27 Loadbearing Structural Walls

This chapter considers the potential and the forms of loadbearing walls for commercial buildings. The potential for low-rise, multi-storey buildings as well as applications to large open single-storey buildings to support roof structure will be introduced. Multi-storey options in masonry, concrete and timber walls are considered along with their favoured floor construction to form the whole building. Options to take the loads from single-storey industrial roofs in both masonry and concrete are introduced, where their potential height and length have to be taken into account in the detailing and specification.

Broad options

While most commercial and industrial buildings will have structural solutions based on framed structures, the use of loadbearing structural walls to carry the vertical loads may prove a viable alternative in some circumstances. Multi-storey construction can be successfully achieved with structural walls, as long as the internal spaces (governing the floor spans) are relatively small and repeated over the full height of the building, or at least to a podium level around first-floor level where a framed transfer structure could be envisioned. For wind stability and the prevention of the potential rotational collapse of high buildings the overall width/height ratio of the building needs to be considered to limit slenderness, as well as the need for internal walls to give either a cellular or cross-wall configuration. The cellular layout has combinations of external and internal walls that form boxes on plan, acting as cores throughout the building. Cross walls act as stiffening shear walls, so it is preferable to have cross walls in both directions but floor layouts that show cross walls predominantly in one direction can be stabilised by return ends on the cross walls or with the connection between the wall and the floor, as in the box frame construction described below.

These internal arrangements once established cannot be easily altered during the life of the building and there normally needs to be other performance requirements, such as sound or fire, for the walls that would demand substantial construction even if a frame were specified. Buildings that fit this configuration would include flats, study room accommodation and hotels.

Designs based on the masonry cavity construction with masonry internal walls as introduced in Chapter 19 can achieve buildings in excess of 10 storeys (timber-framed less), but it is also possible to consider walls constructed in reinforced concrete, either in situ or precast for multi-storey construction, and this will be discussed below.

Some low-rise designs may also offer the opportunity to consider a structural wall solution. While the layout constraints are less easily generalised than those for multi-storey, some clues can be suggested to spot the potential for economy in these designs. Designs that are open and light are less likely to be amenable to structural wall solutions. If the walls can be thicker, heavier and require limited openings, typical commercial floor spans can be accommodated. Mixed structures may be considered with some floors and roofs carried on walls and some on frames using columns.

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Single-storey long-span roof structures can be supported on walls rather than on columns. Like all loadbearing options, the functions of cladding and structure become combined into the one element and the appearance of the building is likely to be significantly influenced by the choice of this structural form.

Floors and roofs

While there are unlikely to be beams associated with the floor construction for loadbearing walls, the slabs will be similar to those used in framed multi-storey structures. While the joisted floors will probably achieve the structural spans associated with many loadbearing wall projects other than the single domestic dwelling, they are unlikely to provide the sound and fire performance requirements between rooms in multi-storey occupations without significant modification to that of the standard house joisted floor. Almost certainly reinforced concrete slabs would be specified, possibly with precast components. The floor construction is most likely to be chosen to match the wall construction. Block walls may use plank or beam and block floors, while precast walls will almost certainly use precast slab floor units and in situ walls will have in situ floors. These choices match the site handling and operative expertise to give continuity to production processes.

Long-span roof elements can also be similar to those described in the previous chapter. While the moment action of the portal cannot be replicated when structural walls are used, trusses, space frames and solutions such as curved precast shell roof units can be successfully used with wall structures. In these buildings the production match between walls and roof is not as critical as the choice of wall and floor in the multi-storey building. The wall–floor cycle is not repeated with a single-storey building and economy can be best achieved with the appropriate choice of wall and roof structure. However, the junction of wall and roof becomes a significant detail not only to achieve structural performance but also to facilitate the production process.

Multi-storey construction

Multi-storey masonry walls

It is desirable to develop the external cavity wall to exploit its weathering and insulation potential, but the specification and detailing for the structural performance of multi-storey structures will have to be reconsidered as well. This reassessment of strength will have to be extended to the consideration of the loadbearing internal walls. In house construction the strength properties of the brick/block and mortar are unlikely to be the governing factors. Weathering and overall stability and even thermal and sound performance are most likely to be the performance choices that govern the thickness of the wall and the choice of bricks, blocks and mortar. In multi-storey building the masonry will have to be subject to structural design to gain the potential economies associated with efficient wall thickness.

In designed masonry the strength of the brick/block and the mortar combine to give strength to the wall as a whole. These need to be reflected not only in the specification but also in the on-site quality-control procedures for both materials and workmanship. While pre-mixed mortar may reduce the variability of site mixing operations, laying with full beds and curing are crucial to achieving overall wall strengths. Cement mortars will be required but significant proportions of lime can be introduced without significant loss of strength. Lime mixes of around 1:1½:1½ can produce strengths only 95% of a cement-only 1:3 mix. In designed masonry it is possible to achieve up to around 14-storey flats with 300 mm external masonry cavity walls and 175 mm internal block walls.

