7.4 Flexural strength of members with shear and with or without axial load

7.4.1 *Flexural strength requirement*

Design of cross sections of members subjected to flexure, shear and with or without axial loads is based on:

$M^* \leq \phi M_n$ .... (Eq. 7–1)

Where M^* is the design bending moment at the section derived from the ultimate limit state loads and forces and M_n is the nominal flexural strength of the section.

$$\rho = \frac{M^*}{\emptyset 0.925 b d^2 f_y}$$

7.4.2.7 *Equivalent rectangular concrete stress distribution*

For the ultimate limit state, the requirements of 7.4.2.6 may be considered satisfied by an equivalent rectangular concrete compressive stress distribution defined by the following:

(a) Concrete stress of $\alpha_1 f_c'$ shall be assumed uniformly distributed over an equivalent compression zone bounded by edges of the cross section and a straight line located parallel to the neutral axis at a distance $a = \beta_1 c$ from the fibre of maximum compressive strain;

(b) The distance, c, from the fibre of maximum compressive strain to the neutral axis shall be measured in a direction perpendicular to that axis;

(c) The factor α_1 shall be taken as 0.85 for concrete strengths, f_c', up to and including 55 MPa. For strengths, f_c', above 55 MPa, α_1 shall be taken as:

$\alpha_1 = 0.85 - 0.004\,(f_c' - 55)$ .... (Eq. 7–2)

but with a minimum value of 0.75.

(d) Factor β_1 shall be taken as 0.85 for concrete strengths, f_c', up to and including 30 MPa. For strengths above 30 MPa, β_1 shall be taken as:

$\beta_1 = 0.85 - 0.008\,(f_c' - 30)$ .... (Eq. 7–3)

but with a minimum value of 0.65.

9.3.8 *Longitudinal reinforcement in beams and one-way slabs*

9.3.8.1 *Maximum longitudinal reinforcement in beams and one-way slabs*

For beams and slabs the amount and distribution of longitudinal reinforcement provided shall be such that at every section, the distance from the extreme compression fibre to the neutral axis is less than $0.75c_b$. Where moment redistribution in accordance with 6.3.7 at a section is utilised, the neutral axis depth shall also comply with 6.3.7.2(f).

9.3.8.2 *Minimum longitudinal reinforcement in beams and one-way slabs*

9.3.8.2.1 *Minimum reinforcement in beams*

At every section of a beam, except as provided in one of 9.3.8.2.2, 9.3.8.2.3 or 9.3.8.2.4, (where tension reinforcement is required by analysis), the reinforcement area A_s provided shall be greater than that given by:

$A_s = \frac{\sqrt{f_c'}}{4 f_y} b_w d$ .... (Eq. 9–1)

but equal to or greater than $1.4\, b_w d / f_y$.

2.3.2.2 *Strength reduction factors, ultimate limit state*

The strength reduction factor, ϕ, shall be as follows:

(a) For actions which have been derived from overstrengths of elements in accordance with the principles of capacity design (see 2.6.5) 1.00

(b) Anchorage and strength development of reinforcement 1.00

(c) Flexure with or without axial tension or compression 0.85

(d) Flexure and shear in singly reinforced walls for in-plane actions only……...0.70

(e) Shear and torsion... 0.75

(f) Bearing on confined and unconfined concrete 0.75

(g) Tension in plain concrete ....not applicable[1]

(h) Strut and tie models 0.75

	Cross-sectional Area (mm^2)								
	Bar Diameter (mm)								
No. of Bars	**10**	**12**	**16**	**20**	**24**	**28**	**32**	**36**	**40**
1	78	113	201	314	452	616	804	1020	1260
2	156	226	402	628	904	1232	1608	2040	2520
3	234	339	603	942	1356	1848	2412	3060	3780
4	312	452	804	1256	1808	2464	3216	4080	5040
5	390	565	1005	1570	2260	3080	4020	5100	6300
6	468	678	1206	1884	2712	3696	4824	6120	7560
7	546	791	1407	2198	3164	4312	5628	7140	8820
8	624	904	1608	2512	3616	4928	6432	8160	10080
9	702	1017	1809	2826	4068	5544	7236	9180	11340
10	780	1130	2010	3140	4520	6160	8040	10200	12600
Min. Hole (mm)	12	15	20	25	29	34	39	44	49

