

CNZ BG 01:2016

Concrete and Concrete Masonry Basement Design Guide



Concrete New Zealand

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Preface

This Basement Design Guide is intended as an overview to inform the initial design process for underground structures. It covers the use considerations for basements and its site characteristics, describes suitable design methods, and discusses the selection of materials.

New Zealand is currently undergoing a densification process as never experienced before. This is due to increasing numbers of immigrants, more couple and single households than in previous times, and a lack of land to build many more standalone properties. In cities like Wellington, Christchurch and especially Auckland, land costs have reached unprecedented heights.

Basements maximise available land space by giving us more room without increasing the building footprint or occupying further land. Basements also create storage areas for the many bulky items we wish to store as well as places for unappealing and possibly noisy plant equipment, refuse collection, car and bicycle parking, workshops and even residential spaces.

Which material is better suited to basement construction than concrete or concrete masonry! Concrete is incredibly durable, hardwearing, fireproof and structurally sound even under the influence of water. While concrete is not generally waterproof it can be made so either by incorporating admixtures, additional reinforcing and increased compressive strength or by the application of membranes.

Ralf Kessel, CNZ Architect, October 2016

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Requirements for basement design

Basement design in New Zealand is a specialised task. Basements are subject to Specific Engineering Design (SED). There are no Acceptable Solutions supporting their design so they will always be alternative solutions with respect to the New Zealand Building Code. Accordingly, Building Consent Authorities will require substantial evidence that a basement structure will withstand all forces and remain waterproof.

The design of a basement structure requires solving many technical issues up front. Many problems can occur if detailing has been neglected and the construction has been executed incorrectly. For example, most legal cases in Germany's building sector are in relation to basements; and this is in a country known for its high level of standards. This may be an indication of how complicated it is to make underground structures watertight.

There are relevant New Zealand Standards and Building Code clauses dealing with concrete specification, workmanship and general design: these must be considered for Code compliance in the first instance. A further requirement is for close collaboration between the structural engineer and a waterproofing specialist, such as the technical expert of a membrane manufacturer or a material specialist, from day one.

Note: The Resources section on page 28 contains a list of relevant standards, codes and specifications as well as some recommended publications. A Glossary of terms is on page 30.

The only New Zealand Standard dealing with in-ground structures is NZS 4229¹, in which masonry retaining walls are covered. However, the content only extends to structures partially in-ground such as houses built on a slope. The construction principles underlying partially in-ground structures can not be applied to fully in-ground structures, although the reverse can apply.

The absence of any New Zealand Standards dealing specifically with fully in-ground basements or in-ground construction makes a reliance on overseas standards a necessity. Accordingly, this guide references British Standards and European Norms.

Watertight basements should be designed in accordance with BS 8102:2009^A. The concrete used must comply with NZS 3104. Additional construction standards are described in NZS 3101 and NZS 3109, while further information can be found in BS EN 1992-3:2006.

BS 8102 covers three basement waterproofing construction types, Type A which relies on membranes, Type B on waterproof concrete and Type C on a drained cavity.

¹ NZS 4229:2013 - Concrete masonry buildings not requiring specific engineering design

^A BS 8102:2009 provides recommendations and guidance on methods of dealing with and preventing the entry of water from surrounding ground into a structure below ground level.

It covers:

- waterproofing barrier materials applied to the structure,
- structurally integral watertight construction,
- drained cavity construction,
- the evaluation of groundwater conditions,
- risk assessment,
- options for drainage outside the structure.

It applies to structures which extend below ground level and those on sloping sites.

The principle of “Watertight Concrete” (Type B) follows the rationale of BS 8500-1:2015 2 and BS EN 1992-3:2006, where:





- the appropriate cement is chosen for the conditions.
- the water/cement ratio is 0.45 or below to ensure the minimum residual capillaries within the hardened concrete, and
- the level of consistency chosen fits with the method of placement chosen by the contractor.
- high strength concrete is used to enhance watertightness.
- reinforcement is placed to limit crack widths^B.
- waterproofing admixtures may be added to induce self healing that seals cracks.

However, most reliable outcomes are achieved with membrane (Type A) and cavity wall (Type C) systems. Solutions relying on “Watertight Concrete” only are bearing a higher risk of failure when under strain.

^B Walls shall be monitored and every crack observed shall be repaired with appropriate methods, such as epoxy or polyurethane injections, as soon as discovered. Undesired water carried into the wall by cracks may cause corrosion of reinforcement over the long term which potentially compromises the structural integrity.

Basement uses

The guide distinguishes four categories for basement use, each requiring different levels of moisture protection. Table 1 describes these categories and the relevant requirements for the basement’s internal climate.

Table 1			
Basement use categories and their performance requirements			
Category	Basement use examples	Performance requirements	Appearance example
1	Basic plant rooms Refuse collectors	Minor seepage and patches accepted	
2	Dry plant rooms Car park Workshops	No seepage but moisture vapour accepted	
3	Retail storage Restaurants Leisure centres	Dry ambience	
4*	Residential Offices Archives	Totally dry and thermally insulated	
<p>NOTES:</p> <ul style="list-style-type: none"> - * The performance requirements for category 4 can most likely only be achieved with thermal insulation forming part of the wall build-up. - The client must be consulted to understand their expectations and he must be advised to achievable outcomes accordingly. 			

Key steps

The key steps for basement design and construction are shown below and explained later in this guide.

Step 1: Determine the site conditions

Engage geotechnical expertise where necessary to:

- assess the soil characteristics
- establish the ground water level and determine the water type
- identify hydraulic pressures
- estimate permeability characteristics of soil
- identify any poisonous substances, gases or chemicals
- identify the risk of land slips
- identify the earthquake zone and likely movements
- get information about possible past earthworks or excavation

Step 2: Decide on a suitable structural design

A structural engineer in collaboration with waterproofing experts will decide on a suitable basement design considering its intended use, taking account of the findings from Step 1 and designing the structure to address:

- soil conditions
- ground water levels
- hydraulic pressures
- seismic forces
- thermal contraction and concrete shrinkage
- possible earth movements from land slips or earlier excavations
- site constraints and work space limitations
- foundation and services of other existing structures in the vicinity
- time schedule
- costs
- maintenance and repair options after completion

Step 3: Finalise the design, waterproofing and drainage details

Next, focus on materials and the waterproofing system:

- decide on the waterproofing system and any drainage plan
- consider ventilation and insulation requirements
- consider future repairs
- select suitable waterproofing materials and/or concrete admixtures, taking into account the connections of different waterproofing elements
- consider issues associated with joints and buildability

Step 4: Construction and quality control

Engage suitably experienced personnel to:

- construct the basement
- apply the waterproof layers according to current standards, material compatibility characteristics and manufacturers' guidelines

Implement stringent quality control to:

- ensure the construction and waterproofing (eg detailing and compatibility) is executed to the correct and highest standard

Step 1: Determine the site conditions

Engage geotechnical expertise where necessary to:

- assess the soil characteristics
- identify the risk of land slips
- identify the earthquake zone and likely movements
- get information about possible past earthworks or excavation
- establish the ground water level and determine the water type
- identify hydraulic pressures
- identify any poisonous substances, gases or chemicals

Soil characteristics and ground water level

The first step in basement design is to gather information on the ground conditions. A geotechnical engineer shall assess the soil type, geology, contaminants, gases, hydrogeology, drainage options and the ground water level (the water table). The water type shall also be determined as this can affect the basement's design and waterproofing (for example, aggressive soil adds to the complexity).

The geotechnical engineer may identify perched water tables above the actual water table. This means fluctuating water levels in response to climatic conditions (ie levels higher in winter than in summer). This disparity is called the "zone of intermittent saturation" and should be allowed for in the design.