Stability considerations include the individual wall elements and the overall stability of the building against wind loading and rotational collapse. This stability is achieved by the bonding of the bricks and blocks to form panels and then the bonding of return walls to limit the length of individual panels and to stiffen the whole structure. The connections of the floors

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can then offer restraint to the walls, influencing the effective height of the panel. As with all masonry construction it is important to ensure that there are no tensile stresses in the structural elements.

The wall panels will be subject to buckling where slenderness determined by the height/thickness ratio will be a major influence on how much load can be taken before buckling. With economic thickness established to ensure strength, the control of slenderness needs to consider the dimensions of the panel, particularly the height. If the floors can provide constraint, the effective height of the wall can be taken to be less than the actual height, and the support provided by return walls will affect the effective length. With buildings for flats or hotel rooms with limited storey heights and frequent internal walls, achieving this stability is not a significant problem but care is needed in the connection of the floor and the wall to provide the lateral restraint. These limits to effective length and height and the lateral restraint of return walls and floors will also stiffen the structure to resist rotational collapse of the whole building. Floors may also have to be across the cavity every second or third storey. While this will spread the load across both skins of the cavity wall, it will create a cold bridge and require detailing if the appearance of continuous brickwork is required across the face of the whole building.

The whole building will also be subject to wind loading. The basic cellular or cross-wall nature of the structure and the enhanced resistance of the floor connections ensure the transfer of the wind loads from the external walls to be resisted by the whole structure. Given a reasonable ratio of width at the base and the height to limit the overall slenderness of the building, the stiffening of the structure will limit deflection. In addition pre-compression of the brickwork by loads from the floors above will limit the risk of tensile forces arising in the masonry from all but the top floors.

Openings will reduce the area of brick- or blockwork taking the vertical loads and will reduce the stiffness of the panels. For these reasons openings may have to be limited both in size and how close together they can be arranged. As openings become taller and closer together the masonry takes on the characteristics of a column rather than a wall panel and, along with the width of the opening, the stiffness of the whole panel is reduced. These are structural design considerations. While localised wall thickenings, called piers, can stiffen walls and masonry can be reinforced or even pre-stressed to overcome these conditions, designs requiring large openings may be better to employ a framed structure.

Multi-storey concrete walls

Concrete wall structures can be achieved in both in situ and precast forms. Although it is possible to construct walls that do not experience tensile forces in plain concrete, nearly all designs will be reinforced.

In situ concrete relies for its economy on the simplicity and repetition of the formwork and falsework, which becomes an option if there are to be dimensionally repetitive spaces vertically throughout the building. In addition cross-wall layouts can provide an opportunity for formwork/falsework systems that do not have to be disassembled between pours and can be lifted to the next level. This requires structures that are open on one side, allowing the striking and lifting of large sections of formwork. Such a structural form that offers all these opportunities for the formwork/falsework is the box frame, which is illustrated in Figure 27.1. The stability of the frame against racking is provided by the connection between the floor and the slab. The illustration shows the cross walls across the building, as this is the normal direction in which walls with high performance specifications for fire and sound are required. However, if the major internal walls are in the length of the building, casting sections that effectively extrude the cross section of the structure before being lifted to the next level can be envisioned.

In box frame construction the wall and floor cast in one operation with a formwork/

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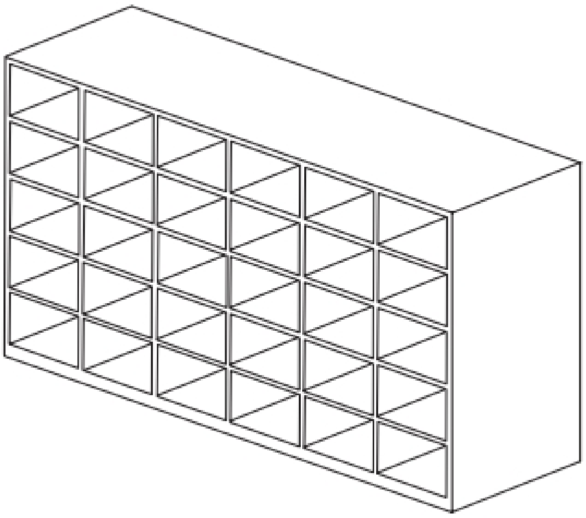

Figure 27.1 In situ box frame cross-wall structure.

falsework unit is called a tunnel form. Kickers are cast on the newly formed slab to receive the formwork that is brought up from below after the wall reinforcement has been fixed. When the slab reinforcement is fixed, the next lift can be poured. Both walls and floors will be around 150 mm thick. Openings can be formed in the cross walls during casting and this leaves the front and back elevations to be treated as any framed building. The end elevations will have relatively few, if any, openings and will need insulating and a facing to provide a fully functioning wall.