9.3.8.3 *Spacing of reinforcement in slabs*

The spacing of principal reinforcement in slabs shall not exceed the smaller of two times the slab thickness or 300 mm. For reinforcement perpendicular to the principal reinforcement, the maximum spacing of reinforcement shall not exceed the lesser of three times the slab thickness, 300 mm for bridges or 450 mm for buildings. The spacing of reinforcement in *in situ* concrete topping in floors containing precast units shall be equal to or less than 400 mm for reinforcement which is either above the precast units or parallel to the precast units. For reinforcement which crosses infills, with a width greater than 300 mm, the spacing shall be equal to or less than 200 mm and the reinforcement shall be fully developed on each side of the infill.

8.8 Shrinkage and temperature reinforcement

8.8.1 *Floor and roof slab reinforcement*

Reinforcement for shrinkage and temperature stresses normal to the principal reinforcement shall be provided in structural floor and roof slabs where the principal reinforcement extends in one direction only. At all sections where it is required, such reinforcement shall be developed for its lower characteristic yield strength in conformance with 8.6.1 or 8.7.2. Such reinforcement shall provide at least the ratio of reinforcement area to gross concrete area of $0.7/f_y$, but equal to or greater than 0.0014.

Table 2.1 – Minimum thickness of non-prestressed beams or one-way slabs

f_y (MPa)	Member	Minimum thickness, h and value of k_1							
		Members not supporting or attached to partitions or other construction likely to be damaged by large deflections							
		Simply supported		One end continuous		Both ends continuous		Cantilever	
		h	k_1	h	k_1	h	k_1	h	k_1
300	Solid one-way slabs	$\frac{L}{25}$	1.0	$\frac{L}{30}$	1.1	$\frac{L}{35}$	1.2	$\frac{L}{13}$	1.0
	Beams or ribbed one-way slabs	$\frac{L}{20}$	1.0	$\frac{L}{23}$	1.0	$\frac{L}{26}$	1.0	$\frac{L}{10}$	1.0
500	Solid one-way slabs	$\frac{L}{18}$	1.0	$\frac{L}{20}$	1.1	$\frac{L}{25}$	1.2	$\frac{L}{9}$	1.0
	Beams or ribbed one-way slabs	$\frac{L}{14}$	1.0	$\frac{L}{16}$	1.0	$\frac{L}{19}$	1.0	$\frac{L}{7}$	1.0

NOTE –
The values given shall be used directly for members with normal density concrete ($\rho \approx 2400$ kg/m³). For lightweight concrete having a density in the range of 1450-1850 kg/m³, the values shall be multiplied by $(1.65 - 0.0003\rho)$ where ρ is the density in kg/m³.

C6.7 Simplified methods of flexural analysis

C6.7.1 *General*

The simplified methods of analysis contained in this clause are appropriate for hand calculation.

C6.7.2 *Simplified method for reinforced continuous beams and one-way slabs*

This clause provides a simple, approximate and conservative method for evaluating the moments and shears in certain continuous reinforced beams and one-way slabs.

If moment reversals occur during construction caused by temporary propping or similar actions, a separate analysis will be required.

Note that the moment values at different cross sections are not statically compatible and so should not be used for deflection calculations.

