RESIDENTIAL SLABS AND FOOTINGS IN SALINE ENVIRONMENTS

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1. INTRODUCTION

Salts exist in coastal regions and are present throughout the landscape including the drier inland areas of Australia. These salts have the potential to not only affect the landscape and agriculture, but also the built environment. Increasingly, existing townships (buildings and infrastructure) have to deal with the problems caused by salinity. Investigations for new developments are sometimes required to evaluate both the current situation and the potential for future salinity hazards. Where saline conditions exist, or are likely to develop over time, the requirements for concrete in contact with the ground need to be assessed to ensure its durability and satisfactory performance over the design life of the structure.

In terms of concrete as a building material, the knowledge has for some time been available to design and build concrete structures in severe marine exposure conditions. The same principles can be used to ensure the concrete used for residential footings will provide the required performance when subjected to saline oil/groundwater.

This guide considers urban salinity, its measurement, classification and covers the effects of saline conditions on concrete within the soil/groundwater. It covers issues relating to the design, detailing and construction of concrete. It also provides guidance on the quality issues that need to be addressed when placing concrete to ensure its long-term performance in saline environments. Strategies to minimize the effects of salinity are also given. While the information may apply to all concrete members, this document focuses on residential slabs and footings.

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2   SOURCES OF SALINITY

2.1 GENERAL

Sources of salinity within the environment include naturally occurring salts from marine sediments, salts released from the process of soil/rock weathering, salts transported from the ocean and deposited by rainfall or use of recycled 'grey' water containing salts.

The type of salinity is usually defined by the area in which it occurs. For example; dryland salinity in rural areas, 'irrigation salinity' in irrigated farming lands and 'urban salinity' in built-up areas. This guide deals only with urban salinity. Less commonly, salinity is referred to as either primary, where it occurs naturally within the landscape or secondary, where human intervention has directly contributed to the development or expansion of salinity (e.g. poor drainage and rising water tables bringing salt to the surface).

Problems with salinity are generally linked to the groundwater system, as water transports the salts through the soil. Water moves through the ground in all landscapes, generally from higher to lower areas. The parts of the landscape where the majority of water enters the water table are known as the recharge areas. As the water flows through the soil, salts will be dissolved and transported. Any rising of the water level will thus also bring any dissolved salts closer to the surface. Sometimes, the groundwater level will reach the surface and water (carrying salts) will emerge and leave salt deposits on the surface as the water evaporates. Areas where the groundwater and salts are able to reach the surface are known as discharge areas.

2.2 URBAN SALINITY

Sites can be split into three categories in respect of urban salinity:

- ***Sites with low salinity hazard.*** Typical are those where there are low levels of salts, good drainage (leaching of salts) or those with stable, deep water tables.
- ***Sites that have existing salinity hazard***. Salt-related problems in urban environments include staining of surfaces (white deposit), fretting brickwork, dying vegetation, bare clay 'scalded' surfaces and rapid corrosion of metallic items. For new developments, soil investigations can readily identify whether there is a problem with salinity.
- ***Sites that have the potential to develop a salinity hazard***. Salts are present, but are well below the surface. Because salinity is a dynamic system involving many variables, change in climate, land use and land cover (urbanisation) may result in rising water tables over time. Salts may also be imported to the area.

While some actions can be taken to reduce the risk of a salinity hazard developing, predicting how dynamic systems that depend on so many variables will perform over the typical 50-year design life of a building is difficult.

For sites classified as having the potential to develop a salinity hazard, the best approach is to accept that at some point in the future the hazard will exist. The designer must ensure that building materials are capable of providing the required performance in the future environment.

As land is becoming a scarce resource, it is important that the strategies adopted to deal with salinity allow the development potential of all areas to be realised at an affordable cost to the consumer. Strategies need to be thought through carefully, so that money is invested in actions that deliver the most cost-effective solution. For example, adding to the cost of the land by 'estate' filling over saline areas may not be an effective long-term solution if there is still the potential for capillary action to draw salts to the surface. It could be more economical to keep the land price down and put more resources into the building design, materials and construction to ensure that they are appropriate for the conditions that exist on the site.

2.3 POTENTIAL FOR URBAN SALINITY

The water table (and dissolved salts) is normally at some depth within the soil profile. If the water table is raised sufficiently, the salts that are brought towards the surface can affect vegetation, building elements (footings and walls), services within the ground and infrastructure built on the ground (e.g. roads). The difficulty is being able to determine the impact of a development on the natural system. Another challenge is to predict what changes will occur to the water table over the design life of structures (such as houses) and whether these changes will have the potential to create a salinity hazard.

The key difficulty stems from the naturally occurring variables within the soil that affect the position of the water table, such as:

- The depth of any impermeable layer such as rock.
- The type of soil and ease with which water can infiltrate through it.
- The presence of deep-rooted trees/vegetation that have the ability to not only intercept water before it reaches and adds to the water table but also to draw water from considerable depths, often from the water table itself.

- The amount and variability of rainfall.
- The rate of evaporation of moisture from the soil.
- The capillary suction of the soil (this may raise water by up to 2m in clay soils).
- The uniformity of the soil (if an impermeable layer within the soil profile rises closer to the surface at some point, it may result in a constriction to the flow of groundwater, causing it to rise closer to the surface and possibly emerge/discharge).
- The distance between recharge and discharge areas. For large residential developments or possibly townships, the cumulative amount of recharging along a slope could exceed the capacity of the soil to drain the groundwater. The effect of this will be to raise groundwater to the surface.
- The presence of perched water tables.

A perched water table is where an elevated area has impermeable material underneath the surface, preventing water from draining. These areas are commonly subject to waterlogging.

The variables present in the natural system are increased by additional variables introduced through human intervention which include:

- Estate development including clearing of vegetation, construction of artificial water features, detention basins and estate cut and fill over large areas.
- Single-lot developments and minimal control over the water usage on the site. Increased water addition through excessive watering of lawns and gardens often occurs.
- Reducing natural evaporation and natural recharge by covering the surface with impermeable pavements and structures.
- Use of water that may contain dissolved salts (e.g. 'grey' water reticulation systems, bore water, etc.).
- The use of rubble pits or sullage pits, recharge to the water table.
- Leaking service pipes such as water and storm-water.

It can be seen that many variables influence the position of the water table and thus create a potential salinity hazard. It is also important to realize that the groundwater system within a development may be affected by changes and activities within the development as well as by changes that occur on the surrounding land (possibly many kilometres away).

3 SALINITY ASSESSMENT AND CLASSIFICATION

3.1 GENERAL

No single resource or prescriptive list of tests can provide all the information required to determine the potential for salinity at a particular location. The processes by which salt moves through the landscape are complex, making it difficult to determine the salinity hazard at a specific location.

