Waterproofing practices in Australia for building construction

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Abstract. Waterproofing is an essential component in building construction to maintain the integrity of buildings with reduced maintenance cost. A comprehensive waterproofing system is an integrated combination of factors, and includes product selection, membrane detail, substrate preparation, design, installation and maintenance. It is designed to work under different environmental conditions, substrates and applications. Proper understanding of the issues related to waterproofing membrane systems is important to minimise the waterproofing failures in both commercial and residential buildings. This paper aims to discuss Standards and Codes; membrane systems and performance, waterproofing practices, design and installation techniques, inspection and testing and quality assurance adopted by the waterproofing industry in Australia.

1 Introduction

Waterproofing is a fundamental and vital construction activity to maintain the integrity of both commercial and residential buildings over its service life. It minimises the post-completion problems mainly caused by water damages such as mould growth and rusting. A comprehensive waterproofing system is an integrated combination of factors, includes product selection, membrane detail, drainage design, substrate preparation, design, installation, quality assurance and maintenance. The advancements in technology have led to the development of various waterproofing membrane systems, namely liquid, sheet and spray-applied membranes. Each of these systems has its advantages and disadvantages. This paper aims to discuss Standards and Codes; membrane systems and performance, waterproofing practices, design and installation techniques, inspection and testing and quality assurance adopted by the waterproofing industry in Australia.

2 Standards and building codes in Australia

AS3740 [1] (Waterproofing of domestic wet areas) and AS4654.1/2 [2, 3] (Waterproofing membrane systems for exterior use) are current Australian standards used by the building and construction industry in Australia. AS4654.1 [2] lists the conditions and requirements that membranes will be subjected to test its durability. This includes time, humidity, water

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immersion, chemical resistance, tensile and adhesive bond strengths, abrasion and puncture resistance, and ultra-violet (UV) testing.

Table 1. Australian standards durability testing for membranes.

Exposure	Conditions	Requirements	Pass / Fail Criteria
Control samples	7 days at 23 ± 2°C and 65 ± 15% relative humidity	Record the tensile strength and elongation at break	N/A
Water immersion	7 days at 23 ± 2°C and 65 ± 15% relative humidity plus 7, 28, and 56 days immersed in 1 L of deionized water at 23 ± 2°C, surface dry and test	Record the tensile strength and elongation at break. Note any significant change in appearance, e.g., blistering	Elongation at break shall be not less than 25% retention of elongation at break of the controls
Chemical resistance testing			
Detergent	7 days at 23 ± 2°C and 65 ± 15% relative humidity plus 7, 28, and 56 days immersion in 1 L 2% solution of N8* at 23 ± 2°C, surface dry and test	Record the tensile strength and elongation at break. Note any significant change in appearance, e.g., blistering	Elongation at break shall be not less than 25% retention of elongation at break of the controls
Heat ageing	Condition where necessary for 7 days at 23 ± 2°C and 65 ± 15% relative humidity then plus 14 days heat ageing at 80 ± 2°C plus 2 days at 23 ± 2°C and 65 ± 15% relative humidity	Record the tensile strength and elongation at break. Note any significant change in appearance, e.g., blistering, etc.	Elongation at break shall not be less than 50% of the result recorded for the controls
UV	Condition where necessary for 7 days at 23 ± 2°C and 65 ± 15% relative humidity then plus 1000 hours of exposure in a Q-Panel Ultraviolet (QUV) weatherometer	Record the tensile strength and elongation. Note any significant change in appearance, e.g., blistering	Elongation at break shall not be less than 40% of the result recorded for the controls
Bio resistance	Due to the diversity of testing for different materials, it is recommended that the manufacturing guidelines for bio resistance should be followed		

* or equivalent. N8 is a generic type of detergent.

NOTE: Passing the 'heat ageing' requirement listed in Table A4 will automatically meet the requirement of the 'heat ageing' requirement of AS/NZS 4858.

These standards set out the minimum requirements for the materials, design and installation of waterproofing to these specified areas. AS4858 [4] specifies the standard testing procedure to evaluate the moisture penetration of waterproofing membranes. There are no current standards for waterproofing systems for below-ground use. Hence waterproofing to retaining walls, lift pits and basement under-slabs must be installed according to the manufacturer's specifications by the licensed and approved applicators.

Building Code of Australia (BCA) sets the minimum health, safety and sustainability requirements in the building industry. As the BCA in enforced by the law, it must be complied with by the designers and contractors. In relation to waterproofing works, all internal wet areas must be designed and constructed in accordance with the performance requirements set by the BCA. The objective of waterproofing is to protect the occupant and the structure from the accumulation of moisture build-up entering the building (BCA, 2012). BCA Code 3.8.1 [5] sets the waterproofing and water-resistant requirements for building elements for high, medium and low risk wet areas. Wet areas must meet deem to satisfy the performance requirements by following BCA Code 3.8.1 [5] construction practices or as outlined in AS3740 [1]. It is common practice in the building industry to meet both requirements to ensure that proper construction practices are performed.

Technical data sheets (TDS) on membrane products are important to understand the composition of membrane, application, application procedure, material properties, coverage rate and safety advice. TDS and material safety data sheet (MSDC) should be used in conjunction with each other to give vital information on the product in regard to its use, installation and safety information. In Australia, all material safety data sheets must be no older than 5 years old. National Occupational Health and Safety Commission (NOHSC) require all current material safety data sheets to be prepared in a specific way.