The type of surrounding soil will influence the quantity of water touching the basement structure and the soil characteristics will also have a large influence on the waterproofing requirements. It is self-evident that free draining soils which are always above the ground water table will create fewer problems than badly draining or non-draining soils such as clays or soils in temporary or permanent ground water.

Poisonous gases and chemicals

Some soils may also contain chemicals with the potential to damage the basement's waterproofing system. Sulphates, chlorides, VOCs and hydrocarbons are amongst these. In addition, natural gases such as radon or methane may be present and, if so, can harm the health of the occupants. Note that if a hazardous gas is present the designer cannot rely on a Type B structure but will need a membrane solution (construction types are described in Step 2).

Note:

Ireland is an example of a country with a high occurrence of radon in the soil, so placing radon barriers around basement structures there is very common.

There are membranes available on the market that will protect basement structures from both gases and water at the same time.

Common soil types and their drainage characteristics

Tables 3a and 3b are based on Arthur Casagrande's classification system² and provide generalised drainage characteristics of the most common soil types. These tables can help determine the ability of the soil to retain water and develop water pressure, which is important to know before deciding on the waterproofing systems as shown in Table 4.

Note that the soil around a basement may consist of various materials and may not be uniform. Probes should be taken at least from all perimeter sides of the structure before assessing the soil's overall characteristics. A geotechnical engineer or someone of similar expertise shall conduct the assessment.

Table 3a			
Characteristics of well-draining soils			
Symbol	Soil	Identification	Drainage characteristics
GW	Well-graded gravels & gravel-sand mixtures, little or no fines	Wide range in grain sizes & substantial amounts of all intermediate particle sizes. Over 50 % > sieve 0.074 mm. Over 50 % of gravel > sieve 4.75 mm.	Extremely good
GP	Poorly-graded gravels & gravel-sand mixtures, little or no fines	Predominantly one size or a range of sizes with some intermediate sizes missing. Over 50 % > sieve 0.074 mm. Over 50 % of gravel > sieve 4.75 mm.	Extremely good
GM	Silty gravels, gravel-sand-silt mixtures	Non-plastic fines or fines with low plasticity Over 50 % > sieve 0.074 mm. Over 50 % of gravel > sieve 4.75 mm.	Very good
GC	Clayey gravels, gravel-sand-clay mixtures	Plastic fines. Over 50 % > sieve 0.074 mm. Over 50 % of gravel > sieve 4.75 mm.	Very good
SW	Well-graded sands & gravelly sands, little or no fines	Wide range in grain sizes & substantial amounts of all intermediate particle sizes. Over 50 % > sieve 0.074 mm. Over 50 % of coarse < sieve 4.75 mm.	Good
SP	Poorly-graded sands & gravelly sands, little or no fines	Predominantly one size or a range of sizes with some intermediate sizes missing. Over 50 % > sieve 0.074 mm. Over 50 % of coarse < sieve 4.75 mm.	Good
SM	Silty sand, sand-silt mixtures	Non-plastic fines or fines with low plasticity. Over 50 % > sieve 0.074 mm. Over 50 % of coarse < sieve 4.75 mm.	Medium
SC	Clayey sands, sand-clay mixtures	Plastic fines. Over 50 % > sieve 0.074 mm. Over 50 % of coarse < sieve 4.75 mm.	Medium

² Arthur Casagrande - The Unified Soil Classification System, 1948

Table 3b Characteristic of poorly draining soils					
Symbol	Soil	Identification			Drainage characteristics
	Soils listed below are fine grained soils where over 50 % < sieve 0.074 mm	Dry strength (crushing character)	Dilatancy (reaction to shaking)	Toughness (consistency near plastic limit)	
ML	Inorganic silts, very fine sands, rock flour, silt or clayey fine sands	Slight to none	Quick to slow	None	Poor
CL	Inorganic clays of low to medium plasticity, gravely clays, sandy clays, silty clays, lean clays	Medium to high	None to very slow	Medium	Poor
OL	Organic silts and organic silty clays of low plasticity	Slight to medium	Slow	Slight	Poor
MH	Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts	Slight to medium	None to slow	Slight to medium	Very poor
CH	Inorganic clays of high plasticity, fat clays	High to very high	None	High	Very poor
OH	Organic clays of medium to high plasticity, organic silts	Medium to high	None to very slow	Slight to medium	Very poor
PT	Peat and other highly organic soils	Readily identified by colour, odour and spongy feel and frequently by fibrous texture			None

Step 2: Decide on a suitable structural design

A structural engineer in collaboration with waterproofing experts will decide on a suitable basement design considering its intended use, taking account of the findings from Step 1, and designing the structure to address:

- soil conditions
- ground water levels
- hydraulic pressures
- seismic forces
- possible earth movements from land slips or earlier excavations
- site constraints and work space limitations
- foundation and services of other existing structures in the vicinity
- time schedule
- costs
- maintenance and repair options after completion

The basement's intended use, which could be anything from a basic plant room through to a fully habitable space (refer Table 1 earlier), must be taken into account as this will affect the required level of watertightness, ventilation and insulation.

Step 2 shall ensure that the structural design is fully developed and considers all site conditions, hydraulic pressure and potential earth forces from land slips, excavations if relevant, and seismic forces. Structures should be designed to accommodate settlement and soil movements.

Waterproofing construction types

This guide covers three different types of waterproofing construction (shown in Figure 1):

- **Type A: Tanked/barrier protection** (suitable for masonry, in-situ or precast), which has no integral protection against water ingress and which relies on the applied waterproofing system
- **Type B: Structurally integral protection** (suitable for in-situ and precast), which relies on the design and construction of the basement as an integral shell, using a concrete of low permeability and appropriate joint detailing. As Type B structures are specifically designed to be water resistant they only need further waterproofing if additional control against free water or water vapour is considered necessary.
- **Type C: Drained protection** (suitable for masonry, in-situ or precast), which incorporates a drained cavity, with at least the inner wall providing an additional means of watertightness such as a pore blocker or membrane.

The designer should determine which of these types best suit the conditions and proposed basement use – and even whether a combination of types might be the most appropriate solution. The risk matrix (Table 4) on page 16 should help with this selection.

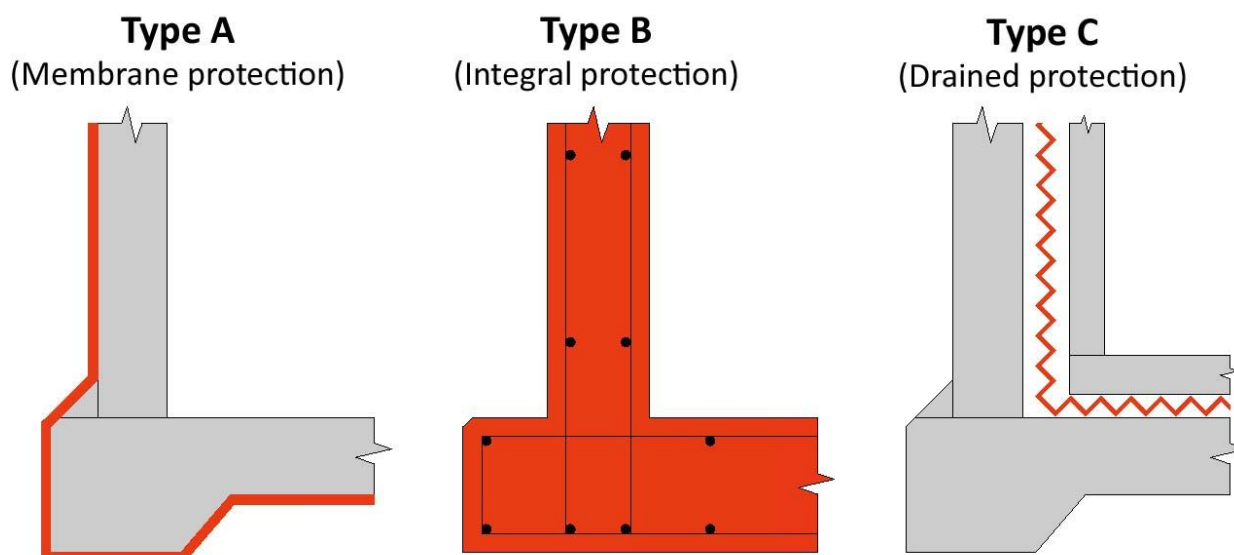


Figure 1: Waterproofing construction types (indicative sketches only to demonstrate concepts)

Type A: Tanked/barrier protection

(Construction suited: masonry, in-situ, precast)

Type A structures are often made of masonry, but in-situ or precast structures are also suitable. The structure is regarded as having no integral protection against water ingress so it relies on the applied waterproofing system to provide the necessary control.