3.2 BROAD-SCALE RESOURCES

Broad-scale resources such as salinity-hazard maps are general planning tools that identify areas of known salinity and may rank the potential salinity risk as high, moderate or low.

In urban areas, precise identification of individual house lots on broad-scale maps is very difficult, as much of the existing information is available at scales too small for use in urban areas. However, information from broad-scale resources can be used to identify the need for further investigation if the house lot is in an area classified as salt affected or potentially at risk from saline conditions.

3.3 INFORMATION FOR NEW SINGLE LOTS

For single lots, information available from the Developer, Local Council and relevant State Government Department should be checked, as should any Local Council requirements for testing to identify the salinity risk. If it is identified that the lot is within an area that has an existing problem or the potential to develop a salinity hazard, actions will need to be taken. These actions include determining the extent and level of the salinity hazard or risk by sampling and testing. A typical basic investigation would be the excavation of a single randomly located pit, with the salinity of the soil tested at 500mm intervals down to a depth of between 2.5m and 3.0m. This will establish the approximate depth at which saline conditions will occur, the level of salinity and possibly the position of the water table. To determine the types of salts present will require further testing.

For small structures such as a workshop/shed floor, the cost of sampling and testing may be as much as the cost of the floor itself (including measures to address the saline environment) and therefore not warranted. Even for house footings, the cost of the testing has to be weighed against the additional cost of implementing measures to deal with the potential saline conditions. These measures may include increasing the concrete strength and upgrading the vapour barrier beneath the

slab to a damp-proofing membrane (see Section 6.6). Damp-proofing membranes have higher impact resistance than vapour barriers and hence greater resistance to puncturing and moisture penetration.

3.4 INFORMATION FOR EXISTING PROPERTIES

It is likely that information on the potential for salinity is available on existing properties. State Government Departments may have broad scale maps of the area or Local Councils may be aware of areas at risk from salinity. Note that due to the variability of ground conditions, even in areas not known for salinity, the occasional house may suffer damage due to salt attack.

An inspection of existing older buildings on or adjacent to the site may reveal whether or not saline conditions exist in the area. Evidence includes white staining/crusting on the walls and fretting or eroded bricks (usually near the ground), bare patches of lawn (possibly with white appearance from dried salts) and dying vegetation.

If there is evidence of salt, then precautions need to be taken. The soil can be tested to determine the level of salinity or alternatively a conservative approach can be taken where some basic items such as the concrete strength and/or plastic membrane are attended to in the construction to provide the required durability.

3.5 MEASUREMENT

The currently accepted way of determining the salinity level at a site is by measuring the electrical conductivity (EC) of the soil in deci-Siemens per metre (dS/m). Note that a salinity level of 1 dS/m is approximately equivalent to a total soluble salt level of 640 ppm or 640 mg/L.

The procedure measures the current between two electrodes. Sufficient water to dissolve the salts and provide a circuit between the electrodes is therefore required. Two methods are available[2]:

- **Saturated extract electrical conductivity, EC_e.** The soil is saturated with water and the electrical conductivity (EC_e) measured. This procedure takes into account the soil texture as the sample is not broken down by mixing with water. Soil texture is an important factor as the salt attack on concrete depends on the rate of water movement (and therefore the salts) through the soil and how rapidly salts can be supplied/replenished at the face of the concrete. This is discussed in more detail below.

- **Extract electrical conductivity, EC (1:5).** The soil is mixed with water in the ratio of 1 part soil to 5 parts water and the electrical conductivity is measured. As

the soil texture affects the conductivity, conversion factors (**Table 1**) are used to estimate the saturated extract electrical conductivity (ECe) of the actual soil, rather than the soil/water mixture.

The extract electrical conductivity test is a simpler and faster test method, giving results (even after applying the conversion factors) that are accurate enough for determining the requirements for the concrete. With the saturated extract electrical conductivity test, it may take a considerable time to reach the saturation point with soils such as heavy clays.

3.6 CLASSIFICATION OF SALINE SOILS

Table 2 gives a broad definition of salinity classes and their effects on vegetation. The division between a non-saline and saline soil is generally regarded as an EC_e value of 4 dS/m. To give some perspective to the values, the maximum limit for human drinking water is an EC value of 2.5 dS/m. Saline water would be regarded as 6 dS/m, while the Pacific Ocean has an EC value of about 59 dS/m. It should be noted that the classification in **Table 2** was developed to assess the likely impact of salinity on agricultural crops. It is also considered a reasonable classification for salinity in urban areas[1].

Table 1 Factors for converting EC (1:5) to EC_e (based on Abbott[3] and Shaw[4])

Soil texture group*	Multiplication factors
Sands	17
Sandy loams	14
Loams	10
Clay loams	9
Light clays	8.5
Light medium clays	8
Medium clays	7
Heavy clays	6

* Groups are classified for texture on the degree to which soil can be rolled out in the palm of the hand, see *Site Investigation for Urban Salinity*[5] for details.

Table 2 EC_e values of soil salinity classes (after Richards[6])

Class	EC_e dS/m	Comments
Non-Saline	<2	Salinity effects mostly negligible
Slightly Saline	2-4	Yields of very sensitive crops may be affected
Moderately Saline	4-8	Yields of many crops affected
Very Saline	8-16	Only tolerant crops yield satisfactorily
Highly Saline	>16	Only a few very tolerant crops yield satisfactorily

4 EFFECTS ON CONCRETE

4.1 GENERAL

Salt attack occurs from the action of soluble salts. While the problems associated with salinity are often referred to simply as 'salt damp', it is important to realise that there are many different salts that can be present, each having a different deterioration mechanism in terms of concrete.

The ratio of the individual salts present is expressed as an ion concentration. **Table 3** compares the ion concentrations for typical seawater with those found in groundwater tests carried out in the Wagga Wagga[7] (NSW) area and in the soil at Second Ponds Creek[8] (a major residential development) in Sydney. Common salts are chlorides (Cl) and sulfates (S) of magnesium (Mg), calcium (Ca), sodium (Na) or potassium (K).

Measured by the concentration of chloride ions, the groundwater in the worst location at Wagga Wagga is about 33% that of seawater. While at the worst site, Second Ponds Creek - where salts are emerging from the creek bank, the chloride levels are approximately only 20% that of seawater. Hence it is important to realise that urban salinity is generally not the same as the perception of a salt water environment and that at the levels present, designing and constructing concrete residential slabs and footings for durability can be a straightforward process.

