9.4.3.5 *Maximum diameter of longitudinal beam bars passing through interior joints of ductile structures*

9.4.3.5.1 *General*

The maximum diameter of Grades 300 and 500 longitudinal beam bars passing through an interior joint shall be computed from either 9.4.3.5.2 or 9.4.3.5.3 below provided one of the conditions, (a) to (d), given below is satisfied:

(a) Grade 300 reinforcement is used;

(b) The inter-storey deflections divided by the storey height at the ultimate limit state does not exceed 1.8 % when calculated using the equivalent static or modal response spectrum methods;

(c) The beam-column joint zone is protected from plastic hinge formation at the faces of the column (as illustrated in Figure C9.19);

(d) The plastic hinge rotation at either face of the column does not exceed 0.016 radians.

If none of these conditions is satisfied the permissible diameter of Grade 500 beam reinforcement passing through an interior joint shall be determined by multiplying the diameter given by 9.4.3.5.2 or 9.4.3.5.3 below by γ, where:

$\gamma = (1.53 - 0.29\delta_c)$, but not greater than 1.0 .... (Eq. 9–20)

where

δ_c is the inter-storey drift to inter-storey height expressed as a percentage calculated in accordance with NZS 1170.5.

9.4.3.5.2 *Basic ratio of maximum longitudinal beam bar diameter to column depth*

For beam bars passing through a column at a beam-column joint, the ratio of maximum longitudinal bar diameter to column depth shall comply with the appropriate value given in (a) or (b) below:

(a) Where potential plastic regions exist at the column faces:

$$\frac{d_b}{h_c} \le 3.3\alpha_f\alpha_d\frac{\sqrt{f_c'}}{1.25f_y} \quad \text{............ (Eq. 9–21)}$$

The value of f_c' in Equation 9–21 shall not exceed 70 MPa:

(i) When beam bars pass through a joint in two directions, as in two-way frames, α_f = 0.85. For beam bars in one-way frames, α_f = 1.0

(ii) When the potential plastic hinges are classed as:

(A) Ductile plastic regions α_d = 1.0

(B) Limited ductile plastic regions α_d = 1.2.

(b) When the beam potential plastic hinges are located at a distance of at least the smaller of h or 500 mm away from the column faces so that the beam reinforcement remains in the elastic range on each side of the joint zone, the requirements of 9.3.8.4 shall be satisfied.

9.4.3.5.3 *Alternative ratio of maximum longitudinal beam bar diameter to column depth*

Alternatively by considering additional parameters, the ratio of maximum longitudinal beam bar diameter to column depth may be determined by:

$$\frac{d_b}{h_c} \le 6\left(\frac{\alpha_t\alpha_p}{\alpha_s}\right)\alpha_f\alpha_d\frac{\sqrt{f_c'}}{1.25f_y} \quad \text{............ (Eq. 9–22)}$$

where the variables are defined as follows:

(a) Values of α_f and α_d are as in 9.4.3.5.2;

(b) α_t = 0.85 for a top beam bar where more than 300 mm of fresh concrete is cast below the bar

α_t = 1.0 for all other cases

(c) To allow for the beneficial effect of compression on a column:

$$\alpha_p = \frac{N_o}{2f_c'A_g} + 0.95 \quad \text{............ (Eq. 9–23)}$$

with the limitation of $1.0 \le \alpha_p \le 1.25$.

N_o is the minimum design overstrength axial load determined by capacity design in accordance with appendix D.

(d) The coefficient, α_s, allows for the more severe bond stress conditions at overstrength acting on beam reinforcement passing through a beam-column joint, where the strength of the reinforcement in the compression zone is less than the flexural tension force resisted by the beam and tension flanges. The value of α_s is given by:

$$\alpha_s = [2.55 - R]\frac{1}{\alpha_d} \quad \text{............ (Eq. 9–24)}$$

where R is the ratio of $\phi_{o,fy} A_s' f_y$ to the flexural tension force sustained by the beam and flanges at overstrength, with the limitation $0.75 \le R \le 1.0$.

10.4.6.6 *Maximum longitudinal column bar diameter in beam-column joint zones*

The maximum diameter of longitudinal bars passing through a beam-column joint zone shall satisfy the appropriate requirement of (a) or (b) given below:

(a) Where columns have been designed by Method B in Appendix D, or by Method A in Appendix D and the joint zone being considered is below the mid-height of the second storey:

$$\frac{d_b}{h_b} \le 3.2\frac{\sqrt{f_c'}}{f_y} \quad \text{............ (Eq. 10–31)}$$

(b) Where columns have been designed by Method A and the joint zone being considered is above the mid-height of the second storey, the maximum diameter is given by:

$$\frac{d_b}{h_b} \le 4.0\frac{\sqrt{f_c'}}{f_y} \quad \text{............ (Eq. 10–32)}$$

This requirement need not be met if it is shown that stresses in extreme column bars during an earthquake remain in tension or compression over the whole bar length contained within the joint.

