Leaking Concrete Structures – The Beginning of the End?

Udaya Sathiamurthy
Senior Consultant, BG&E

Abstract
The occurrence of leakage within concrete structures are surprisingly more common than most think, including professionals within the construction industry. Leakage at any point in the life of the structure is not ideal primarily due to the disruption it creates to asset operation, impact on the durability and aesthetics of the structure and the impact on public perception regarding the safety of the structure. Often the primary technique utilized to remediate such leakage is injection of resins under high pressure. This technique relies on the resin's ability to react with the moisture within the concrete creating a foam that increases in volume and hardens quickly to arrest the leak. This approach is considered a hit and a miss as it may require several attempts to fill the path of water within the concrete. With increased scrutiny over materials performance, the durability of such resins is being questioned. This paper discusses the various techniques that can be adopted to increase the durability of injection methods and other methods to remediate leakage including techniques that can be adopted to extend the service life of the structure in addition to treatments adopted to arrest leakage.
Prevention being better than cure, this paper also discusses innovative options that can be adopted during design stage, including concrete mix designs, to eliminate or at the very least minimize the leakage that occur within the structure and / or minimize the impact on the durability of the structure in the event of such leakage.

Keywords: leakage, concrete injection, injection resin, durability, crack remediation, waterproofing design.

1. Introduction

Expansion of urban development is inevitable due to rapid population growth in cities. Density of residential and commercial developments in central business districts increase steadily to accommodate this rise in population and the subsequent demand for office, short-term and long-term residential space. As the number of high-rise structures increase, so does the demand for space. Whilst the industry's strategy to increase floor space by extending the structure below ground to multiple levels is inevitable, it comes with its own set of risks and challenges.
One such key challenge is establishing and maintaining an appropriate level of watertightness. Leakage is a common occurrence owing to several factors. This paper discusses the benefits of selecting an appropriate watertightness grade for new construction, and remediation methods that are currently utilized to arrest such leakage. Success of such methods and the longetivity or durability are discussed.
This paper also includes options for designers to incorporate during the design stage itself that reduce the risk of leakage during the structures' service life.

2. Understanding Waterproofing Grades

Selection of an appropriate waterproofing grade enables designers to develop an appropriate strategy to achieve the required waterproofing grade. Table 2 from BS 8102:2009 describes various grades of waterproofing.

Table 2 **Grades of waterproofing protection**

Grade	Example of use of structure[A)]	Performance level
1	Car parking; plant rooms (excluding electrical equipment); workshops	Some seepage and damp areas tolerable, dependent on the intended use[B)] Local drainage might be necessary to deal with seepage
2	Plant rooms and workshops requiring a drier environment (than Grade 1); storage areas	No water penetration acceptable Damp areas tolerable; ventilation might be required
3	Ventilated residential and commercial areas, including offices, restaurants etc.; leisure centres	No water penetration acceptable Ventilation, dehumidification or air conditioning necessary, appropriate to the intended use

A) The previous edition of this standard referred to Grade 4 environments. However, this grade has not been retained as its only difference from Grade 3 is the performance level related to ventilation, dehumidification or air conditioning (see BS 5454 for recommendations for the storage and exhibition of archival documents). The structural form for Grade 4 could be the same or similar to Grade 3.

B) Seepage and damp areas for some forms of construction can be quantified by reference to industry standards, such as the ICE's *Specification for piling and embedded retaining walls* [1].

Several factors should be considered prior to selecting a waterproofing grade. BS 8102:2009 provides guidance on such factors:

1) Initial capital costs compared with costs for future maintenance and any necessary upgrades;
2) The scope for testing during installation;
3) The risks associated with aggressive groundwater and other ground contaminants, which might require the use of a specific protection barrier;
4) The need of ability to provide heating and / or ventilation and the consequences arising in terms of water vapour.

Designers should make clients aware of the advantages and disadvantages of the various waterproofing grades in order to enable them to make informed decisions based on the above factors and occupancy type or usage.