Note that the usual test for salinity, electrical conductivity (see Section 3.5), only measures the total soluble salts. The test does not give an indication as to which types of soluble salts are present. By knowing the composition of salts present, a more accurate assessment of the salt attack mechanisms and durability requirements of concrete elements can be made and more effective salinity management strategies implemented.

The three main mechanisms by which salts in the groundwater can attack reinforced concrete are:

* Physical attack.
* Chemical attack.
* Corrosion of reinforcement.

Common to each is the requirement for water to dissolve and transport the salts to the concrete surface. A highly saline soil can be in contact with the concrete and yet have no effect if the soil is dry.

Note that as the salts may dissolve into solution slowly, some codes of practice tolerate concentrations in the soil several times greater than in the groundwater[9].

4.2 PHYSICAL ATTACK

Moisture from the soil can enter the concrete and lead to rising damp and crystallisation of salts (both chlorides and sulfates) as the water evaporates. Depending on the pressure exerted by the crystallisation process and on the strength of the concrete, some disruption of the concrete at the surface can occur. Eventually the surface layer of the concrete may be 'weakened' and possibly fret away, exposing a fresh surface.

In the case of buried concrete elements, fresh surfaces do not generally become exposed to further attack. The exposed and weakened surface layer will typically slow down the rate at which concrete will be further attacked. The rate of attack will also depend on the types of sulfates present, their concentration, movement of groundwater, pressure, temperature and the presence of other ions.

4.3 CHEMICAL ATTACK

In saline groundwater environments, not only are chloride ions present, but naturally occurring sulfates of sodium, potassium, calcium or magnesium can sometimes be found in the soil or dissolved in the groundwater. At certain concentrations these sulfates can chemically attack the concrete. The severity of the attack will depend on the types of sulfates present, their concentration, movement of groundwater, pressure, temperature and the presence of other ions.

Potential sources include:

- Groundwater containing dissolved sulfates.
- Dissolved sulfates formed from oxidation of sulfide minerals in the ground.
- Sulfates from back fill of coal ash or coal washery reject.

Sulfate attack typically involves a reaction between the sulfate and constituents of the concrete to form products that occupy a larger volume than the original compounds. The resulting swelling within the concrete leads to cracking, which in turn allows easier access for further penetration of aggressive elements, thus leading to further deterioration.

Attack from calcium, sodium and potassium sulfates is classified as 'moderate', while magnesium and ammonium sulfates are potentially more severe in their action. This is because they attack a greater number of the concrete constituents.

Note that the groundwater test results for Wagga Wagga (see **Table 3**) indicate that the potassium levels were almost non-existent. Calcium content averaged half that of seawater for the worst nine bore holes and sodium content was only about 12% that of seawater. Thus the sulfate attack would be substantially less aggressive than from seawater. At Second Ponds Creek the values were considerably less again.

Where dense, good-quality concrete of low-permeability is in contact with a solution of sulfates, continuing reaction depends on a renewable source of soluble sulfates. If there is little or no water movement (i.e. static water table), the rate of replenishment of diluted salts from the surrounding soil will be slow, as will be the rate of formation of reaction products. As a result of this the attack will be limited. More details can be found in AS 3735 and the supplementary commentary[10].

The sulfate resistance of buried concrete has been investigated extensively both in Australia and overseas. Findings from these investigations include recommendations for protection measures (e.g. constituents, mix design).

The importance of addressing quality issues such as compaction and curing are also highlighted as they have a major influence on the permeability and hence durability of concrete in these conditions. More information can be found in Stark[11] and Harrison[12].

Particular sulfates in soils can also lead to highly acidic conditions (acid sulfate soils).

While the recommendations in this Guide will also assist in these conditions, more specific recommendations for exposure to these environments are beyond the scope of this document and can be found in BRE Digest 363[9].

4.4 CORROSION OF REINFORCEMENT

4.4.1 General

The concrete surrounding reinforcement provides a highly alkaline environment (pH of around 12) which results in the steel being protected by the formation of a highly impermeable oxide layer on its surface. This effectively protects the steel from corrosion, even in the presence of moisture and oxygen.

The concrete cover to the reinforcement provides a physical barrier against the ingress of substances such as salts. Generally, as the severity of the exposure increases, so will the required quality of the concrete cover. There are two main mechanisms by which the protection of the steel can be impaired and corrosion initiated:

- Reduction in the alkalinity of the concrete which prevents the protective oxide layer forming.
- Ingress of salts such as chlorides which, if present in sufficient concentration, will cause corrosion even in an alkaline environment.

4.4.2 Reduction in the alkalinity of concrete

Reduction in the alkalinity or pH levels of the concrete can occur through the processes of carbonation or leaching. Carbonation is a process where calcium hydroxide in the concrete reacts with carbon dioxide from the atmosphere to form less-alkaline products. Leaching involves the removal of soluble alkali hydroxides (high pH) from within the concrete. Because carbonation requires contact with the air, it is unlikely to cause corrosion problems in slabs and footings buried in the ground, particularly if in moist environments.

Leaching is also unlikely to cause problems as the flow of water through the soil and across the surface of a buried slab or footing is generally insufficient to remove or 'wash out' any soluble alkalis. Leaching of alkalies is possible in acidic soils.

Thus the main factor causing corrosion of reinforcement in slabs and footings is the ingress of salts.

4.4.3 Ingress of salts

Chloride-induced corrosion tends to be associated with intense localised attack of the reinforcement. Referring

to **Table 3**, the highest ion concentration is that of chloride. It is these soluble chloride ions that gradually penetrate into the concrete and cause corrosion of the reinforcement.

Table 3 Major ions (mg/l) in water/soil

Ion	Sea Water	Ground Water at Wagga Wagga, NSW[7]		Soil at Second Ponds Creek, Sydney[8]		
		Worst Site	Average of 9 worst sites	Worst Site (Creek Bank) 1:5 Extract*	Average of 3 sites** (Away from Creek). 1:5 Extract	Average of 3 sites** (Away from Creek). Saturation Extract
Cl	19500	6160	2788	4050	1253	2140
Na	11000	2900	1512	546	201	1425
S	2700	1720	761	24.6	20.1	109
Mg	1400	648	307	13.4	3.0	82
Ca	410	496	244	2.0	0.2	62
K	390	5.7	8.3	1.5	1.7	11.1

Notes: *Maximum values measured at the site.

**The average includes the maximum value at each location.

When the concentration of chloride ions at the steel reaches a certain level, a breakdown in the passive oxide film around the steel occurs, even under conditions of high alkalinity, causing the steel to be activated and corrosion to be initiated. In the presence of moisture and oxygen, corrosion continues or propagates with spalling of the concrete taking place once the expansive forces caused by the rust exceed the tensile capacity of the concrete.