Masonry walls may require flush pointing or a cement rendering to provide an acceptable substrate before the waterproofing system is applied.

The waterproofing system tolerates certain construction cracks or minor defects and fine hairline cracks up to 0.3 mm wide. Any larger or unusual cracks will require remedial action before the waterproofing system is installed.

Additional information is provided with British Standard BS8102:2009

Type B: Structurally integral protection

(Construction suited: in-situ, precast)

Type B structures (refer Table 2) are generally reinforced in-situ or precast concrete structures. Their water resistance relies in the design and construction of the basement as an integral shell, using a concrete of low permeability and appropriate joint detailing.

Since these structures are specifically designed to be water resistant, further waterproofing is only required where additional control against free water or water vapour is considered necessary.

However, defects have to be avoided or at least minimised. Successful Type B structures require correct design, accurate specification and careful construction.

Adding a crystalliser admixture in the ratio of 1-2 to 100 kg cement can help to minimise cracks and in addition provide the concrete with a ‘self healing’ property. Any noticeable cracking or defect should be brought to the designer’s attention.

Additional protection may be used to safeguard Type B structures from aggressive chemicals.

Table 2	Details for Type B structures
Features	Comments
<p>Design – general</p>	<ul style="list-style-type: none"> • Waterproof concrete basements should be designed in accordance with EN 1992-3:2006³ to waterproof but not vapour proof. • Additional construction information is described in NZS 3109. Also refer BSI British Standards BS8102:2009 and EN 1992-3:2006. • Reinforcement should be designed to limit crack widths. If no self-healing admixtures are used, any crack which passes through section may lead to leakage, regardless of the crack width. • Waterproofing admixtures such as crystalline mineral additives to limit crack widths and to enhance self-healing of cracks may be added in which case the admix supplier shall communicate and agree the final design with the structural engineer. • A minimum section thickness of 250 mm when no waterproofing admixtures are used and 175 mm if waterproofing admixtures are used is recommended⁴. <p>Note: Type B concrete structures are to be constructed as integral water resistant shells. Accordingly, all floors, ceilings and walls below external ground level, including the junctions between them, should be designed to resist the passage of water and moisture to the internal surface.</p>
<p>Design – joints</p>	<p>Control and construction joints, and especially penetrations are potential problem areas and require additional sealing. Water stops should be used to provide enhanced resistance to water transmission at any joints.</p> <p>Water stop options include:</p> <ul style="list-style-type: none"> • Rubber or PVC extruded profiles cast into the concrete either on both sides of the joint or mid-depth • Metal bar strips placed mid-depth • Hydrophilic strips or crystallisation slurries forming a monolithic, waterproof compound with the concrete structure (these are applied to the joint at depth before the second cast) • Permeable hose or other sections fixed to the construction joint surface before casting the second pour, to facilitate the injection of a specialist sealing resin into the joint. <p>Movement joints should be avoided. If this is not possible, they shall be accessible for maintenance and specialist advice should always be sought. There are many types and materials used for waterproofing movement and expansion joints, including mechanical steel and rubber, asphalt, pitch mastic, elastomeric polyurethanes, polyurethane epoxies and hypalon strips bonded with adhesives.</p>

³ EN 1992-3:2006 - Euro Code 2. Design of concrete structures. Liquid retaining and containing structures.

⁴ Recommended by National House-Building Council UK, CH 5.4, Waterproofing of basements and other below ground structures.

Table 2	Details for Type B structures
Features	Comments
Design – joints (continued)	<p>Note: The selection and type of material/fabrication of the joint will depend on the anticipated/calculated movement and also the exposure of the joint (eg will it be exposed to traffic or chemicals?) The individual application MUST be addressed by the design team. Appropriate selection is important and the manufacturer’s advice should be sought when specifying.</p>
Selection of suitable concrete and admixtures	<p>The principle of “Waterproof Concrete” follows the logic behind BS 8500-1:2015⁵, where the appropriate cement is chosen for the conditions; the water/cement ratio is 0.45 or below to ensure the minimum residual capillaries within the hardened concrete; and the level of consistency chosen fits with the method of placement the contractor has decided to use.</p> <p>Considerations include:</p> <ul style="list-style-type: none"> • Required structural strength according to the basement’s structural design • Soil, water table and possible contaminants the structure will be exposed to, and • Performance requirements depending on the basement use (refer Table 1). <p>Requirements include:</p> <ul style="list-style-type: none"> • The concrete mix specification depends on the above but shall have a maximum water/cement ratio of 0.45. • The contractor shall specify the consistency in line with his or her proposed method of placement: this is usually no less than class S3⁶. • The admixture supplier shall recommend admixtures to waterproof the concrete, based on all the above information. • The concrete supplier shall hold a current audit certificate from the NZRMCA plant audit scheme. He or she shall receive all the above information. The concrete used shall comply with NZS 3104.
Construction	<ul style="list-style-type: none"> • Work shall be executed by educated and trained personnel. • The construction and its system have to be fully understood by the site personnel. Meetings shall be held up front to ensure that all staff has understood the system and its outcome. • For control purposes the materials and systems used, quantities, executing personnel, time and weather conditions of the construction period shall be recorded. This shall include photo documentation, mix design certificates, test cylinders and test results for all individual pours. • Sufficient and careful vibration (and potentially re-vibration) is essential to achieve required densities and consistencies. • Early age shrinkage control by understanding ways to prevent rapid loss of moisture from the surface of the concrete and the influence of the climate conditions at the time of the pour.

⁵ BS 8500-1:2015 – Concrete. Complementary British Standard to BS EN 206 – Concrete specification, performance, production and conformity

⁶ S3 - Concrete slump class to BS EN 12350-2. Concrete slump of range between 100 - 150 mm with tolerances of ± 20 mm.

Note: Typical reasons why Type B structures could fail are:

- permeable concrete
- honeycombing through lack of compaction
- contamination of cold joints
- cracks due to thermal contraction, shrinkage and ground movements
- poor and inadequate placement of waterbars, hydrophilic strips and joints.

Type C: Drained protection

(Construction suited: in-situ, precast, masonry)

Type C structures incorporate a drained cavity to manage any water that enters the structure. The drainage channels must be properly formed and positioned, free from obstructions and free flowing. It is good practice to flood test the system prior to installing the floor membrane.

For cavity construction this requires at least the inner wall providing an additional means of watertightness, such as a pore blocker or a membrane. If the outer layer allows seepage there will always be the drained cavity and a pump to drain any unwanted water.

As flooding could be the consequence of system failure, Type C systems shall come with a maintenance plan.

Note:

While pore blockers provide a means of watertightness, a wall or slab may experience some form of seepage over the long term. One example is a basement carpark underneath a garden area: seepage through the ceiling slabs could damage the cars below.

Risk matrix for selecting a waterproofing construction type

The risk matrix below (table 4) can help with the choice of a suitable waterproofing construction type or types.

