Chapter 2
Basis of design and materials

2.1 Structural action

It is necessary to start a design by deciding on the type and layout of structure to be used. Tentative sizes must be allocated to each structural element, so that an analysis may be made and the sizes confirmed.

All liquid-retaining structures are required to resist horizontal forces due to the liquid pressures. Fundamentally there are two ways in which the pressures can be contained:

(i) by forces of direct tension or compression (Figure 2.1);
(ii) by flexural resistance (Figure 2.2).

Structures designed by using tensile or compressive forces are normally circular and may be prestressed (see Chapter 4). Rectangular tanks or reservoirs rely on flexural action using cantilever walls, propped cantilever walls or walls spanning in two directions. A structural element acting in flexure to resist liquid pressure reacts on the supporting elements and causes direct forces to occur. The simplest illustration (Figure 2.3) is a small tank. Additional reinforcement is necessary to resist such forces unless they can be resisted by friction on the soil.

2.2 Exposure classification

Structural concrete elements are exposed to varying types of environmental conditions. The roof of a pumphouse is waterproofed with asphalt or roofing felt and, apart from a short period during construction, is never externally exposed to wet or damp conditions. The exposed legs of a water tower are subjected to alternate wetting and drying from rainfall but do not have to contain liquid. The lower sections of the walls of a reservoir are always wet (except for brief periods during maintenance), but the upper sections may be alternately wet and dry as the water level varies. The underside of the roof of a closed reservoir is damp from condensation–because of the waterproofing on the external surface of the roof, the roof may remain saturated over its complete depth. These various conditions are illustrated in Figure 2.4.

Experience has shown that, as the exposure conditions become more severe, precautions should be taken to ensure that moisture and air do not cause carbonation in the concrete cover to the reinforcement thus removing the protection to the steel and causing corrosion, which in turn will cause the concrete surface to spall (Newman, 2003). Adequate durability can normally be ensured by providing a dense well-compacted concrete mix (see Section 2.5.2) with a concrete cover (cast against formwork) in the

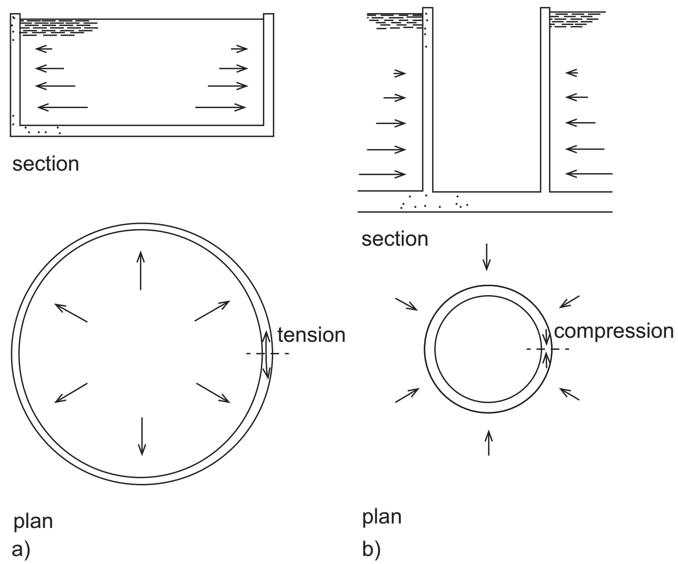

Figure 2.1 *Direct forces in circular tanks. (a) Tensile forces (b) Compressive forces.*