For corrosion of reinforcement to be initiated and to continue, three major conditions must exist simultaneously, viz the presence of salts (e.g. chlorides), moisture and oxygen. It is generally agreed that in a continuously submerged situation, corrosion of reinforcement is negligible due to the lack of oxygen, the diffusion of salts through the saturated pores of the concrete being slow and in some cases, the pores becoming blocked with insoluble products.

In zones that are subjected to repeated wetting and drying, saline water may be drawn through the pores of the concrete by capillary action.

4.4.4 Cracking

Cracking in any concrete element may impact on the concrete durability because it provides a direct passage for moisture (possibly containing aggressive agents such as salts) and oxygen to enter the concrete. Depending on their depth, width and the aggressiveness of the exposure conditions, early corrosion of the reinforcement may occur, causing localised failure and spalling.

5 SITE MANAGEMENT

5.1 GENERAL

In urban areas, salinity management strategies can either be on a broad scale, involving large areas of land such as a subdivision or on a localised scale such as a single-lot development. Strategies to deal with salinity issues vary considerably between subdivisions and single-lot developments. In terms of using concrete in saline environments, the same principles apply to both subdivisions and single lot developments – assess the degree of exposure and provide an appropriate concrete strength and cover.

5.2 SUBDIVISIONS

The development of subdivisions has the potential to alter any existing salinity on a broad scale, including those on adjacent properties and developments. Changing the landform, varying the vegetation in recharge and discharge areas, siting of infrastructure, siting of services and use of grey water can all affect the groundwater and/or salinity levels.

While the short-term impacts may be fairly accurately assessed, predicting the final outcomes of urbanisation over the period (e.g. the design life) is far more difficult due to the many variables involved (see Section 2.3).

If investigations reveal no existing or potential salinity problems, then work can proceed normally. However, if an existing or potential problem is identified, the following should be considered:

- *Salt loading.* Groundwater (containing salts) will flow downward and may emerge in low-lying areas such as creeks and rivers or at the base of a slope. If groundwater is intercepted along the slope through activities such as cut-and-fill construction, provision of retaining walls and installation of roads/services then diverted to storm-water drains, a similar salt loading should reach the creek/river. However, intercepting ground-water can create some opportunities including being able to divert salts to evaporation basins, controlling the height of the water-table and leaching salts out of the soil (see **Figure 1**). The size of the evaporation basin can be designed to perform adequately for the majority of light rain showers experienced in our climate, while in heavy downpours, salts will be diluted and flushed through the system.

- *Slabscaping.* This is a term used to describe the construction of level building blocks by terracing the slopes as part of the subdivision development. Because of the quantity and easy access during development, retaining walls can be provided at a lower cost. While housing lots will cost more, the savings offered to the home owner through economical slab-on-ground construction involving no cut-and-fill or retaining walls far outweighs the increase. In terms of urban salinity, this good all-round solution for sloping sites has similar benefits to individual cut-and-fill construction on single lots, while allowing greater control of the drainage issues (see **Figure 2**).

- *Levels.* The finished surface levels on blocks should be provided with adequate falls to the street to allow runoff of water and prevent water ponding, waterlogging of the soil and to reduce the infiltration of rainfall into the ground.

- *Estate cut-and-fill.* While this may expose some saline material, concrete elements such as house slabs, drains, retaining walls and infrastructure, can be designed to provide the required durability. Depending on the salinity levels, the greatest impact may be the short-term effect on the vegetation such as trees, lawns and gardens. Careful design of the major earthworks should be able to overcome most of these problems. For example, keeping the saline materials covered. For

the long term, the ground levels and design of the drainage system should be able to control the level of the groundwater table. In this way, any salts present near the surface should be gradually leached further down.

- *Concrete retaining walls.* Adequate drainage should be provided behind walls. In saline soils a plastic membrane behind the wall will also assist with reducing the risk of efflorescence on the exposed face of the wall. The walls should have appropriate concrete strength and cover to the reinforcement.

- *Storm-water/subsoil drains.* For level/low-lying areas, storm-water drains along roads can be used to control groundwater levels (see Figure 3). Depending on the situation, these could be installed at greater depth to further lower the ground-water table. Alternatively, to reduce the distance between drains, subsoil drains could be installed along property boundaries.

- *Filling.* If the level of a low-lying area is to be built up by filling (with non-saline material), a drainage layer should be provided beneath the fill to prevent ground-water rising to the surface. Note that this layer should be drained.

- *Capping layers.* Covering saline soils with a layer of non-saline material (perhaps an impermeable clay material) may be an option to avoid disturbance of the affected soil horizon/material, but the long-term effectiveness needs to be evaluated. The material may interfere with the natural evaporation process and cause the groundwater level to rise to the underside of the fill layer. Capillary action, particularly in the types of clay materials that might be used as a capping layer, may then draw the groundwater and salts closer to the surface where building elements and landscaping may be affected.

If there is an existing salinity problem, then all elements within the subdivision will need to be designed to allow for this. The design of the subdivision should also enable an improvement of the situation over time (ie reduction in the salinity) through procedures such as estate tree planting and drainage design to lower groundwater levels and allow leaching of the salts.

Where there is the potential for a salinity hazard to develop, the design process should either guarantee that no future problems will arise, or require that certain basic measures are incorporated into the design of concrete elements (e.g. house footings) to ensure their durability if the situation changes. Note that such a guarantee may be difficult to offer over the typical 50-year design life of a building.
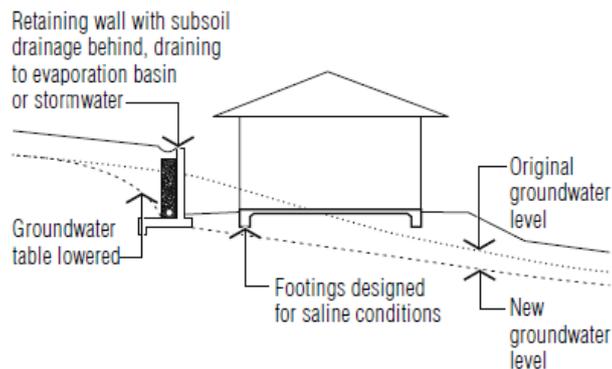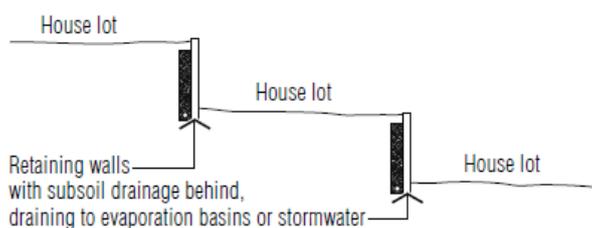
FIGURE 1 Cut-and-fill construction