Table 4 Risk matrix: suitable construction types depending on site conditions and basement use						
Risk	Site conditions		Basement use			
	Water table	Soil drainage	1 (eg basic plant rooms)	2 (eg dry plant rooms, car parks)	3 (eg retail storage)	4 (eg residential)
Low	Structure permanently above water table	Extremely good to medium	Any	Any	Any	Type A or B when insulated Type C when insulated
Medium	Structure permanently above water table	Poor to very poor	Any	Any	Type A Combination of A & B	Type A or B when insulated Type C when insulated
High	Structure exposed to fluctuating water table	Any	Type C Combination of A & B or A & C or B & C	Type C Combination of A & B or A & C, or B & C	Combination of A & B or A & C, or B & C	Combination of A & B or A & C or B & C + all insulated
Very high	Structure permanently within water table	Any	Type C Combination of A & B, A & C or B & C	Combination of A & B or A & C or B & C	Combination of A & B or A & C, or B & C	Combination of A & B or A & C or B & C + all insulated
Notes:						
<ul style="list-style-type: none"> • Basement uses 1 to 4 as described in Table 1 • Waterproofing construction Types A to C as described earlier in Step 2 • 'Any' means Type A, B or C are suitable • 'Insulated' for Types A and B means the exterior of the basement wall shall be insulated to keep it at a consistent temperature. 'Insulated' for Type C means the exterior of the inner wall shall be insulated. • Type B structures are not suitable if the soil contains poisonous substances. In this case a membrane solution to Type A or a combination of Type A and C shall be used. 						

Step 3: Finalise the design, waterproofing and drainage details

Next, focus on materials and the waterproofing system:

- decide on the waterproofing system and any drainage plan
- consider ventilation and insulation requirements
- consider future repairs
- select suitable waterproofing materials and/or concrete admixtures, taking into account the connections of different waterproofing elements

Waterproofing considerations

As specifying waterproofing systems is a specialised task, a suitably qualified and experienced person or company should be consulted for advice at the early stages. The entire waterproofing system must be flexible so it can cope with movement arising from settlement and seismic forces as considered by SLS⁷ design.

Note:

BS 8102:2009 (Code of practice for protection of below ground structures against water from the ground) is an exemplary standard providing detailed guidance.

The connections of different waterproofing elements (eg the underslab and wall membranes) must be considered. Using appropriate materials and wall build-ups is essential. This includes a fully developed drainage system as well as an understanding that access around basement walls is almost impossible post-completion. Later defects and the possibility of repairs or any back-up system must be considered as part of the overall water-resisting design for the structure.

Basement waterproofing should not allow any water to pass through and consideration must be given to the worst case scenario when a defect in the waterproofing system may allow seepage. Having said this, Type B basements may allow some minor seepage, which can be acceptable for basement uses in category 1 (refer Table 1); eg for basements used as basic plant rooms.

Any possible damage to the construction/ waterproofing in well-draining sites will not be as severe as compared to poorly drained sites. While good draining soils will not enable the build-up of hydrostatic water pressure, poorly drained soils carry this risk if there is heavy and/or lengthy rainfall.

Basements constructed in poorly drained soils may require a back barrier in addition to the initial waterproofing system. This barrier is also required for basements set below the ground water table.

⁷ SLS - Serviceability Limit State to NZS 1170. Level of Strain to a building which after exposure can continue to be used for its intended purpose without the need for repair.

Selection of waterproofing materials and admixtures

Table 5 lists waterproofing materials and concrete admixtures currently available in New Zealand. It includes brief comments on their suitability for various site conditions and construction types, as well as noting their strain capacity (as low, medium or high).

Specific information should be obtained from the relevant manufacturers and suppliers. It is particularly important that all materials used in basement construction are compatible with each other as they have to function as one system over the building's lifetime.

While stresses and strains can be accommodated to some degree by waterproofing systems, some systems perform better than others. For example, bonded membrane sheets and mastic asphalt membranes usually perform reasonably well. However, more consideration has to be given to cementitious crystallisation; particularly at joints and direction and shape changes of the structure.

Some soils or ground water may be contaminated with poisonous substances, aggressive chemicals or gases such as methane or radon. Contaminated soil may harm the building or occupants if no additional protection has been installed. Examination and determination of any contaminates is essential. The manufacturer of the waterproofing system or membrane must advise on their suitability, effectiveness and durability in these circumstances.

Table 5		Waterproofing materials				
Material	Bond	Surface	Shape of structure	Soil suitability	Suitable construction Types	Strain capacity
Bitumen and composite polymeric sheet membranes	Cold or heat adhered	Dry, clean, even.	Simple only	Ground water. Aggressive soil.	A or C	high
Bentonite clay active membrane²	Self bonding when poured against	-	Medium complicated	Ground water. Limited in aggressive soils.	A or C	medium
Needle punched Bentonite membrane²	Cold applied	-	Simple only	Ground water. Limited in aggressive soils.	A or C	medium
Liquid applied membrane	Cold applied	Dry, clean, even.	Complicated	Ground water. Aggressive soil.	A or C	low
Mastic asphalt membrane	Hot applied	Dry, clean.	Simple only	Ground water. Aggressive soil.	A or C	high

Table 5		Waterproofing materials				
Material	Bond	Surface	Shape of structure	Soil suitability	Suitable construction Types	Strain capacity
Cementitious render with waterproofing component	Slurry coating	Saturated, clean, even. Occurrence of free lime.	Complicated	Ground water. Aggressive soil.	A or C	low
Polyolefin membrane	Self bonding when poured against	-	Medium complicated	Ground water. Aggressive soil.	A or C	high
Crystallines	Spray applied	Saturated, clean, even.	Complicated	Ground water. Aggressive soil.	A or C	low
Crystallines	Admix	-	Complicated	Ground water. Aggressive soil.	B or C	low

NOTES:

1. 'Aggressive' indicates that a waterproofing material will cope with aggressive soils in general. However, advice must be obtained from the product manufacturer regarding its suitability for the specific chemicals present.
2. Bentonite membranes require confining pressure from both sides to achieve their full waterproofing potential; hence their use against drainable backfill has to be approached with care. Their full waterproofing potential can be gained by the application of rigid boards such as coreflute boards between the soil and the Bentonite membrane. Any unstable ground conditions or perched water tables draining, leaving a void against the wall behind, bear the risk of failure of bentonite membranes.

Drainage

The design of the drainage system depends on the topography of the land and the direction and movement of rain water and any ground water. If no permanent ground water is present, a ring or perimeter drain system that connects into the sewerage system should be provided around the bottom perimeter of the structure.

In every case, the top of the drainage shall be below any finished basement floor level.

Ideally, any existing drains should be left in place uninterrupted. If these drains are in the way of the new structure they will either have to be redirected or, if possible, intercept with the new system.

To enhance draining, a free draining backfill shall be placed around the entire structure. This shall be at least 500 mm wide at the bottom where the ring drainage will be placed and rise upwards at an angle of preferably no less than 30 degrees to ensure no silts or clays will fill the drainable fill.

The ring drainage system shall be covered with at least 500 mm x 500 mm permanent gravel. This gravel shall be surrounded with a woven filter medium to assure no non-draining material will come near the drainage system and cause congestion.

Where no external drain can be installed and the wall sits immediately against the soil (for example, for in-ground 'excavated and cast' wall construction systems such as diaphragm walls) a Type C wall with a drained cavity wall system is recommended. The outer wall shall be reinforced to achieve waterproofing and shall have a concrete with no more than 0.45 w/c ratio. The cavity bottom in Type C walls is at the same time the drain channel and sits at least 150 mm below any internal floor level. The drain channel shall be built with collection dents and a pump system to remove any water that passes into the cavity.

For basements in permanent ground water, the floor shall also be drained. A double floor system allows for water collection below the finished floor and a pump system will remove any water passing through the walls or the floor.

Ventilation and insulation

While the main aspects of basement design relate to its structure and protection against any ground or drain water, it is also important that no internally generated moisture or condensation shall harm the building, its kept goods or occupants.