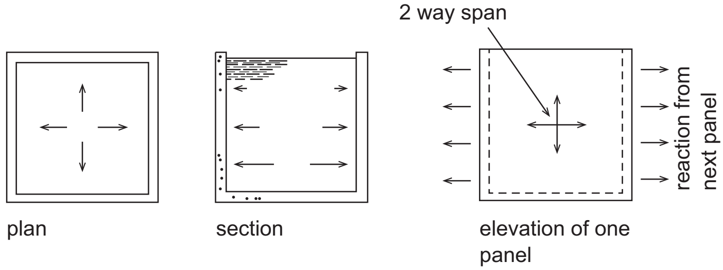

Figure 2.2 *Direct forces of tension in wall panels of rectangular tanks.*

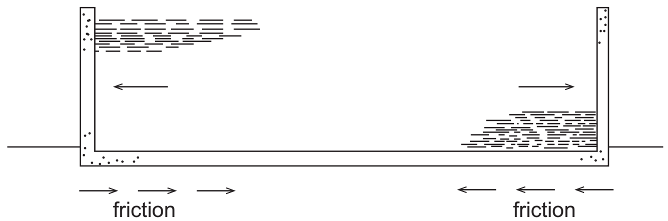

Figure 2.3 *Tension in floor of a long tank with cantilever walls.*

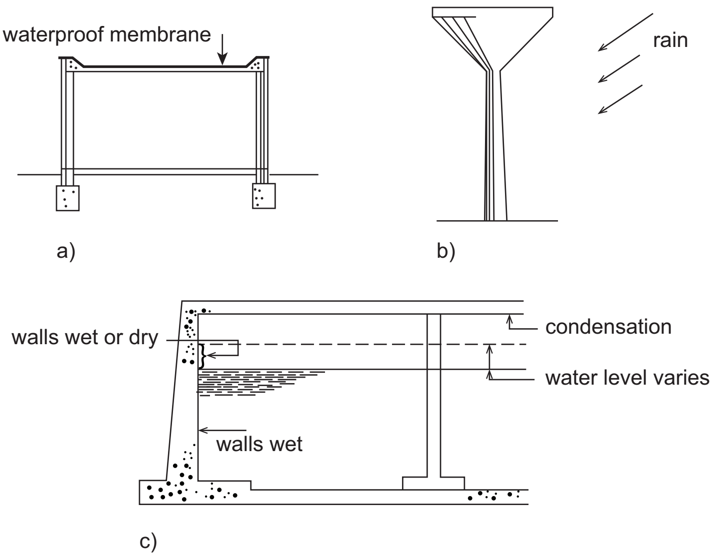

Figure 2.4 *Exposure to environmental conditions: (a) pumphouse roof, (b) water tower and (c) reservoir.*

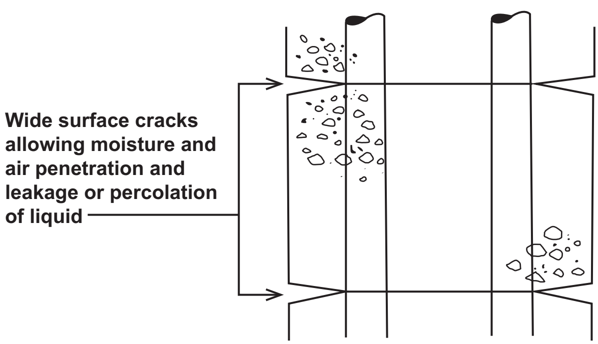

Figure 2.5 *Effect of cracks.*

region of at least 40 mm (BS 8500-1), but it is also necessary to control cracking in the concrete, and prevent percolation of liquid through the member (see Figure 2.5).

Previously, for design purposes, BS 8110 conveniently classified exposure in terms of relative severity (i.e. mild, moderate, severe). However, exposure classification in Eurocode 2 is now related to the deterioration processes, i.e. carbonation, ingress of chlorides, chemical attack from aggressive ground and freeze/thaw. Acting alongside Eurocode 2 is a more comprehensive guide, BS 8500 (Parts 1 and 2), to assist in determining cover. For less severe exposure conditions, BS 8500 is perhaps less onerous than BS 8110. However, for more severe conditions the requirements of BS 8500 are different. This is important, as BS EN 1992-3 requires that all liquid-retaining structures should be designed for at least 'severe' conditions of exposure. Where appropriate the 'very severe' and 'extreme' categories should be used. As an example, a water tower near to the sea coast and exposed to salt water spray would be designed for 'very severe' exposure.