Precast panel construction is another option for cellular or cross-wall floor configurations requiring both external and internal structural walls. The use of precast compared to in situ concrete for structural walls will limit the need for falsework and will give potential gains in the quality of finish and the accuracy of construction but increasing transport costs and change in the joint behaviour in performance. Joints between precast panels will have less resistance to racking forces, making the building less able to resist wind forces with the need to provide wind stability, most probably using cores. These joints also make the building more susceptible to disproportional collapse. This is a failure condition where the accidental removal of one member (in this case a wall panel) will cause the building to suffer a collapse disproportionate to the cause. This will require panels to be tied together and back into the floors over and above the needs of the joints to transfer the normal building and wind loads.

Precast structural wall panels are normally matched with precast panel floors often of similar size and weight to give continuity in the production process and the efficient use of common resources. In the second half of the twentieth century this construction was used for flats and took advantage of the ability to provide not only an external finish on the concrete but also a sufficiently fine internal finish to make it ready for decoration. In an era where thermal performance requirements were minimal the concrete offered good fire and sound resistance and could be produced to be weatherproof. The external joints between the panels then had to be water- and wind-proofed to produce a weather-tight wall. This solution is unlikely to be applicable at the beginning of the twenty-first century. Not only have thermal performance requirements increased but also the appearance of concrete panels, however well finished, is unlikely to be a preferred external finish.

If precast panel construction is used, it is likely to provide only the structural element of the external wall. It will still provide good fire and sound resistance but the external appearance, thermal and waterproofing functions will be provided by other elements of the external wall. The internal walls will not require these functions and the quality of finish for internal decoration could still be considered.

For structural needs the walls are likely to be around 125 to 175 mm thick. Openings can be formed in the panels for both windows and doors, but it is difficult to form openings across more than one panel. Joints between panels are normally formed in the thickness of the panels, as shown in Figure 27.2. Edge profiles and pockets on the panels provide for steel loops from adjacent panels to be tied

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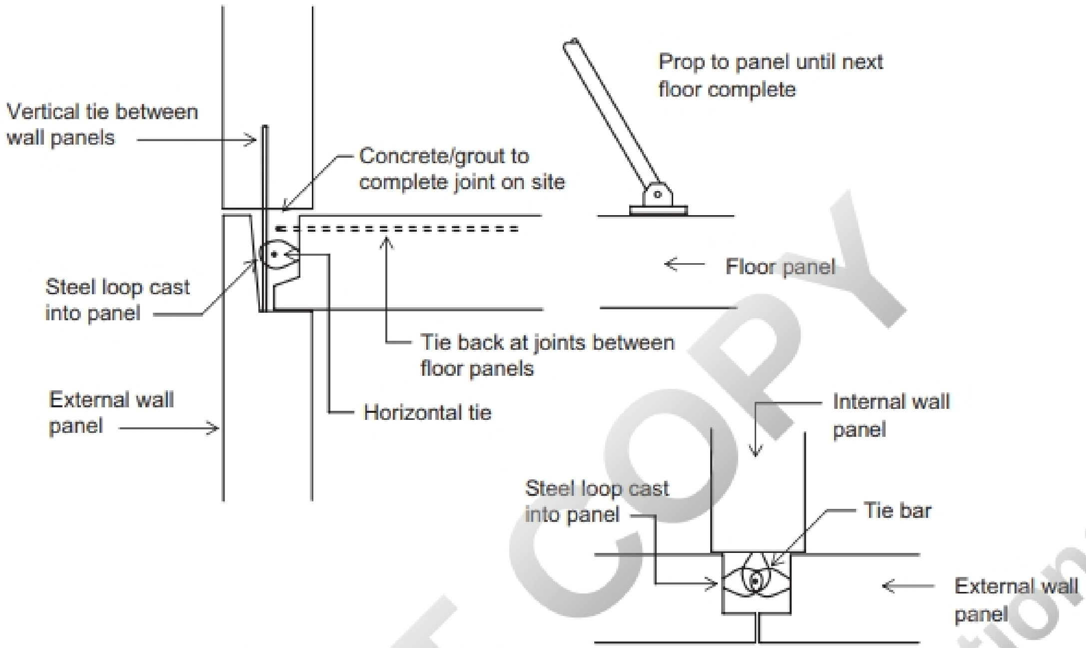

Figure 27.2 Precast concrete panel construction.

together with rods or wires and an in situ filling completing the joint when the panels are in their final position. Wall panels will require propping until the joints are completed for the floor above. Slots have to be formed between the floor panels to receive the reinforcement to provide the horizontal tying which becomes effective when the slot is filled with in situ concrete.