Ventilation/ air exchange and/or thermal insulation may be necessary:

- to minimise or prevent condensation
- for reasons of health and hygiene, and
- to meet performance requirements for the basement's proposed use (refer Table 1).

Minimising condensation

Relative humidity levels in many parts of New Zealand are such that at 12.5°C the air is saturated and condensation will form on surfaces (this is known as the dew point). According to NIWA⁸, the mean earth temperature at 10 cm depth will drop below this level during the four months from June to September.

Considering that in-ground structures can contain greater humidity, condensation may form even at higher temperatures. Frequent surface condensation can cause mould which affect's people's respiratory health and can damage interior artefacts such as carpets, furniture or stored items.

Bearing in mind that basement walls are made waterproof and therefore do not allow permeability to the exterior as above ground walls do, designers must take steps either to guide any surplus moisture out of the basement or to ensure the ambient temperature is always above dew point.

⁸ National Institute of Water and Atmospheric Research

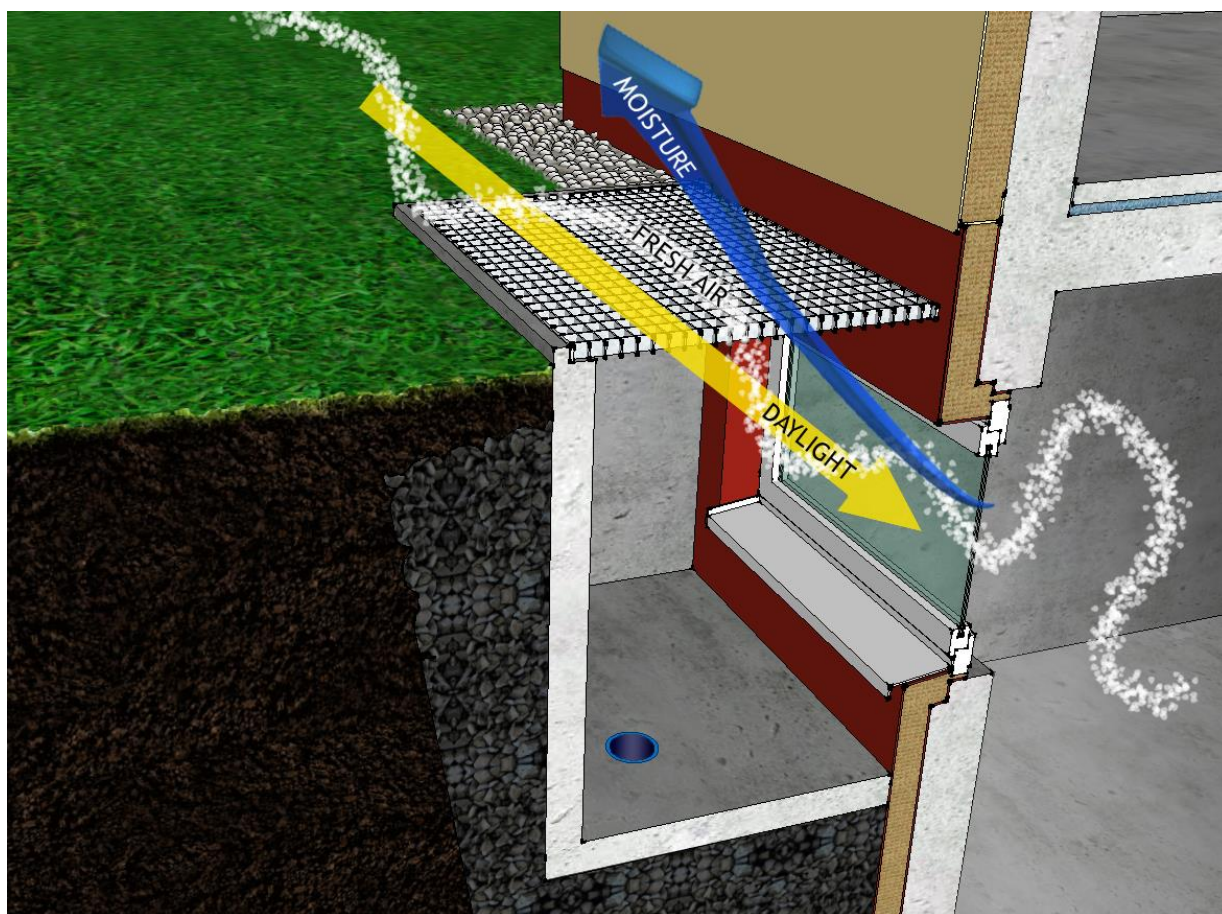
There are several useful online dew point calculators⁹ available providing mould risk and preservation evaluations based on the project's specific ground and ambient temperatures and occurrence of relative humidity.

Professional and accurate measurements of the hydrothermal behaviour can be obtained by using a dynamic building simulation tool such as WUFI®¹⁰.

Ventilating the basement

Ventilation is important to help address condensation, moisture to escape and also to provide suitable air quality for the basement's intended use. Ventilation can either be provided naturally, through windows or louvres, or mechanically. As mechanical ventilation is rather expensive this should be an incentive to find a natural ventilated solution.

To ensure natural ventilation, as well as the infiltration of daylight, basement light wells can be installed. Light wells create an unroofed space on the exterior of the wall that connects to the open air. Light wells are commonly manufactured of precast concrete, are self-draining and contend with ground soil pressure. They are connected to the main structure via cast-in steel bars or prefixed hook systems. Light wells made of synthetic materials are also available, but durability requirements must be considered.



A self draining precast concrete basement light well (image below), attached to the basement wall, enables for daylight infiltration and for natural ventilation and moisture escape when opening the window.

⁹ Online dew point calculator suggestions: www.dpcalc.org, www.dew-point.com

¹⁰ WUFI® (Waerme und Feuchte instationaer) Measuring heat and moisture transport through building envelopes

Thermal insulation

Thermal insulation of the wall and the floor may also be required to help prevent condensation and so the basement is suitable for its intended use. To avoid surface condensation, thermal insulation has to be installed to move the dew point away from the inner surface. This shall be installed at the exterior and must be moisture resistant (eg XPS or foamglass). Thermal insulation should also be provided around any windows where the temperature, especially in winter, drops below the dew point.

Exterior insulation protects the structure and waterproofing membrane from the extremes of the soil and from climate swings. The wall and floor maintain a stable temperature and thus thermally induced expansion and contraction is reduced to a minimum. This minimises the risk of cracks. The temperature of externally insulated walls and floors will always be near the indoor temperature and, therefore, humid interior air is unlikely to condense on the inner basement surfaces.

Note:

Internal insulation risks the accumulation of condensation moisture within itself. If this moisture is not removed it can lead to fungal growth and a mouldy environment.

Exterior basement insulation shall be moisture proof and able to keep its volume under hydraulic and soil pressure so its thermal performance is not compromised. Ideally, the exterior side of this insulation should have a drain dimple sheet applied to enhance drainage down the wall.

Further recommendations

It is not recommended to line basement walls with any material that is likely to promote mould growth.

Prior to the installation of any wall lining, the concrete must first dry fully. The average time for 25 mm thick concrete to dry is about one month. As such, a 200 mm wall requires at least 8 months to dry. Due to the impermeability of the external water proofing membrane the concrete will only dry to the inside.

Avoid using vinyl or paper based wallpaper and vapour barrier paints. It is not recommended to line the walls with plaster boards as its paper layer is prone to mould growth. Emulsion paints and lime plaster are acceptable coatings. Lime plaster in particular has extremely good mould resisting properties.

Future repairs

As any watertightness system could fail and result in flooding it is important at the design stage to consider either installing back-up protection installed or specifying a repair regime. Note that Type C walls always have the advantage that the cavity will function as back up, whereas failure of a Type A or B wall is likely to require excavation to repair the exterior protection.

