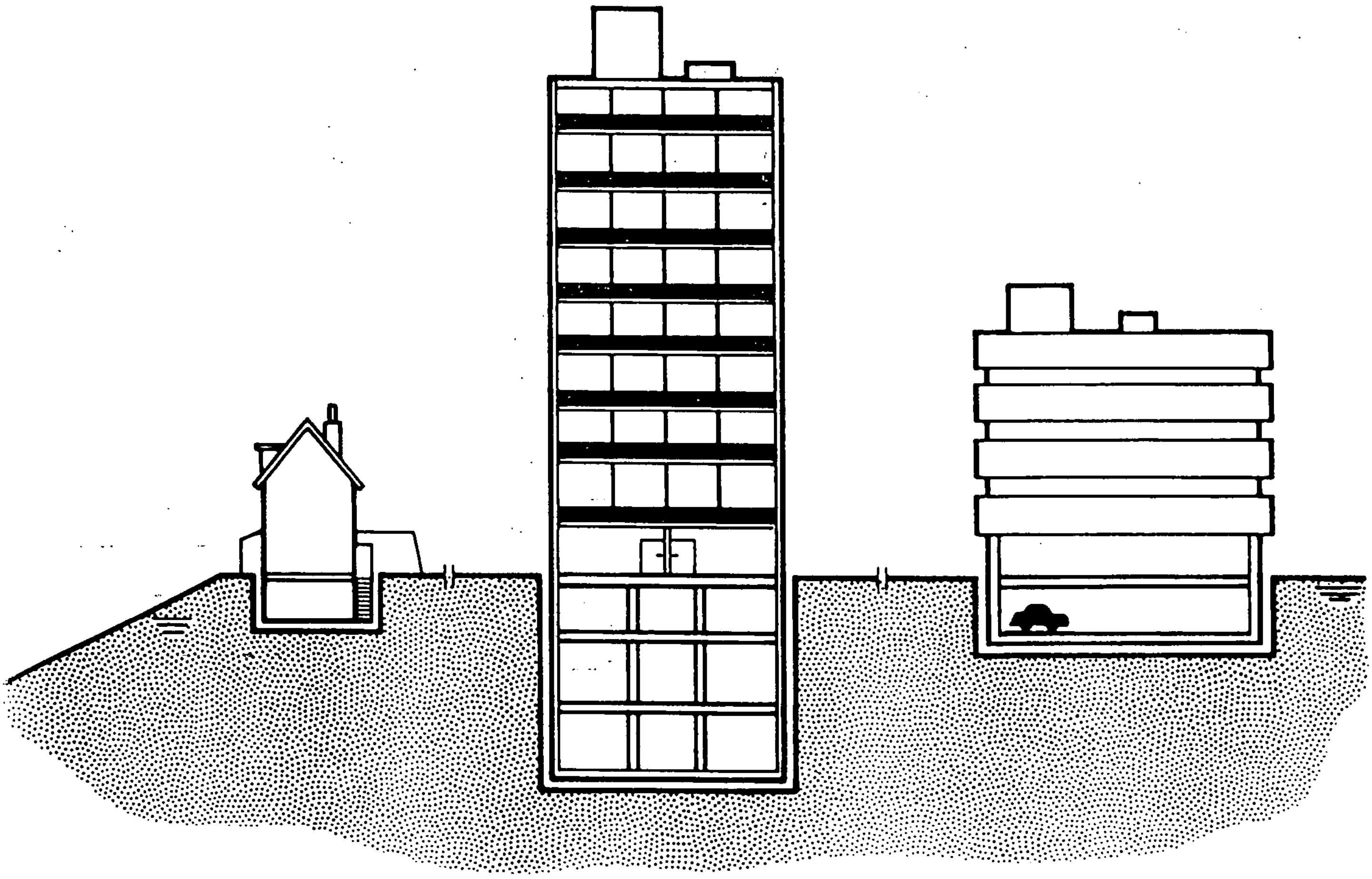
REPORT 139

Water-resisting basements



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3 Design of new basements

3.1 DESIGN OBJECTIVES

The designer should first be clearly briefed on the client's requirements for the internal environment of the basement. The client, in turn, should be advised by the designer on the reliability of the proposed solution and the cost implications of the requirements arising from the limitations of the individual elements and methods comprising the environmental control system. The costs, associated with achieving *complete* or *limited environmental control* (see Section 2.1), are proportional to the initial, maintenance and operating costs of the system, and the specified level of control should be considered.

3.1.1 System reliability

The design of the environmental control system should select the project-specific set of elements that are required to control reliably the ingress of moisture into the basement. The system should only comprise the necessary elements and no others. The reliability of the system will be dependent on the reliability of the individual elements from which it has been assembled. For each element of the proposed system the reliability of lower-bound performance level can be assessed. It is not possible to quantify accurately the reliability of some elements, particularly where the quality of workmanship during installation plays a dominant role in determining whether the element performs as expected. Hence a probabilistic approach, to determining the reliability of the system cannot be fully adopted. A simplified approach which accepts the probability of failure as one (certain) or zero (impossible) can, however, be adopted for individual elements when designing the environmental control system. The consequences of failure of a particular element can then be catered for technically (by remedial measures, see Chapter 5), operationally (by the procedures adopted for the management of the environmental control system) and financially (by estimating and making provision for any necessary costs).

Where a high level of environmental control (c*omplete control*) is required, and where the consequences of failure are severe, the reliability of the adopted system must be virtually absolute. This will almost certainly necessitate the adoption of a multi-phase protection strategy in order to ensure that the required environment will be achieved and maintained through the life of the structure. The achievement of *complete environmental control* will have a significant cost implication, which should be made clear to the client. Where the initial costs are required to be reduced the number of elements that make up the environmental control system may be reduced and the client may prefer to accept *limited environmental control.*

3.1.2 Complete environmental control

In circumstances where complete environmental control is required the system is likely to comprise a combination of both active and passive precautions.

The elements that may be combined to form the environmental control system comprise:

Passive precautions (see Section 1.4.2)

- External drainage
- The structural envelope (incorporating Type B protection)
- Membrane protection (external, reverse, internal, Type A protection)
- Internal drained cavities (Type C protection)
- Remedial works required to overcome defects in the other passive precautions

Active precautions (see Section 1.4.2)

- Internal drained systems (pumped)
- Environmental conditioning
- Building management and control systems

The designer responsible for the passive precautions will select, specify and ensure the performance level and standard of reliability of appropriate elements of the system in association with the building services engineer responsible for the design of active precautions, heating, ventilation and pumping to satisfy the requirements for protection and to achieve the most suitable environmental control system for the particular basement. The client, in approving such a brief, should be aware of, and accept, the cost of construction, maintenance, operation and possible replacement of parts of the system over the life of the building.

3.1.3 Limited environmental control

Where limited environmental control is agreed, the client may reduce the initial construction costs by eliminating precautions that may not be required. However, by his approval of a system of limited control, he accepts that:

1. amounts, location and frequency of potential moisture ingress, must be tolerated (within the agreed limits, see Sections 2.1 and 2.2), permanently or temporarily, in terms of the basement environment, building function or business operations,

2. the costs, direct and indirect (including disruption to user operations, relocation, loss of earnings, etc), of any essential remedial repair and maintenance will be acceptable and can be funded.

3.2 DESIGN CONSIDERATIONS

Basement design is an interactive process requiring decisions to be made relating to all the sections of this report. The flowchart in Figure 3.1, shows the relationship between the various sections of the report and the information and decisions required.

During the initial design stage, the full range of feasible basement construction methods, to suit the external conditions, should be considered. The choice of construction method and structure protection type will be fundamentally influenced by:

- the client's required internal environment in relation to the site and external soil conditions

- whether the basement can be built in an open excavation, and the available access for construction

- the basement depth, extent and volume, including the mass of the structure above it and whether it extends beyond the perimeter of the building above, i.e. it has a buried roof

- the passive precautions (structure protection type) that can be accommodated within the constraints of the site

- the extent to which active precautions for ventilation, heating and insulation inside the basement and drainage inside and outside the basement are to be used to achieve the required internal environment.

The solution should be the one that has the greatest probability of achieving the required internal environment and is also the most cost-effective.

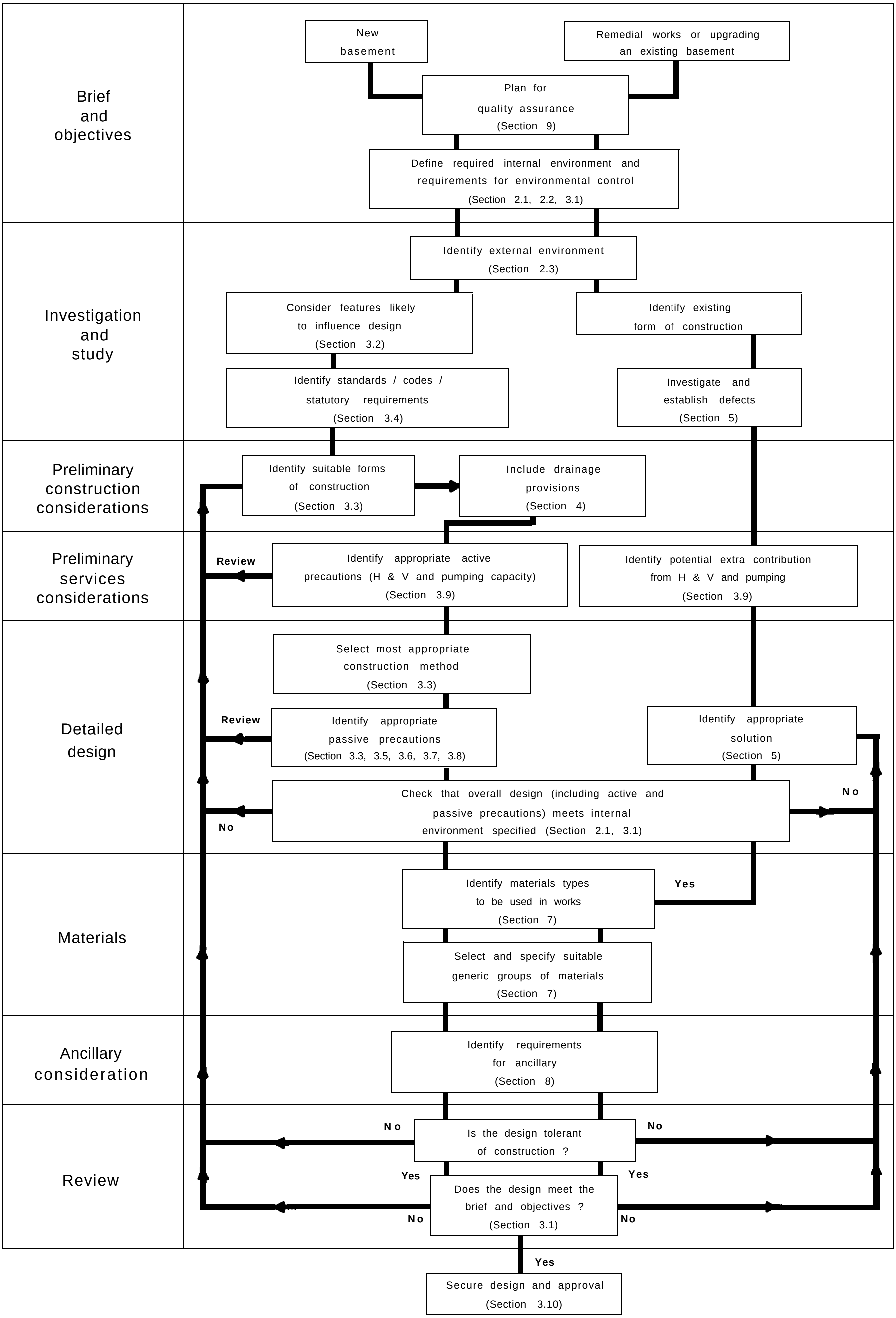


Figure 3.1 Water-resisting basement design: flowchart giving outline of method

The designer should review all the available solutions and take account of comparative costs, the usable floor areas provided, limitations on services and access restrictions, together with the following checklist of items from Clause 3.3 of BS8102, some of which reflect the fundamental restraints listed above.

‘(a) *The consequences of any leakage or condensation or dampness.*
(b) *The feasibility and form of remedial works.*
(c) *The scope for testing during construction (e.g. the controlled application of a head of water).*
(d) *The risk of aggressive groundwater penetrating inadequately water-tight construction and causing it damage.*
(e) *The risk of changes to the surrounding groundwater regime.*
(f) *The need and/or ability to incorporate movement joints within the structure.*
(g) *The need or ability to provide heating and/or ventilation and the consequences arising in terms of humidity.*
(h) *The need or ability to provide particular floor or wall surface treatments in response either to the users wishes or to meet some risk perceived by the designer (e.g. (a) or (g) above).*
(i) *The impact of the chosen method of construction and the consequential risk attendant upon less than adequate workmanship.*
(j) *The balancing of cost against risk in choosing whether further construction cost or future maintenance cost will assume priority or in choosing whether the building contract will place greater or less emphasis on a performance requirement.*’

At the preliminary design stage, the following influences on construction method, design codes, structure protection, drainage and services and maintenance costs are relevant.

3.2.1 Construction methods

This should take into consideration all appropriate construction techniques in relation to the position of walls, internal columns, movement and construction joints of superstructure, etc.

A basement should be designed in conjunction with the superstructure of the building, as the position and number of movement joints, walls and columns have a significant effect on the final cost and possibility of achieving the design objectives. This is even more important when using ‘top-down’ construction, which allows the superstructure to be built at the same time as the basement. The selection of basement construction method should also consider the overall mass of the structure in order to minimise potential problems from settlement and ground heave, as well as avoiding the risk of flotation, which may possibly result in the fracture of service entries.

The designer should aim to produce the simplest possible plan shape. Complicated sections in walls and slabs are difficult to form, reinforce and construct satisfactorily and often develop localised stress concentrations from shrinkage or thermal movement. Similarly, in irregularly shaped masonry walls, cracking and relative movements are greater. Emphasis should be placed on simplicity, ‘buildability’ and durability.

Where it is not possible to design the basement as a simple box, detailed attention must be paid to sudden changes in slab or wall direction and thickness. These cause particular problems when tanking protection is adopted (see Figure 3.2, and Section 3.6.5.2). The wall-to-floor joint is particularly prone to leakage, especially at the intersection with vertical corners (see Figures 3.3-3.5). Sealing ground slabs around pile caps requires special provisions. The use of ‘buildability’ aids, such as reinforcement couplers, may improve water-resistance by making it easier to prepare the joint face than where bars project or have to be bent out (see Figure 3.4).