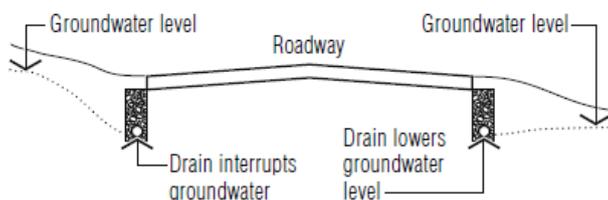**FIGURE 2** Slabscaping provides control of drainage

FIGURE 3 Storm-water drains control ground-water

5.3 SINGLE-LOT DEVELOPMENTS

The opportunities to respond to salinity on single-lot developments are limited to on-site actions such as building and service design, storm-water management and landscaping[13]. However, the impact on the overall salinity system should not be underestimated as each single lot can contribute to the recharging of the water table.

In areas affected by urban salinity, some items to consider are:

- *Cut and fill*. The majority of sloping sites will be cut-and-filled to create a level building platform. This may expose some saline material, in which case the concrete footings, retaining walls and paving should be designed to provide the required durability.

- *Suspended floors*. Note that the strip footings used to support suspended floors are generally deeper than

the edge beams for stiffened-raft type footings. Strip footings generally extend further into the ground, increasing the risk of exposure to saline conditions, especially if there is a high groundwater table.

- *Strip and pad footings*. As a damp-proofing membrane is seldom provided for strip or pad footings, the concrete for these should be designed for the exposure conditions present on the site. If a damp-proofing membrane is installed and a reduced concrete strength and cover used, the member should be completely encased by the membrane[15].

- *External paving*. Where paving (including driveways) is being placed on saline soils, the provision of a plastic membrane such as a damp-proofing membrane under the paving will assist in preventing salts coming through the paving materials. These salts may cause efflorescence and possible physical, chemical and corrosion damage to paving.

- *Concrete retaining walls*. As for subdivisions, adequate drainage should be provided behind concrete retaining walls. A plastic membrane behind the wall will also reduce the risk of efflorescence and possible physical damage to the exposed face of the wall. Concrete retaining wall systems should be designed with the appropriate concrete strength and cover to the reinforcement.

- *Drainage*. Ground and paving levels should ensure that water does not pond on the property as the increased infiltration will raise the water table. Subsoil drains behind retaining walls and around buildings and drains at the base of batters should be effectively drained to avoid water ponding within the trenches/drains. For flat sites, subsoil drainage can be installed to control the level of the groundwater table.

- *Landscaping*. Planting deep-rooted vegetation will assist in controlling the level of the water table by reducing infiltration. Depending on the salinity level, salt-resistant turf and plants could be considered.

- *Sundry buildings and retaining walls*. For items such as garden sheds and small retaining walls, the required design life may only be 10 to 20 years, instead of the nominal 50 years required of new houses. In these circumstances, the normal 20MPa concrete strength may be satisfactory. It is still recommended that the concrete be placed on a membrane such as a vapour barrier to control moisture and efflorescence from the salts in saline environments.

6 CONCRETE SLABS AND FOOTINGS

6.1 GENERAL

This section provides recommendations on concrete strength, cover to the reinforcement, compaction and curing together with measures to control cracking. The

aim of these measures is to ensure the durability of concrete slabs and footings exposed to urban salinity.

The recommendations in this section take account of the relevant requirements in not only AS2870 *Residential Slabs and Footings*[14] but also in AS3600 *Concrete Structures*[15], *AS2159 Piling – Design and Installation*[16], AS3735 *Concrete Structures for Retaining Liquids* and its Commentary[10] and in the National Construction Code[17]. All of these codes are based on a design life of either 40–60 years or 100 years. Currently the National Construction Code[17] and Standards require the use of a minimum 20MPa concrete for residential slabs and footings, regardless of the salinity of the soil, on the basis that adequate protection is offered by the damp-proofing membrane, as it isolates the concrete element from its surroundings. It implies that correct installation and maintenance of the membrane can be guaranteed. Also, there are no requirements for strip and pad footings, the wrapping of which in a damp-proofing membrane is impractical.

A more practical solution is to provide the appropriate concrete strength and cover for the urban salinity exposure conditions present on the site. For slab-on-ground construction, the plastic membrane, apart from fulfilling its primary function of controlling water vapour rising through the slab, can then be regarded as an additional safeguard (if installed correctly). This will also further increase the design life of the concrete element. This approach applies particularly to strip and pad footings where no specific requirements for protection are provided in the Standards.

6.2 CONCRETE

6.2.1 Quality

The permeability of concrete is probably the most important factor affecting its durability, since it will determine the degree of penetration of aggressive agents from the environment. Concrete of high permeability will allow the penetration of salts, moisture and oxygen leading to the deterioration mechanisms (of both the concrete and any embedded steel) discussed previously.

Concrete permeability is influenced by numerous factors, the most significant being the water-cement ratio and the length of time for which the concrete is cured. The cement content is an important factor in producing a cohesive and workable mix, thus facilitating placing and compaction to produce a dense concrete.

It should be recognised that concrete permeability is controlled by factors that are related to the concrete's strength (e.g. water-cement ratio), cement content and degree of hydration/curing. As a result and also

because it is the most convenient method of specification and control, the strength of concrete is the common measure of its quality.

6.2.2 Strength

Adopting the usual philosophy of specifying durability in terms of concrete strength and cover, **Table 4** gives the recommended Normal grade concrete strengths (e.g.N20) for the various salinity classes. These are the standard strength grades of concrete manufactured by pre-mixed suppliers to comply with the requirements of AS1379[18].

Note that while the use of an arbitrary EC_e value for determining the impact of salinity on buildings and infrastructure is a simplification. For concrete durability where the difference in strength between the standard concrete strength grades is about 25% (ie 20 MPa, 25 MPa, 32 MPa, 40 MPa, etc.), the impact of small variations in the EC_e on the selection of the appropriate concrete strength is minimal.

In Section 3.6, it was shown that saline soils are generally regarded as those with ECe values greater than 4dS/m. Therefore, both the non-saline and slightly saline classes would be regarded as nonaggressive soils in terms of concrete durability, leading to satisfactory use of N20 grade concrete for these classes.

Recommended minimum concrete strengths for the salinity classes identified in **Table 2** are shown in **Table 4**.

Table 4 Recommended Concrete Strengths for Salinity Classes.