C9.4.3.5 *Maximum diameter of longitudinal beam bars passing through interior joints of ductile structures*
At interior beam-column joints, such as shown in Figure C9.21, extremely high bond stresses can develop when a frame sustains large inelastic deformations due to seismic motions. Beam bars may be forced to yield in tension at one column face and be subject to a high compressive stress at the opposite column face. Also, yield penetration along a beam bar from either face of an interior column may considerably reduce the effective anchorage length of the bar.

Thus the limit for the ratio of bar diameter d_b to the column depth (h_c in Figure C9.21), is intended to ensure that a beam bar will not slip prematurely through the joint core during cyclic reversed inelastic displacements [9.35, 9.36]. However, when potential plastic hinges are designed so that yielding in the beam bars cannot develop nearer than half a beam depth to the column face, as shown in Figure C9.19, better bond conditions exist and consequently larger diameter beam bars may be used [9.32, 9.37, 9.38 9.39]. For paired or bundled bars, the diameter should be taken as the diameter of a single bar of equivalent area.

Tests have shown that with increased yield stress levels in reinforcement there is a decrease in the bond performance of beam bars passing through beam-column joint zones when they are subjected to cyclic conditions involving yielding. The degradation arises due to cyclic yielding of the beam reinforcement in the joint zones. The higher strains associated with high grade reinforcement result in a more rapid degradation in bond and consequently the criteria developed for Grades 300 and 430 reinforcements need to be modified for use with Grade 500 reinforcement. Analysis of test results on internal beam-column joints, published in the literature, show that the current criteria for Grade 300 reinforcement works adequately for Grade 500 reinforcement provided the inter-storey drifts are limited to 1.8 % calculated in accordance with NZS 1170.5.

Failure in bond of beam bars passing though an internal beam-column joint generally results in a very significant loss of stiffness and it can be associated with a loss in strength [9.40].

In low-rise structures in which column sidesway mechanisms are permitted, shallow columns are common. Since the beam reinforcement may be controlled by gravity loading considerations, a large

excess of strength under seismic forces may exist, and beam bar stresses at the moment capacity of the columns may be of one sign (for example tensile) through the full width of the joint.

The limitations set in 9.4.3.5.2 are derived for the condition of beams hinging, at flexural overstrength, at both faces of the column, producing bar stresses ranging from tensile yield at one face of the column to compressive yield at the other. Where such conditions do not exist, such as where the bar force remains tensile through the joint, lower bond stresses will result, and consequently increased bar sizes are permitted. In addition, any loss of anchorage caused by deteriorating bond conditions within the joint may, under these conditions, be accommodated in the opposite beam without detriment to the structural performance. The relaxation permitted will alleviate the congestion caused by the need for abnormally small bar diameters otherwise required by the shallow columns.

When the criteria in 9.4.3.5.2 are difficult to satisfy, the somewhat more elaborate procedure[9.32], which considers the beneficial effects of additional parameters, may be applied. This may enable larger diameter beam bars to be used.

When the flexural compression force acting in a plastic region subjected to cyclic loading conditions is significantly greater than the force that can be resisted by the reinforcement in the compression zone, extensive yielding in both tension and compression occurs in this reinforcement. This action accelerates the break down in bond in beam-column joint zones. Allowance for this effect is made in subclause 9.4.3.5.3(d) of the clause. This situation may arise where either:
(a) The area of reinforcement on one side of a beam is appreciably greater than the area on the other side; or
(b) Where a beam flange contributes a significant portion of the flexural tension force to the beam plastic region under overstrength conditions.

In the second situation, a significant portion of the flexural tension force may be provided by prestressed units and reinforcement located in the effective flange width (see 9.4.1.6.2).

C10.4.6.6 *Maximum longitudinal column bar diameter in beam-column joint zones*
Generally columns are given protection against the simultaneous formation of plastic regions on each side of a joint zone. Consequently the bond conditions for longitudinal bars are considerably better than for the corresponding condition for beam bars, where simultaneous yield of bars in compression and tension may be expected on each side of the joint zone. Hence less restrictive bar diameter to beam depth ratios may be used for column bars. Where a high level of protection against plastic hinge formation occurs in columns (as in method A in Appendix D) the maximum permitted bar diameter is further increased.

Elongation of beams can force plastic hinges to occur in columns immediately above or below the joint zone at the first elevated level in moment resisting frames. For this reason equation 10–32 should not be used for bar diameters in the columns adjacent to the first level.