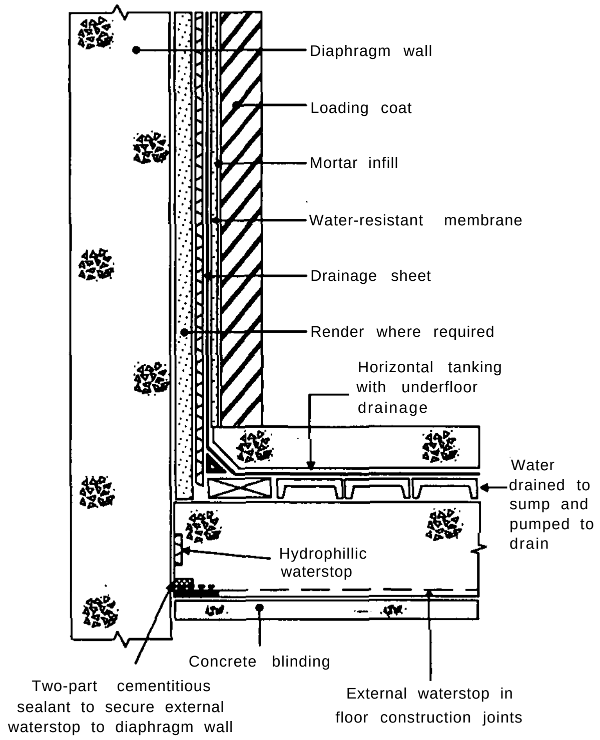


Figure 3.2 Preformed self-adhesive membrane; internal tanking with internal drainage. An example of Type A protection combined with Type C

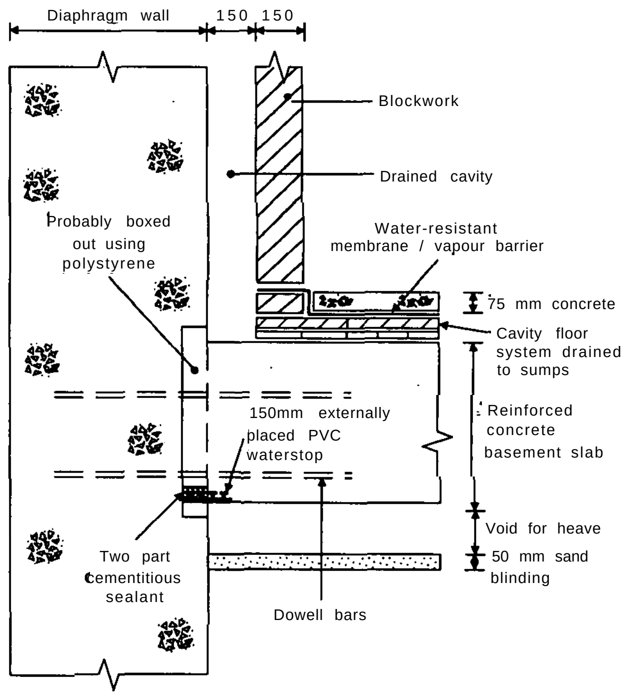


Figure 3.3 Detail of base slab / diaphragm wall junction. An example of Type C protection indicating special provisions at the wall / floor joint

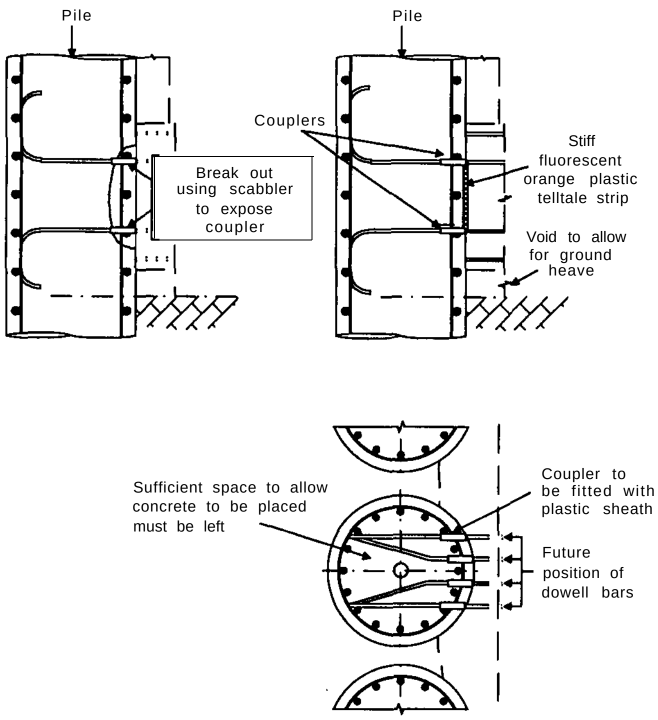


Figure 3.4 Detail of base slab / piled wall junction. A construction detail which makes it difficult to use either Type A or Type C protection

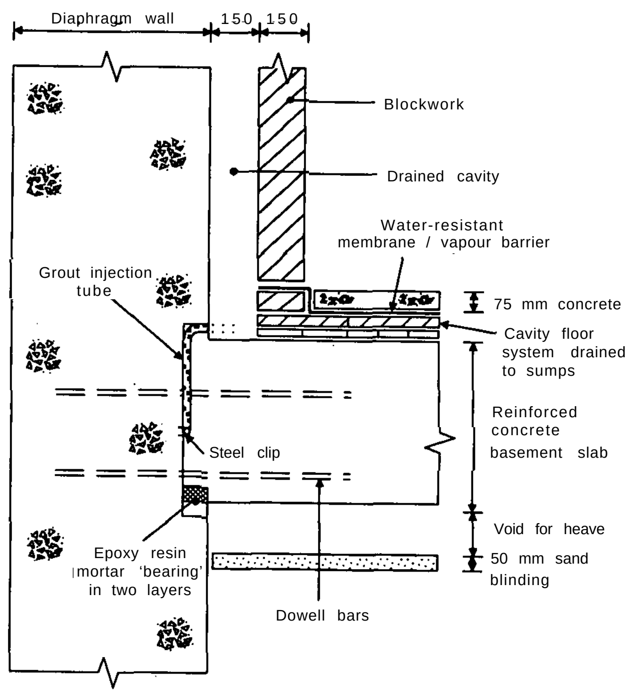


Figure 3.5 Detail of base slab / diaphragm wall junction. An example of Type C protection indicating special provisions at the wall / floor joint

3.2.2 Design codes

The guidance of relevant British Standards and Codes of Practice for durability and structural considerations, including crack width limits and the requirements of the Building Regulations (and British Standards) for materials and workmanship, fire safety, site preparation and resistance to moisture should be incorporated into the design process.

3.2.3 Structure protection

Information gained from the soil and groundwater survey (such as the presence of methane[3.1] or radon[3.2] etc.), the proximity of services and other buildings, site access and other constraints influence the design and layout of the whole building, the choice of construction methods and the elements of the environmental control system adopted.

The requirements for protection of the structural elements should be identified (i.e. tanking) and/or whether the structure requires complete or limited control to achieve the selected grade of internal environment.

The level of passive protection that may be required in typical instances of basement use is given, as a general guide, in Table 2.1. However, to provide a sound basis for client approval it will be necessary to describe, in outline, the environmental control system as a whole and the interdependence of its parts. The critical characteristics of the performance of both complete and limited control systems should be identified and quantified where possible.

3.2.4 Drainage and services

The provision of external drainage to control groundwater levels should be used wherever practical.

Active measures for heating and ventilation should be provided where complete control is considered necessary to supplement the structure protection.

Care must be taken to avoid leakage into the basement around pipes and other services that pass through the basement walls. Internal wall fixings, cable support brackets and lightning conductors must not damage the structure protection. Measures that facilitate future remedial works to seal leaks, such as the provision for post-grouting construction joints (see Figure 3.5), may also be incorporated (grout tubes should be capped to prevent a leakage path occurring prior to injection).

3.2.5 Maintenance and costs

All structures need some maintenance to achieve their design life, particularly where complete environmental control is required. Leakage into basements should be avoided by careful attention to construction details. If failure occurs, the remedial measures may be very expensive, e.g. grouting or the installation of drained cavities and drained floors.

Where pumps are required as part of the system some duplication may be worthwhile (see also Section 3.1.1) to enable equipment to be removed for regular maintenance. Equipment that runs only intermittently is more likely to break down. Typical costs of maintenance are approximately 1% of basement construction value per year.

Heating and ventilation costs will be less than for above-ground space.

3.3 CONSTRUCTION METHODS

Before suitable construction methods and materials are selected the basement should be categorised as either:

1. Deep — A basement with more than one storey, which will generally be subject to hydrostatic pressure, or

2. Shallow — A basement of one storey (including basements for residential use), which may or may not be subject to hydrostatic pressure.

This general categorisation together with the internal environment (Grades 1 to 4) enables the range of appropriate basement construction methods (and materials) to be identified. It also assists in the choice of structure protection type (A, B or C).

Table 3.1 (extending the approach of BS8102) outlines construction types and passive precautions available for different grades of internal environment in relation to deep and shallow basements, above and below groundwater level. Shallow basements, above groundwater level, often associated with residential development justify a separate more detailed categorisation (described in Chapter 6).

The principal construction materials and methods for basements are:

- concrete, plain or reinforced (precast or in-situ reinforced concrete box, diaphragm or piled walls)
- masonry
- steel sheet piling.

The appropriate use of these materials in basement construction is described in Chapter 7.

3.3.1 Deep basements

The various methods of deep basement construction, given in the report of the Institution of Structural Engineers' Committee on Deep Basements[3.3], can be summarised into the following:

- construction in open excavation
- bottom-up construction
- top-down construction.

Combinations of bottom-up and top-down systems of basement construction may be adopted.

This section describes available combinations of construction methods and examples of passive precautions for reinforced concrete deep basements subjected to a permanent hydrostatic head. The permeability of the ground will be an important factor in determining the choice of suitable construction methods. As deep basements are generally constructed using diaphragm or piled walls, it is rarely feasible to protect them with external tanking.

In general, deep basements will require a concrete structure, which will also act as a barrier to the ingress of water. Internal environment Grades 2, 3 and 4 are likely to require additional passive measures to attain the necessary resistance to moisture penetration. Internal drained cavities can normally be provided in conjunction with tanking if necessary, to achieve the highest grades.

Table 3.1 Construction methods and examples of passive precautions available to achieve the required Grade of internal environment in deep or shallow basements

Basement depth and construction materials	Target internal environment / examples of construction methods and passive precautions			
	Grade 1 (basic utility)	**Grade 2 (better utility)**	**Grade 3* (habitable)**	**Grade 4* (special)**
	Limited environmental control possibly adequate (Low cost, low reliability)			*Complete environmental control* normally required (High cost, high reliability)
	Some water penetration acceptable	Water penetration unacceptable	Increasing requirements for vapour control	
Shallow (assumed no hydrostatic pressure, i.e. groundwater level below basement floor or drainage provided) likely to be residential **Masonry, reinforced masonry, plain or reinforced (precast or in-situ) concrete or steel sheet piling**	Grade not usually acceptable for residential basements	Masonry or plain concrete plus tanking (Type A) or drained cavity (Type C) protection ------------ Reinforced concrete box (Type B) protection	Masonry or plain concrete plus tanking (Type A) protection and/or Type C protection ------------ Reinforced concrete box (Type B) plus tanking vapour barrier (Type A) or drained (Type C) protection	If grade required the methods and precautions for shallow basements with permanent hydrostatic pressure should be followed
Shallow (with permanent hydrostatic pressure) **Masonry, reinforced masonry, plain or reinforced (precast or in-situ) concrete or steel sheet piling**	Masonry, plain or reinforced concrete box construction plus tanking (Type A) or drained (Type C) protection ------------ Reinforced concrete box (Type B) protection ------------ Steel sheet piling in conjunction plus drained (Type C) protection	Masonry, plain or reinforced concrete box construction plus tanking (Type A) or drained (Type C) protection ----------- Reinforced concrete box (Type B) protection	Masonry or plain concrete plus tanking (vapour barrier, Type A) *and* drained (Type C) protection -------------- Reinforced concrete box (Type B) plus tanking (vapour barrier, Type A) or drained (Type C) protection	Reinforced concrete box (Type B) with tanking (vapour barrier, Type A), plus drained (Type C) protection Passive precautions alone are not likely to be sufficient
Deep (with permanent hydrostatic pressure) **Reinforced concrete including piled or in-situ perimeter wall.**	Reinforced concrete box (Type B) protection Concrete piled wall, possibly requiring drained cavity (Type C) protection	Reinforced concrete box (Type B) protection ------------ Concrete piled wall or reinforced concrete box (Type B) plus drained (Type C) protection	Concrete piling or reinforced concrete box (Type B) plus an internal vapour barrier (Type A) or drained (Type C) protection Passive precautions alone are not likely to be sufficient	Concrete piling or reinforced concrete box (Type B) plus tanking (vapour barrier, Type A) and drained (Type C) protection Achieved only at high cost Passive precautions alone are not likely to be sufficient

Notes: When tanking is required, external or sandwich tanking systems are recommended for both new and existing basements where it is possible to use them. Such systems become feasible either by virtue of an existing permanent external surface (including faced sheet piling) or where working space is created through open excavation. The choice of tanking system also requires an assessment of the external hydrostatic pressure and its effect on the basement wall design and construction. For deeper basements, or where excavation is impracticable, internal protection by cavity construction with internal or reverse tanking may be used. This implies a reduction in usable basement volume or increased excavation volume. Integral protection must not be damaged by wall fixings. The costs of available options and associated risks will need to be evaluated. Where significant quantities of water are likely to accrue in sumps on a regular basis the drainage authority should be approached at an early stage to request acceptance of the discharge.

* The design for Grade 3 or Grade 4 should take account of the contribution of active precautions (heating and ventilation, etc.) in achieving the required internal environment.

For more information on appropriate design standards for concrete basements, see Section 3.4.

Grade 1 (basic utility) and Grade 2 (better utility) internal environments can usually be achieved using in-situ reinforced concrete construction without any additional protection if:

- the basement foundation slab is thick, and
- maximum calculated crack widths, due to contraction and load effects, are kept to a minimum to limit excessive leakage (see Section 3.7.2.1), and
- particular care is taken with the 'floor to piled wall joints' and 'piled comers', and
- the ground is of low permeability.

Where the structural walls and floor cannot be relied upon to exclude water sufficiently, the simplest solution is to install a drained cavity. Similarly, a drained floor should be provided, which allows for an air space between the main structural slab and the floor. Any water that collects in the cavities should be drained to sumps and pumped away.

Grade 3 (habitable) and Grade 4 (special) internal environments generally require vapour control and Grade 4 may also need humidity control. Vapour can be removed by installing a naturally or mechanically ventilated drained cavity.

Deep basement construction in the form of diaphragm, contiguous or secant piled walls (which may not comply fully with the BS8007 requirements, for spacing and percentage of reinforcement for crack control) can still achieve all grades of internal environment when constructed in conjunction with additional active and passive precautions. Leak sealing/grouting can be included in the contract, or as a requirement when water levels return to normal if de-watering has been used. Further guidance on design standards for deep basements is given in Section 3.4.2.

Drained and ventilated cavity walls and floors (with the structural elements forming the primary barrier to moisture ingress) can provide a high degree of vapour control and, although not in every case essential, may be of long-term benefit where there is a risk of a future rise in groundwater level.

The passive precautions that may be used as part of the environmental control system are summarised in Table 3.2.

3.3.2 Shallow basements

This section describes the available combinations of methods for shallow basements subjected to a permanent hydrostatic pressure and constructed of:

- masonry
- concrete, plain or reinforced (precast panels or in-situ)
- steel sheet piling.

Where hydrostatic pressure is not expected, reference may be made to Section 3.3.3. Additional information on appropriate design standards for concrete basements is given in Section 3.4.2.

The measures that are likely to achieve the desired internal environment in shallow basements are similar to those summarised in Section 3.3.1 for deep basements, except that external tanking is more likely to be feasible for shallow basements. The passive precautions that may be used as part of the environmental control system are summarised in Table 3.3.

Grade 1 (basic utility) internal environment; basements for non-critical applications (e.g. car parks, insensitive storage) may be achieved, when constructed to an appropriate standard of workmanship from masonry, plain concrete, steel sheet piling or reinforced concrete 'boxes' (i.e. monolithic walls and floor continuously reinforced, in two faces, in both directions).

Table 3.2 Alternative water and vapour control measures (and combinations) likely to achieve particular internal environments in deep basements (subject to hydrostatic pressure)

Water and vapour protection measures	Internal environment									
	Grade 1			Grade 2			Grade 3		Grade 4	
External tanking [Type A]	X			X			X		X	
Internal tanking, vapour barrier (where necessary) [Type A]	X	X	X	X	X	X	✓	✓	✓	✓
Structurally integral protection [Type B]*	✓	X	✓	✓	X	✓	X	✓	X	✓
Internal drained cavity (drained protection) [Type C]	X	✓	✓	X	✓	✓	✓	✓	✓	✓.
Active precautions	X			X			✓		✓	
External drainage	X			X			X		X	

* Design standards for concrete basements are given in Section 3.4.2.

Each column represents one possible combination of measures in the environmental control system.

Key:

X Not usually necessary (sometimes not feasible).
✓ Precautions that may be included in the environmental control system.

Table 3.3 Alternative water and vapour control measures (and combinations) likely to achieve particular internal environments in shallow basements (subject to hydrostatic pressure)

Water and vapour protection measures	Internal environment														
	Grade 1				Grade 2				Grade 3					Grade 4	
External tanking, vapour barrier (where necessary) [Type A]	✓	X	X	X	✓	X	X	X	✓	X	✓	X	X	✓	X
Internal tanking, vapour barrier (where necessary) [Type A]	X	✓	X	X	X	✓	X	X	X	✓	X	✓	X	X	✓
Structurally integral protection [Type B]*	X	X	✓	X	X	X	✓	X	X	X	✓	✓	✓	✓	
Internal drained cavity (drained protection) [Type C]	X	X	X	✓	X	X	X	✓	✓	✓	X	X	✓	✓	
Active precautions	X				X				✓					✓	
Low level, below floor, external drainage (where possible and beneficial)	✓				✓				✓					✓	

* Design standards for concrete basements are given in Section 3.4.2.

Each column represents one possible combination of measures in the environmental control system.

Key:

X Not usually necessary (sometimes not feasible).
✓ Precautions that may be included in the environmental control system.

Grade 2 (better utility) internal environment; basements constructed as a reinforced concrete 'box', with early thermal crack control to BS8007, may be sufficiently water-resistant without any additional protective measures. For basements constructed with masonry, plain concrete or steel sheet pile walls, the provision of drained or tanked protection is likely to be necessary, where visible leakage will not be acceptable.

