b. **Cased struts.** Struts of single I section or of two channels back to back in contact or spaced apart not less than ¾ in or more than half their depth and battened or laced in accordance with the requirements of Clauses 35 and 36 may be designed as cased struts when the following conditions are fulfilled:

1. The steel strut is unpainted and solidly encased in ordinary dense concrete, with ⅜ in aggregate (unless solidity can be obtained with a larger aggregate) and of a works strength not less than 3000 lbf/in² at 28 days when tested in accordance with BS 1881*.

2. The minimum width of solid casing is equal to $b + 4$ in, where b is the width overall of the steel flange or flanges in inches.

3. The surface and edges of the steel strut have a concrete cover of not less than 2 in.

4. The casing is effectively reinforced with wire complying with BS 4482, 'Hard drawn mild steel wire for the reinforcement of concrete'. The wire shall be of at least $^3/_{16}$ in diameter and the reinforcement shall be in the form of stirrups or binding at not more than 8 in pitch, and so arranged as to pass through the centre of the covering to the edges and outer faces of the flanges, and to be supported by and attached to longitudinal spacing bars not fewer than 4 in number. *As altered June, 1970*

Alternatively, the casing may be reinforced with fabric complying with BS 4483, 'Steel fabric for the reinforcement of concrete', or with bars complying with BS 4449, 'Hot rolled steel bars for the reinforcement of concrete', provided in either case that the same requirements of diameter, spacing and positioning are met. 2

The radius of gyration r of the strut section about the axis in the plane of its web or webs may be taken as $0{\cdot}2\,(b + 4)$ in. The radius of gyration about its other axis shall be taken as that of the uncased section.

In no case shall the axial load on a cased strut exceed twice that which would be permitted on the uncased section, nor shall the slenderness ratio of the uncased section, measured over its full length centre-to-centre of connections, exceed 250.

In computing the allowable axial load on the cased strut the concrete shall be taken as assisting in carrying the load over its rectangular cross section, any cover in excess of 3 in from the overall dimensions of the steel section of the cased strut being ignored. This cross section of concrete shall be taken as assisted in carrying the load on the basis of a stress equal to the allowable stress in the steel (as given in Table 17) divided by three times the numerical value of p_{bc} given in Table 2 for the grade of steel concerned.

NOTE. This clause does not apply to steel struts of overall sectional dimensions greater than 40 in × 20 in, the dimension of 40 in being measured parallel to the web, or to box sections.

c. **Angles as struts.** (i) For single-angle discontinuous struts connected to gussets or to a section either by riveting or bolting by not less than two rivets or bolts in line along the angle at each end, or by their equivalent in welding,

* BS 1881, 'Methods of testing concrete'.

the eccentricity of the connection with respect to the centroid of the strut may be ignored and the strut designed as an axially-loaded member provided that the calculated average stress does not exceed the allowable stresses given in Table 17, in which l is taken as 0·85 times the length of the strut, centre-to-centre of intersections at each end, and r is the minimum radius of gyration.

Single angle struts with single-bolted or riveted connections shall be treated similarly, but the calculated stress shall not exceed 80 % of the values given in Table 17, and the full length l centre-to-centre of intersections shall be taken. In no case, however, shall the ratio of slenderness for such single angle struts exceed 180.

(ii) For double angle discontinuous struts, back-to-back connected to both sides of a gusset or section by not less than two bolts or rivets in line along the angles at each end, or by the equivalent in welding, the load may be regarded as applied axially. The effective length l shall be taken as between 0·7 and 0·85 times the distance between intersections, depending on the degree of restraint, and the calculated average stress shall not exceed the values obtained from Table 17 for the ratio of slenderness based on the minimum radius of gyration about a rectangular axis of the strut. The angles shall be connected together in their length so as to satisfy the requirements of Clause 37.

(iii) Double angle discontinuous struts back-to-back, connected to one side of a gusset or section by one or more bolts or rivets in each angle, or by the equivalent in welding, shall be designed as for single angles in accordance with c(i) and the angles shall be connected together in their length so as to satisfy the requirements of Clause 37.

(iv) The provisions in this clause are not intended to apply to continuous angle struts such as those forming the rafters of trusses, the flanges of trussed girders, or the legs of towers, which shall be designed in accordance with Clause 26 and Table 17.