If excavation is not feasible for some reason, the design should provide for a process of remedial works to reseal from the inside. Internal membrane and waterproofing solutions are possible if

they are compatible with the initial system. Particular attention is required at all joint, junctions and penetrations.

Generic design details

Examples of design details for Types A and C construction systems are provided on the following pages.

Details 101, 102 and 103 are suitable for all Table 1 categories including 'Residential'. Thermal insulation ensures the wall and floor dries consistently to the interior, while also managing ground moisture, ground source vapour drive, interior condensation and construction moisture effectively.

However, Detail 101 has the potential to retain sufficient moisture that enables the development of mould when the room is not heated and ventilated¹¹. The inner wall to floor section is particularly at risk, where the lack of insulation creates cold bridging. This detail is only suitable for Table 1, Category 4 if the space is heated to a consistent temperature of at least 18°C and ventilated properly at all times.

It is recommended that all below ground residential spaces are maintained at temperatures between 18°C and 24°C and are regularly ventilated, natural or mechanical.

Note:

At intersections of waterproofing membranes, eg floor to wall, ensure membranes are compatible and bond so the waterproofing is not compromised. Some membranes require a transition membrane.

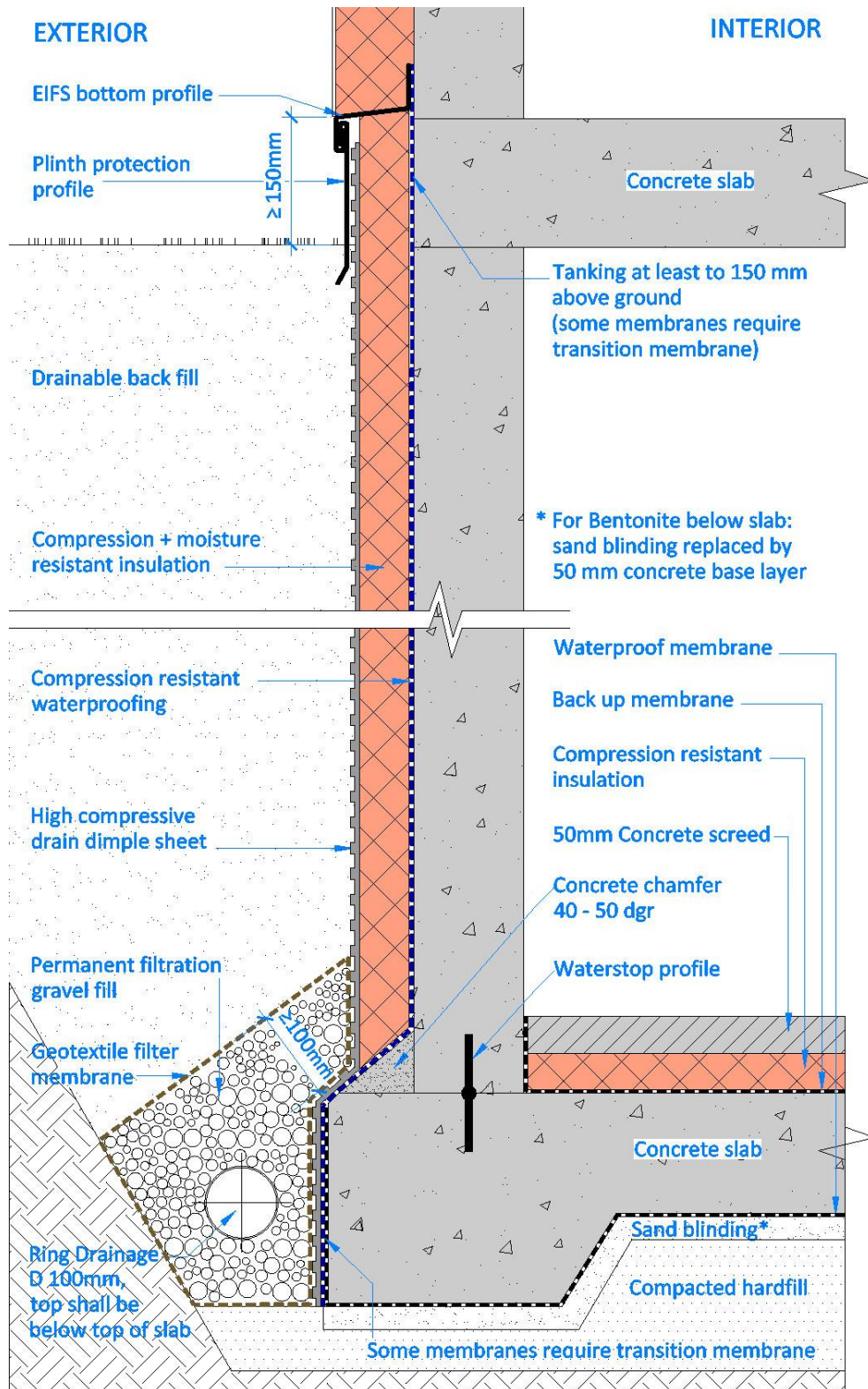
¹¹ CCANZ Foundation Detail WUFI® 2D modelling by Sustainable Engineering Ltd. 10 Oct 2016

Detail 101: Type A Basement Wall/ Foundation

In-situ, precast, masonry - partly thermally insulated

Suitable for Table 1 categories 1, 2, 3, 4.

Comments: - Structural layout is indicative only and is subject to individual project design.
 - Drawing not to scale