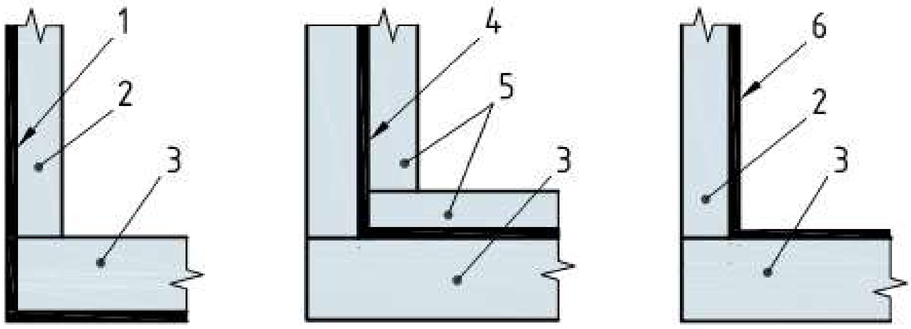
3. Waterproofing Strategy

Developing a waterproofing strategy based on the selected waterproofing grade would be beneficial in ensuring various disciplines including architects, ventilation designers, drainage designers, and geotechnical designers are involved and aware of the impact of the waterproofing system to the overall design of the structure.

BS 8102:2009 provides guidance on the various types of waterproofing protection that can be selected:

a) Type A (barrier) protection
b) Type B (structurally integral) protection
c) Type C (drained) protection

Figure 1, Figure 2 and Figure 3 are extracted from BS 8102:2009 and provide schematic illustrations of Type A, Type B and Type C waterproofing protection.

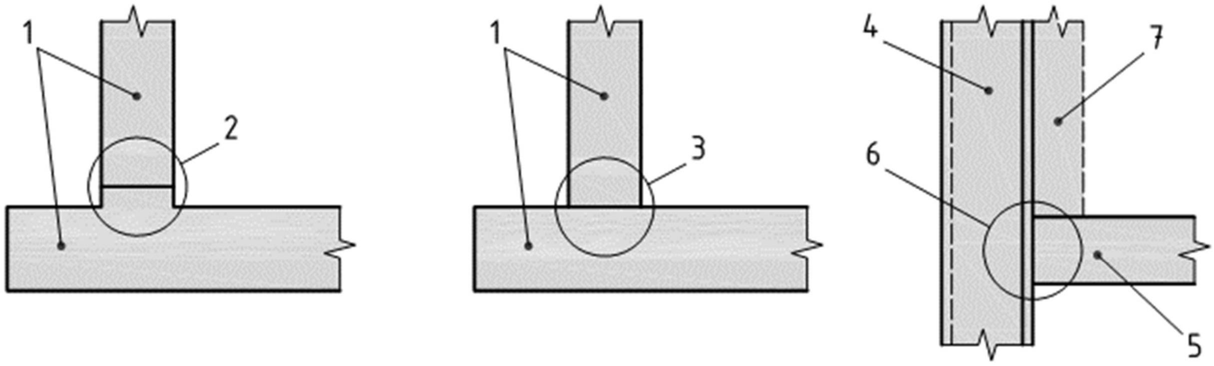


a) Type A (barrier) protection

Key

1 External waterproofing
2 Masonry or concrete wall, as appropriate (see Table 1)
3 Concrete floor slab
4 Sandwiched waterproofing
5 Loading coat
6 Internal waterproofing

Figure 1 Type A (Barrier Protection)



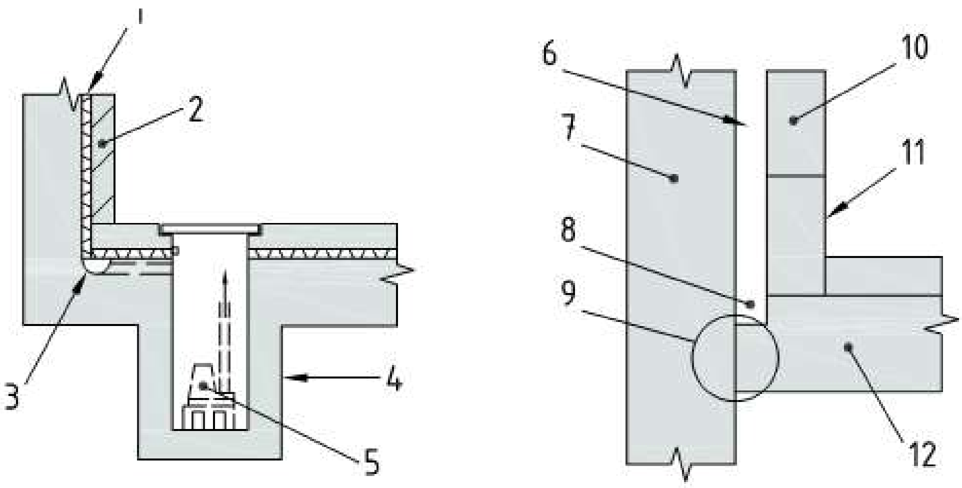
b) Type B (structurally integral) protection