EFFECTIVE LENGTH OF COMPRESSION MEMBERS

31. *a.* **Struts.** For the purpose of calculating l/r for struts (see Clause 30) the effective length l shall be taken as follows:

1. Effectively held in position and restrained in direction at both ends — $l = 0{\cdot}7L$
2. Effectively held in position at both ends and restrained in direction at one end — $l = 0{\cdot}85L$
3. Effectively held in position at both ends, but not restrained in direction — $l = L$
4. Effectively held in position and restrained in direction at one end, and at the other partially restrained in direction but not held in position — $l = 1{\cdot}5L$

5. Effectively held in position and restrained in direction at one end, but not held in position or restrained in direction at the other end $l = 2{\cdot}0L$

where L = Length of strut from centre-to-centre of intersections with supporting members.

b. **Stanchions.** Appendix D (Figs. 6 to 20) gives typical cases of how the effective length of a stanchion, as affected by its end and beam connections, shall be assessed for the purpose of this British Standard.

The stanchions shown in the examples for single-storey buildings act as 'propped' cantilevers, and the values given in the figures do not necessarily apply to stanchions in which the reactions at the caps of the stanchions due to wind or other horizontal forces are resisted by horizontal girders.

At the caps of stanchions in single-storey buildings, the horizontal deflections due to lateral forces shall not exceed 1/325 of the height of the stanchion except in cases where greater deflections would not impair the strength and efficiency of the structure or lead to damage to finishings.

The use of the effective lengths stated for the examples of stanchions in single-storey buildings is conditional upon:

1. The bases of the stanchions being properly held in position and restrained in direction; and
2. The caps of the stanchions being properly held in position by the provision of diagonal or portal bracing in a vertical plane in at least one longitudinal bay in each line, or by other adequate means.

In cases where the beam connections are eccentric with respect to the axes of the stanchion, the same conditions of restraint shall be deemed to apply, provided the connections are carried across the flange or web of the stanchion as the case may be, and the web of the beam falls within, or is in direct contact with, the stanchion section.

Where practical difficulties prevent this, the effective length shall be estimated to accord with the case appropriate to no restraint in direction.

DESIGN DETAILS

32. *a.* **General.** The thickness of an outstanding leg of any member in compression, unless the leg is stiffened, shall be not less than one-sixteenth of the outstand for grade 43 steel and not less than one-fourteenth of the outstand for grade 50 steel and not less than one-twelfth of the outstand for grade 55 steel.

Unless effectively stiffened, the unsupported width of a plate forming any part of a member primarily in compression, measured between adjacent lines of rivets, bolts or welds connecting the plates to other parts of the section, shall not exceed the following:

90t for grade 43 steel
80t for grade 50 steel
70t for grade 55 steel.

where t is the thickness of a single plate, or the total thickness of two or more plates effectively tacked together (see Clause 51).

However, in computing the effective area and radius of gyration, the unsupported width of a plate shall be reckoned as not more than 50t for grade 43 steel, and not more than 45t for grade 50 steel, and not more than 40t for grade 55 steel. In computing other sectional properties, the full area of the plate shall be taken.

b. Joints. Where the ends of compression members are faced for bearing over the whole area, they shall be spliced to hold the connected members accurately in place and to resist any tension where bending is present.

Where such members are not faced for complete bearing the joints shall be designed to transmit all the forces to which they are subjected.

Wherever possible, splices shall be proportioned and arranged so that the centroidal axis of the splice coincides as nearly as possible with the centroidal axis of the members jointed, in order to avoid eccentricity; but where eccentricity is present in the joint, the resulting stresses shall be provided for.

MAXIMUM SLENDERNESS RATIO OF STRUTS

33. The ratio of the effective length, or of the length centre-to-centre of connections, to the appropriate radius of gyration, shall not exceed the following values:

1. For any member carrying loads resulting from dead weights with or without imposed loads and for single bolted or riveted single angle struts. 180
2. For any member carrying loads resulting from wind forces only, and provided that the deformation of such member does not cause an increase of stress, in any part of the structure, beyond the permissible stress. 250

(See also Subclause 44*a*.)

ECCENTRICITY FOR STANCHIONS AND SOLID COLUMNS

34. *a.* For the purpose of determining the stress in a stanchion or column section, the beam reactions or similar loads shall be assumed to be applied 4 in from the face of the section or at the centre of the bearing, whichever dimension gives the greater eccentricity, and with the exception of the following two cases:

1. In the case of cap connections, the load shall be assumed to be applied at the face of the column shaft or stanchion section, or edge of packing if used, towards the span of the beam.