As well as defining cover, durability requirements are also achieved by controlling cracking. For the serviceability limit state, the maximum (limiting) crack width is between 0.05 mm and 0.2 mm, depending on the ratio of the hydrostatic pressure to wall thickness. It should be noted that these limiting crack widths are actually equivalent to total crack width, i.e. in theory, early age, long term and loading (see comments in Chapter 1). The range of crack widths provided above is provided in BS EN 1992-3. General guidance on crack control is provided in Section 7.3 of BS EN 1992-1-1. Additional guidance is given in BS EN 1992-3 because of the nature of the structure. Early age thermal cracking may result in through cracks, which can lead to seepage or leakage. In water-retaining structures this could be deemed a failure. BS EN 1992-3 therefore provides a 'Classification of Tightness', shown below in Table 2.1. This tightness represents the degree of protection against leakage: 0 (zero) represents general provision for crack control in-line with BS EN 1992-1-1; 3 represents no leakage permitted. Tightness class 1 is normally acceptable for water-retaining structures.

The requirement for 'No leakage permitted' does not mean that the structure will not crack but simply that the section is designed so that there are no through cracks. There is no crack width recommendation of 0.1 mm for critical aesthetic appearance in the new Eurocodes as there was in BS 8110. No rational basis for defining the aesthetic appearance of cracking exists. BS EN 1992-3 claims that for Tightness class 1 structures, limiting the crack widths to the appropriate value within the range stated above should result in the effective sealing of the cracks within a relatively short time. The ratios actually represent pressure gradients across the structural section. As such, the claim that cracks of 0.2 mm will 'heal' provided that the pressure gradient does not exceed 5 has not changed much to the claim in BS 8007. For crack widths of less than 0.05 mm, healing will occur even when the pressure gradient is greater than 35. The fact that these cracks do seal is not strictly only due to autogenous healing (i.e. self-healing due to formation of hydration products) as was claimed in BS 8007, but also possibly due to the fact that the crack becomes blocked with fine particles. As mentioned above, sealing under hydrostatic pressure is discussed in Clause 7.3.1 of BS EN 1992-3 and for serviceability conditions, the limit state appropriate for water retaining structures, crack widths are limited to between 0.05 and 0.2 mm. When considering appearance and durability, further guidance with respect to crack widths and their relationship with exposure conditions can be found in Clause 7.3.1 of BS EN 1992-1-1 and its NA (Table NA.4).

Table 2.1 *Tightness classification.*

Tightness class	*Requirements for leakage*
0	Some degree of leakage acceptable, or leakage of liquids irrelevant.
1	Leakage to be limited to a small amount. Some surface staining or damp patches acceptable.
2	Leakage to be minimal. Appearance not to be impaired by staining.
3	No leakage permitted

2.3 Structural layout

The layout of the proposed structure and the estimation of member sizes must precede any detailed analysis. Structural schemes should be considered from the viewpoints of strength, serviceability, ease of construction, and cost. These factors are to some extent mutually contradictory, and a satisfactory scheme is a compromise, simple in concept and detail. In liquid-retaining structures, it is particularly necessary to avoid sudden changes in section, because they cause concentration of stress and hence increase the possibility of cracking.

It is a good principle to carry the structural loads as directly as possible to the foundations, using the fewest structural members. It is preferable to design cantilever walls as tapering slabs rather than as counterfort walls with slabs and beams. The floor of a water tower or the roof of a reservoir can be designed as a flat slab. Underground tanks and swimming-pool tanks are generally simple structures with constant-thickness walls and floors.

It is essential for the designer to consider the method of construction and to specify on the drawings the position of all construction and movement joints. This is necessary as the detailed design of the structural elements will depend on the degree of restraint offered by adjacent sections of the structure to the section being placed. Important considerations are the provision of 'kickers' (or short sections of upstand concrete) against which formwork may be tightened, and the size of wall and floor panels to be cast in one operation.