Key

1 Water-resistant reinforced concrete wall and slab
2 External or internal (within wall) waterstop, as required
3 Waterstop required at junction between wall and slab and at all construction joints
4 Concrete/steel piled wall
5 Water-resistant reinforced concrete floor slab or slab with added barrier
6 Waterstop at junction to follow profile of wall
7 Piled wall might need to be faced to achieve desired water resistance (see Table 1)

NOTE Seek the manufacturer's advice with respect to waterstops to suit the specific construction.

Figure 2 Type B (structurally integral) protection



c) Type C (drained) protection

Key

1 Cavity drain membrane
2 Inner skin (render, dry lining or walling, depending on system)
3 Maintainable drainage channel with pipe connection to suitable discharge point
4 Sump formed in situ or pre-formed
5 Pump
6 Wall cavity
7 Reinforced concrete/steel pile or diaphragm wall
8 Drainage channel
9 Waterstop at junction to follow wall profile
10 Internal block wall
11 Access point(s) to drainage
12 Floor slab with integral protection and/or added membrane (internal or external)

Figure 3 Type C (drained) protection

A combination of the above types can be selected based on the required waterproofing grade and project requirements where:

1) The assessed risks are deemed to be high;
2) The consequences of failure to achieve the required internal environment are too high; or
3) Additional vapour checks are necessary for a system where unacceptable water vapour transmission can occur.

Reference can be made to BS EN 1992-3:2006 during the design stage for guidance on crack width limits which can be adopted in the absence of more specific requirements, where crack widths are typically limited to encourage self-healing of cracks at an early age to minimise future remediation requirements prior to asset handover.

4. Watertight Concrete

Watertight concrete is an approach that utilises a concrete mix with a very low permeability to water ingress (through the use of cement replacements and/or proprietary additives and admixtures) in combination with very strict detailing of reinforcement to manage crack widths and detailing of joints to prevent water ingress.

The intent of this approach is to minimise or eliminate the requirement for external waterproofing requirements such as membranes and is reliant on the thickness of the wall and slab elements constructed from high performance concrete to exclude water. Typically, this approach is suitable for structures where the head of water is not more than 5m. Unfortunately, utilising watertight concrete does not provide immunity to the potential for leakage and requires significant care and diligence in detailing and execution during the design and construction phases to ensure success.

5. Remediation Strategies

In the event of a leakage or water ingress, the following assessment can be made prior to selection of a remediation strategy:

1) Effect of leakage on building / asset occupancy;
2) Effect of water ingress on remaining service life of the structure (i.e. impact on durability);
3) Specified waterproofing grade/performance expectations;
4) Accessibility constraints;
5) Installed waterproofing system;
6) Whole of life cost.

Leakage rectification methods that are commonly used are as follows:

a) Application of penetrative or surface treatments;
b) Installation of additional drains to drain off water ingress;
c) Application of waterproofing membranes or coatings;
d) Grouting and;
e) Treatment using high pressure injection.

Concrete Treatments

Concrete treatments can be broadly classified as two types;

a) Hydrophobic treatment and;
b) Hydrophilic treatment.

Hydrophobic treatments are applied either as a surface treatment or a penetrative treatment. They act by sealing linked pores within the concrete or as a continuous film over surface thereby preventing the ingress of water into concrete. Hydrophilic Treatments are generally penetrative treatments that react with available moisture to form crystals which expand in volume and act as a concrete sealer.

Adequate data regarding the longetivity of such treatments in relation to environmental aggressivity is currently unavailable. This method of sealing also does not address leakage through cracks and joints, being more suited to general treatment of larger uncracked concrete surfaces (such as car park decks, balconies and the like that are otherwise well drained).