(a) *Negative design moment*

The negative design moment at the critical section, taken for the purpose of this clause at the face of the support, shall be as follows (where W_u is the uniformly distributed design load per unit length, factored for strength):

(i) At the first interior support:
  (A) Two spans only .... $W_u L_n^2/9$
  (B) More than two spans .... $W_u L_n^2/10$
(ii) At other interior supports .... $W_u L_n^2/11$

(iii) At interior faces of exterior supports for members built integrally with their supports:
  (A) For beams where the support is a column .... $W_u L_n^2/16$
  (B) For slabs and beams where the support is a beam .... $W_u L_n^2/24$

(b) *Positive design moment*

The positive design moment shall be taken as follows (where W_u is the uniformly distributed design load per unit length, factored for strength):
  (A) In an end span .... $W_u L_n^2/11$
  (B) In interior spans .... $W_u L_n^2/16$

(c) *Transverse design shear force*

The transverse design shear force in a member shall be taken as follows (where W_u is the uniformly distributed design load per unit length, factored for strength):

(i) In an end span:

(A) At the face of the interior support .... $1.15\ W_uL_n/2$

(B) At mid-span .... $W_uL_n/7$

(C) At the face of the end support .... $W_uL_n/2$

(ii) In interior spans:

(A) At the face of supports .... $W_uL_n/2$

(B) At mid-span .... $W_uL_n/8$

Table 3.6 – Minimum required cover for a specified intended life of 50 years

Exposure classification	**Cement binder type**	**Specified compressive strength f'_c (MPa)**							
		20	**25**	**30**	**35**	**40**	**45**	**50**	**60 – 100**
		Minimum required cover (mm)							
A1	GP, GB or HE	25	25	20	20	20	20	20	20
A2	GP, GB or HE	40	35	30	30	25	25	25	20
B1	GP, GB or HE	50	40	35	35	30	30	30	25
B2	GP, GB or HE	-	-	45	40	35	30	30	25
C (1) (2)	30 % FA	-	-	-	-	60	50	50	50
C (1) (2)	65 % GBS	-	-	-	-	-	50	50	50
C (1) (2)	8 % MS	-	-	-	-	-	60	50	50

NOTE –

(1) For zone C the total binder content shall be equal to or greater than 350 kg/m^3, and water-to-binder ratio shall not exceed 0.45.

(2) The minimum cover for the C zone shall be 50 mm.

Table 3.7 – Minimum required cover for a specified intended life of 100 years

Exposure classification	**Cement binder type**	**Specified compressive strength f'_c** (MPa)						
		25	**30**	**35**	**40**	**45**	**50**	**60 – 100**
		Minimum required cover (mm)						
A1	GP, GB or HE	35	30	30	30	30	30	25
A2	GP, GB or HE	50	40	40	35	35	35	30
B1	GP, GB or HE	55	50	45	40	40	35	30
B2	GP, GB or HE	-	65	55	50	45	40	35
C (1) (2)	30 % FA	-	-	-	-	60	50	50
C (1) (2)	65 % GBS	-	-	-	-	60	50	50
C (1) (2)	8 % MS	-	-	-	-	-	60	60

NOTE –

(1) For zone C the total binder content shall be equal to or greater than 350 kg/m^3 and water to binder ratio shall not exceed 0.45.

(2) The minimum cover for the C zone shall be 50 mm.

9.3.9.3.4 *Nominal shear strength provided by the concrete for normal density concrete, Vc*

The nominal shear strength resisted by concrete, V_c, shall be taken as:

$V_c = v_c A_{cv}$ .... (Eq. 9–4)

where v_c is the shear resisted by concrete.

The value of v_c is given by:

$v_c = k_d k_a v_b$ .... (Eq. 9–5)

where v_b is equal to the smaller of $(0.07+10p_w)\sqrt{f_c'}$ or $0.2\sqrt{f_c'}$, but need not be taken as less than $0.08\sqrt{f_c'}$.

In the calculation for v_b the value of f_c' shall not be taken as greater than 50 MPa.