These connections provide for load transfer and resistance to disproportionate collapse. If the walls provide a cellular layout, these connections should give the structure its overall stability; otherwise, in situ concrete or braced structural steel circulation cores could be erected before the precast work begins. However, stacks of precast volumetric units could be specified to provide the stability as the work proceeds. These volumetric units could be circulation cores but might also be conceived as rooms complete with floors. The most likely rooms are the bathrooms that will be located one above the other for servicing. The volumetric solution also offers the opportunity to prefabricate parts or all of the room services and finishes, eliminating a concentrated and lengthy process from the site programme.

Multi-storey timber

The concepts of large panel construction can be achieved in timber. Although currently unable to reach the number of storeys possible with masonry or concrete, it can be considered for flats and accommodation blocks with their limited floor spans offering the opportunity to provide the floors in timber panels or cassette. Panels can be based on the framed panel similar to the details given in Chapter 19. Similar details can also be achieved with steel studs rather than timber.

The development of solid structural panels based on composite boards such as SIPs (structural insulated panels) and solid wood construction can provide an alternative to the framed panel. These are shown in Figure 27.3. Both can be made into panels between around 70 and 250 mm thick but sections of around

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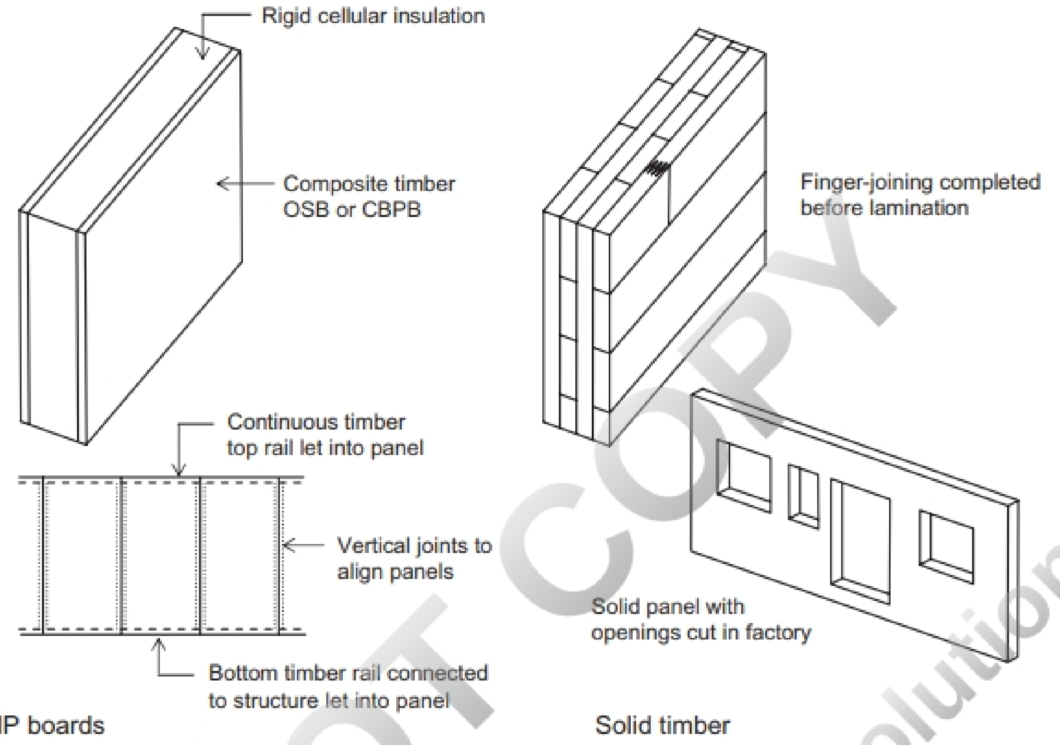

Figure 27.3 SIP and solid timber walls.

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100 mm are more common for this form of construction.

SIP panels are two composite timber boards bonded to a core of a rigid cellular insulation. The composite boards are likely to be oriented strand board (OSB) or possibly cement-bonded partial board (CBPB) between 8 and 15 mm thick. The rigid cellular insulation can be self-adhesive polyurethane or polyisocyanurate or boards of polystyrene or mineral fibre that have to be bonded to the facing boards. Panels are normally produced in sheets 1.2 metres wide by either a standard 2.4-metre boards or specifically for storey-height panels. Many of these systems are propriety and the nature of the site joint varies with the manufacture but some location and interlock is required with some preparation of the edges of the panels at the factory. Edge profiles will normally involve some machining out of the insulation to let in timber sections to make the connections required between panels and to other elements of the structure. These panels offer good insulation, even in 100 mm thick panels, but will still require an internal finish and an external cladding with weatherproofing performance. Structurally these panels can take vertical loads for walls both internal and external but cannot take bending. Floors will have to be constructed with joists and boards similar to timber frame detailing. However, the insulating performance of this composite can be used with panels over the rafters at roof level.