EC_e Range dS/m	Salinity Class (from Table 2)	Concrete Grade
<2	Non-Saline	N20
2-4	Slightly Saline	N20
4-8	Moderately Saline	N25
8-16	Very Saline	N32
>16	Highly Saline	$\geq$N40

Note that the concrete strengths given in **Table 4** are a guide for saline conditions and may not be adequate in highly acidic soils. Testing at Wagga Wagga[7] revealed the groundwater from all bores to have neutral to slightly alkaline pH values, so no problems with acid deterioration would be expected. At Second Ponds Creek[8], pH values of the 1:5 soil extracts ranged from about 5 to 9. In AS2159[16] this is considered as non-aggressive in low-permeability soils such as silts and clays. This requires a minimum 25MPa concrete for durability of the concrete itself. For highly permeable soils such as sands, where the groundwater at the surface of the concrete can be replenished more easily, the environment would be considered mildly aggressive and require a

minimum 32MPa concrete strength for durability. Note that in this instance these concrete strengths are consistent with those required for durability against chloride and sulfate ions.

6.2.3   *Cover to reinforcement*

In addition to the chemical protection afforded to the reinforcing steel by the alkalinity of the concrete, the concrete cover to reinforcement provides also a physical barrier to the ingress of aggressive agents. The effectiveness of this barrier depends on both its thickness and its quality. Thus adequate cover of good quality concrete is vital in providing durable concrete in aggressive conditions.

Recommended covers to reinforcement are:

* Slabs and internal beams protected by a damp-proofing membrane
    o   To internal surface: 20mm
    o   To membrane in contact with the ground:
                                                    30mm

* Perimeter beams/strip footings not protected by a damp-proofing membrane
    o   Non-aggressive soils: 40mm
    o   Moderately saline soils: 45mm
    o   Very saline soils: 50mm
    o   Highly saline soils: 55mm

The recommended covers for slabs and internal beams protected by a membrane comply with the requirements of AS 2870[14]. Perimeter beams around stiffened rafts and strip or pad footings, where the concrete may not be protected by a suitable membrane, should have increased reinforcement cover.

6.2.4   *Materials*

Concrete is basically a combination of cement, aggregate (fine and coarse) and water. Admixtures and other ingredients are often added to impart particular properties to the concrete in the fresh or hardened state.

It is important to ensure that concrete is manufactured and supplied in accordance with AS1379[18], as this will ensure that the ingredients have also been checked for compliance with the requirements of the relevant Australian Standards.

6.2.5   *Uncontrolled water addition*

The importance of not adding more than the specified amount of water cannot be overemphasised. As water is added to the concrete mix, the water-cement ratio is increased, resulting in lower strength and more permeable concrete that is less able to resist the

physical damage it may be subjected to in a saline environment (see **Figures 4 and 5**).

As a general rule, the more water that is added, the more permeable the concrete will be and hence the less durable. Also, excess water may increase drying shrinkage cracking and produce a weaker surface prone to excessive wear and dusting
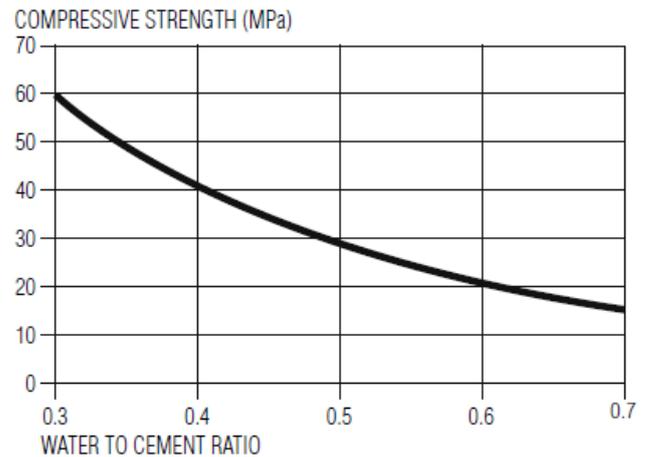

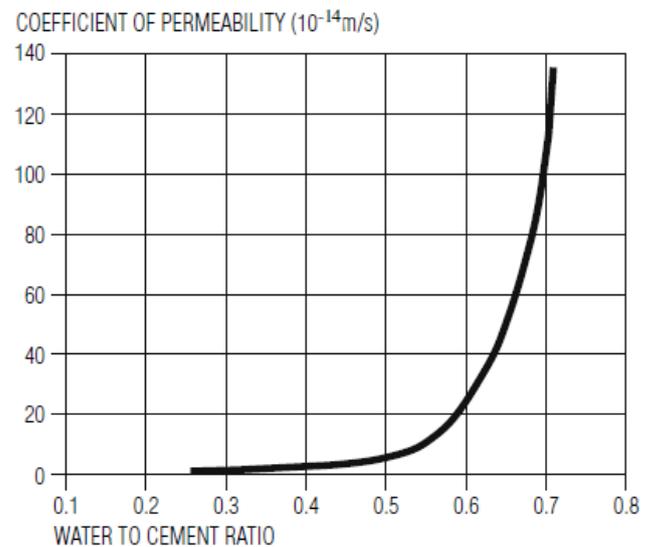**FIGURE 4** Typical effect of water/cement ratio on strength

FIGURE 5 The effect of water/cement ratio on the water permeability of concrete

6.3 REINFORCEMENT

6.3.1   *Fixing of reinforcement*

Reinforcement should be fixed in position to prevent movement during placing of the concrete and to provide the required concrete covers. Comprehensive information can be found in *Guide to Concrete Construction*[19].

6.3.2 Alternative materials

Options for an extended design life include the use of galvanised, stainless steel and epoxy coated reinforcement. For residential slabs and footings, the cost of the latter two options may be prohibitive and a more practical and cost-effective approach is generally to increase the concrete strength or increase the concrete cover to reinforcement.

6.4 CONCRETING

6.4.1 General

The three major phases of concreting are placing, compacting and curing. Each has a significant influence on the quality of the resulting concrete and in particular on its ability to perform satisfactorily in saline environments. Some of the more important aspects of these site practices are outlined here. A comprehensive coverage of all facets of concreting work is provided in *Guide to Concrete Construction*[19].

6.4.2 Placing and compacting

Concrete should be placed to avoid segregation and honeycombing of the mix, as porous concrete will provide an ineffective concrete cover to protect the reinforcement. Any water or debris in the base of piers, footings and thickenings should be removed prior to placing the concrete to avoid problems with increasing water-cement ratio, segregation or washing out of cement paste from the aggregate. Each of these will affect the durability of the concrete.