The factor k_a, in Equation 9–5, allows for the influence of maximum aggregate size on the shear strength. For concrete with a maximum aggregate size of 19 mm or more k_a shall be taken as 1.0. For concrete where the maximum aggregate size is of 10 mm or less, the value of k_a shall be taken as 0.85. Interpolation may be used between these limits.

(a) For members with shear reinforcement equal to or greater than the nominal shear reinforcement given in 9.3.9.4.15, $k_d = 1.0$;

(b) For members with a depth equal to or less than 400 mm and greater than 200 mm, the value of v_c may be calculated either by:
   (i) Taking k_d equal to 1.0 in (c), or
   (ii) By linear interpolation in terms of effective depth between equivalent members with the same p_w value and concrete strength as the member being considered:
      (A) v_c for a member with an effective depth of 400 mm using Equation 9–5, and
      (B) v_c for a member with an effective depth of 200 mm given by (e);

(c) For members with an effective depth greater than 400, $k_d = (400/d)^{0.25}$ where d is in mm;

(d) For members with longitudinal reinforcement in the web, with a ratio of 0.003 or more, for the area between the principal flexural tension reinforcement and the mid depth of the beam, and with a bar spacing which does not exceed 300 mm in any direction, k_d, is given by $k_d = (400/d)^{0.25}$, but with limits of $0.9 \le k_d \le 1.0$;

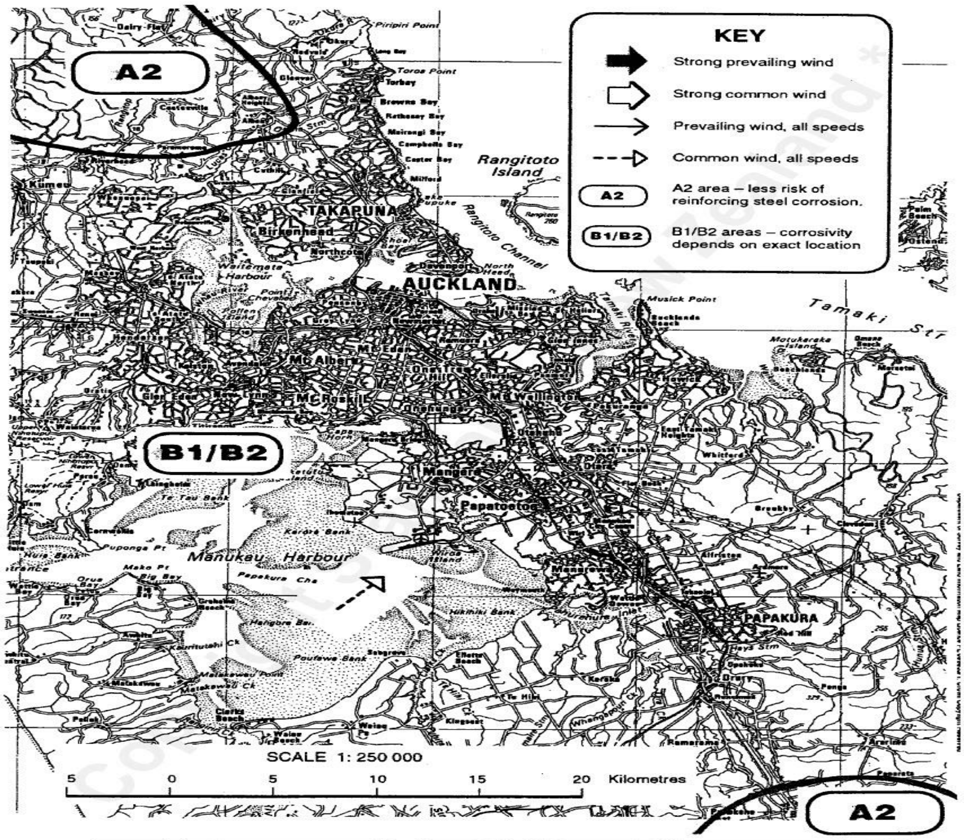
(e) For members with an effective depth equal to or less than 200 mm the value of v_c may be taken as the larger of $0.17 k_a \sqrt{f_c'}$ or $(0.07 + 10 p_w) k_a \sqrt{f_c'} \le 0.2 k_a \sqrt{f_c'}$.