Solid wood is produced by laminating using offcuts and other short lengths of timber, finger-jointed and laid up as cross-ply. The laminating process can produce boards up to 4 metres wide and 18 metres long, depending on the capacity of the factory. This material has good bending characteristics so can be lifted flat and used as floor slabs. Openings can be cut out of solid panels, which can then be transported to site. All the panels have square edges providing simple detailing between wall and floor panels, where the joints can be taped for airtightness. Insulation and a cladding to the external face can be provided as on-site operations. This material can be used directly as the internal finish.

The lower weight of the timber panels over the concrete allows more to be transported on each lorry. This has given this type of prefabricated construction the term 'flat-pack', with whole buildings being delivered on a limited number of lorries.

Multi-storey volumetric

Prefabrication can be taken even further with the potential to provide volumetric units. When rooms are repetitive in layout and limited in size (width of around 3 metres) to be transported to the site whole, room units can be stacked on top of each other to create the structural system itself. If the room layouts are sufficiently repetitive, not only on plan but also vertically throughout the building, then whole sections of the building could be considered for construction with volumetric units that also form the structural system. One such combination of room pods is shown in Figure 27.4. Mixed structures where the lower floors may be a framed structure supporting the repetitive rooms on the upper floors may be another combination. This approach has been successfully employed for hotels, student accommodation and flats. This offers the opportunity for high levels of prefabrication and reduced site-erecting time, although project time taking into account design and factory production may not provide an overall time reduction for the client from commissioning to occupation.

The use of concrete for volumetric construction is an option but its weight limits the size of units so other options may be considered. Framed panel walls in timber or steel studs may be considered. It may be that the pods need to be stacked on strengthened corner sections to carry the load. The size and weight of units will determine transport and cranage requirements but the potential rigidity of the pod allows larger internal spaces to be considered, at least for medium-rise buildings. Units can be delivered with open sides that, when connected, provide these larger spaces. This may need the introduction of beams in the structure and temporary bracing for transport. It could be argued that these are no longer loadbearing walls but form a hybrid structure. Levels of services and finishes to be included in the prefabrication may add weight and increase the susceptibility to damage in handling, so care must be taken in devising site sequence and procedures for subsequent activities.

It is not only the level of prefabrication for the internal services, finishes and fittings that needs to be chosen but also the external wall treatment. Units can be produced with an external finish and weathering joints detailed to make the building weather-tight, but it may be preferable to add a facing to the pods to provide an appearance similar to other cladding solutions discussed in Chapter 29, although this will add to site production time.

Single-storey industrial construction

Walls for industrial buildings need to be high and long normally without the lateral support or stiffening effects of internal walls and floors. This makes both element buckling and wind stability major problems for open industrial buildings. Lateral restraint will be provided at the top of the wall by the roof structure, which, when sufficiently braced, will resist the overturning of the wall. The uninterrupted length of walls for these buildings also introduces the need for movement joints for the inherent deviations from both moisture and thermal movements. Options have been developed in both structurally designed masonry and reinforced concrete.

In masonry where tensile forces cannot be resisted there is a need to increase the effective width of the wall to increase both the buckling resistance and to limit the bending forces induced by wind loading on the stabilised wall. Traditionally this has been achieved with piers at regular intervals. This approach can be