2. In the case of a roof truss bearing on a cap, no eccentricity need be taken for simple bearings without connections capable of developing an appreciable moment.

b. In effectively jointed and continuous stanchions the bending moments due to eccentricities of loading at any one floor or horizontal frame level may be taken as being:

1. Ineffective at the floor or frame levels above and below that floor.

2. Divided equally between the stanchion lengths above and below that floor or frame level, provided that the moment of inertia of either stanchion section, divided by its actual length, does not exceed 1·5 times the corresponding value for the other length. In cases exceeding this ratio the bending moment shall be divided in proportion to the moments of inertia of the stanchion sections, divided by their respective actual lengths.

LACING AND BATTENING

35. *a.* **General.** Struts composed of two main components laced and tied should, where practicable, have a radius of gyration about the axis perpendicular to the plane of the lacing not less than the radius of gyration at right angles to that axis.

As far as practicable the lacing system shall not be varied throughout the length of the strut. The lacing of compression members shall be proportioned to resist a total transverse shear force F_q at any point in the length of the member equal to 2½ % of the axial force in the member, which shear force shall be considered as divided equally among all transverse lacing systems in parallel planes.

Except for tie plates as specified in Subclause *h* below, double intersection lacing systems and single intersection lacing systems mutually opposed in direction on opposite sides of the main components shall not be combined with members or diaphragms perpendicular to the longitudinal axis of the strut unless all forces resulting from deformation of the strut members are calculated and provided for in the lacing and its fastenings.

For members carrying the bending stress calculated from the eccentricity of loading, applied end moments or lateral loading, the lacing shall be proportioned to resist any shear due to the bending, in addition to the abovementioned 2½ %.

b. **Determination of section of lacing bars.** The required section of lacing bars for compression members, or for tension members subject to bending, shall be determined by using the appropriate permissible stresses, subject to the requirements in Subclauses *c* and *d* below.

For tension members under direct stress only, the lacing bars shall be subject to the requirements of Subclauses *c*, *d* and *e* below.

The ratio l/r of the lacing bars for compression members shall not exceed 140.

In riveted construction, the effective length of lacing bars for the determination of the permissible stress shall be taken as the length between the inner end rivets of the bar for single intersection lacing, and as 0·7 times this length for double intersection lacing effectively riveted at intersections.

In welded construction these effective lengths shall be taken as the distance between the inner ends of effective lengths of weld connecting the bars to the members and 0·7 times this length respectively.

c. **Width of lacing bars.** In riveted construction the minimum width of lacing bars shall be:

2½ in for ⅞ in diameter rivets
2¼ in for ¾ in diameter rivets
2 in for ⅝ in diameter rivets

d. **Thickness of lacing bars.** The thickness of flat lacing bars shall be not less than 1/40 of the length between the inner end rivets or welds for single intersection lacing, and 1/60 of this length for double intersection lacing riveted or welded at the intersections. Rolled sections or tubes of equivalent strength may be used instead of flats.

e. **Angle of inclination.** Lacing bars, whether in double or single intersection systems, shall be inclined at an angle of not less than 40° nor more than 70° to the axis of the member.

f. **Spacing.** The maximum spacing of lacing bars, whether connected by riveting or welding, shall be such that the maximum slenderness ratio l/r of the components of the strut between consecutive connections is not greater than 50, or 0·7 times the most unfavourable slenderness ratio of the member as a whole, whichever is the less, where l is the distance between the centres of the connections of the lacing bars to each component.

Lacing bars shall be so connected that there is no appreciable interruption in the triangulation of the system.

g. **Attachment to main members.** The riveting or welding of lacing bars to the main members shall be sufficient to transmit the load in the bars. Where welded lacing bars overlap the main members, the amount of lap shall be not less than 4 times the thickness of the bar or mean thickness of the flange of the member to which the bars are attached, whichever is the less. The welding shall be provided at least along each side of the bar for the full length of lap.

Where lacing bars are fitted between the main members they shall be connected to each member by fillet welds on each side of the bar or by full penetration butt welds.

h. **Tie plates.** Laced compression members shall be provided with tie plates at the ends of lacing systems and at points where the systems are interrupted.