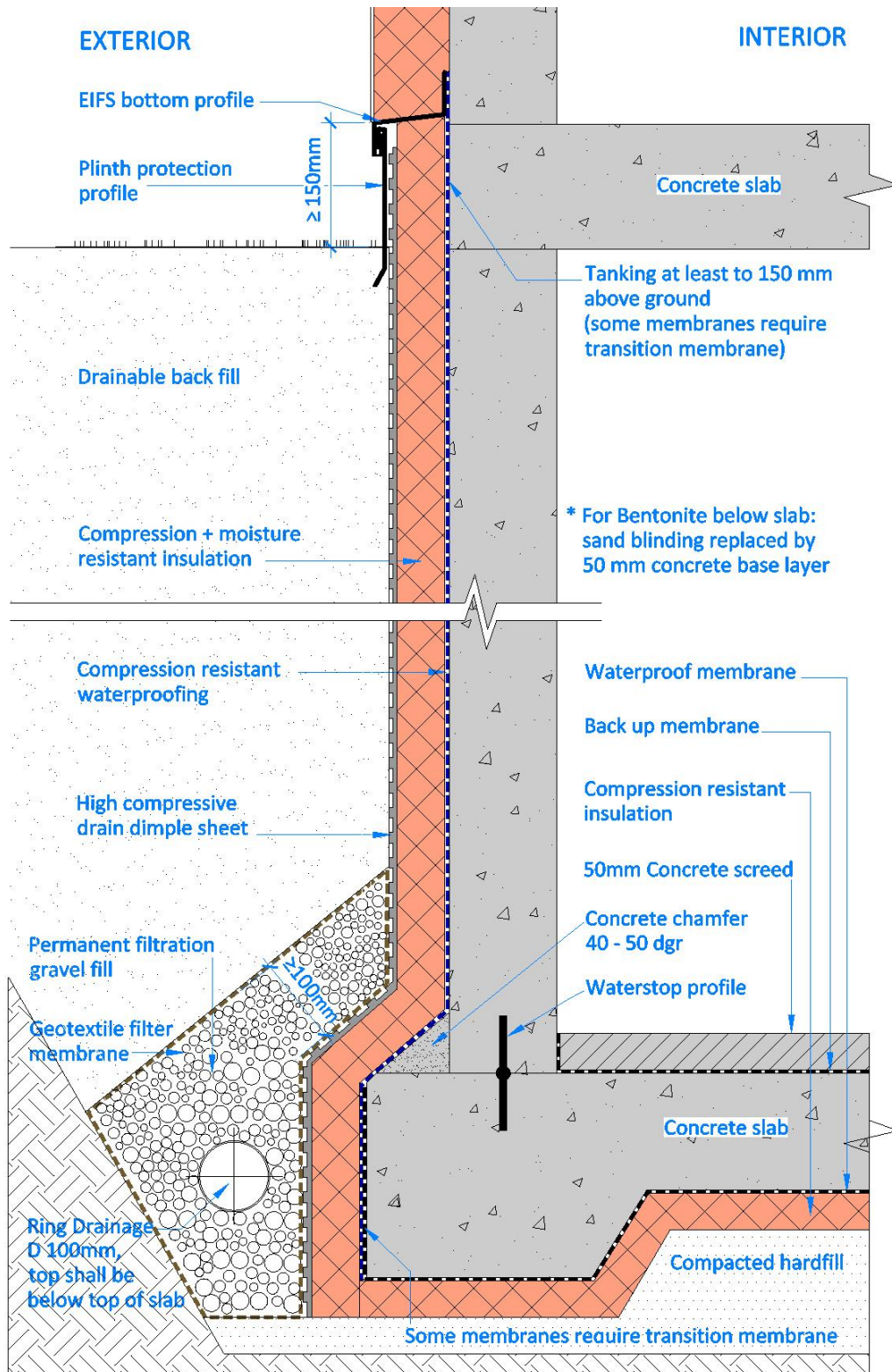


Detail 102: Type A Basement Wall/ Foundation

In-situ, precast, masonry - thermally insulated

Suitable for Table 1 categories 1, 2, 3, 4.

Comments: - Structural layout is indicative only and is subject to individual project design.
 - Drawing not to scale

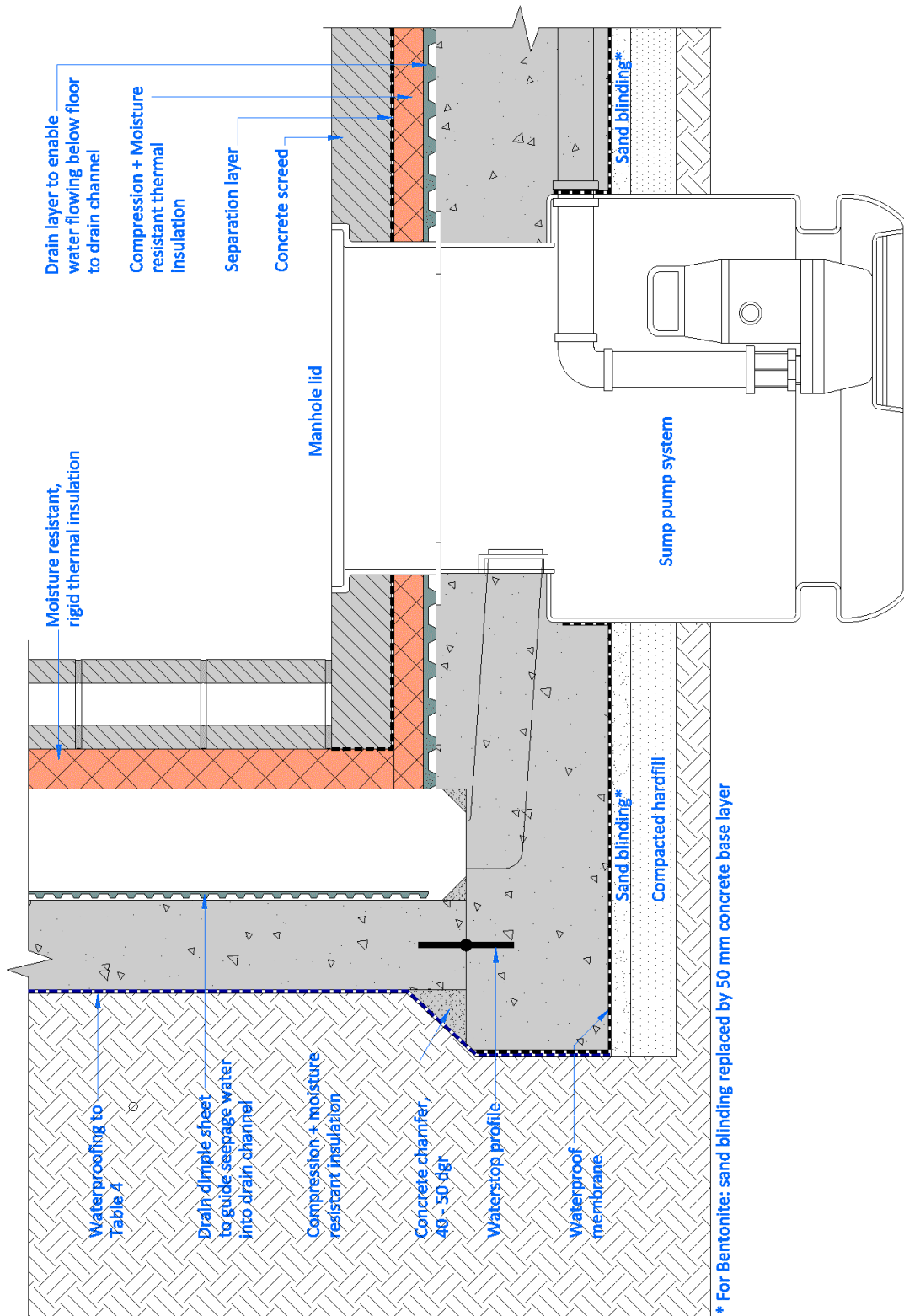


Detail 103: Type C Drained Basement Wall/ Foundation

In-situ, precast, masonry - thermally insulated

Suitable for Table 1 categories 1, 2, 3, 4.

Comments: - Structural layout is indicative only and is subject to individual project design.
 - Drawing not to scale



Step 4: Construction and quality control

Engage suitably experienced personnel to:

- construct the basement
- apply the waterproof layers according to current standards, material compatibility characteristics and manufacturers' guidelines

Implement stringent quality control to:

- ensure the construction and waterproofing application (eg detailing and compatibility) is executed to the correct and highest standard

Step 4 of the process includes constructing the basement, installing any associated drainage and applying any waterproofing that is required.

It is essential that this step is carried out by experienced personnel and that the waterproof layers are applied according to current standards, material compatibility characteristics and manufacturers' guidelines. As noted earlier, all materials must be compatible with each other as they have to function as one system over the building's lifetime.

For all basement types counts, any joints and especially penetrations are potential problem areas and require additional sealing. Water stops should be used to provide enhanced resistance to water transmission at any joints.

Water stop options include:

- rubber or PVC extruded profiles cast into the concrete either on both sides of the joint or mid-depth
- metal bar strips placed mid-depth
- hydrophilic strips or crystallisation slurries forming a monolithic, waterproof compound with the concrete structure (these are applied to the joint at depth before the second cast)
- permeable hose or other sections fixed to the construction joint surface before casting the second pour, to facilitate the injection of a specialist sealing resin into the joint.

Step 4 also requires stringent quality control. This not only includes material and system checks but also observation of the works to ensure that the construction and waterproofing application (eg detailing and compatibility) is executed to the correct and highest standard.

It should be self-explanatory that a functioning drainage system is one of the first steps after excavation works have been accomplished. Installing a perimeter footing drainage system that connects into the sewerage will relieve hydrostatic pressure from surface water and table water in any drainable soil. The larger the slab, the more susceptible it will be to pressure from the water table. Accordingly, for larger slabs consider having a minimum 100 mm layer of rounded gravel distributed evenly below the slab area for drainage.

Install drainable backfill when all construction is completed. However, delay backfilling until all concrete has gained the full target strength. Early backfilling against green (non-cured) concrete puts huge pressure on the walls - cracking and failure is the usual outcome.

