The first two methods require a finite element approach and are unsuitable for design purposes, although the results obtained from such realistic methods are invaluable for producing results which can lead to meaningful design procedures. A number of papers using this approach have been published, which allow not only for the nonlinear material effects but also dynamic loading.

The third approach is conservative in that having assumed the removal of a loadbearing element in a particular storey an assessment of residual stability is made from within that storey.

These theoretical methods of analysis together with experimental studies as mentioned in section 9.3 have led to design recommendations as typified in BS 5628 (section 9.5).

## 9.5 USE OF TIES

Codes of practice, such as BS 5628, require the use of ties as a means of limiting accidental damage. The provisions of BS 5628 in this respect have been summarized in Chapter 4.

The British code distinguishes, in its recommendations for accidental damage design, between buildings of four storeys or less and those of five storeys or more. There are no special provisions for the first class, and there are three alternative options for the second (see Chapter 12).

It is convenient at this stage to list the types of ties used together with some of the design rules.

### 9.5.1 Vertical ties

These may be wall or column ties and are continuous, apart from anchoring or lapping, from foundation to roof. They should be fully anchored at each end and at each floor level.

Note that since failure of vertical ties should be limited to the storey where the accident occurred it has been suggested that vertical ties should be independent in each storey height and should be staggered rather than continuous.

In BS 5628 the value of the tie force is given as either of

$$T=(34A/8000)\,(h/t)^2\ \mathrm{N} \tag{9.1}$$

or

$$T=100\mathrm{kN/m}\ \text{length of wall or column}$$

whichever is the greater, where $A$=the horizontal cross-sectional area in $mm^2$ (excluding the non-loadbearing leaf of cavity construction but including piers), $h$=clear height of column or wall between restraining surfaces and $t$=thickness of wall or column.

The code assumes that the minimum thickness of a solid wall or one loadbearing leaf of a cavity wall is 150mm and that the minimum characteristic compressive strength of the masonry is 5N/mm². Ties are positioned at a maximum of 5 m centres along the wall and 2.5 m maximum from an unrestrained end of any wall. There is also a maximum limit of 25 on the ratio *h/t* in the case of narrow masonry walls or 20 for other types of wall.

*Example*
Consider a cavity wall of length 5m with an inner loadbearing leaf of thickness 170mm and a total thickness 272mm. Assume that the clear height between restraints is 3.0m and that the characteristic steel strength is 250N/mm².

Using equations (9.1), tie force is the greater of

$$T = (34/8000) \times 5000 \times 170 \times (3000/272)^2 \times 10^3 = 439.5 \text{ kN}$$

$$T = 100 \times 5 = 500 \text{ kN}$$

Thus

$$\text{tie area} = (500/250) \times 10^3 = 2000 \text{mm}^2$$

So use seven 20 mm diameter bars. This represents a steel percentage of (2000×100)/(5000×272)=0.15%.

### 9.5.2 Horizontal ties

Horizontal ties are divided into four types and the design rules differ for each. There are (a) peripheral ties, (b) internal ties, (c) external wall ties and (d) external column ties.

The basic horizontal tie force is defined as the lesser of the two values

$$F_t = 20 + 4N_s \text{ kN}$$

$$F_t = 60 \text{ kN} \tag{9.2}$$

where $N_s$=the number of storeys, but the actual value used varies with the type of tie (see below).

*(a) Peripheral ties*

Peripheral ties are placed within 1.2m of the edge of the floor or roof or in the perimeter wall. The tie force in kN is given by $F_t$ from equations (9.2), and the ties should be anchored at re-entrant corners or changes of construction.