End tie plates shall have a length of not less than the perpendicular distance between the centroids of the groups of rivets or welds connecting them to the main members, and intermediate tie plates shall have a length of not less than three-quarters of this distance.

The length of a tie plate refers to the dimension measured along the longitudinal axis of the member.

The pitch of rivets in the plate shall not exceed the values given in Subclause 51*c*.

Where the tie plates are welded on, the welds shall comply generally with the requirements in Clause 36 for batten plates.

Tie plates and their fastenings shall be capable of carrying the forces for which the lacing system is designed, in accordance with the method for calculating battens.

The thickness of tie plates shall be not less than 1/50 of the distance between the innermost connecting lines of rivets or welds, except where they are stiffened on their edges; where such stiffening is provided the plates shall be not less than ⁵⁄₁₆ in thick.

j. As an alternative to the tie plates described in Subclause *h* above, a cross-braced panel of the same effective strength may be used.

BATTENED COMPRESSION MEMBERS

36. *a.* Compression members should preferably have their two main components of the same cross section and symmetrically disposed about their X-X axis. They shall comply with the following:

1. The battens shall be placed opposite each other at each end of the member and at points where the member is stayed in its length and shall, as far as practicable, be spaced and proportioned uniformly throughout.
2. The number of battens shall be such that the member is divided into not less than three bays within its actual length centre-to-centre of connections.

b. In battened compression members in which the ratio of slenderness about the Y-Y axis (axis perpendicular to the battens) is not more than 0·8 times the ratio of slenderness about the X-X axis, the spacing of battens centre-to-centre of end fastenings shall be such that the ratio of slenderness l/r of the lesser main component over that distance shall be not greater than 50 or greater than 0·7 times the ratio of slenderness of the members as a whole, about its X-X axis (axis parallel to the battens).

In battened compression members in which the ratio of slenderness about the Y-Y axis is more than 0·8 times the ratio of slenderness about the X-X axis, the spacing of battens centre-to-centre of end fastenings shall be such that the ratio of slenderness l/r of the lesser main component over that distance shall be not greater than 40 or greater than 0·6 times the ratio of slenderness of the member as a whole about its weaker axis.

c. The battens shall be designed to carry the bending moments and shears arising from a transverse shear force F_q of $2\frac{1}{2}$ % of the total axial force on the whole compression member, at any point in the length of the member, divided equally between parallel planes of battens.

d. Battens shall be of plates, channels or I-sections and shall be riveted or welded to the main components so as to resist simultaneously a longitudinal shear force $F_1 = F_q d/na$ and a moment $M = F_q d/2n$

where d = the longitudinal distance centre-to-centre of battens.

a = the minimum transverse distance between the centroids of the rivet groups or welding.

F_q = the transverse shear force as defined in *c* above.

n = the number of parallel planes of battens.

e. End battens and those at points where the member is stayed in its length shall have an effective length, longitudinally, of not less than the perpendicular distance between the centroids of the main members, and intermediate battens shall have an effective length of not less than three-quarters of this distance, but in no case shall the effective length of any batten be less than twice the width of one member in the plane of the battens.

f. The effective length of a batten shall be taken as the longitudinal distance between end rivets or end welds.

g. Battened plates shall have a thickness of not less than 1/50 of the minimum distance between the innermost lines of connecting rivet groups or welds except where they are stiffened at their edges. Where channels or I-sections are used as battens with their flanges perpendicular to the main members this requirement does not apply.

h. The length of weld connecting each longitudinal edge of the batten plate to a member shall, in the aggregate, be not less than half the length of the batten plate, and at least one-third of the weld shall be placed at each end of the longitudinal edge. In addition, the welding shall be returned along the ends of the plate for a length equal to at least four times the thickness of the plate.

Where the tie or batten plates are fitted between main members they shall be connected to each member by fillet welds on each side of the plate, equal in length to at least that specified in the preceding paragraph, or by complete penetration butt welds.

j. Battened compression members composed of two angles forming a cruciform cross section shall conform to the above requirements except as follows:

(1) The battens shall be in pairs placed one against the other, unless they are welded to form cruciform battens.

(2) A transverse shear force of $F_q/\sqrt{2}$ shall be taken as occurring separately about each rectangular axis of the whole member.

