To ensure proper placing and compaction of concrete around reinforcement, a maximum steel content is also specified. Thus the maximum area of tension reinforcement in a beam should not exceed 4 per cent of the gross cross-sectional area of the concrete.

The area needed should generally be provided by not less than two bars and not more than eight bars. If necessary bars may be in groups of two, three or four, in contact. For the purpose of design such groups should be considered as a single bar of equivalent area. In addition the size of main bars used should normally not be less than 16 mm diameter.

The areas of round bar reinforcement are given in Table 3.8.

Table 3.8 Areas of round bar reinforcement (mm^2)

Diameter (mm)	Mass (kg/m)	Number of bars 1	2	3	4	5	6	7	8	9	10
6	0.222	28	57	85	113	142	170	198	226	255	283
8	0.395	50	101	151	201	252	302	352	402	453	502
10	0.617	79	157	236	314	393	471	550	628	707	785
12	0.888	113	226	339	452	565	678	791	904	1 017	1 130
16	1.58	201	402	603	804	1005	1206	1407	1 608	1 809	2 010
20	2.47	314	628	942	1256	1570	1884	2198	2 512	2 826	3 140
25	3.86	491	983	1474	1966	2457	2948	3439	3 932	4 423	4 915
32	6.31	804	1608	2412	3216	4020	4824	5628	6 432	7 236	8 040
40	9.87	1257	2513	3770	5027	6283	7540	8796	10 053	11 310	12 566

3.9.5 Minimum spacing of reinforcement

During concreting the aggregate must be allowed to move between the bars in order to achieve adequate compaction. For this reason BS 8110 Part 1 recommends a minimum bar spacing of 5 mm greater than the maximum coarse aggregate size h_{agg}. That is,

$$\text{Minimum distance between bars or group of bars} = h_{agg} + 5\,\text{mm}$$

When the diameter of the main bar or the equivalent diameter of the group is greater than $h_{agg} + 5$ mm, the minimum spacing should not be less than the bar diameter or the equivalent diameter of the group.

A further consideration is the use of immersion type (poker) vibrators for compaction of the concrete. These are commonly 40 mm diameter, so that the space between bars to accommodate their use would have to be at least 50 mm.

3.9.6 Maximum spacing of reinforcement

When the limitation of crack widths to 0.3 mm is acceptable and the cover to reinforcement does not exceed 50 mm, the maximum bar spacing rules given in BS 8110 Part 1 may be adopted. Hence for the tension steel in simply supported singly reinforced beams, the maximum clear distance between adjacent bars or groups would be as follows:

(a) When f_y is 250 N/mm^2, clear distance = 300 mm
(b) When f_y is 460 N/mm^2, clear distance = 160 mm.

3.9.7 Bending ULS

We know from the theory of bending that when bending is induced in a rectangular beam the material fibres above the neutral axis are subjected to compressive stresses and those below to tensile stresses. Concrete has excellent qualities for resisting compression. However, its resistance to tension is so poor that it is ignored. Instead, steel reinforcement is introduced to resist the tension.

On this basis simply supported rectangular beams are designed so that the concrete above the neutral axis is capable of resisting the induced compression, and tensile reinforcement capable of resisting the induced tension is introduced below the neutral axis. This reinforcement is positioned near the bottom of the beam where it will be most effective. Concrete beams designed in this way are described as singly reinforced.

For any beam to be adequate in bending, its internal moment of resistance must not be less than the externally applied bending moment. Therefore the design ultimate resistance moment M of a concrete beam must be greater than or at least equal to the ultimate bending moment M_u:

$$M \geqslant M_u$$

The ultimate bending moment is calculated in the normal manner but using the ultimate design loads. The design ultimate resistance moment of the beam can be obtained by reference to BS 8110 in any one of the following three ways:

(a) Using formulae derived from the short term stress/strain curves given in BS 8110 Part 1 Section 2.
(b) Using the design charts given in BS 8110 Part 3, which are based on the aforementioned stress/strain curves.
(c) Using the design formulae for rectangular beams given in BS 8110 Part 1, which are based on a simplified concrete stress block.

The singly reinforced rectangular beam examples included in this manual are based on method (c), for which the beam cross-section and stress diagram are shown in Figure 3.3. In one of the examples the result obtained using the formulae will be compared with that using the BS 8110 Part 3 design charts. For this purpose Chart 2 is reproduced here as Figure 3.4.

By considering the stress diagram shown in Figure 3.3 in conjunction with the theory of bending behaviour, the simplified design equations for