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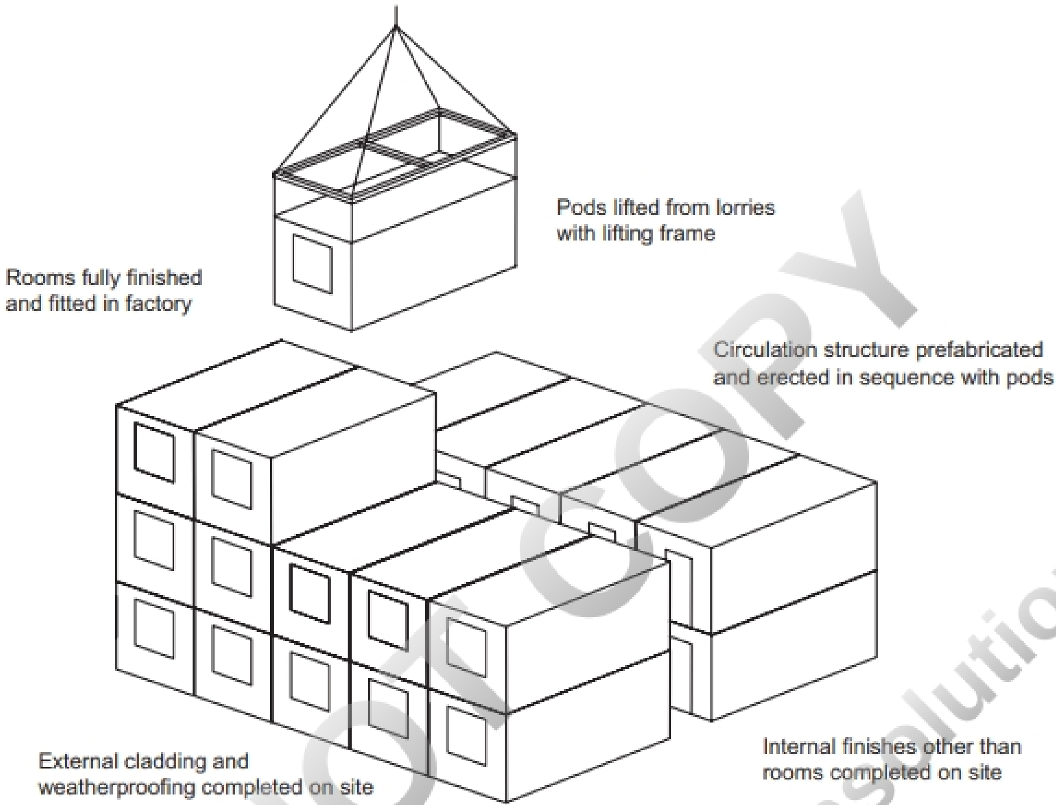

Figure 27.4 Volumetric construction.

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adopted for these industrial walls but the piers become more than thickening and need to be much deeper, perhaps between 1 and 2 metres, forming the appearance of fins, and this has led to this approach being known as fin wall construction. This approach is shown in Figure 27.5.

The fins are normally expressed on the outside of the building formed in the outer skin of a cavity wall, which can then adopt standard detailing with ties and insulation. While smaller openings can then be formed in the cavity wall using standard details, the larger openings often required in industrial buildings are normally formed by removing a section of wall between the fins. If the fins form the jamb of the opening, they may have to be thicker to stiffen the edge of the wall at the opening.

The centres of the fins would normally coincide with the spacing of the roof structural elements to provide the bearing (onto a pad stone) and tied connection required to transfer the load and provide the lateral restraint. This detail may have to include a reinforced concrete ring beam to achieve this connection. Movement joints would also have to coincide with the fins, as indicated in Figure 27.5.

An alternative to the fin wall is the diaphragm wall, as shown in Figure 27.6. This construction form increases the width of the wall by increasing the cavity and then ties the walls with cross ribs of brickwork or blockwork to ensure a single structural action against buckling and wind forces. The sizing of the wall is dependent on the modular size of the brick discussed in Chapter 19. The overall thickness of the wall would normally be between 1.5 and 2.5 bricks (approximately 550 mm), although wider walls may be necessary depending mainly on the height of the wall. The centres of the

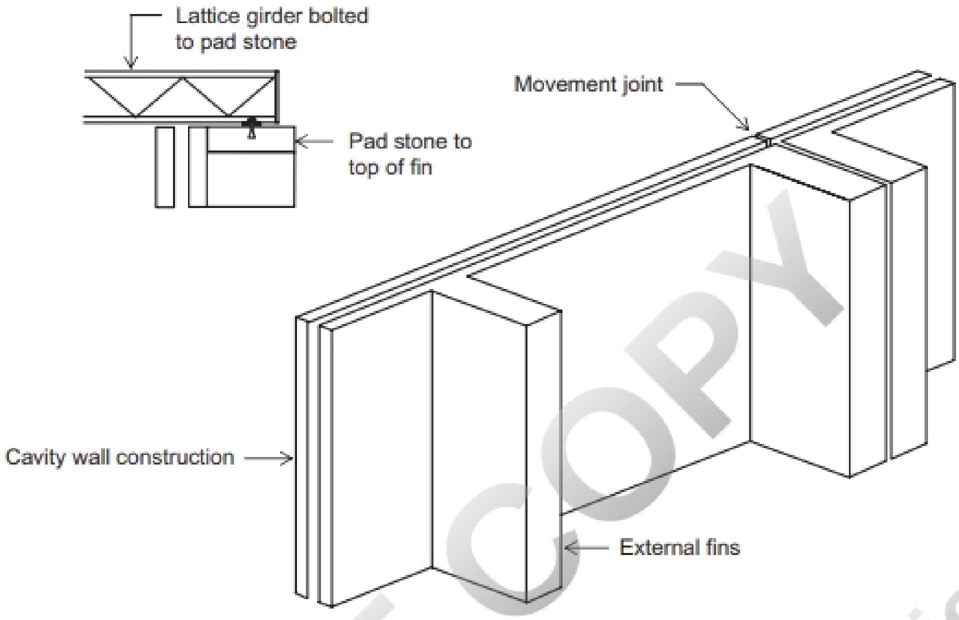

Figure 27.5 Fin wall construction.