(3) A longitudinal shear force of $F_l/\sqrt{2}$ and the moment $M/\sqrt{2}$ shall likewise be taken in respect of each batten in each of the two planes, except where the maximum l/r can occur about a rectangular axis, in which case each batten shall be designed to resist a shear of 2½ % of the total axial force.

F_q, F_l and M are as defined in Subclause *d* above, with $n = 1$.

k. Battened compression members not complying with these requirements or those subjected, in the plane of the battens, to eccentricity of loading, applied moments or lateral forces shall be designed according to the exact theory of elastic stability or empirically from the verification of tests, so that they have a load factor of not less than 1·7 in the actual structure.

COMPRESSION MEMBERS COMPOSED OF TWO COMPONENTS BACK-TO-BACK

37. Compression members composed of two angles, channels or tees, back-to-back in contact or separated by a small distance, shall be connected together by riveting, bolting or welding so that the maximum ratio of slenderness l/r of each member between the connections is not greater than 40 or greater than 0·6 times the most unfavourable ratio of slenderness of the strut as a whole, whichever is the less.

In no case shall the ends of the strut be connected together with less than two rivets or bolts or their equivalent in welding, and there shall be not less than two additional connections spaced equidistant in the length of the strut. Where the members are separated back-to-back the rivets or bolts through these connections shall pass through solid washers or packings, and where the legs of the connected angles or tables of the connected tees are 5 in wide or over, or where webs of channels are 6 in wide or over, not less than two rivets or bolts shall be used in each connection, one on the line of each gauge mark.

Where these connections are made by welding, solid packings shall be used to effect the jointing unless the members are sufficiently close together to permit welding, and the members shall be connected by welding along both pairs of edges of the main components.

The rivets, bolts or welds in these connections shall be sufficient to carry the shear forces and moments (if any) specified for battened struts, and in no case shall the rivets or bolts be less than ⅝ in diameter for members up to and including ⅜ in thick; ¾ in diameter for members up to and including ⅝ in thick; and ⅞ in diameter for members over ⅝ in thick.

Compression members connected by such riveting, bolting or welding shall not be subjected to transverse loading in a plane perpendicular to the washer-riveted, bolted or welded surfaces.

Where the components are in contact back-to-back, the spacing of the rivets, bolts or intermittent welds shall not exceed the maximum spacing for compression members as given in Subclauses *51c* (i) and *54c*.

STANCHION AND COLUMN BASES

38. *a.* **Gusseted bases.** For stanchions with gusseted bases, the gusset plates, angle cleats, stiffeners, fastenings, etc., in combination with the bearing area of the shaft shall, where all the parts are fabricated flush for bearing, be sufficient to take the loads, bending moments and reactions to the base plate without exceeding the specified stresses.

Where the ends of the stanchion shaft and the gusset plates are not faced for complete bearing, the fastenings connecting them to the base plate shall be sufficient to transmit all the forces to which the base is subjected.

b. **Slab bases.** Stanchions with slab bases need not be provided with gussets, but fastenings shall be provided sufficient to retain the parts securely in place and to resist all moments and forces, other than direct compression, including those arising during transit, unloading and erection. When the slab alone will distribute the load uniformly, the minimum thickness of a rectangular slab shall be:

$$t = \sqrt{\left\{\frac{3w}{p_{bct}}\left(A^2 - \frac{B^2}{4}\right)\right\}}$$

where t = the slab thickness in inches.
A = the greater projection of the plate beyond the stanchion in inches.
B = the lesser projection of the plate beyond the stanchion in inches.
w = the pressure or loading on the underside of the base in tonf/in².
p_{bct} = the permissible bending stress in the steel (12 tonf/in²—see Table 2).

When the slab will not distribute the load uniformly or when the slab is not rectangular, special calculations shall be made to show that the stresses are within the special limits.

For solid round steel columns in cases where loading on the cap or under the base is uniformly distributed over the whole area including the column shaft, the minimum thickness, in inches, of a square cap or base shall be:

$$t = \sqrt{\left(\frac{9W}{16p_{bct}} \cdot \frac{D}{D - d}\right)}$$

where t = the thickness of the plate in inches.
W = the total axial loading in tonf.
D = the length of the side of cap or base in inches.
d = the diameter of the reduced end, if any, of the column in inches.
p_{bct} = the permissible bending stress in the steel (12 tonf/in²).