Installation of additional drains to capture and divert water ingress

This method appears to be gaining popularity in the recent years where it expected joints or cracks will leak and provision is made for water ingress to be drained off into storm water collection points. This approach is not feasible in all situations of water ingress such as:

a) Where services are in place and availability of space for addition of a conduit or drain is limited;
b) Leakage is diverted to storm drains designed for collecting surface water run off – heavy rain can cause an overflow of drains which can result in property damage;
c) Water is aggressive to the concrete leading to durability concerns (so should not be allowed to penetrate the structure);
d) Aesthetic limitations.

Application of Waterproofing Membranes

This method is suitable for applications where positive waterproofing is required. Several membrane application options are available including but not limited to:

a) Bitumen based membranes;
b) Polymer modified cementitious coatings;
c) Spray applied coatings such as polyureas and polyurethanes;
d) Acrylic applications.

If applied correctly, such applications can provide an impermeable application over the concrete surface for extended periods of time depending on the type of membrane and environmental exposure. Such applications however are not suitable for negative waterproofing and are generally not feasible for retrofit unless the application is a roof.

Grouting

This method works by creating an impermeable layer behind leaking slabs or walls. Various types of grouts can be used in this method such as:

a) Cement;
b) Bentonite;
c) Acrylics;
d) Polyurethanes;
e) Polyester resins.

Although this method utilizes durable materials, it also carries risks such as control of flow of grout material, uncertainty in some applications over the integrity of the waterproofing layer created in this manner, relies heavily on the skill and experience of the operator and high cost.

Injection Treatment

Injection is currently the most popular method of treatment of water ingress. This method relies on injection of resins or gels under pressure to fill the voids within concrete thereby sealing the available pores in concrete. This method can be used for treatment of cracks, damp patches and joints and seals leakage through cracks/voids by pumping injection material under pressure using injection ports. As the injection is conducted under pressure, the material seals available voids and interstices within concrete, reacts and cures to form an impermeable barrier, thereby sealing the concrete.

Various injection materials are available for this type of treatment such as:

a) Polyurethane foam resins;
b) Polyurethane resins;
c) Polyurethane gels;
d) Acrylate gels;
e) Acrylate resins;
f) Epoxy resins (most epoxy resins are not be suitable for injection within damp concrete);
g) Cementitious grouts;
h) Polyester resins.

Success of the injection method relies on material selection, skill and experience of the operator and the equipment used for injection. Although the method might be successful in treating the zone or area injected, water typically finds alternate paths to ingress/egress. Continued treatment is necessary as and when water reappears in order to establish complete watertightness. This "hit and miss" approach often leads to some amount of frustration for clients who may perceive the reappearance of water as a failure of the treatment itself. Such drawbacks should be discussed with clients prior to commencing treatment works.

The durability of injection materials has come under scrutiny in recent years. Some materials perform better than others from a durability perspective. Polyurethane foam resins for instance are suitable for short term sealing of flowing water. This is then followed up with injection using gels or resins to form a more permanent leakage treatment.

Treatments using gels and resins are expected to be more durable (compared to the polyurethane foams) as they contain greater active material concentrations and once cured form a more impermeable seal. Acrylic gels and resin systems have the added benefit of customization of reaction time to suit project conditions.

Selection of an injection material should consider the following factors:

a) Damp tolerance for active leaks;
b) Ability to accommodate movement;
c) Durability;
d) Environmental condition.

6. Conclusions

Below ground construction although a necessity in urban developments, comes with a high risk of leakage especially for structures located within groundwater and podium slabs with landscaping and water features. The onus of enabling clients to make informed decisions on selecting an appropriate waterproofing grade for the project should rest with designers.

1) A waterproofing strategy should be developed by various disciplines within the design team prior to detailing for successful delivery of the strategy developed. BS 8102:2009 provides guidance on waterproofing types that can be adopted in the design either singly or as a combination of systems.
2) The benefits of designing the concrete mix to resist water ingress should be explored as part of the waterproofing strategy.
3) Various options for remediation of leakage can be adopted in the event of water ingress.
4) Durability of the remediation strategy utilized should also be considered as some methods may not be capital intensive, but will require ongoing maintenance at varying intervals, compared to more capital-intensive solutions.

7. Acknowledgement

I would like to thank David Millar, Chief Executive Officer for Concrete Institute Australia for his patience and Rob Kilgour, Materials Lead – BG&E Perth, for his support and review.

8. References

1. BS 8102:2009 – Code of practice for protection of below ground structures against water from the ground.
2. BS EN1992-3:2006 – Design of concrete structures. Liquid retaining and containing structures