Grade 3 (habitable) internal environment; basements constructed from masonry, plain concrete or reinforced concrete require tanked or drained protection. Where external tanking is not possible or cannot be relied upon to give complete protection, the provision of drained protection in conjunction with a vapour barrier provides the maximum reliability against water and vapour penetration. Adequate design for heating and ventilation (active precautions) should be provided to ensure that the vapour barrier does not cause internal and/or interstitial condensation.

Grade 4 (special) internal environment; these environments are often achieved by using a reinforced concrete box structure (designed to BS8007) with vapour-resisting tanking and drained protection, together with the highest quality of workmanship. Heating and ventilation are usually essential, and relative humidity control may be required.

Piled, shallow basements are not usually economic, but using the methods described for deep basements (Sections 3.3.1 and 3.4.2) they can be designed to achieve similar standards.

3.3.3 Residential basements

A shallow residential basement may be used for storage or for habitable accommodation. Semi-basements are constructed on sloping ground. This section assumes (because of the provision of drainage or sloping ground), that such structures will not be subjected to hydrostatic pressure. If this assumption is incorrect refer to the guidance in Section 3.3.2 and Table 3.1.

The principal construction materials used in residential basements include:

- masonry (bricks or blocks)
- concrete, plain or reinforced (precast or in-situ).

Residential basements are usually Grade 3, while Grade 2 may be acceptable for utility rooms. Grade 1 is unlikely to be acceptable and Grade 4 objectives are not usually necessary.

Grade 1 (basic utility) internal environment which permits 'some seepage and damp patches' is unlikely to be acceptable even for a residential garage, although BS8102 includes parking in this grade.

Grade 2 (better utility) internal environments may be achieved using any of the protection types.

Grade 3 (habitable) internal environments will generally require some control of vapour for health reasons as well as for protection against damage through moisture ingress. To satisfy the requirements of BS8102 and the Building Regulations 1991, complete protection by a combination of methods may be necessary.

The methods of protection for residential basements are detailed in Chapter 6.

Possible passive precautions available to achieve a Grade 2 or 3 internal environment in a residential shallow basement subject to regular hydrostatic pressure are as defined in Section 3.3.2, and summarised in Table 3.3.

3.4 DESIGN STANDARDS

This section summarises the salient points from the principal British Standards concerned with the design of reinforced concrete, plain concrete or masonry basements.

A full comparison of the relevant documents is given in Appendix B and in Table B.l for reinforced concrete basements and Table B.2 for plain concrete and masonry basements. The fundamental elements of design that are considered to affect directly the water resistance of a structure, namely materials properties, cracks, construction joints, movement joints, waterproofing treatments and drainage, are discussed below.

3.4.1 The Building Regulations (SI 1991 No. 2765)

The Building Regulations state that *'the walls, floors and roof of the building structure should adequately resist the passage of moisture to the inside of the building'*. The Building Regulations [(3.4)] do not deal separately with basements but treat them as part of a building.

Approved Documents[(3.4)] particularly relevant to basement construction include the following:

Approved Document B1 provides guidance for means of escape in case of fire, and B2/3/4 deal with fire safety and fire spread requirements generally for the above-ground storeys of buildings. However, Section 1.17 of B1 is aimed specifically at *'venting of heat and smoke from basements'*. It recognises the necessity to improve the fire safety of semi-basements by providing doors and windows on at least one external wall. In other cases, and with larger structures, more than one staircase is required for inhabited basements (Section 2.40/2.42).

Approved Documents C1/2/3 deal with site preparation, site drainage and contaminants in the ground associated with general construction practice. Approved Document C4 sets out the performance requirements in respect of a floor next to the ground which should *'prevent undue moisture from reaching the upper part of the floor'*. To achieve this level of performance, technical solutions are offered for ground-supported concrete floors not subjected to water pressure, which would therefore not be adequate for all basements. Where conditions are more onerous, the Approved Documents refer the reader to solutions from CP102: 1973[(3.5)] (for capillary rise of moisture) and BS8102: 1990[(3.6)] (for the protection of structures from water in the ground by tanking). A determination by the DoE[(3.7)] carries the important implication that reliance may be placed on heating and ventilation to achieve the required grade of internal environment.

3.4.2 Concrete basements to BS8110: 1985, BS8007: 1987 and BS8102: 1990

There are three codes of practice particularly relevant to the design of concrete basements, BS8110: 1985[(3.8)], BS8007: 1987[(3.9)] and BS8102: 1990. The scope of, and relationship between, these standards is discussed and a detailed comparison of their individual requirements is given in Appendix B, Table Bl (BS8004: 1986 *Code of Practice for Foundations* may also be relevant).

BS8110 states that *'water retaining structures ... are more appropriately covered by other codes'*. BS8007 *'provides recommendations for the design and construction of normal reinforced and prestressed concrete structures used for the containment or exclusion of aqueous liquids'* but *'does not cover ... the damp-proofing of basements'*. BS8102 provides *'guidance on methods of dealing with and preventing the entry of water from surrounding ground into a building below ground level'*.

Detailed guidance on crack control during the design of reinforced concrete basements, including an innovative design philosophy that overcomes this problem, is presented in Section 3.7.2.1.

3.4.3 Masonry basements to BS5628 and BS8102

Two codes of practice are relevant to masonry construction, BS5628: Part 3: 1985[3.10] and BS8102. The former gives recommendations on the prevention of moisture ingress, but not specifically for basements, while BS8102 details the requirements specific to basements.

3.4.4 Welded steel sheet piling

There are no codes that detail the requirements for welded steel sheet pile basements. There are a number of codes that give material and fabrication requirements.

Structural steel sheet piling should be a weldable, low-carbon type. In the UK, structural steel is obtained to BS4360: 1990, in which the most commonly used grades are 43 (mild) and 50 (high tensile steel). The grades are further designated by a letter (e.g. 43A, 43B) which denotes the requirements for Charpy V-notch impact testing. BS4360 also gives specific requirements for the chemical composition and mechanical properties of weather-resistant (WR50) grades rolled in the UK. The requirements for thickness are given in BS5950.

3.5 PASSIVE PRECAUTIONS (STRUCTURE PROTECTION TYPES A, B AND C)

Three forms of protection types have been illustrated and described previously in Figure 1.1, with a commentary on the information given in BS8102.

The decision on whether to rely entirely upon structurally integral protection (Type B) is crucial to basement design, and the factors which influence that decision are discussed in Chapter 2. These include:

- the degree of acceptable leakage into the basement
- durability risks from chemical deterioration of structural elements
- the risk of gas migration into the basement
- feasible methods of protection related to construction methods
- the risk of leakage associated with the protection method
- the anticipated hydrostatic pressure.

Deep basement construction is generally carried out in reinforced concrete (including piled walls). This is described more fully in Section 3.7.

Basements with buried roofs, e.g. underground car parks, etc., may require special consideration of the passive precautions to ensure compatibility with the measures adopted for the walls. Methods available for the protection of buried roofs are described in CIRIA Technical Note 145[3.11].

Table 3.1 indicates the construction method (structure and protection) likely to achieve each environment grade. It may be used, with a proposed construction method in mind, to obtain details of the passive precautions that may be required.

The required moisture penetration characteristics may not always be achieved by the passive precautions adopted, owing, for example, to construction defects. Where this is the case, recourse may be made to the remedial measures outlined in Chapter 5.

3.5.1 Water or water and vapour penetration

The internal environment grades, given in BS8102 are based upon the performance level of a protection type (A, B or C) to resist water or water and vapour penetration into the basement for particular types of usage.

The acceptable risk of moisture penetration associated with each type of structure (reinforced concrete box, piled walling, masonry, etc.) must be evaluated in view of the existing and possible future ground conditions (principally groundwater levels and type of drainage associated with soil type).

For shallow (or residential) basement construction, where there is no permanent hydrostatic head, any environment grade can be achieved utilising any of the structural materials with any of the three types of protection, although practicality and cost will vary. This is described further in Sections 3.2 and 3.3. Where slope or natural drainage do not guarantee these conditions, additional precautions may be necessary to minimise water or water and vapour penetration.

3.5.2 Aggressive ground conditions

The presence of sulphates, chlorides, acids, gases etc. in the ground and groundwater affects the durability of the structural elements below ground level (see Section 2.3).

If the risk of moisture penetration through the structural walls and floor or the likely durability of the structure or its protection is unacceptable, two options are available to achieve the specified basement internal environment:

1. Improve the protection provided by the construction materials (i.e. by modifying the existing method and materials or by selecting an alternative method (see Section 3.5.3)).

2. Supplement the protection provided by the structural elements (by the addition of other passive systems (see Section 3.5.4)).

3.5.3 Structures without additional protection (Type B)

Where the use of additional protection to supplement that provided by the structural elements is not feasible and/or desirable, alternative construction methods and materials may be evaluated. This may require repeating the initial design procedure outlined in Sections 3.1 and 3.2.

3.5.4 Structures requiring additional protection (Type A and C)

The protection provided by the structural elements may be supplemented principally by two methods:

1. Tanking protection ~ external, sandwiched or internal tanking; and/or

ii) Drained protection ~ internal drained cavity.

The main features of each protection type are defined in Chapter 1 of this report. More detailed guidance and the relative merits of the protection types are presented in subsequent sections.

Table 3.1 indicates the construction method (structure and protection) likely to be used for each environment grade. It can be used with a proposed construction method in mind to obtain details of the passive precautions that may be appropriate.

3.6 TYPE A: TANKING PROTECTION

Tanking (Type A) protection provides a continuous barrier system which excludes water and/or water vapour and may exclude gases (see Section 2.3.3.7). It can be installed:

- on the exterior face of walls and floors (external)
- onto some external source of support (reversed)
- within the construction (sandwiched), or
- on the interior face of walls (internal).

Figure 3.6 illustrates the types of tanking.

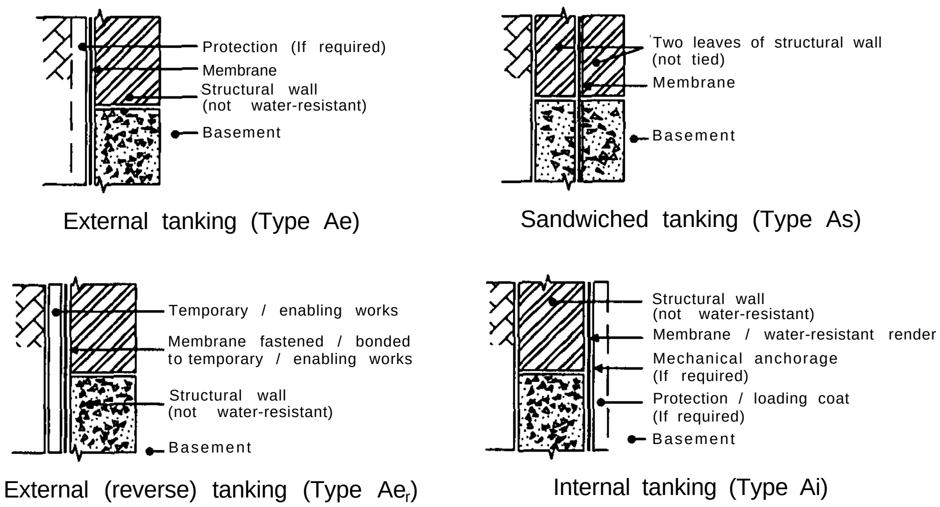


Figure 3.6 Tanking protection (Type A)

The reliability of tanking systems is primarily reliant on:

- the formation of adequate joints where sheet systems are used
- the prevention of damage to the membrane during construction
- achieving a satisfactory bond to the substrate.

They are not generally applied to exposed, floor surfaces because they lack the necessary wearing properties and are unable to resist external hydrostatic pressure.

A tanked structure is generally required to be monolithic, with a minimum of movement (especially transverse) at joints. The tanking system should be selected to accommodate the movements that are likely to occur. For large deep basements (with a permanent hydrostatic head) tanking is only practicable with reinforced box construction, except where walls are cast onto steel piling, but may not be necessary.

For each project a full exchange of information between all the parties concerned with the design and construction of the basement and the tanking system may be beneficial. A detailed specification should be prepared, with a general arrangement and detail drawings for each section of the basement to be tanked.

The tanking system (external) should be continuous from the lowest part of the structure to at least 150 mm above finished ground level. Continuity with damp-proof courses (DPCs) or cloaking with a cavity tray are important, particularly in masonry structures.

It is important that all partition walls are also provided with DPCs at their bases, where they butt against exterior walls and around services and openings.

In masonry substructures DPCs are generally installed by the bricklayers, with dry lap joints that offer little resistance to internal water pressure. This increases the risk of leakage. DPCs should be checked to ensure that they provide continuity within a tanking system and that they can be built as detailed.

Mastic asphalt tanking details have not been included in the report but are well covered in BS8102: 1990, Section 3, BS8000: Part 4: 1989, Section 3, and the Mastic Asphalt Council & Employers Federation's, *'Tanking Handbook'*[(3.12)].

3.6.1 External tanking

The use of an external tanking system is generally preferred, if site and design conditions permit, so that external water pressure will force the membrane against the structure. Where a permanent hydrostatic head exists, the structure should be designed either to resist water penetration (Type B: structurally integral protection, see Section 3.7) or to control movement and cracking to a degree that can be reliably accommodated by the membrane. Special care should be taken where settlement of fill may occur, especially if this is used in conjunction with piling, as ground movement may rupture the membrane at vertical/horizontal interfaces. Hydrophilic membranes can be considered, as these have self-healing properties provided they have been fully hydrated and are not unduly dehydrated in service (see Section 7.3.1.3).

Figure 3.7 shows an example of this system of protection for a concrete basement. It also uses the reverse tanking derivative of this for the floor slab (see Section 3.6.2).

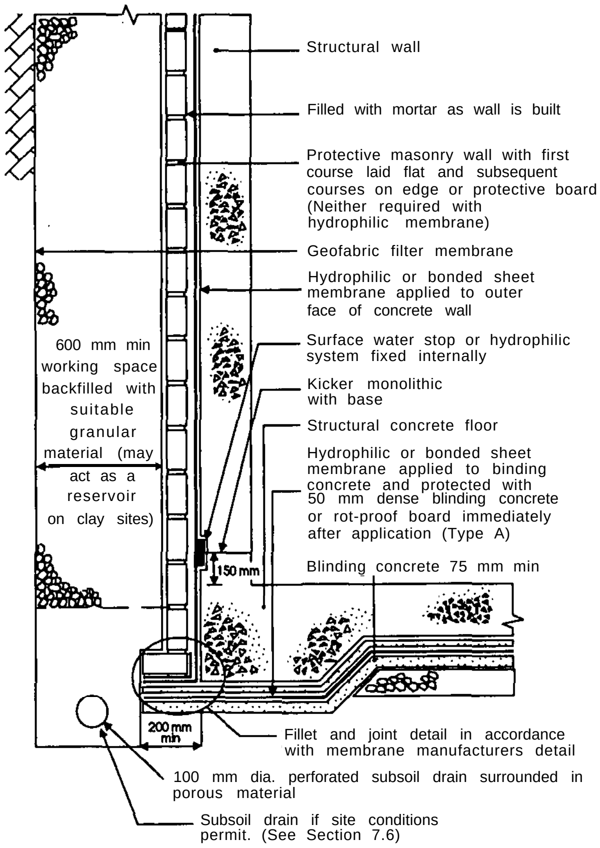


Figure 3.7 Concrete structure with external membrane (Type Ae)

Figures 3.8 and 3.9 give examples of external tanking for a masonry basement using a sheet membrane and a hydrophilic membrane respectively.

