between interior bearing walls and exterior non-bearing wall shear flanges, the exterior wall will undergo more thermal movement and less elastic and creep-induced movement than the interior wall. The connection between these elements must accommodate such movement or transfer shear stress. Each building must be analyzed for differential movement characteristics and provisions made to relieve the resulting stresses. The MSJC Code is the first to include design coefficients for masonry thermal expansion, moisture expansion, shrinkage, and creep.

12.3.3 Unreinforced Masonry

Although the compressive strength of unreinforced masonry is high, its flexural strength depends on three things: (1) the type and design of the masonry unit, (2) the type of mortar and its materials, and (3) the quality of workmanship. Higher flexural strengths are developed with solid masonry units because the wider mortar bed provides more bonding surface. Failure in lateral loading usually results from bond failure at a ruptured bed joint, so factors that affect mortar bond also affect the flexural strength of the wall. Full, unfurrowed joints, good mortar flow and consistency, proper unit absorption, and moist curing all improve bond (see Chapter 15).

When lateral loads are applied perpendicular to a wall, they are transmitted to vertical and horizontal edge connections. The proportion of the load transmitted either vertically or horizontally will depend on the flexural resistance and rigidity of the wall in each direction, the degree of fixity or restraint developed at the edges, the horizontal-to-vertical span ratio, and the distribution of the loads as they are applied to the wall. The lateral stability of loadbearing masonry walls is greater than that of non-bearing or lightly loaded walls. Applied vertical loads produce compressive stresses which must be overcome by the tensile stress of the lateral load before failure can occur. In the lower stories of loadbearing buildings, compressive stresses generally counteract tension, but in the upper stories of tall buildings, where wind loads are higher and axial loads smaller, the allowable flexural tensile stresses may be exceeded, thus requiring steel reinforcement to be added at those locations.

12.3.4 Reinforced Masonry

Reinforced masonry is used where compressive, flexural, and shearing stresses are higher than those allowed for unreinforced masonry. Designs that incorporate reinforcing steel neglect the flexural strength contribution of the masonry altogether, and rely on the steel to resist 100% of the tensile loads. (This is called the cracked section theory).

Reinforced masonry walls may be of double-wythe construction with a grouted cavity to accommodate the steel reinforcing, or of single-wythe hollow units with grouted cores. Steel wire reinforcement may be laid in horizontal mortar joints as long as code requirements for wire size and minimum mortar cover are met. Vertical reinforcement must be held in position at the top and bottom of the bar as well as at regular vertical intervals.

Vertical reinforcing steel contributes to the load-carrying capacity of masonry columns and pilasters because lateral ties are required in columns to prevent buckling and confine the masonry within. The vertical steel in walls does not take any of the axial load unless it is also restrained against buckling. Reinforcing steel also helps masonry resist volume changes due to temperature and moisture variations, and its effect should be considered in the calculation of differential movement and the location and spacing of movement joints.

The size and placement of steel reinforcement are determined by design analysis of service load conditions. Different combinations of bar sizes and spacing can give the same ratio of steel area to masonry area, and some consideration must be given to achieving the analytical requirements economically. Steel spaced too closely will slow construction, can inhibit grout placement, and may be unnecessarily expensive. For instance, No. 3 bars at 8 in. on center give the same area of steel per foot of wall as No. 7 bars at 48-in. centers, but the closer spacing requires more labor expense than is necessary to produce the same result. Bar size and spacing, however, must also take into consideration the size of the grout space and the code requirements for minimum protective coverage of reinforcement (see Chapters 6 and 15).

12.3.5 Wind and Seismic Loads

Buildings must be capable of resisting all lateral seismic forces, assumed to act nonconcurrently in the direction of each of the main axes of the structure. In addition to the calculation and resolution of total seismic forces, consideration must also be given to individual structural and non-structural elements of the building. Parts or portions of structures, non-structural components, and their anchorage to the main structural system must be designed for lateral seismic forces.

The MSJC Code includes requirements for structures in different Seismic Design Categories. Prescriptive requirements for minimum reinforcing steel are summarized in *Fig. 12-34*. The minimum amount of steel required is based on test results and empirical judgment rather than engineering analysis of stress or performance. The prescriptive ratio of steel to wall area is provided to increase the ductility of the masonry structure in seismic events. Where analytical design indicates that more steel is required, the prescriptive minimum may be included as part of the total. If analysis indicates that less steel is required, the prescriptive minimum seismic reinforcing must still be provided. Joint reinforcement cannot be used for seismic resistance. All reinforcing steel designed to resist seismic loads must be fully embedded in grouted cores, cavities, or bond beams. *Figures 12-35 and 12-36* illustrate the minimum reinforcing requirements of the code, and *Fig. 12-37* summarizes the requirements for shear walls.

Reinforced masonry structures designed in compliance with modern building code requirements have successfully withstood substantial seismic forces, and the rigidity inherent in the masonry systems often reduces or eliminates secondary damage. Reinforced masonry buildings as tall as 10 stories survived near the epicenter of the 7.1 Loma Prieta, California, earthquake in 1989 and the 6.7 Northridge, California, earthquake in 1994 without structural damage, glass breakage, pipe separations, or even cracking in the drywall or door jambs. Such secondary safety is critical in the construction of essential facilities such as hospitals, fire stations, communications centers, and other facilities required for emergency response. The only masonry buildings to sustain significant damage were older unreinforced masonry structures built before modern building code requirements and not yet retrofitted to meet stricter performance criteria. Older buildings which had been retrofitted in accordance with the City of Los Angeles Division 88 ordinance fared much better.