Compaction of the concrete is critical and leads to an increase in density of the concrete. Good compaction enhances the ultimate strength of the concrete and the bond with the reinforcement. It also increases the concrete's abrasion resistance, decreases its permeability and therefore enhances its general durability.

Proper compaction also ensures that the formwork is completely filled (i.e. there are no pockets of honeycombed material) so that the required finish is obtained on vertical surfaces.

When first placed, normal concrete will contain between 5% and 20% by volume of entrapped air. The aggregate particles, although coated with mortar, tend to arch against one another and are prevented from slumping or consolidating by internal friction.

Compaction of concrete is therefore a two-stage process. First the aggregate particles are set in motion and slump to fill the form, giving a level top surface. In the second stage, entrapped air is expelled, see **Figure 6**.

It is important to recognise the two stages in the compaction process because with vibration, initial consolidation of the concrete can often be achieved relatively quickly. The concrete liquefies and the surface becomes level, giving the impression that the concrete is compacted. Entrapped air takes a little longer to rise to the surface. Compaction must therefore be prolonged until this is accomplished (i.e. until air bubbles no longer appear on the surface).

As can be seen from **Figure 7**, the effect of compaction on compressive strength is dramatic. For example, the strength of concrete containing 10% of entrapped air may be as little as 50% that of the concrete when fully compacted.

Permeability may be similarly affected because compaction, in addition to expelling entrapped air, promotes a more even distribution of pores within the concrete. This causes the pores to become discontinuous and results in improved durability of the concrete..

While the deeper strip footings and beams within slabs on ground (both edge and internal) should be compacted using an immersion vibrator, for 100mm thick slabs on ground, adequate compaction can usually be achieved through the placing, screeding and finishing processes. Sometimes, surface vibration will be used in the form of a small hand-held vibrating screed. Immersion vibrators are not recommended for a 100mm thick slab on ground, as the slab depth does not allow proper immersion of the vibrator head and damage may be caused to the vapour barrier/damp-proofing membrane. The proper compaction of concrete is essential to the durability of concrete in saline environments.

6.4.3 Curing

Curing is the process that controls the loss of moisture from concrete after it has been placed in position (or during the manufacture of concrete products). Curing allows time for complete hydration of the cement to occur. Since the hydration of cement takes time (days and even weeks rather than hours), curing must be undertaken for a reasonable period of time if the concrete is to achieve its potential strength and durability. Curing may also encompass the control of temperature since this affects the rate at which cement hydrates. **Figure 8** illustrates the importance of curing by comparing the strength (at 180 days) of concrete which has been:

- Kept moist for 180 days.
- Kept moist for various periods of time and then allowed to dry out.
- Allowed to dry out from the time it was first made.

As demonstrated by **Figure 8**, concrete allowed to dry out immediately achieves only 40% of the strength of the same concrete water cured for the full period of 180 days. Even three days water curing increases this figure to more than 60%, whilst 28 days water curing increases it to about 95%. Keeping concrete moist is therefore a very effective way of increasing its ultimate strength.
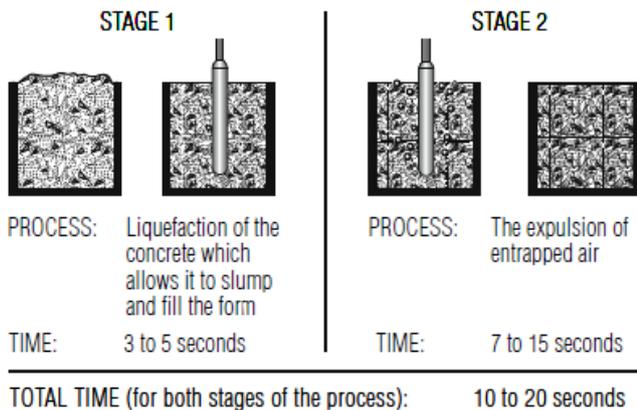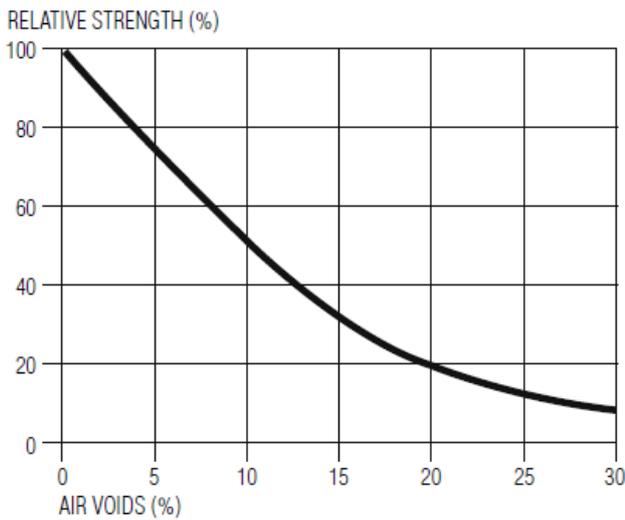

FIGURE 6 The process of compaction of concrete

FIGURE 7 Loss of strength through incomplete compaction of concrete
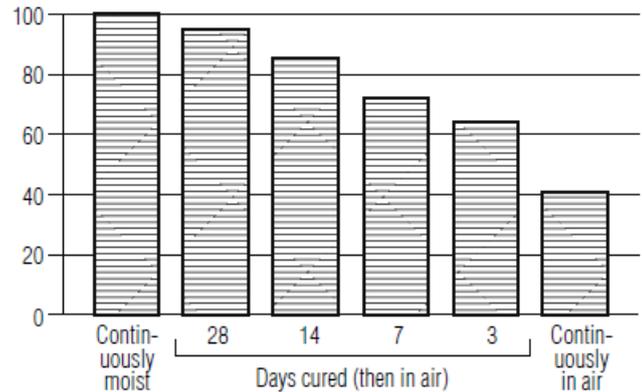
FIGURE 8 Effect of duration of water curing on the strength of concrete

The curing period will depend on the properties required of the concrete, the purpose for which it is to be used and the ambient conditions (i.e. the temperature and relative humidity of the surrounding atmosphere). Keeping concrete moist by preventing the loss of moisture can be achieved by either:

- Preventing an excessive loss of moisture by leaving formwork in place, covering the concrete with an impermeable membrane after the formwork has been removed (e.g. plastic sheeting, chemical curing compound), placement against a plastic membrane or by a combination of such methods.
  Or

- Continuously wetting the exposed surface thereby preventing the loss of moisture from the concrete (ponding or spraying the surface with water are typical methods used).