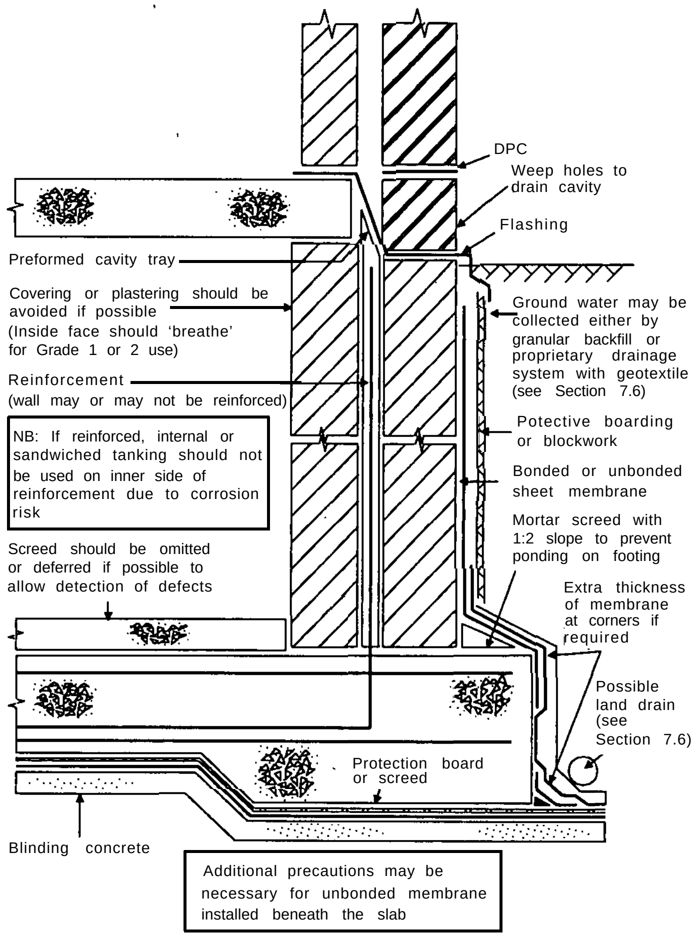


Figure 3.8 Masonry structure with external tanking (Type Ae)

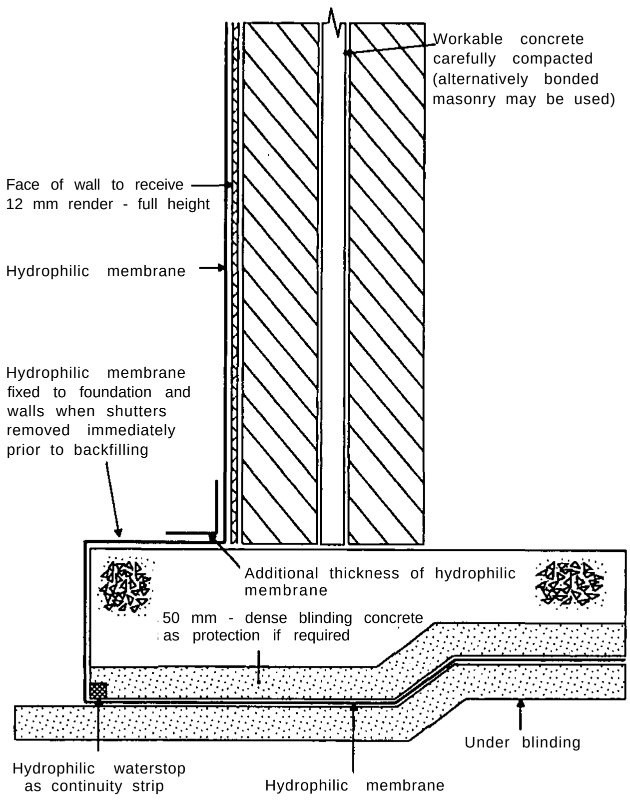


Figure 3.9 Masonry structure with external hydrophilic tanking (Type Ae) (Details similar for other types of structural wall)

Tanking is generally reliable in the medium term (assuming no construction defects), but may be costly to install and requires a skilled contractor. External tanking cannot generally be applied to piled walls or in other situations of restricted access.

3.6.2 Reverse tanking

This is a variation of external tanking where the tanking is applied to a surface prior to construction of the structural elements against it. Figure 3.10 gives an example of the use of reverse tanking where the membrane is applied to the exposed face of sheet piling, or to an existing non-loadbearing external wall, prior to construction of the structural walls against the tanking.

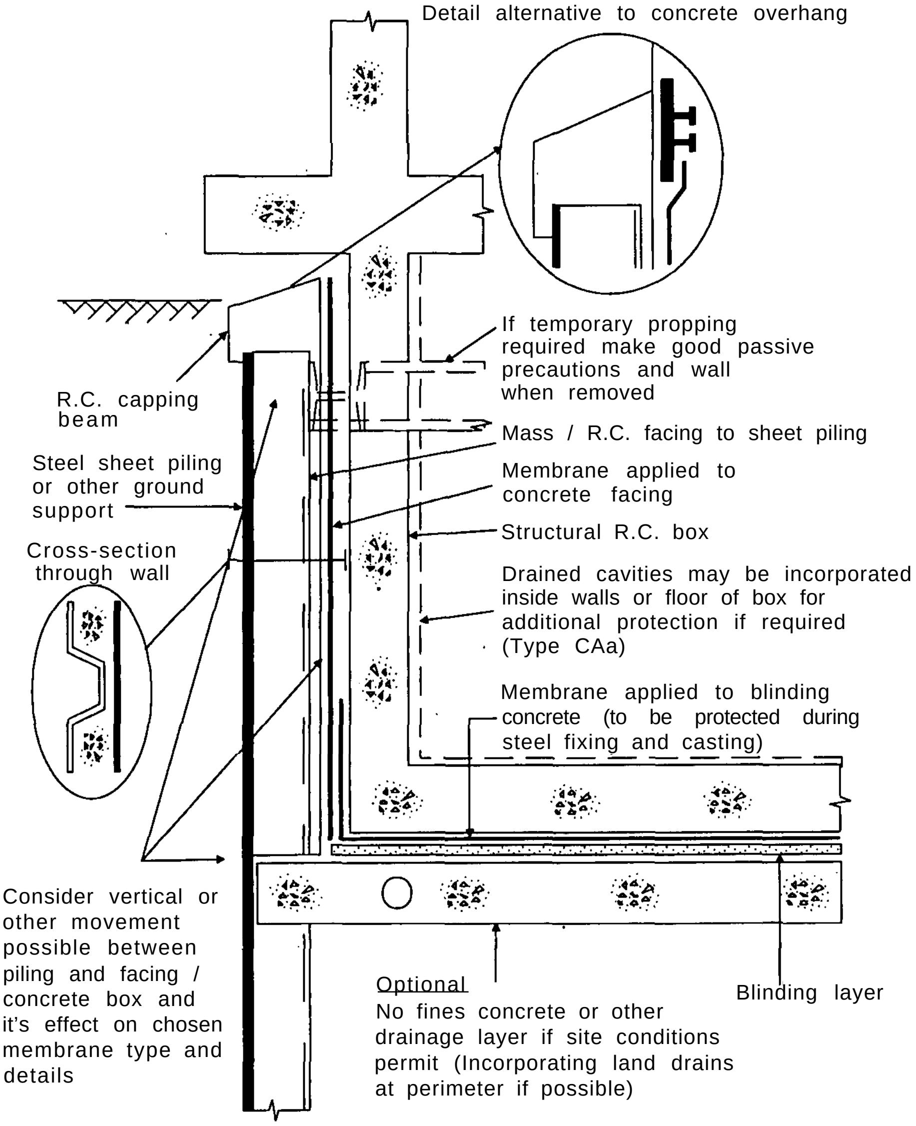


Figure 3.10 Example of external tanking applied to inner face of sheet piling (reverse tanking) (Type Ae_r)

This method is also commonly used with floor slabs, where an adhesive membrane is applied to the blinding layer and protected by a screed, before the floor slab is cast. The membrane is taken sufficiently far from the edge of the base slab to permit a lap joint to be formed with the wall membrane (see Figure 3.11).

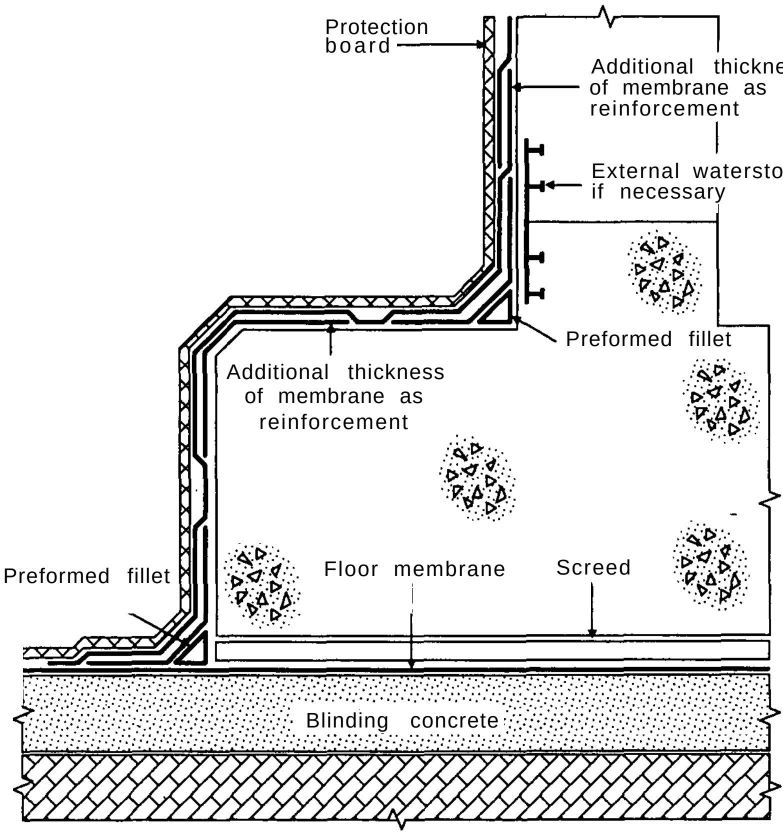


Figure 3.11 Example of jointing between floor and wall; external tanking membranes (Type Ae)

It is important that the effects of any differential movements on the integrity of the waterproofing membrane are considered, particularly at the foot of the wall, as these may be large and continue for some time after the completion of the building.

Reverse tanking would be similar to the use of an unbonded membrane, should a leak occur, in that a potential moisture path exists over the surface of the structure. The risk of damage to the membrane is likely to be greater than for a bonded membrane owing to the greater level of activity adjacent to it while constructing the structural walls and floor. This problem may be avoided by the use of membranes that are initially mechanically fixed, at selvages, to the ground support system, but which bond to concrete poured against them, by means of a specially formulated pressure sensitive adhesive (see also Section 7.3.1.2).

3.6.3 Sandwiched tanking

Figure 3.12 gives an example of this system of protection for a masonry basement.

When sandwiched tanking is used it generally provides a membrane internal to a structural masonry wall and should only be considered when external tanking is impracticable for reasons of construction procedure, access or ground conditions. Whenever sandwiched tanking is installed it should be fully supported by a loading coat of sufficient weight to prevent it from being 'pushed away' from the surface owing to groundwater pressure. A loading coat would probably take the form of a concrete slab on the floor and blockwork for the walls (the cavity between the wall and the membrane being filled with mortar). The loading coat should be constructed as soon as possible after the membrane has been installed.

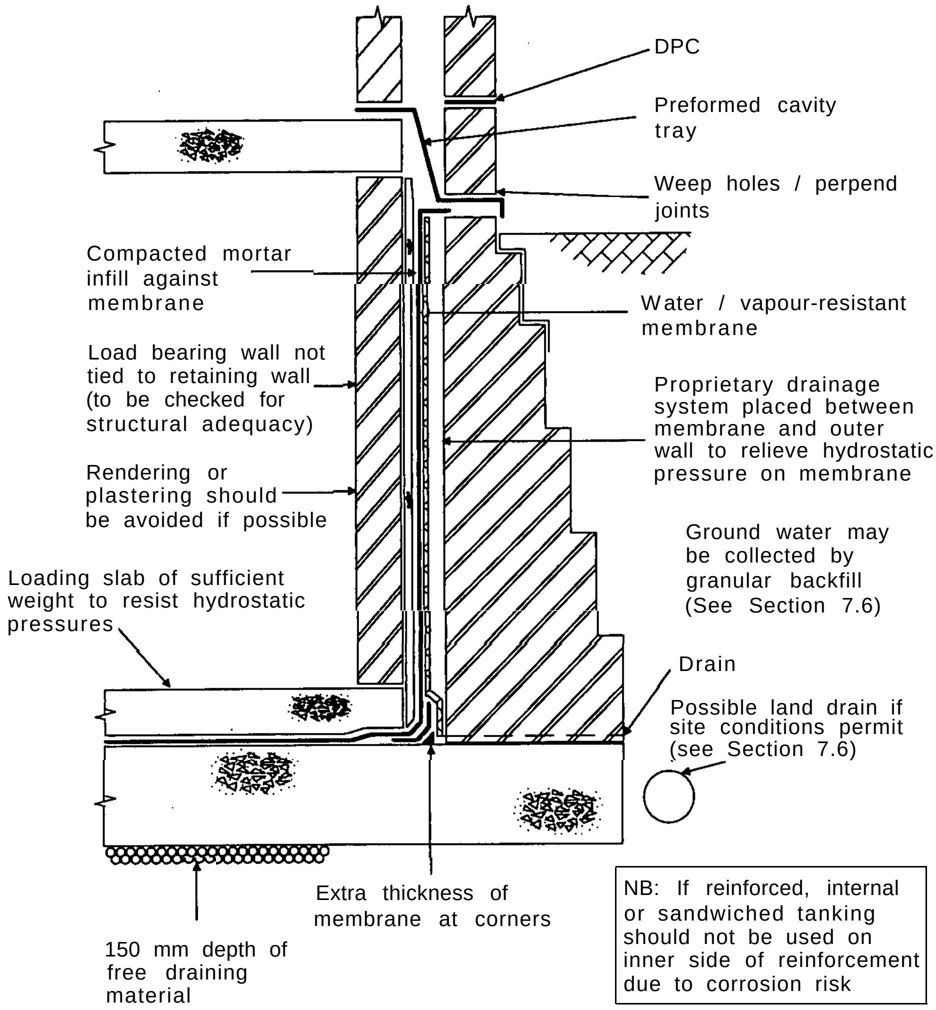


Figure 3.12 Masonry structure with sandwiched tanking (Type As)

3.6.4 Internal tanking

An internal tanking membrane is applied to the inside of the structural walls. Consideration must, however, be given to preventing the separation of the membrane from the substrate due to hydrostatic pressure. In the case of applied renders this may be achieved by providing a mechanical anchorage; adhesive sheet membranes may be retained by sandwiching them between the structural wall and a non-structural inner skin.

Where internal walls abut the exterior walls and floor that form the external water-resistant envelope of the basement, the continuity of the membrane must be maintained. This may be achieved by installing the membrane on the outer envelope prior to constructing the inner walls, by incorporating a damp-resistant membrane at the junction, which could be integrated with the tanking membrane when installed, or by continuing the tanking membrane to cover all the faces of the inner walls, where these are small.

3.6.5 Application of Type A protection

The use of external tanking is generally preferred, where site and design conditions permit, so that external water pressure will force the membrane against the structure. Where a permanent hydrostatic head is possible, considerable leakage may occur through defects or if the membrane is punctured. The opportunities to repair external tanking membranes are rare. Where considered necessary the structure should either be designed to resist water penetration (Type B protection), or alternatively to control movement and cracking to a degree that can be reliably accommodated by the membrane.

If the outer layer of the structure is impermeable while the remainder of the wall construction permits free passage of water vapour, condensed moisture may accumulate in the wall, ultimately saturating the material (see Section 3.9.4). This becomes most severe when humidity within the basement is consistently high. If this is considered possible, a ventilated cavity should be formed either between the cladding and the wall, or preferably within the structural envelope, so that any moisture passing through the wall is removed.

3.6.5.1 Sheet (bonded and unbonded) membranes

It is important that tanking materials are given appropriate protection against damage during and after laying. Some also require protection from ultraviolet and solar heating if they are not to be immediately covered. The weather conditions during application, e.g. rain, fog or mist, may result in adhesion problems, which can necessitate the reapplication of primers. The membrane under a base slab should generally be covered with a 50 mm sand/cement screed or non-rotting protection board of appropriate thickness (leakage through the membrane will, however, allow water to use the board as a moisture path beneath the floor slab). On the walls most types of membrane should be covered by protection boards or a blockwork wall leaving a 40 mm gap between the wall and the membrane, which should be filled with mortar as the work proceeds. This may not be the best position for hydrophilic membranes however, as they are intended to react to the presence of water. The membrane manufacturer's recommendations for location and protection should be followed.

Tanking membranes should be made continuous with the DPC to protect the superstructure. Mastic asphalt and bonded preformed sheet membranes adhere to walls, which will theoretically prevent water from spreading in the event of a puncture. Hydrophilic membranes will become bonded after hydration. Bonded membranes are preferred for use under base slabs, not polythene, as they are less susceptible to punctures and will provide more effective lap joints.

All tanking systems require a high quality of care and workmanship during design and construction. The requirements for surface profile and preparation in order to achieve a good bond between the structure and tanking membrane should be considered before final selection of a particular type. The costs and reliability (see Section 3.1.1) of a membrane system should also be considered in conjunction with its application during the construction sequence.

Bonded membranes, where needed, are generally selected for their ease of application and reliability.