2.4 Influence of construction methods

Designers should consider the sequence of construction when arranging the layout and details of a proposed structure. At the excavation stage, and particularly on water-logged sites, it is desirable that the soil profile to receive the foundation and floors should be easily cut by machine. Flat surfaces and long strips are easy to form but individual small excavations are expensive to form. The soil at foundation level exerts a restraining force (the force develops from the restraint of early thermal contraction and shrinkage) on the structure, which tends to cause cracking (Figure 2.6). The

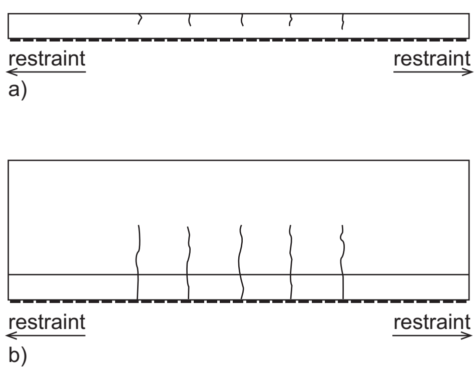

Figure 2.6 *Cracking due to restraint by frictional forces at foundation level (a) Floor slab (b) Wall (indicative only).*

frictional forces can be reduced by laying a sheet of 1 000 g polythene or other suitable material on a 75 mm layer of 'blinding' concrete. For the frictional forces to be reduced, it is necessary for the blinding concrete to have a smooth and level surface finish. This can only be achieved by a properly screeded finish, and in turn this implies the use of a grade of concrete that can be so finished (BS 8500-1, 2006; Teychenne, 1975; Palmer, 1977). A convenient method is to specify the same grade of concrete for the blinding layer as is used for the structure. This enables a good finish to be obtained for the blinding layer, and also provides an opportunity to check the strength and consistency of the concrete at a non-critical stage of the job. It also reduces the nominal cover, c_{nom} (BS 8500-1, 2006).

The foundations and floor slabs are constructed in sections that are of a convenient size and volume to enable construction to be finished in the time available. Sections terminate at a construction or movement joint (Chapter 5). The construction sequence should be continuous as shown in Figure 2.7(a) and not as shown in Figure 2.7(b). By adopting the first system, each section that is cast has one free end and is enabled to shrink on cooling without end restraint (a day or two after casting), although edge restraint will still exist (see Chapters 1 and 5). With the second method, considerable tensions are developed between the relatively rigid adjoining slabs.

Previously, BS 8007 provided three design options for the control of thermal contraction and restrained shrinkage: continuous (full restraint), semi-continuous (partial restraint) and total freedom of movement. On the face of it, it appears that BS EN 1992-3 does not allow semi-continuous design and therefore partial contraction joints have been excluded. Therefore, Part 3 only offers two options: full restraint (no movement joints) and free movement (minimum restraint). For the condition of free movement, Part 3 recommends that complete joints (free contraction joints) are spaced at the greater of 5 m or 1.5 times the wall height. (This is similar to the maximum crack spacing of a wall, given in BS EN 1992-1-1 Section 7, with no or less than $A_{s,\,min}$ bonded reinforcement within the tension zone, i.e. 1.3 times the height of the wall.) However, BS EN 1992-3 also states 'a moderate amount of reinforcement is provided sufficient to transmit any movements to the adjacent joint'. This appears contradictory. Hence continuity steel, less than $A_{s,\,min}$ is still permitted and semi-continuous joints are therefore still allowed.

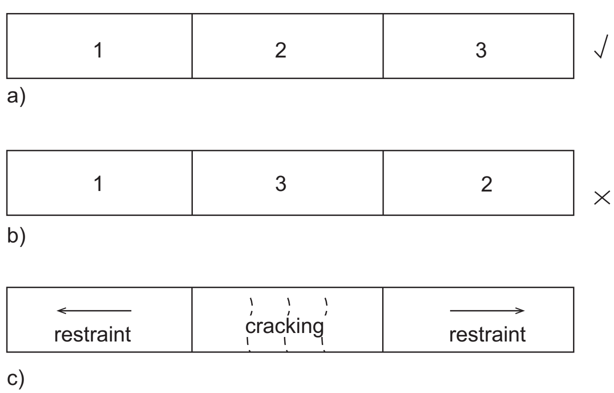

Figure 2.7 *Construction sequence (a) Preferred sequence (b) Not recommended (c) Effect of method (b) on third slab panel (cracks shown are illustrative only).*