Resources

Relevant standards, codes and specifications

- New Zealand Building Code, Schedule 1 to the Building Regulations 1992
- NZS 3101:2006, Concrete structures standard - The design of concrete structures
- NZS 3104:2003, Specification for concrete production
- NZS 3109:1997, Concrete construction
- NZS 3106:2009, Design of concrete structures for the storage of liquids
- NZS 3122:2015, Specification for Portland and blended cements (General and special purpose)
- NZS 3121:1986, Specification for water and aggregate for concrete
- BS EN 1992-3:2006 Eurocode 2: design of concrete structures, liquid retaining and containing structures
- BS 8102:2009 Code of practice for protection of below ground structures against water from ground
- BS EN 12970:2000, Mastic asphalt for waterproofing - Definitions, requirements and test methods
- DIN EN 18195:2011-12 (Part 1-10), Waterproofing of buildings
- BS EN 13969:2004, Flexible sheets for waterproofing. Bitumen damp proof sheets including bitumen basement tanking sheets. Definitions and characteristics.
- BS EN 13967:2012, Flexible sheets for waterproofing. Plastic and rubber damp proof sheets including plastic and rubber basement tanking sheet. Definitions and characteristics.
- ASTM Test D471 - Standard Test Method for Rubber Property
- ASTM Test D5471 - Standard Specification for O-Xylene 980
- ASTM D6222M-11 - Standard Specification for Atactic Polypropylene (APP) Modified Bituminous Sheet Materials Using Polyester Reinforcements
- ASTM D6223M - 02(2009)e1 - Standard Specification for Atactic Polypropylene (APP) Modified Bituminous Sheet Materials Using a Combination of Polyester and Glass Fiber Reinforcements
- ASTM D6509M - 09 - Standard Specification for Atactic Polypropylene (APP) Modified Bituminous Base Sheet Materials Using Glass Fiber Reinforcements
- ASTM D6134 - 07(2013) - Standard Specification for Vulcanized Rubber Sheets Used in Waterproofing Systems

Recommended publications

- Association of Specialist Underpinning Contractors (ASUC): Guidelines on safe and efficient basement construction directly below or near to existing structures 2013.
- British Cement Association (BCA): Basement Waterproofing Design Guide 1994
- British Cement Association (BCA): Basement Waterproofing Site Guide 1994
- Building Research Establishment (BRE), Special Digest 1:2005 - Concrete in aggressive ground

- BS EN 1992-1-1:2014+A1:2014, Eurocode2: Design of concrete structures, part 1-1 general rules and rules for buildings
- BS EN 206:2013, Concrete, part 1: Specification, performance, production and conformity
- BS 5454:2012, Recommendation for the storage and exhibition of archival documents BSI 2000
- BS 8002:2015, Code of practice for earth retaining structures
- BS 8500:2015, Parts 1&2, Concrete - Complementary British Standard to BS EN 206-1
- British Structural Waterproofing Association (BSWA), Waterproofing Existing Basements 2005
- Construction Industry Research and Information Association (CIRIA), Report C660, Early - age thermal crack control in concrete 2007
- Construction Industry Research and Information Association (CIRIA) Report R140, Water resisting basements 1995
- Mineral Products Association (MPA), Concrete Basements: Guidance on design and construction of in-situ concrete basement structures 2012
- National House-Building Council (NHBC), Waterproofing of basements and other below ground structures 2015
- AS/NZS 4058, 2007 Precast concrete pipes (pressure and non-pressure)
- The Basement Information Centre (TBIC), The Building Regulations 2010 - Basements for Dwellings Guidance Document 2014
- The Basement Information Centre (TBIC): Basements: Waterproofing - General Guidance to BS 8102: 2009 (Design Guide)

Glossary

The following glossary includes terms used in this guide as well as others common to the concrete industry and basement design.

Term	Definition
Autogenous healing	Self-repair of cracks by re-hydration of cement within the hardened concrete.
BS	British Standards
BSWA	British Structural Waterproofing Association
CIRIA	Construction Industry Research and Information Centre UK
Crystallisation	Development of crystalline structures within the concrete to block pores and capillaries
Capillary	A hair-thin tube within a material
Capillary action	The migration of liquid through a capillary or tube form
Capillary moisture	Moisture held in the capillaries of a material. Capillary moisture can move upwards and eventually reach areas and joints which cannot deal with hydrostatic pressure.
Construction joint	A joint formed on site when continuity is not possible, eg because of height restrictions given by construction gear, formwork, etc.
Day joint	Joint in in-situ structures deriving from interrupted pour, eg because of insufficient concrete quantity. Also referred to as pour joint.
Expansion joint	Joint that enables movement caused by expansion and contraction due to changes of moisture or temperature
GGBS	Ground granulated blast furnace slag, a by-product of steel manufacturing used as a cement replacement. GGBS can improve the chemical resistance and slightly brightens the appearance of concrete.
Geotextile filter membrane	A membrane that prevents infiltration of fines into drainage systems to protect the system from clogging and blockage but which has high flow rate drainage characteristics.
Honeycombing	Air voids in the concrete as a result of poor compaction
Hydration	Chemical reaction between cement and water when cement forms 'binding stings' to bind aggregates together
Hydrostatic head	Water pressure, expressed as an equivalent depth of water
Hydrostatic pressure	Water pressure exerted as a result of hydrostatic head, pressure created by water
Interstitial condensation	Condensation occurring inside the system
Kicker	Small concrete up stand, cast above floor level to position wall or column formwork for the next lift
Kicker less construction	A mechanical means of retaining formwork in position, eliminating a kicker
OPC	Ordinary Portland Cement (OPC without additions is classified as Cem 1)

Term	Definition
Perched water table	Accumulation of groundwater that is above the water table. The groundwater is usually trapped above an impermeable soil layer, such as clay, and actually forms a lens of saturated soil within the unsaturated soil zone.
PFA	Pulverised fuel ash, a by-product of coal burning power stations used as a cement replacement
Plaster	Any applied coat whose cementing action comes from either gypsum or cement/lime
Plastic cracking	Produced when fresh concrete in its plastic state is subjected to rapid moisture loss (eg in warm weather)
Plasticiser	Admixture added to concrete to improve workability and / or reduce the water content. Also known as water reducing agent (WRA).
Render	Any applied coat which is made up of a sand: cement mix only, and can be used for coatings applied internally or externally. It may incorporate water-resisting admixtures, accelerators, plasticisers or other approved additives.
Seepage	Slow transmission of water through discrete pathways of a structure
Pore blocker	An inert material that is deposited in the capillaries of concrete and so forms a physical barrier, eg a crystalliser
Shrinkage	The contraction or decrease in volume of the concrete. This occurs as when a mixture of cement and water hardens the resultant material occupies a lesser volume than when in its plastic state. Around 50% of the shrinkage occurs within the first four months, but this can continue for up to a year.. The time sequence and shrinkage deformation level are influenced mainly by the start of drying, ambient conditions and the concrete composition.
Shrinkage control joint	Joint to relieve the tensile stress of shrinkage from volume loss during concrete curing
SED	Specific engineering design
Stress	The pressure that builds up within the elements of a structure to resist applied loads and/or pressures
Tanking	Compression resistant waterproofing that is applied to a structure to prevent penetration of liquid, either by capillary action or hydrostatic pressure
Vapour control barrier	A layer which reduces the passage of water vapour, per requirements
VOC	Volatile organic compound
Waterproof	Impervious to the passage of water (also under pressure)
Waterproofing admixtures	Admixtures whose main function is to reduce either the surface absorption into the concrete and/or the passage of water through the hardened concrete. Sometimes called 'water resisting' admixtures and may also be called 'permeability reducing' admixtures.
Water resistant	High resistance (but not impervious) to the passage of water under pressure
WRA	Water reducing agent (see Plasticiser)