3.6.5.2 Hydrophilic membranes

The use of hydrophilic membrane systems (see Section 7.3.1.3(b)) is becoming more common, as they possess many of the advantages of both bonded and unbonded membranes. They are unbonded while being fitted, but subsequently bond to the structure when wetted. They also have self-healing properties, which makes them more tolerant of minor damage during subsequent works. Care must be taken to avoid premature wetting, however, and the basement design should allow for the expansive forces that may be generated during the take-up of water.

In near surface external environments where dehydration and rehydration of the membrane may occur, temporary short-term leakage may result (if other precautions are not included in the environmental control system, e.g. Type B protection), owing to the reduction in water resistance of the membrane while rehydration occurs. The water-resistance properties of the material return on complete rehydration; however, any periods of leakage may not be acceptable for some grades of internal environment.

3.6.5.3 Cementitious renders

Multiple-coat cementitious renders can also be used with good effect on residential basements, and other similar applications. The render must be of sufficient thickness to bridge existing cracks or other defects in the substrate. It will not accommodate the movement of 'live' cracks.

3.6.5.4 Liquid-applied membranes

Health and safety considerations generally prohibit the use of spray-applied liquid membranes internally.

Internal tanking, with liquid-applied membranes, is not normally considered appropriate for new basements (see Sections 7.3.1.4 and 7.3.2.4).

3.7 TYPE B: STRUCTURALLY INTEGRAL PROTECTION

Type B protection depends on the ability of the structure, by itself, to minimise water penetration. These basements are usually constructed as a reinforced concrete box designed to resist hydrostatic pressure and other loadings. Protection against water penetration relies on the design and construction[3.13] of high-quality concrete, with cracking controlled to prevent the penetration of moisture to an unacceptable degree.

Care should be taken when detailing joints to keep them simple, as details that are difficult to construct are likely to be more prone to leakage and more difficult to rectify. The inclusion of waterstops in construction joints should only be considered where concrete can be effectively compacted around them and their configuration remains unaltered (see Figure 3.13 and Section 7.4). Surface-mounted or hydrophilic waterstops may, for that reason, be preferable to the use of centrally fitted bulb or flat waterstops.

Reinforced concrete designed and constructed to BS8007 or BS8110 can be used in conjunction with Type A or C protection to achieve all grades of internal environment.

3.7.1 Reinforced concrete construction

All grades of basement internal environment can be achieved, at varying cost, utilising any of the three types of passive structure protection (A, B or C) with reinforced concrete (in-situ or piled walls). The merits and disadvantages of each construction type (see Table 3.4) should be evaluated in conjunction with an assessment of the reliability of the system (see Section 3.1.1), particularly the risk of failing to meet the criteria for internal environment for new reinforced concrete, deep or shallow basements, as summarised in Table 3.1.

The degree of water and vapour resistance achievable generally increases with construction costs; however, complete environmental control, by Type B protection alone, cannot be guaranteed in practice for any construction method. Systems with a large number of joint interfaces, e.g. piled walls, are more likely to result in water penetration, but these may be dealt with during construction, or after the addition of a reinforced concrete internal lining wall.

A wide variety of means are available to form basement perimeter walls. These range from temporary support methods, which allow traditional construction techniques to be adopted, to wall types used as either temporary or permanent works.

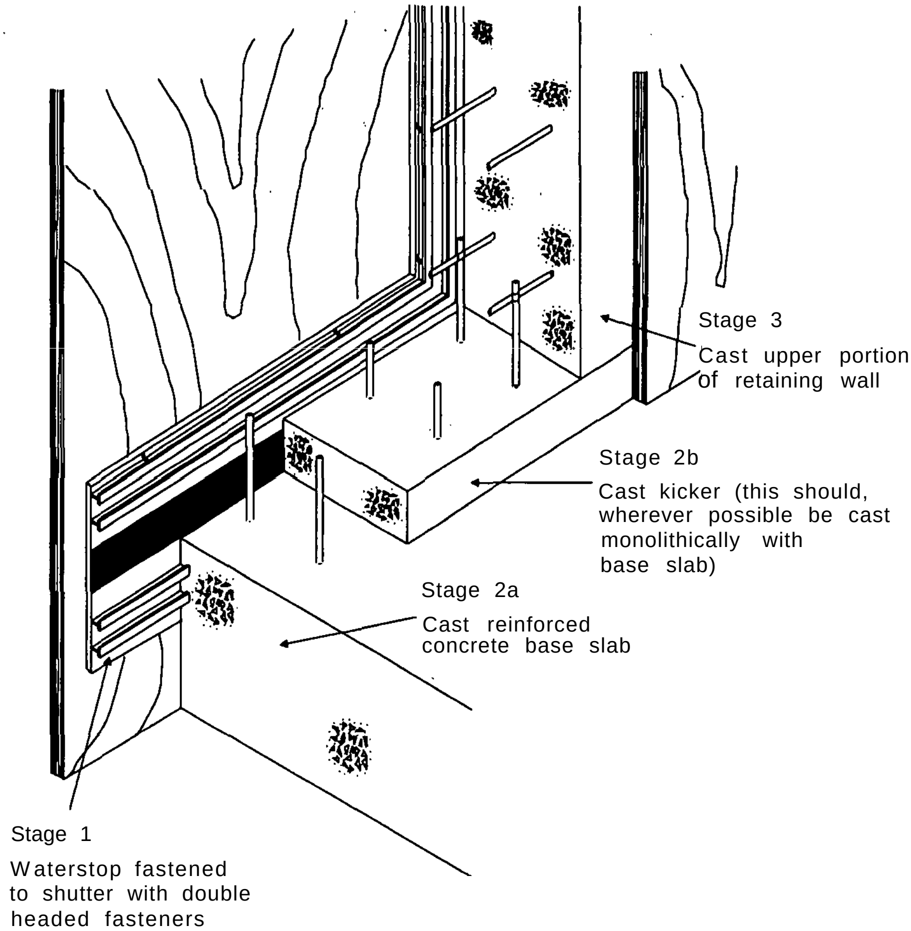


Figure 3.13 Typical detail for external waterstop at kicker of reinforced concrete retaining walls

Methods of basement construction that can be incorporated into the permanent works, using reinforced concrete, are summarised in Table 3.4 and illustrated in Figure 3.14.

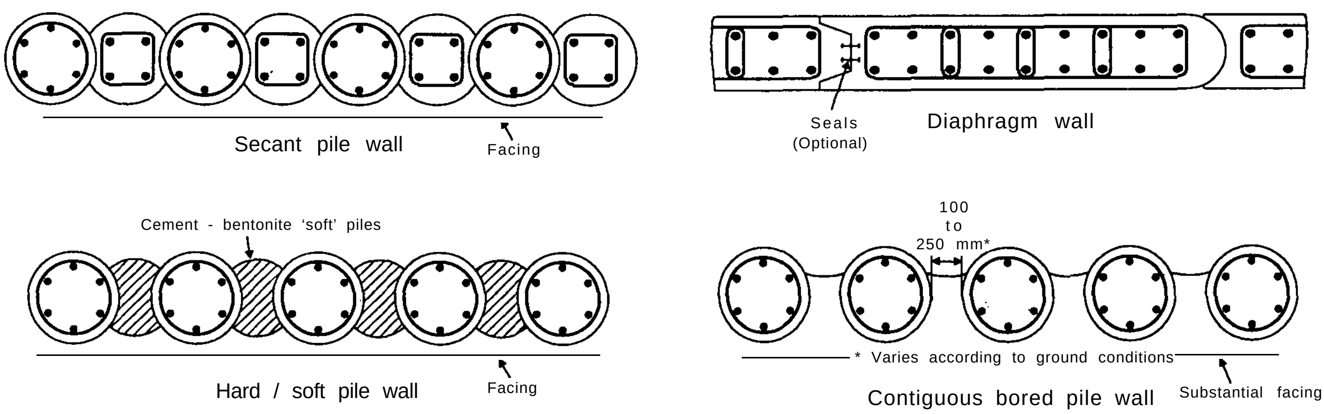


Figure 3.14 Construction methods for reinforced concrete basements (excluding monolithic box)

Table 3.4 Considerations for reinforced concrete and structural steel construction methods

Construction type	Construction method	Floors	Walls	Resistance to water or water and vapour penetration	
				Primary precautions	Secondary precautions
R.C. box	Open excavation	Monolithic	Integral	Low permeability concrete	External membrane
R.C. box	Temporary steel sheet piling	Monolithic	Integral	Low permeability concrete	Drained protection
Diaphragm walling	Excavate later	Become struts	As cast or faced	Low permeability concrete	Drained protection
Secant piles	Excavate later	Become struts	Facing	Facing	Drained protection
Contiguous piles	Excavate later	Become struts	Substantial facing	Substantial facing	Drained protection
Steel sheet piling	Excavate later	Become struts	Concrete facing	Weld joints	Drained protection

Note: Details of alternative construction methods are given in the Institution of Structural Engineers report on Deep Basements[3.3].

It is important to recognise the difficulties in excluding water from bored pile-walled structures and the high cost penalties involved in attempting to do so. It may be more practical to accept some water penetration, and design for its positive removal (Type C precautions). In using such a system, it is necessary to consider the possible effects of groundwater penetration or of groundwater damming on the surrounding environment and its effect on the hydrology of the surrounding area[3.14].

All single propped bored-pile walls share the same stability requirements; failure modes are illustrated in CIRIA Report 104[3.15], with factors of safety and design criteria being thoroughly discussed for stiff over-consolidated clays (which are equally relevant to other soils).

Guidance on pile type and construction is clearly explained in the CIRIA *Pile Guide series*[3.16]

Example details of the more common forms of reinforced concrete construction are shown in Figures 3.2~3.5 and the combinations of passive precautions associated with integral protection (Type B) are shown in Figure 3.15.

3.7.1.1 Monolithic box

This includes structurally integral reinforced or possibly prestressed concrete floors and walls within open excavation or temporary steel sheet piling or 'soft' contiguous piles. Various temporary works options are available to provide support to the sides of the excavation, enabling conventional construction methods be used to build the permanent structural members.

Temporary works may include:

- open cut
- vertical or trench cut
- sheet piles
- driven steel sections
- permeation grouting
- jet grouting
- soil mixing
- soil nailing.

3.7.1.2 *Diaphragm walling*

Diaphragm walls are well suited to situations that require large-dimension wall sections, and are more appropriate for permeable soils than other piled wall types.

Care should be taken with detailing the interlocking panels and, attention should be paid to the implications of wall tolerances, particularly horizontally, for the dimensions of the permanent works. The accurate placement of reinforcement cages and 'box-outs' to connect the walls with the floors of the permanent works is also essential.

Where concrete is placed by displacement of bentonite slurry, used to stabilise the excavation, care should be taken to prevent premature withdrawal of tremie tubes as this results in bentonite inclusions in the concrete.

3.7.1.3 *Contiguous piled walling*

Contiguous piled walling tends to be adopted in clay subsoils, where groundwater flow is limited, as granular materials require deep and expensive temporary casing. Groundwater flow in such clay soils is limited and will not relieve local excess pore pressures. The soil face could theoretically be left exposed but this is seldom undertaken.

Depending on the nature of the soil it may be sufficient to infill the pile cusps with 'no fines' concrete; alternatively a proprietary drainage sheet may be connected to positive drainage at the bottom of the wall, where there is a possibility of water flow and fines being drawn through the wall. It is possible to apply a water-resisting inner skin, but this is seldom economic and often leads to difficult and expensive wall/pile connections.

3.7.1.4 *Secant piled walling*

Secant walls attempt to replace the need for 'structural' internal walls by intermarrying piles with a good structural bond.

True secant walling (oscillator-formed piles) has been accepted as a reasonable alternative to diaphragm walling in the provision of 'watertight' walling but not, so far, pseudo-secant walls. Typically, cement/bentonite mixes or pfa/cement mixes have been explored for the soft intermediate pile. Insufficient long-term evidence of water exclusion is available to predict design lives, particularly with the use of the more friable bentonite mixes. Attempts to use stronger mixes increase deviation problems with augers, unless the rate of strength development is delayed.

3.7.1.5 *Hard/soft piled walling*

Hard/soft interlocking piled walls consist of alternate soft 'female piles' formed from combinations of cement, pfa, ggbs, bentonite and other suitable materials and hard 'male piles' of reinforced concrete.

The long-term durability of the wall, particularly where it may be exposed to wetting, drying or freezing cycles, should be checked to determine the need for any permanent lining. This form of retaining wall is generally more suited to basements constructed in granular soils below the water table, where a contiguous bored pile wall may not be appropriate.

3.7.2 Reinforced concrete design

The design of a concrete mix is important, and whether the concrete is site-mixed or ready-mixed it should be produced in accordance with BS5328. To achieve the best result, a compromise must be made between the conflicting requirements of strength, high workability, high aggregate/cement ratio, low water/cement ratio and economy. Where the mix design recommendations in BS8110 and BS8007 differ, preference should be given to the latter, except where aggressive ground conditions are expected.

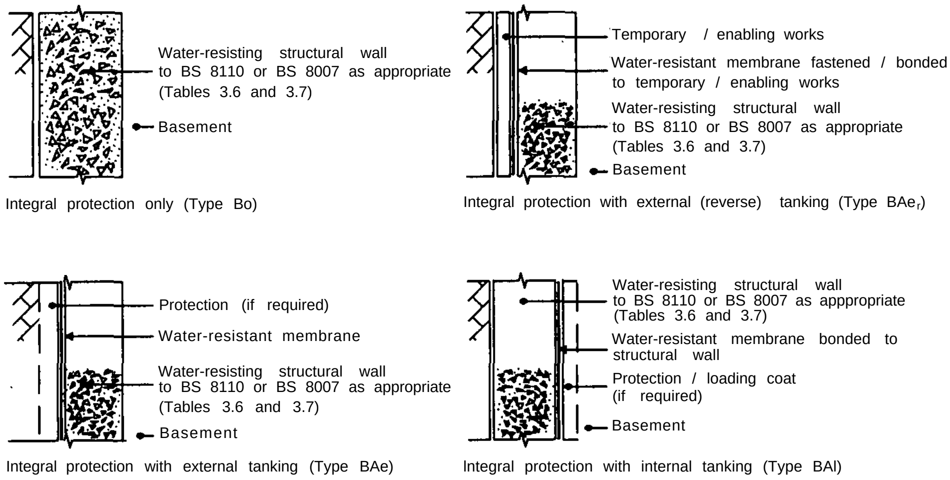


Figure 3.15 Integral protection (Type B)

Experience has shown that crack widths calculated in accordance with the principles adopted by BS8110 may be significantly underestimated (see Section 3.4.2) and structural design to the principles adopted by BS8007 has shown that the factors influencing crack width have a much larger coefficient of variation than the formula for calculating them allows. The principal problems relate to the behaviour of adjacent pours together with ‘in-pour’ variability of early strength and temperature change. The resulting crack widths can be in the range from zero up to twice the design value. The recommendations for the maximum acceptable leakage rates in BS8007: 1987 : Section 9.2 allow a rate of entry that is barely acceptable even for a Grade 1 basement.

For total crack control it is not sufficient simply to follow the recommendations for reinforcement diameter and spacing in BS8007, as these must be viewed in relation to construction and workmanship factors including:

- overall shape of the structure
- changes in section
- positioning of construction and movement joints
- casting patterns (construction sequence/daywork joints/movement joints)
- restraint from adjacent wall panels, base slab and piles
- control of early thermal and moisture effects by mix design and curing
- out-of-vertical pile problems.

In addition, BS8007 does not cover structures subjected to lateral loads (other than contained liquids), nor the very substantial point loads from columns supporting the superstructure.

From the above it can only be concluded that currently there are no British Standards that cover the particular requirements of concrete basement design and construction. Therefore BS8110 and BS8007 must each be used with caution, with an appreciation of the wider aspects of basement design.

In designing reinforced concrete the following features should be taken into account.

3.7.2.1 Crack widths

For durability reasons (such as limiting reinforcement corrosion) in various environments the maximum crack width occurring at the surface must be controlled.

A comparison of clauses from the relevant British Standards for reinforced concrete basement construction is reproduced in Table 3.5. The limits on maximum crack widths apply to different causes and types of crack (see Figure 3.16).