The durability of concrete is affected by a number of factors including its permeability and absorptivity. These are related to the porosity of the concrete and whether the pores and capillaries are discrete or interconnected. Whilst the number and size of pores in cement paste are related directly to its water-cement ratio, they are also related indirectly to the extent of water curing. Over time, water curing causes hydration products to fill the pores and capillaries present (either partially or completely) and hence to reduce the porosity of the paste.

Figure 9 illustrates the effect of different periods of water curing on the permeability of cement paste. As can be seen, extending the curing period reduces the permeability.

In saline environments, a weak concrete surface is less effective in resisting both physical attack from salts and chemical attack from sulfates. The resulting increased permeability of the concrete provides a less effective barrier to the ingress of aggressive substances such as

chloride ions. The concrete cover provided is therefore not as effective as that assumed in the requirements of the Standards and the design life may be reduced.

Note that it is important to cure all exposed faces of the concrete, including the edges, as these generally have the greatest exposure to any aggressive substances in the soil.

The proper curing of concrete is another essential element in the durability of concrete in saline environments.

Recommended curing periods are:

- Slab Surface:
  - Interior: 3 days
  - Exterior: 7 days
- Slab Edge
  - Non-aggressive or saline: 7 days
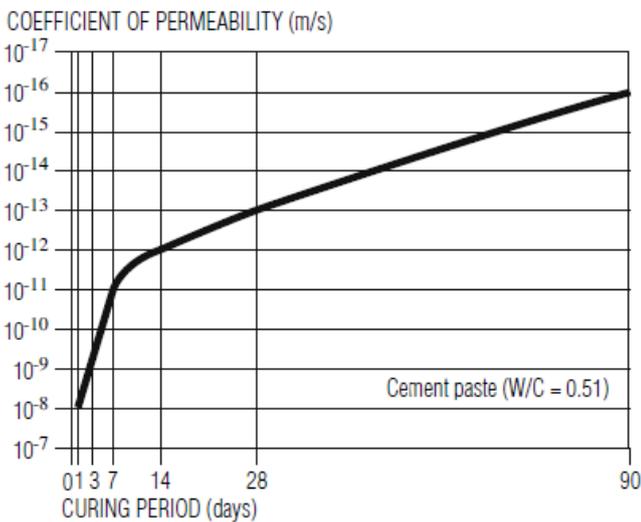
FIGURE 9 Effect of duration of water curing on the permeability of cement paste

6.5 CONTROL OF CRACKING

While cracks are not normally structural problems in house slabs, if wide enough, they may allow the ingress of salts and affect the durability of the concrete in saline environments.

There are many ways to reduce the tendency for the concrete to crack. For normal class concrete, the simplest method is to ensure that no excess water is added on site and the concrete is adequately compacted.

Proper curing of concrete allows it to gain strength so it is better able to resist the tensile forces that cause cracking. Curing not only allows the chemical reactions responsible for strength gain to take place but also delays the drying of the concrete. The increased

strength gain prior to drying will reduce the tendency of the concrete to crack.

More reinforcement is also a simple and relatively inexpensive way to control the size of cracks. Increasing the amount of slab reinforcement by specifying a heavier fabric (e.g. SL92 instead of SL72) will tend to distribute any cracking more evenly. Placing extra reinforcement at points where shrinkage cracking is expected (e.g. trimmer bars at re-entrant corners and specifying overlap of slab fabric in narrow parts of the slab to result in double the amount of fabric in the critical areas) is also effective.

6.6 DAMP-PROOFING MEMBRANE

The installation of a damp-proofing membrane satisfying the requirements of AS2870[14] is recommended for slab-on-ground construction and is mandatory in some States. This should be laid on a minimum 20mm sand layer to minimise the risk of puncturing the membrane and to provide a physical break/barrier to upward movement of ground-water.

Other requirements of AS2870[14] are:

- The entire slab is under-laid by vapour barrier.
- The membrane is lapped 200mm at joints for continuity.
- The membrane is continuous at penetrations by taping or sealing penetrations with a close fitting sleeve.
- The membrane is extended to ground level.

Note that while damp-proofing membranes can be used for strip and pad footings, protection of the top surface (usually below ground level) may be difficult.

7 REFERENCES

1. O 'Flaherty K *Local Government Salinity Initiative – Broad Scale Resources for Urban Salinity Assessment* Department of Land and Water Conservation Sydney, 2002.
2. Rayment G E and Higginson F R *Australian Laboratory Handbook of Soil and Water Chemical Methods* Inkata Press, Melbourne, 1992.
3. Abbott T S *Soil Test Interpretation* Proceedings of a Symposium, Dubbo, NSW, February 1990.
4. Shaw R J 'Soil Salinity', in *Identification of Soils and Interpretation of Soil Data*, pp 145–174, the Australian Society of Soil Science Incorporated, Queensland Branch, Brisbane, 1985.
5. L illicrap A and McGhie S *Local Government Salinity Initiative – Site Investigation for Urban Salinity* Department of Land and Water Conservation, Sydney, 2002.
6. Richards L A *Diagnosis and Improvement of Saline and Alkaline Soils* USDA Handbook No 60, Washington DC, 1954.
7. *Urban Salinity Annual Status Report 1999–2000* Wagga Wagga City Council.
8. Cox J, Fitzpatrick R, Williams B, Davies P and Forrester S *Salinity Investigation at Second Ponds Creek* Consultancy report for Rouse Hill Infrastructure Pty Ltd, July 2002.
9. BRE Special Digest I Concrete in aggressive ground (SD1: 2005).
10. AS 3735 *Concrete structures for retaining liquids* Standards Australia, 2001. AS 3735 Supp1, *Concrete structures for retaining liquids – Commentary*, Standards Australia, 2001.
11. Stark D, *Long time Study of Concrete Durability in Sulfate Soils* Portland Cement Association, Research and Development Bulletin RD086.01T.
12. Harrison W H Sulfate Resistance of Buried Concrete The third report on a long-term investigation at Northwick Park and on similar concretes in ~~sulphate~~ sulfate solutions at BRE Building Research Establishment Report CI/SfB q2(R8), 1992.
13. Western Sydney Salinity Working Party, Western Sydney Salinity Code of Practice, Western Sydney Regional Organisation of Councils, 2003.
14. AS 2870 Residential slabs and footings - Standards Australia, 2011.
15. AS 3600 Concrete structures - Standards Australia, 2018.
16. AS 2159 Piling – Design and installation - Standards Australia, 2009.
17. National Construction Code, Volume 2, Building Code of Australia, Australian Building Codes Board, 2016.
18. AS 1379 Specification and supply of concrete, Standards Australia, 2007 (R2017)
19. Guide to Concrete Construction (T41/HB64) Cement and Concrete Association of Australia and Standards Australia, 2002