANCHOR PULLOUT STRENGTH	The strength corresponding to the anchoring device or a major component of the device sliding out from the concrete without breaking out a substantial portion of the surrounding concrete.
ANCHOR REINFORCEMENT	It is the reinforcement used to transfer the full design load from the anchors into the structural member. See Sec K.5.2.9 or Sec K.6.2.9.
CLARIFICATION FOR ANCHOR REINFORCEMENT	The design and detailing of anchor reinforcement is done specifically for the purpose of transferring anchor loads from the anchors into the structural member. Hairpins are generally used for this purpose (see Clarification for Sections K.5.2.9 and K.6.2.9); however, other configurations that can be shown to effectively transfer the anchor load are acceptable.
ATTACHMENT	The structural assembly, external to the surface of the concrete, that transmits loads to or receives loads from the anchor.