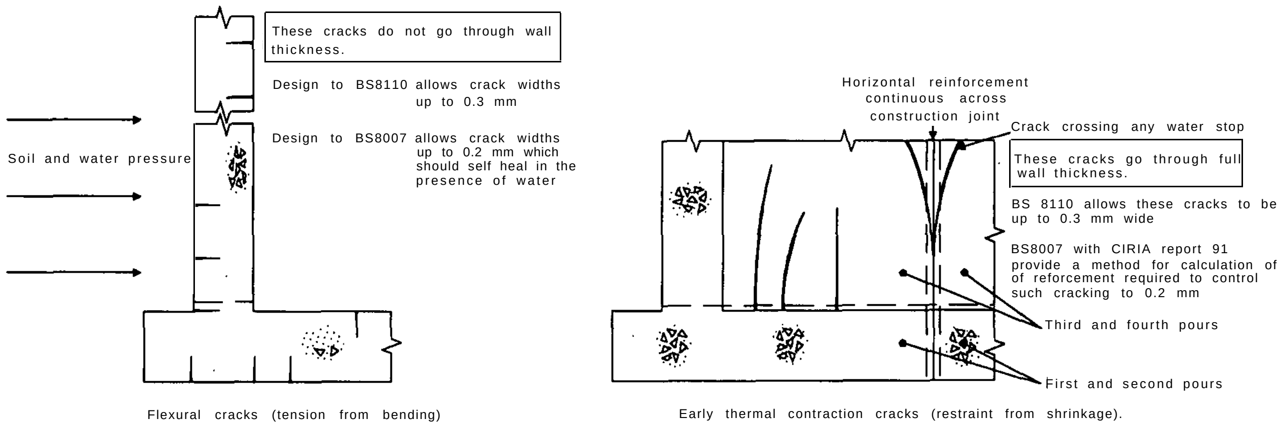


Figure 3.16 Different types of crack in basement construction

Table 3.5 Comparison of British Standard requirements for crack widths in reinforced concrete construction

BS8102: 1990	BS8007: 1987	BS8110: 1985
For Grade 1 basements, design should be to BS8110: Part 2: 1985 with calculated crack widths not exceeding 0.3 mm. For Grades 2, 3 and 4 basements, where reliance is placed upon the structure to prevent the ingress of water, reinforced concrete design and construction should comply with BS8007 and elements should be so proportioned that the concrete strengths and maximum cement contents referred to therein be adhered to.	2.2.3.3 Cracking. For the purpose of defining the serviceability crack width limit state, the maximum design surface crack widths for the exposure conditions defined in **2.7.3** should be taken to be the following. (a) Reinforced concrete. The maximum design surface crack widths for direct tension and flexure or restrained temperature and moisture effects are: (1) severe or very severe exposure: 0.2 mm. (2) critical aesthetic appearance: 0.1 mm. 2.7.3 Exposure and appearance. For the purposes of this code both faces of a liquid-excluding structural member are to be considered as subject to severe exposure as defined in **3.3.4** of BS8110: Part 1: 1985. Surfaces subjected to very severe exposure as defined in **3.3.4** of BS8110: Part 1: 1985 should be designed for a maximum crack width of 0.2 mm (see **2.2.3.3**) and concrete cover and mix complying with the recommendations of BS8110: Part 1: 1985 as well as **2.7.6** and **6.3**.	Part 1, Section 3.3.4 Severe - Concrete surfaces exposed to severe rain, alternate wetting and drying or occasional freezing or severe condensation. Very severe - Concrete surfaces exposed to sea water spray, de-icing salts (directly or indirectly), corrosive fumes or severe freezing conditions whilst wet. Part 2, Section 3.2.4 3.2.4 Excessive cracking. 3.2.4.1 *Appearance*. For members that are visible cracking should be kept within reasonable bounds by attention to detail. As a guide the calculated maximum crack width should not exceed 0.3 mm. 3.2.4.2 *Corrosion.* For members in aggressive environments, the calculated maximum crack widths should not exceed 0.3 mm. 3.2.4.3 *Loss of performance*. Where cracking may impair the performance of the structure, e.g. watertightness, limits other than those given in **3.2.4.1** and **3.2.4.2** may be appropriate.

For Grade 1 basements, BS8102: 1990 states that design should be to BS8110: Part 2: 1985 with calculated crack widths not exceeding 0.3 mm. The requirements for the permanent works of reinforced concrete basement construction to BS8110: Part 2: 1985, Section 3.2.4.3 are vague but do suggest crack width limits lower than 0.3 mm. The 0.1 mm calculated crack width (BS8007: 1987, Section 2.2.3.3 (2) for critical aesthetic appearance) is not likely to be relevant for basements, as it would result in the use of excessive quantities of reinforcement.

There is no guidance in BS8110 for calculating crack widths in relation to minimum quantities of reinforcement, crack spacing, temperature and moisture effects. These criteria are addressed in BS8007: 1987, which gives guidance on the calculation of the frequency and width of cracks.

Table 3.6 sets out the basis for reinforced concrete design and construction for basements, based on the text and Table 3.1 of BS8102: 1990.

Table 3.6 Basis for reinforced concrete design and construction based on BS8102

Internal environment	**Minimum design standards**		
	Structures requiring protection		**Structurally integral protection**
	Type A	**Type C**	**Type B**[(1)]
Grade 1	BS8110: Part 1	No recommendations given	BS8110: Part 2[(2)]
Grade 2	BS8110: Part 1	No recommendations given	BS8007
Grade 3	BS8110: Part 1	BS8110: Part 1	BS8007
Grade 4	BS8110: Part 1	BS8110: Part 1	BS8007

Notes:

1. **Piled walls cannot meet the reinforcement requirements of BS8110 or BS8007 in the horizontal direction and often cannot meet it in the vertical direction**

2. **Calculated flexural crack widths not to exceed 0.3 mm; cracking due to thermal and moisture effects not to exceed 0.2 mm as for BS8007.**

Table 3.7 sets out an alternative to BS8102 where reinforced concrete is to be used in the presence of hydrostatic pressure and additional reliance placed on the self-healing properties of the structure (autogenous healing) to minimise the ingress of water. This has been adopted in major UK cut-and-cover construction[(3.17)].

The crack width limits set out in Table 3.7 are explained below.

Cracking in concrete will occur in all but the simplest and smallest of structures. In a structure subjected to hydrostatic pressure a crack, of any size, that passes through the section can form a water path, which may result in leakage or wet patches occurring. A compression zone in the section reduces the likelihood of a water path. A waterstop system, if it is intersected by a crack, may provide a conduit for water around the basement and for leakage to occur wherever there is a weakness in the system (see also Sections 3.7.2.5 and 7.4). It is the responsibility of the designer to limit design crack widths to a predetermined size to restrict or prevent water from leaking through the concrete into the basement[(3.3)]. However, this does not preclude the possibility that some cracks will be wider than the calculated characteristic crack width.

Table 3.7 Alternative basis to BS8102 for the design and construction of reinforced concrete basements

Internal environment	Minimum design standards					
	Monolithic box(1)			Diaphragm or piled(2) walls		
	Type A	Type B	Type C	Type A	Type B	Type C
Grade 1	BS8110	BS8007#	BS8110	Only internal tanking feasible	BS8110	BS8110
Grade 2	BS8007#	BS8007#	BS8110		BS8110	BS8110
Grade 3	BS8007#	BS8007	BS8007#		BS8110	BS8110
Grade 4	BS8007	BS8007	BS8007		BS8110	BS8110

Notes:

1. Calculated maximum design surface crack widths (for the purposes of this table BS8110 refers to BS8110: Part 2: 1985)

   8110 = 0.3 mm flexural, 0.3 mm thermal
   8007# = 0.3 mm flexural, 0.2 mm thermal
   8007 = 0.2 mm flexural, 0.2 mm thermal

2. Piled walls cannot meet the reinforcement requirements of BS8110 in the horizontal direction and often, cannot meet it in the vertical direction.

The principal causes of cracking are:

1. flexural action, where cracks extend to the neutral axis and are then prevented from growing by a depth of concrete that is in compression, and

2. shrinkage and thermal movement, where cracks tend to be of uniform width through the thickness of the member.

Clearly, the latter type of crack is more likely to allow leakage to occur.

The principal and most effective method to control restrained shrinkage and thermal movement cracking is by the provision of sufficient reinforcement. Additional methods of minimising cracking arising from temperature and moisture changes in concrete structures are outlined in Section 2.6.2.2 of BS8007: 1985. If these are adopted an alternative basis(3.17), given in Table 3.7 as BS8007# can be used involving two different calculated surface crack width limits relevant to the different causes of cracking:

1. For cracking due to flexure: 0.3 mm maximum crack width.

2. For cracking due to moisture and/or thermal effects where there may be a loss of performance of the structure due to water leakage: 0.2 mm maximum crack width.

This represents a possible interpretation of Clause 3.2.4.3 of BS8110: Part 2: 1985.

The quantities of reinforcement calculated for flexural design are not additional to those calculated to control thermal cracking. Provided the greatest area of reinforcement is used for either flexure or thermal crack control the design maximum crack widths will be maintained.

For concrete cast in the ground (i.e. piles and diaphragm walls), the early thermal effects are less severe and there is justification for allowing calculated crack widths up to 0.3 mm. However, long-term contraction may be large, which may result in problems with joints and connections with other elements. It is normally acceptable for calculated flexural cracks to be up to 0.3 mm wide[3.18]. In practice both BS8110: Part 2: 1985 and BS8007 should be used in conjunction with CIRIA Report 91[3.13] for calculation of the quantity of reinforcement required to limit thermal and shrinkage cracking.

Design to BS8007 does not guarantee that there will not be any leaking cracks. The implications of reducing the maximum flexural crack width from 0.3 mm to 0.2 mm are a 50% increase in steel reinforcement and a significant increase in cost. Cracks with actual surface crack widths of 0.2 mm, under a hydrostatic pressure of less than 5 m, may heal autogenously so that only damp patches will occur. The reliability of autogenous healing decreases with increasing crack width; hence the contribution of the element to the environmental control system may be lost.

It is important to relate acceptance criteria for concrete basements to water-resistance performance, not to design crack widths. Contingency plans, in the event of cracks leaking, would depend on the internal environment required and the ability of the other elements in the environmental control system adopted to accommodate the moisture ingress. It should be noted that through-cracks where no leakage is currently occurring and for which no remedial actions are proposed (particularly where design has been based on a system of limited environmental control), may not remain dry throughout the life of the structure. Remedial measures that may be considered are outlined in Chapter 5.

3.7.2.2 Internal facings

Facings to piled walls can be directly connected, as in a thin concrete facing, or totally divorced, as in a blockwork cavity skin wall.

3.7.2.3 Changes in section

Changes in section should be avoided if possible as they tend to encourage cracks wider than provided for in calculation.

3.7.2.4 Columns and other point loads

The slab should be sufficiently deep to provide a spread of load to the soil beneath it, without inducing local settlements and the associated distortion. Local thickening of the slab should only be used with caution, as the cost of, and risk of, difficulties created by the change in thickness are likely to cancel any saving attributable to economy of section.

3.7.2.5 Waterstops

If waterstops are to be included (see also Section 7.4), the design of the structure should provide for the continuity of the waterstop system across all joints and particularly junctions between the floor and wall elements (see BS8007: 1987: Figure 5.1 and BS8102: 1990: Figure 20 for typical application details).

External (vertical and horizontal) and hydrophilic waterstops are generally preferred as their design requires no extra precautions in concrete placement. Any pressure against the structure also ensures that external waterstops remain in position after construction.

Internal (vertical and horizontal) waterstops require special attention so as not to dislodge or fold them during placing and compaction of the concrete.

3.7.3 Welded steel sheet piling

Permanent steel sheet piled basements may achieve a Grade 1 (basic utility) and possibly Grade 2 (better utility) internal environment basement under favourable conditions (e.g. low water table controlled by external drainage). The use of steel sheet piling for Grade 3 or 4 internal environments is unlikely to be satisfactory, owing to the difficulties in achieving the high standard of sealing (welding) necessary.

Welded steel sheet piling can be used in most soils, although difficulties in driving may be encountered in dense gravels or stiff clays, or where there are underground obstructions. Where exclusion of groundwater is required, the reliability with which the clutches can be sealed is critical, and is likely to be related to any difficulties with driving. In some locations the level and duration of noise and vibration may influence the selection of this method.

Basement design should consider the total mass of the structure in order to minimise overall settlement as well as risk of flotation. This is particularly important in steel sheet piled basement walls, where the total mass of the basement is much lower and the 'pull-out' resistance of the walls is much less than for concrete piled walls. However, an increase in base slab thickness, to enhance mass, may more than offset the reduction in material mass.

In designing for durability of steel sheet piling it is necessary to consider the following:

3.7.3.1 Corrosion rates of steel

In the absence of concrete protection, the permissible loss in steel thickness, due to corrosion, at the position of maximum stress in the pile should be evaluated in conjunction with predicted rates of corrosion[3.19]. The remaining steel section should enable the basement to achieve the required (60 year minimum) design life.

Under circumstances where corrosion of steel piling is likely to be significant, measures should be taken to increase the life of the structure. These may include:

- the use of additional steel thickness as a 'corrosion allowance'
- the use of high-yield steels at mild steel stress levels, which can enable additional loss in section to be tolerated without loss of load-bearing capacity
- the use of protective coatings, usually paints
- the use of cathodic protection, with or without protective coatings.

3.7.3.2 Sealing/seepage

Sealants must be provided at locks and at the junction between sheet steel piles and the base slab to ensure water resistance. Such sealants must be able to accommodate any movement that will occur during excavation.

A permanent seal on the sheet pile locks would require the provision of a non-structural quick-deposit sealing weld. Its function is to seal the gap between the sheets by forming weld material of the same integrity as the pile in the naturally occurring 'V' formed by the lock. The effective life of a sealing weld will be dependent on the exposure conditions and the weld thickness.

3.7.3.3 Welded steel sheet piling

Grade 1 and 2 basements may be designed using permanent steel sheet piling but are likely to require additional Type C structure protection.

The use of sheet steel piling is unlikely to reliably achieve Grade 3 or 4 internal environments.

3.7.4 Plain concrete and masonry construction

BS8102 states that plain concrete walls should be designed and constructed to comply with the recommendations for mass concrete in Civil Engineering Code of Practice No. 2 (1951). However, the recommendations in BS8110: 1985 for concrete mix design, durability, joints and workmanship should generally be followed.

For new construction, the floor slab should be constructed in concrete and specifically designed to withstand all water pressures that may be imposed on it.

It is not generally considered possible for plain concrete or masonry to provide Type B protection, and for this reason such structures are excluded from the BS8102 Type B structure classification. Plain concrete or masonry construction usually requires Type A and/or Type C protection.

3.7.5 Application of Type B protection

Type B protection alone may achieve Grades 1, 2, and under particular conditions, Grade 3 internal environments. The protection provided to the internal environment is principally influenced by the type of structural materials selected. These can be summarised as follows:

3.7.5.1 Reinforced concrete

Grade 1 or 2 reinforced concrete basements would normally be designed to BS8007: 1987 where they provide integral protection, or with drained protection, or tanking protection added. Reinforced concrete should only be designed to BS8110 where other precautions are to be included in the environmental control system (see Tables 3.1 and 3.6).

Grade 3 or 4 reinforced concrete basements should always be designed to BS8007: 1987, in combination with additional precautions (see Tables 3.1 and 3.6).

3.7.5.2 Welded steel sheet piling

Grade 1 and 2 basements may be designed using permanent steel sheet piling but are likely to require additional Type C structure protection.

The use of sheet steel piling is unlikely to achieve Grade 3 or 4 internal environments reliably.

3.7.5.3 Masonry or plain concrete

Masonry or plain concrete construction, without added structure protection, should generally be restricted to shallow basement construction, without added structure protection, where there is only occasional, or low, hydrostatic pressure.

Grade 1 and 2 internal environments may be achieved using plain concrete or masonry with additional precautions. Where structure protection is required it may be more economical to use reinforced concrete (see Section 3.3).

A Grade 3 environment may be achieved using plain concrete or masonry construction but is likely to require a vapour-resistant barrier as well as drained protection.

A Grade 4 basement should only be constructed using reinforced concrete with some additional structure protection (see Section 3.3).

3.8 TYPE C: DRAINED CAVITY PROTECTION

For successful application of Type C protection, the structural walls must minimise water penetration. The cavity should not be used to conceal large leaks. Structural walls may be in plain or reinforced concrete, masonry or steel sheet piling. Any moisture that does penetrate the structural wall is collected within the cavity created by the addition of an inner skin to the walls and/or the floor and is discharged to a sump.

A drained cavity system may be used in conjunction with:

- plain concrete or masonry construction
- reinforced concrete (in-situ or piled) construction
- steel sheet piling.

Type C may also be used in conjunction with Type A or B protection (see Figure 3.17).

3.8.1 Drained cavity walls

The inner wall in drained cavities is generally non-load bearing and may need to be designed to be free-standing to prevent moisture paths occurring across ties. Vapour transmission through the fabric of the inner wall may be reduced by providing a vapour-resistant membrane, adequate ventilation of the cavity (mechanically assisted where necessary) or by using a profiled cavity drainage former, which provides an integral vapour barrier (see Figures 3.2, 3.3, 3.5 and 3.18 (detail A)). The latter method cannot be used with wall ties.