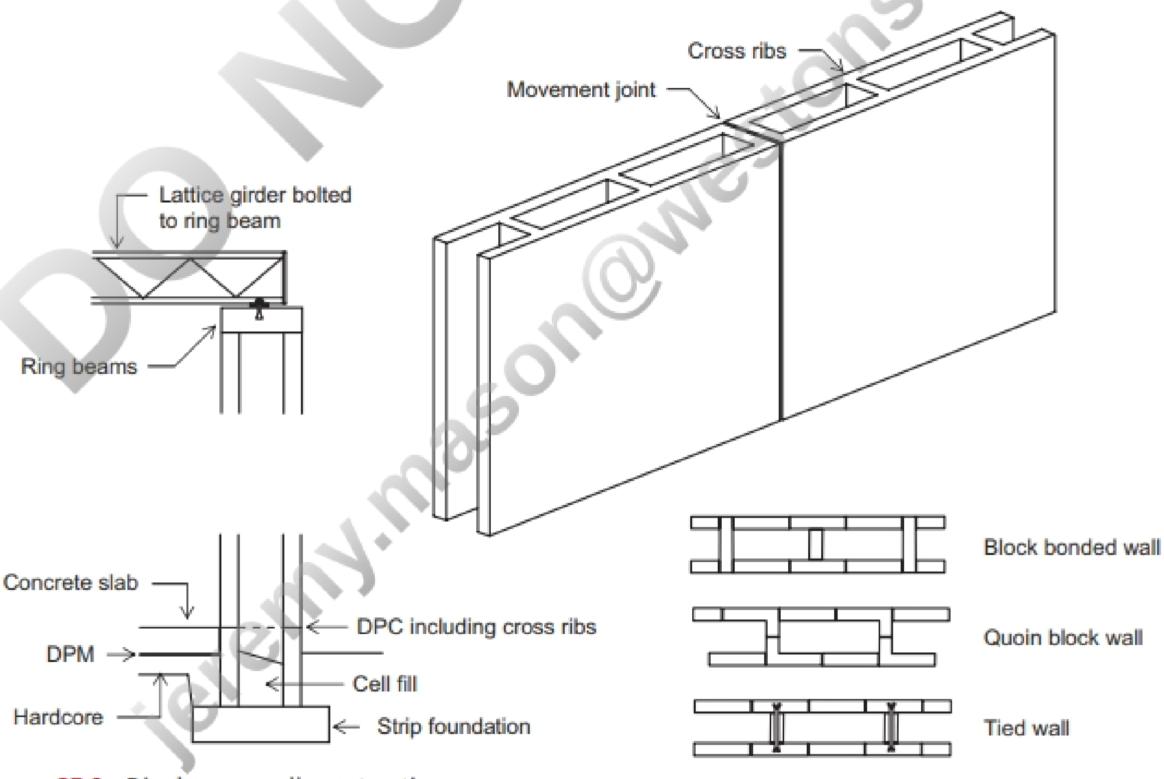

Figure 27.6 Diaphragm wall construction.

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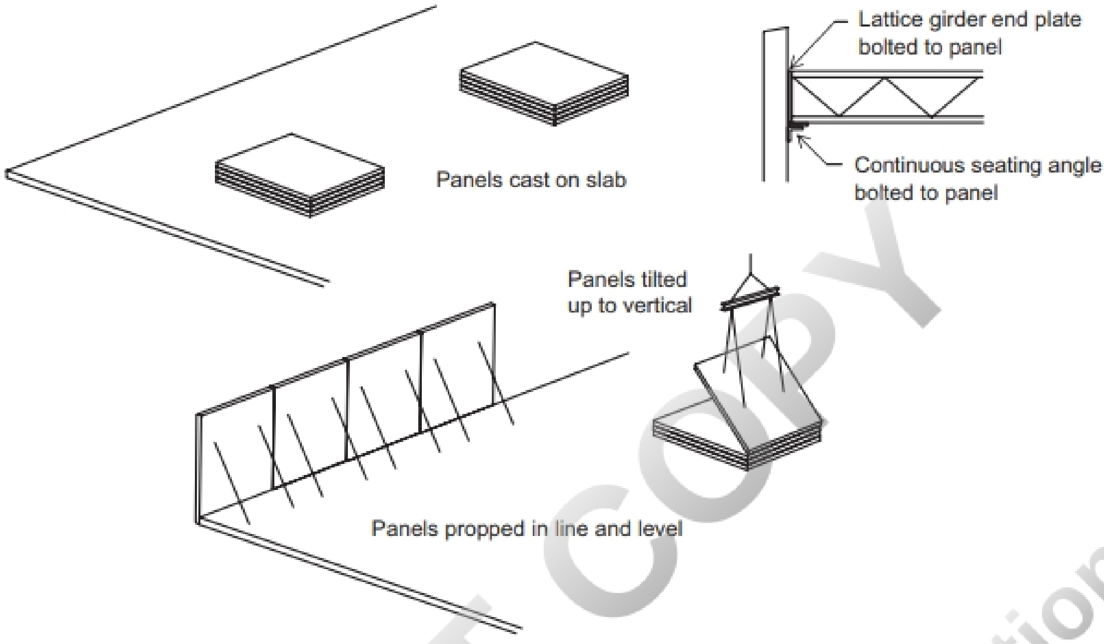