9.3.9.3.5 *Nominal shear strength provided by the concrete for lightweight concrete*

Provisions for the nominal shear strength provided by the concrete, apply to normal density concrete. Where lightweight aggregate concrete is used one of the following modifications shall apply:

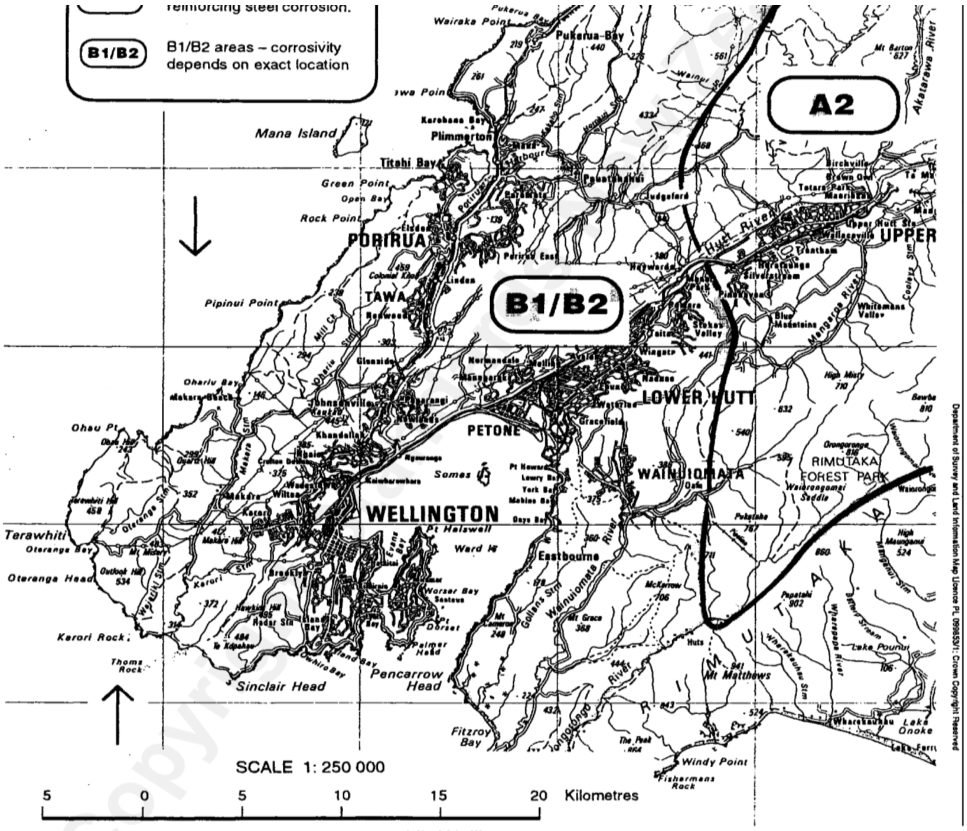
(a) Where f_{ct} is specified and the concrete mix is designed in accordance with NZS 3152, provisions for v_b (in Equation 9–5 shall be modified by substituting 1.8 f_{ct} for $\sqrt{f_c'}$ but the value of 1.8 f_{ct} shall not exceed $\sqrt{f_c'}$;

(b) Where f_{ct} is not specified, all values of $\sqrt{f_c'}$ affecting v_b shall be multiplied by 0.75 for "all-lightweight" concrete, and 0.85 for "sand-lightweight" concrete. Linear interpolation shall be applied when partial sand replacement is used.



(c) Auckland

Figure 3.1 – Exposure classification maps (continued)



(d) Wellington

Figure 3.1 – Exposure classification maps (continued)