Adequate ventilation of the cavity may require a low level vent. Such ventilation of the cavity may increase the quantity of water vapour entering the basement (see Figures 3.18 and 3.19). Where inadequate ventilation of the cavity occurs, owing to the absence of a low level vent, or for other reasons, a vapour barrier may be necessary as a part of the inner wall construction. In such cases, any cover to an opening provided for maintaining the channel, should be sealed.

Profiled cavity drainage systems may be used to form cavities within walls and when used, will reduce the width of the cavity and if the joints are fully sealed will also prevent moisture bridging across the wall cavity. However, it is necessary that the cavity width is uniform to contain the system and should not be considered where a non-vertical external wall is a possibility.

Drained cavities are usually necessary for Grade 3 or 4 internal environments (Table 3.1). The basement cavity ventilation of larger buildings must also be designed with fire compartments where these are required by the fire regulations.

3.8.2 Drained cavity floors

Cavities under floors may be formed from no-fines concrete (where seepage is comparatively slight) or proprietary systems such as profiled drainage sheets or purpose-made tiles (see Figure 3.18 (detail B). An advantage of cavity drainage formers is that they are shallower than conventional methods, requiring less excavation, and are quicker to install. If the joints are sealed they may also form a vapour barrier.

Wider cavities may be formed using precast concrete planks to give a raised floor, which may be useful where access is required e.g for maintenance of drainage channels or for servicing pumps.

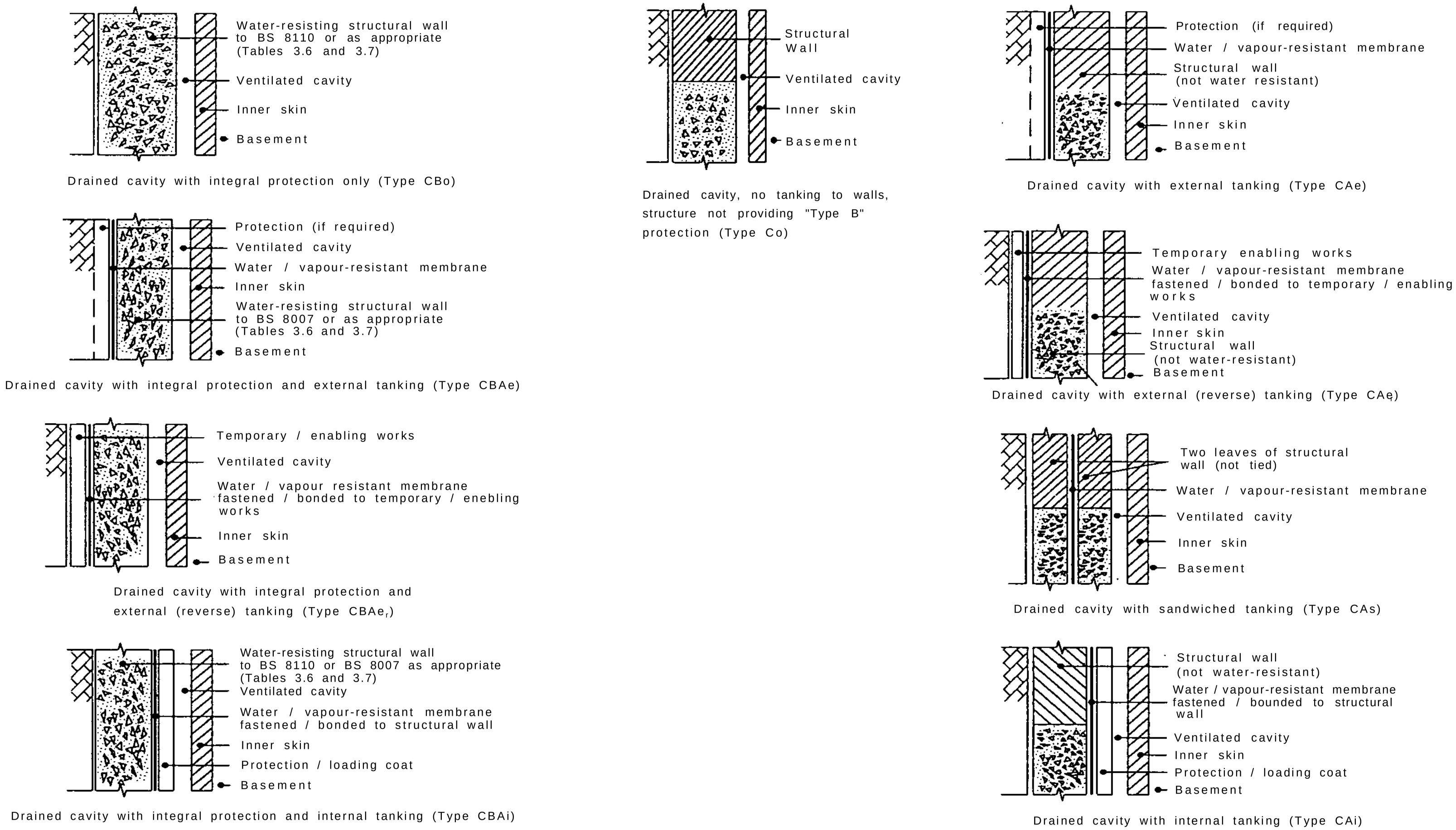
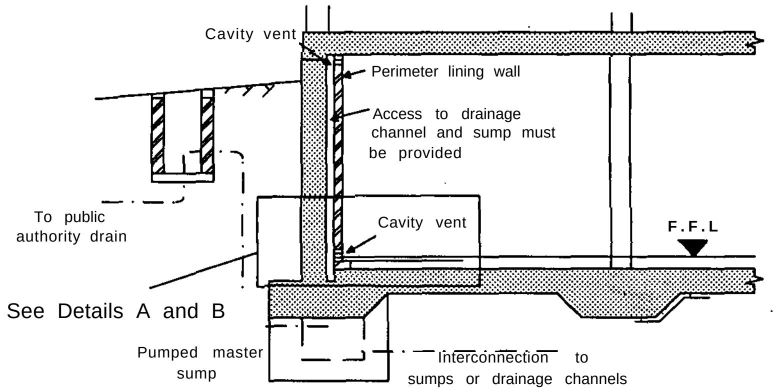
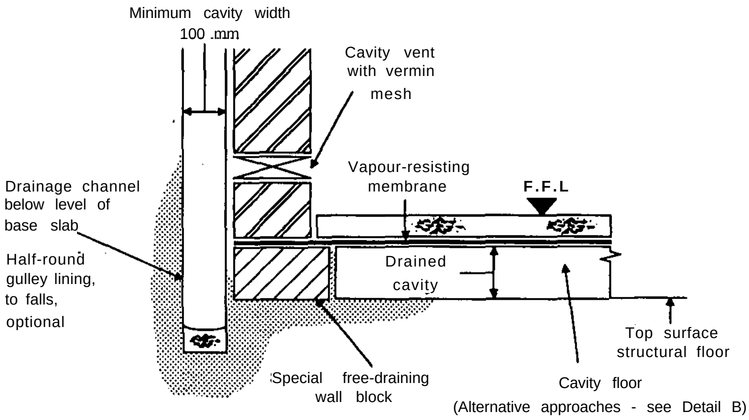


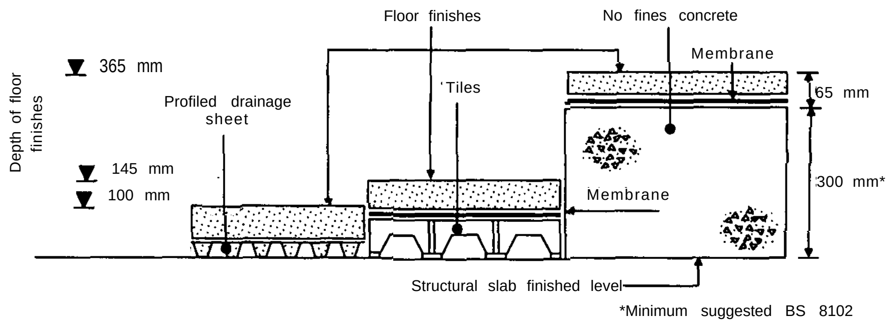
Figure 3.17 Drained cavity protection (Type C)



Key section to show drainage principles and location of Details A and B



Detail A



Detail B

Figure 3.18 Cavity drainage details

3.8.3 Advantages of Type C protection

The principal advantages of drained protection are:

- It is less dependent on primary construction processes, which are more difficult to control, and hence is likely to be more reliable in achieving the required environment.
- Installation of the drainage layer can be undertaken in favourable conditions and outside the construction programme critical path.
- Uncertain labour elements are removed.
- Water ingress through the primary structure may be checked and remedied before final installation of the inner wall.

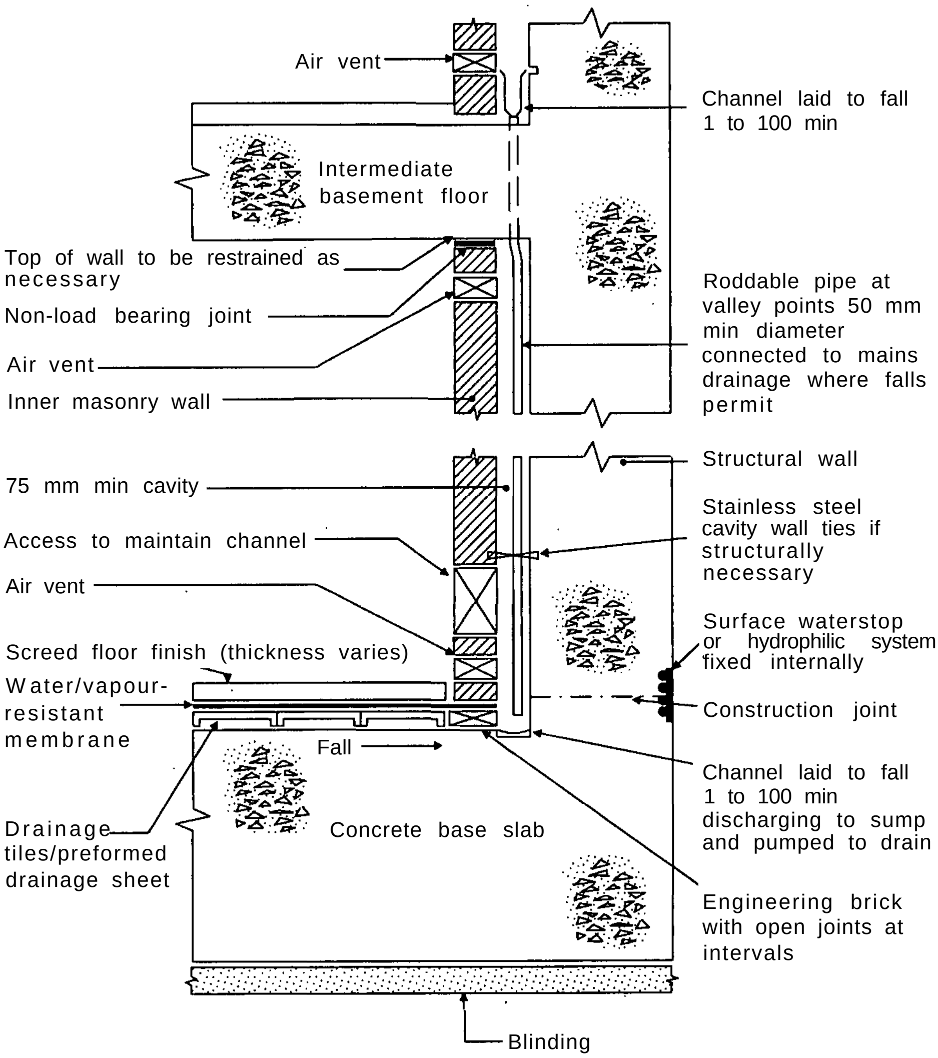


Figure 3.19 Concrete structure with drained wall and floor cavity (Type CBo)

3.8.4 Disadvantages of Type C protection

The principal disadvantages of drained protection are:

- There is a reduction of usable floor area, though this can be minimised by the use of profiled drainage formers.
- Pumps will need to be installed to remove accumulated water.
- If the outer skin is of masonry or plain concrete, under a high hydrostatic pressure, water may penetrate the cavity in excessive quantities, which may not be efficiently drained.
- Access to the external wall for repair will be prevented, after the inner wall has been built.
- Costs of pumping, maintenance of pumps, inspection and cleaning of cavities must be accepted.

3.8.5 Application of Type C protection

In conjunction with masonry or plain concrete, in drained site conditions, drained cavity construction alone without a membrane may achieve the requirements of Grades 1 and 2 environments. In conjunction with either Type A or B protection, drained cavity construction may achieve Grade 3 or 4 internal environments. Further details of proprietary internal drainage systems are given in Section 7.7.

3.8.5.1 Reinforced (in-situ or piled) concrete construction

The addition of a drained cavity to reinforced concrete construction for deep or shallow basements can provide the additional protection necessary to satisfy higher grades of internal environment. Drained protection can also be of benefit when used in conjunction with construction that may not fully comply with all the BS8110 or BS8007 requirements. For example, diaphragm walling, contiguous or secant piled walls may not comply in respect of spacing and percentage of reinforcement for crack control. Figure 3.19 gives an example of drained protection for a concrete basement and Figure 3.20 gives an example for a masonry basement.

Drained cavity protection used in conjunction with either Type A and/or B passive protection may also be used to achieve Grades 3 or 4 internal environments.

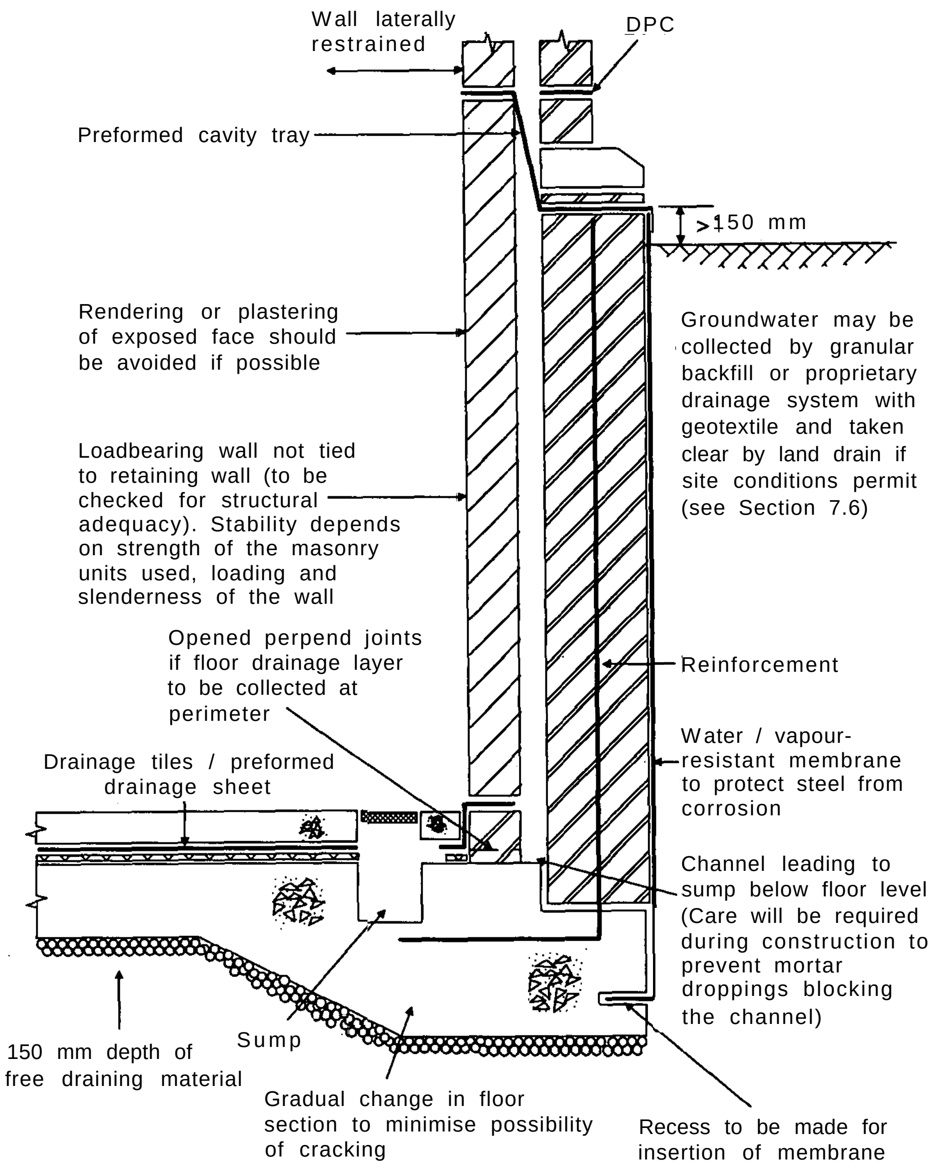


Figure 3.20 Masonry structure with drained cavity (Type CAe)

3.8.5.2 Welded steel sheet piling

Drained protection may be used in conjunction with sheet steel piled primary walls to achieve Grade 1 or 2 internal environments.