Figure 27.7 Tilt-up construction.

cross ribs also have to be brick modules, normally 4.5 or 5.5 to give whole bricks between the bonding headers that tie the cross ribs to each leaf. Alternative bonding arrangements in blockwork are shown in Figure 27.6. Opening and movements joints now have to be arranged between the cross ribs. This wall will need a reinforced concrete ring beam detailed at the top of the wall to provide the bearing and the lateral restraint connection to the roof structure.

The need for the thickness of the masonry wall is not required by reinforced concrete as this can resist tensile forces. Potentially relatively thin structural walls around 150 to 200 mm can be used as long as the roof and the floor can provide the lateral restraint to overturning at the top and sliding at the bottom of the wall. The structural wall will provide good fire, sound and even some weather protection, but the wall will still need to be detailed to ensure full waterproofing, appearance and thermal performance, introducing other components and materials to form a fully functioning wall.

In situ solutions would need to employ a significant amount of formwork and falsework and, if the full-height wall is to be cast in one pour, care needs to taken in the specification of the concrete for its workability and in the methods used to place and vibrate the concrete in deep narrow shutters. If precast concrete is considered, transport requirements may limit the width of the panels as the wall will need to be cast in single-height units to provide the structural integrity that would be difficult to provide in a horizontal joint between two smaller panels. One system that overcomes these transport difficulties is a process known as tilt-up and is illustrated in Figure 27.7.

Large panels are cast flat on the structural slab adjacent to the position where they are to be erected. The slab becomes the formwork for the face of the panel, with formwork being required to form the edge profile of the panel. They can be cast with insulation and finishes or in stacks of structural wall units, the panel below becoming the formwork for the one above. They can also be cast as continuous walls

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and then cut into panels at an early age. Lifting points have to be cast in. The precast panels now only have to be moved a few metres after they have been tilted up into the vertical position, where they are lowered onto the levelled foundations. In order to ensure fixity and restraint at the base of the wall there may be an infill strip at the slab edge to tie in the wall, or the panel may be lowered into a rebate in the slab edge or against a prepared metal fixing. Adjustment is necessary to bring the vertical joint between panels into tolerance before final fixing. They then need to be propped in the vertical position until the roof structure, normally including all the roof bracing, is erected to provide the permanent lateral support. To provide this support the roof structure is normally fixed to the face of the panel that extends above the roof line to form a parapet. The ends of trusses may not only be bolted to the panels but also be fixed to a continuous seat angle connecting all the panels together just below the level of the bottom chord of the truss.

The pace of the production process for this system tends to have the panels erected and fixed before all the drying shrinkage has taken place. While the reinforcement within the panel will be designed to resist the tensile forces induced by the shrinkage in the large panels, the joints and the fixings will have to be designed to absorb a proportion of this early-age shrinkage.

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Summary

1. Loadbearing wall structures may be considered for many buildings and have been developed for both multi-storey and single-storey industrial buildings.
2. With a limited number of storeys loads can be taken on the walls from floors and roofs even with normal commercial spans, although these cannot then be altered in the life of the building.
3. Multi-storey buildings with internal layouts that provide limited spans and a cellular or cross-wall arrangement of external and internal walls can be considered for loadbearing wall structures.
4. The floor construction has to be matched to the choice of wall to match the production process. While in situ floors would be used with in situ walls, precast concrete floors offer a match with both masonry and precast concrete walls. Timber floors would be used with timber walls.
5. Overall stability can be achieved from the cellular or cross-wall arrangements of the internal walls with appropriate connections between floors and walls, although cores similar to framed buildings can also be considered. Volumetric construction has an inherent overall stability.
6. Disproportionate collapse is a major consideration in the construction of the walls and the design of the connection between wall panels and between panels and the floor.
7. Walls for single-storey industrial buildings are potentially high and long, making buckling and movement a feature of the construction detailing. Increasing the effective width and the provision of movement joints are important in the design.
8. Options are possible in precast concrete panels, but the size of the panel makes transport difficult. This has led to the tilt-up system, where panels are cast on the slab adjacent to the final position of the wall.