3.8.5.3 Masonry or plain concrete

Masonry or plain concrete construction should be restricted to shallow basements for Grade 1 or 2 internal environments in less onerous ground conditions.

Drained cavity protection used in conjunction with Type A protection may be used to achieve a Grade 3 internal environment.

3.9 ACTIVE PRECAUTIONS (HEATING AND VENTILATION)

Selection of the most appropriate form of passive water and vapour protection (Type A, B or C), as outlined in Sections 3.2 to 3.8, is the preliminary step to considering the active precautions required to achieve the desired category of internal environment. The wide variety of possible uses within each grade necessitates that the heating and ventilation system be designed to suit the expected requirements of the particular basement, rather than its nominal grade.

After agreeing the required internal environment (Grade 1-4; see Section 3.1) and establishing the likely groundwater conditions (see Sections 2.2 and 2.3) and the passive protection types thought to be most suitable (see Sections 3.2 to 3.8), it is then necessary to assess whether the basement would comply with ventilation, thermal transmission and resistance to moisture penetration requirements. The minimum performance requirements of the Building Regulations and guidance on the quantification of the functional environmental requirements for different levels of usage (Table 2.2) should be considered.

Evaluation of heating and ventilation requirements should take account of the effectiveness of the passive precautions, the size of the basement (including individual rooms) and the emissions (gaseous and liquid) from machinery and/or human activity. Selected illustrations of the diversity of requirements that can arise within each grade are given in Table 3.8.

This section and its appendices provide only an introduction to heating and ventilation design and deal only with the case of a homogeneous slab. They do not cover the design of joint details, general detailing or workmanship.

Once a decision has been made as to the usage of the basement, basement dimensions and the general form of construction, building services engineers in conjunction with the structural design team should design the heating and ventilation system.

3.9.1 Ventilation

The ventilation requirement is defined as the amount of outdoor air (fresh air) needed to meet the design criteria associated with the building use, and should not be confused with the air circulation rate. The air circulation rate is the total quantity of air supplied to a space. In many systems the room air supply is a mixture of outdoor and recirculated air. Natural ventilation alone is usually insufficient within a basement, as it is dependent on the effects of wind and the difference in air temperature between the inside and outside of a building.

The requirements of the Building Regulations must be taken into consideration for residential basements. Guidance is given in Approved Documents C and F, where clause F1 states:

'There shall be adequate means of ventilation provided for people in the building.'

Table 3.8 Heating and ventilation considerations for selected basement use

Grade of basement	Design for:	
	Ventilation purpose	**Thermal transmittance**
Grade 1 (basic utility) Car parking	Vehicle emissions, oil and gasoline fumes	Heating and insulation generally not required
Plant-rooms (equipment not sensitive to moisture).	Equipment emissions	Heating and insulation may be necessary
Grade 2 (better utility). Plant-rooms (equipment sensitive to moisture)	Equipment emissions	Heating and insulation may be required to limit condensation
Retail storage	Little or no ventilation necessary	Heating necessary, insulation may be required
Grade 3 (habitable) Offices	Human activity (smoking, respiration. etc.)	Heating necessary, insulation may be required
Residential, restaurants	Human activity (as above) and from bathrooms, kitchens, etc.	Heating and insulation essential
Leisure centres	Similar to residential and offices	Heating usually required, insulation may be required
Grade 4 (special) Archive rooms	Ventilation may be required	Heating and insulation essential (strictly controlled internal environment)
Underground bunkers	See Grade 3 requirements	Heating and insulation essential

This is further supplemented by basic performance objectives in Approved Document F, which states:

'In the Secretary of State's view the requirement of F1 will be met if ventilation is provided which under normal conditions is capable, if used, of restricting the accumulation of such moisture (which could lead to mould growth) and pollutants (originating within a building) as would otherwise become a hazard to the health of people in the building.

In order to encourage its use the ventilation should not affect necessary security or comfort to a significant extent.'

Approved Document F also recommends provisions for the extraction of moisture and the size of openings for natural or mechanical ventilation. Further guidance on targets for internal environments is given in Section 2.2, Table 2.2.

The ventilation requirements for each of the internal environment Grades 1 to 4 are described in detail in Appendix C.

3.9.2 Thermal transmittance

The construction of all wall/floor slabs needs to conform to the Building Regulations (Approved Document L), which require a thermal transmittance (*U*) value of not greater than 0.45 W/m^{2}K. The floor slabs will be constructed of either concrete or masonry, will be bedded on a blinding layer of sand or lean-mix concrete, and may be overlaid with a sand/cement or polymer screed. Floor and wall construction often includes insulation and a vapour barrier.

3.9.2.1 Insulation

Insulation is essential and floor insulation must be load-bearing. A 50 mm thickness of insulating material is usually satisfactory. The position of the insulating layer may be arranged to maximise the depth of the structure available for heat storage as in Figure 3.21 or to limit the structure heat storage capacity as in Figure 3.22.

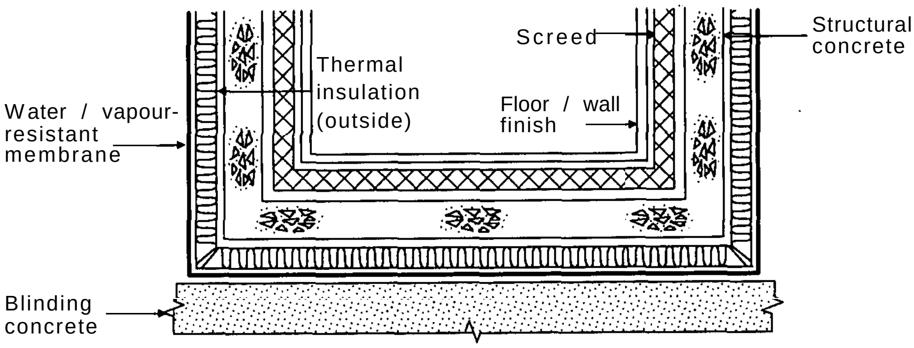


Figure 3.21 Insulating layer positioned to maximise the depth of structure available for heat storage

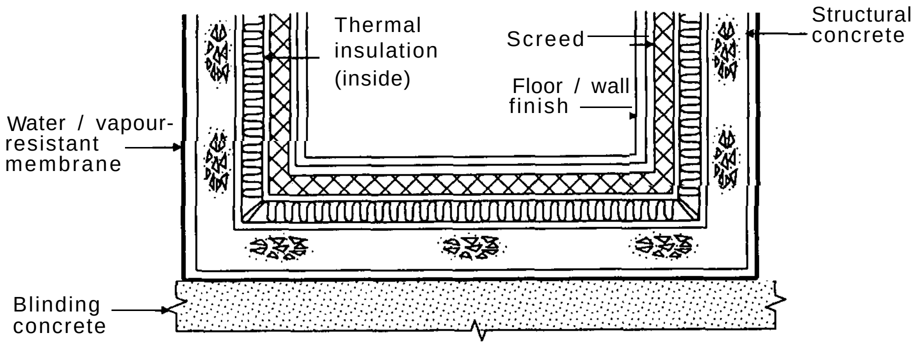


Figure 3.22 Insulating layer positioned to minimise the depth of structure available for heat storage

When properly applied thermal insulation will retard the flow of heat by conduction and will thus serve one or more of the following functions:

- conserving energy by reducing heat loss or gains
- controlling surface temperatures of the structure
- preventing vapour condensation on surfaces by raising the temperature to above the dew-point of the surrounding atmosphere
- reducing temperature fluctuations by virtue of the thermal mass of the fabric within an insulated enclosure when heating or cooling is either not needed or not available
- impeding water vapour transmission.

Example calculations for thermal transmittance and insulation required for a basement are given in Appendix C and summarised in Table 3.9 for the following structures:

- Type A protection in concrete; Grade 1 use (car park)
- Type A protection in concrete; Grade 3 use (residential)
- Type A protection in masonry; Grade 1 use (car park)
- Type B protection in concrete; Grade 1 use (car park)
- Type C protection in concrete; Grade 3 use (residential/office).

Advice on how to satisfy the requirements of the Building Regulations is given in a BRE information paper[3.20].

Table 3.9 Summary values (from example calculations in Appendix C) for moisture loss, thermal transmittance and insulation requirements for different grades of internal environment and protection type

Basement passive protection type	Type A			Type B	Type C
Structure description	Concrete + membrane		Masonry + membrane	Reinforced concrete box	Concrete + cavity wall
Environment and usage	Grade 1 car park	Grade 3 residential	Grade 1 car park	Grade 1 car park	Grade 3 residential
Moisture loss (kg/m^2) (1)					
Summer	0.1	0.1	0.19	0.17	0.165
Winter	-0.03			-0.06	
Thermal transmittance (W/m^2K)					
Wall	0.983	0.983	1.05	1.24	0.66
Floor	0.843	0.993		0.853	0.59
Insulation (mm) (2)					
Wall	48	48	47	56	28
Floor	42	46	-	42	21

(1) The moisture loss is the average of all values calculated for the wall and floors taken over a 60-day period

(2) Insulation requirement is based on phenolic foam, and the tabulated figure is the required thickness of foam to bring the thermal transmittance (*U* value) up to the Building Regulations value of not greater than 0.45 W/m^2K.

3.9.3 Vapour barrier

Most solid materials permit the diffusion of water vapour to some extent, and whenever there is a difference in the vapour pressure across the material, a movement of water vapour takes place. The principal source of water vapour in a basement will be via evaporation of ground moisture from walls and floor surfaces. The use of a vapour barrier may be a more cost-effective and practical method of controlling moisture than by active mechanical ventilation.

3.9.4 Moisture transfer and condensation

Typical moisture losses are illustrated by the example calculations in Appendix C and described above. In Table 3.9, the approximate 60 day losses are given on the basis that there are approximately equal floor and wall areas.

Moisture transfer is dependent upon gains from:

- latent load from occupants
- process load from any products that give up moisture
- exposed water surfaces
- open gas flames
- water vapour migration through gaps around doors
- moisture transmitted from wall and floor surfaces.

Condensation is the change from gas to liquid, and may cause moisture problems. Water vapour condenses when the temperature of the air/vapour mixture falls below the dew-point, a consequence of either:

- vapour flow to a region of lower temperature, or
- a reduction in surface temperature.

Design for heating and ventilation should ensure that there is no internal and/or interstitial condensation, as shown in Figure 3.23. Interstitial condensation can be avoided if ventilation is provided internally to vapour permeable walls or floors (Types B or C protection).

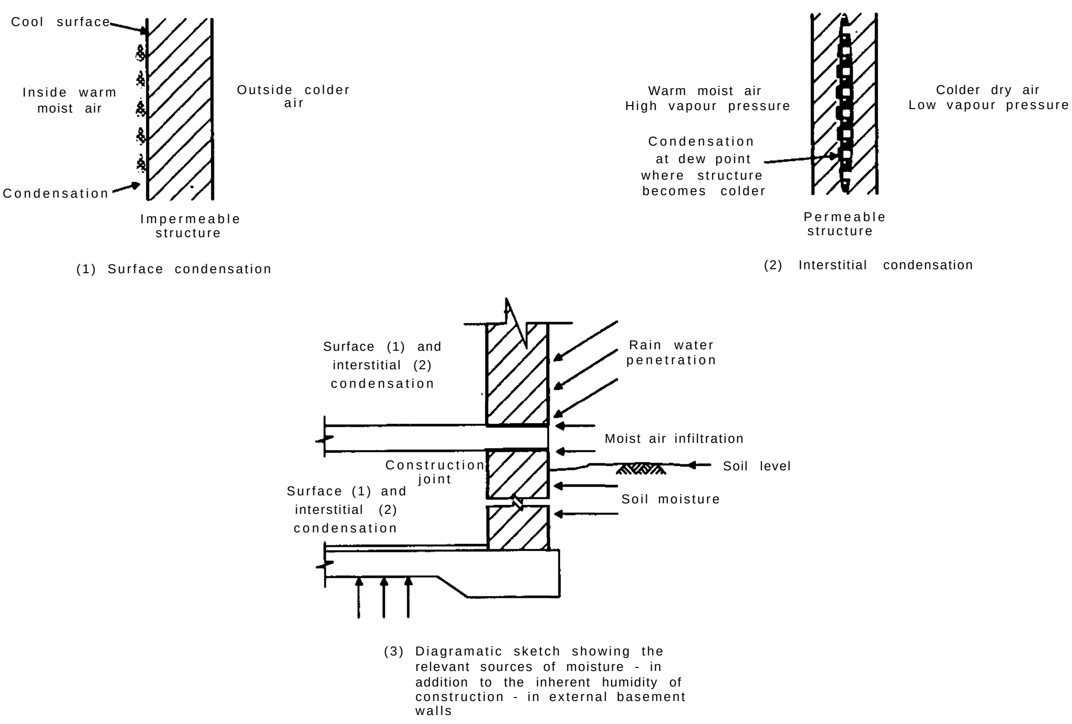


Figure 3.23 Surface and interstitial condensation and moisture sources in external walls

If the outer surface is impermeable (Type A protection) and the basement is not heated or ventilated, condensed moisture may accumulate in the wall and ultimately saturate the material. The situation is most severe where high internal relative humidity occurs.

A vapour-resistant membrane (Type A protection) on the inner face of the basement walls (the potentially warmer side) is relied upon to prevent moisture penetration into the basement from the ground through the walls and floor. The structural materials must not deteriorate by being saturated and should be adequate to resist the forces induced by temperature gradients through them.

Condensation will only occur where the permeability of the walls or floor allows sufficiently moist air to penetrate to a position sufficiently cold to produce dew-point conditions. Calculation methods exist for determining this[3.21 - 27] but three guiding principles can be stated as follows:

1. The design of the active precautions should ensure that the provision of a vapour barrier does not cause internal and/or interstitial condensation. Prevention of water or vapour penetration by an internal vapour-resistant membrane (Type A) or internal drained cavity (Type C) may not require precautions against condensation.

2. Although completely impermeable vapour barriers at the inside surface are difficult to achieve, a partial vapour penetration calculation is still useful.

3. Where a number of different layers make up a construction, as much of the structure as possible should be kept warm. Where it is not easy to apply barrier treatments, insulation materials are better placed towards the outer face, but they must be protected from groundwater. If the bulk of insulation is to be positioned at the inner face, it may be necessary to protect the warm side by a vapour barrier, or carry out a vapour penetration calculation.

3.10 DESIGN APPROVAL

Agreement with the client on the design objectives for the basement (Section 3.1) should establish:

- the requirements for the internal environment (including quantified limits on leakage where appropriate)
- the budgetary controls and constraints on the work
- whether a system of limited or complete protection is to be employed to achieve the aims of the above.

Throughout the design phase the client should be informed of any significant factors likely to affect the protection system and, on completion of the design, the designer should obtain the approval of the client, for the system proposed. A formal agreement should describe:

- what the system, realistically, can be expected to achieve and the costs likely to be associated with it
- capital, maintenance and operating costs for complete protection
- contingency plans for repair or upgrading (see Chapter 5) of a system of limited protection should it be chosen and become inadequate at some future time.

The designer should assess the likely worst instances of failure of the system that will need to be allowed for and inform the client.

Formal design approval should therefore establish:

- how a target internal environment, with moisture ingress not exceeding defined limits (including contingency plans for leakage in a system of limited protection, see Section 3.1), will be achieved, and that
- the client will arrange to fund the future operating costs (heating, ventilation and maintenance, etc.) for a system of complete protection or the direct and indirect costs of possible future repairs to a system of limited protection.

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REPORT 139

Water-resisting basements

This report summarises current best practice and provides guidance on the construction and improvements of water resisting basements. It also addresses any questions unanswered in the relevant British Standards and Codes of Practice.

It will assist architects, engineers, surveyors and their clients with decision making on the control of the basement's internal environment, and the means of construction and maintenance.

It takes account of all viable construction methods (for both deep and shallow basements) together with the active and passive precautions available to achieve the most appropriate and economic environmental control system.

The topics covered include:

- **Internal and external environments**
- **Design of new basements**
- **External drainage positions**
- **Water and vapour resistance of residential basements**
- **Refurbishment and up-grading techniques**
- **Rising groundwater**
- **Comparison of British design codes**
- **Example calculations for heating and ventilation**
- **Materials**

ISBN 0-7277-2042-2

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