3 Classifications of membrane systems

The selection of a proper waterproofing membrane system for a location is important since the membrane type and primer type both determine its adhesion to the substrate. Considering the environmental impact, the waterproofing industry has developed membrane systems, having little or no volatile organic compound (VOC) content without affecting its waterproofing performance. Two main forms of the waterproofing membrane systems are hydrophilic and hydrophobic. Although they are chemically different in composition, both are capable of preventing water penetration into the protected building components. Hydrophilic membrane systems are comprised of particles that crystallise in the presence of water to prevent water ingress. Hydrophobic membrane systems prevent water ingress due to blocking the pores in concrete by fatty acids particles.

3.1 Liquid membranes

Liquid membranes can be applied to different surfaces and have the ability to create a seamless finish to areas that are difficult to access and where surfaces change from floor to walls. They are usually applied by brush or rollers and commonly require a minimum of 2 coats to eliminate air pockets. Fig. 1 shows the application of liquid membrane system on a podium. They come in various forms and can be cold-applied or heat-applied, one or two part systems, depending on the composition and reaction of the membrane system.

Acrylic membrane systems are relatively cheap compared to other membrane systems. They come in three forms which include solid bead form, polymer solution form and emulsion form [6]. They are commonly used in internal wet areas and in some instances balconies due to its durability and ability to be formulated to be ultra-violet (UV) resistant. Emulsion form acrylic membranes are most commonly used due to their low manufacturing costs, less hazardous and altered chemically to suit the application [7].

Fig. 1. Liquid applied membrane system in the process of being applied on a podium.

Polyurethane membranes are known for its robustness, chemical properties, ease of installation and high performance. They are available in various forms including single or two components, aliphatic or aromatic form [8]. These forms cure by the reaction of air moisture and/or hardeners [9]. They can be formulated to contain UV resistant properties or by the application of UV resistant top coat. The advantage of two-part polyurethane systems is that it can be formulated to contain 100% solids without any solvent.

Modified bitumen systems are used at the stage when waterproofing systems started to advance due to its seamless finish and waterproofing properties. Hot-applied bitumen systems require the product to be heated to the required consistency before its application to the substrate. Modified bitumen systems were commonly used on roof areas with the use of reinforcing material, if required. The application of bitumen systems is risky in itself as it involved transporting the buckets of hot bitumen liquid to the roof, introducing the risk of any tips, trips, falls or burns which can cause harm to workers and public. As polymer modified bitumen systems are not UV resistant and cannot withstand pedestrian traffic, adequate protection is required.

Methyl-methacrylates (MMA) flooring systems (also known as an acrylic system) are an advanced acrylic technology, based on a methyl-methacrylate resin [9]. MMA flooring systems are based on a two-part system which when combined, rapidly cure to create a tough, flexible and seamless flooring or decking system. Due to its rapid cure formulation, MMA systems can be installed in most environmental conditions. It is usually installed in areas where there is constant traffic or where a flooring system is required in lieu of a standard sand-cement floor topping such as in commercial kitchens, plant rooms, hospital flooring, bridges and roofs.

3.2 Sheet membranes

Sheet membrane systems have been used due to their precise consistency in thickness and high durability. However, they are labour intensive due to the installation process involving sheet membrane handling, cutting, installing and detaining. Sheet membrane systems also have visible seams where sheets overlap and detailed. The use of detailing to terminate the membrane by a pressure seal introduces the risk of poor detailing where water could seep under the sheet membrane and create ponding in large areas under the membrane. The sheet membrane systems should be installed by experienced and licensed applicators according to the correct manufacturer’s standards and recommendations. Sheet membranes can easily be formulated and reinforced with other materials to make the membrane stronger, UV resistant or root resistant through the use of granules, minerals and reinforcing layers.

Torch-on PVC and bituminous sheet membranes is an old membrane technology. They provide many advantages such as durability, thickness uniformity and flexibility of use in below and above-grade applications. It also has its flaws, namely in the lapping of sheet membranes where they are torched to bond the sheets together. If the seal breaks, water can be trapped behind the sheets making the whole waterproofing system fail. To successfully install multi-layer sheets, full adhesion between the sheet and substrate must occur. It is recommended that sheets should be installed in a different pattern to the previous layer to ensure seams do not occur at the same spot. Detailing to torch-on membrane systems also plays a vital role in its installation as membrane must be mechanically fixed.

Bentonite clay membrane systems are most commonly used in below-ground applications such as basement retaining walls, under-slabs and lift pits which are installed before the concrete is poured. Bentonite clay is a natural mineral derived from sodium bentonite which swells in the presence of moisture (usually caused by the moisture released from concrete), causing the system to swell up to 30 times its original size [10, 11]. The swelling of clay creates a strong impervious membrane system that is resistant to moisture.

3.3 Spray-on membranes

The spray-on membrane systems are surpassing the conventional method of roll, brush or sheet applied systems, making the application of waterproofing systems less labour intensive by creating one continuous and seamless finish. The polyurethane liquid spray applied form has significantly impacted the rate of application, making the application of membrane systems less labour intensive. High resistant solvent free polyurethane spray-applied waterproofing systems have excellent adhesion properties and can easily be built up in thickness, if required. The spray-applied systems bring up the issue of uniform thickness throughout the waterproofed area; as liquid membranes applied by brush or roller can produce a more consistent finish. However, the application by an experienced spray-applied user will produce a relatively consistent finish. To overcome the risk of the spray-applied system being under the specified recommended thickness, testing is performed to the waterproofed area to ensure the application is satisfactory.

4 Types of waterproofing membrane

The use of either incompatible or improper application techniques can cause damages or leakages into structures. The damages can range from affecting the surface profile of the structure to the structural integrity of the building. A comprehensive waterproofing system set is an integrated combination of factors. They are proper product selection, membrane detail, substrate preparation and installation. The selected product should be suitable to the building environment and compatible with other surrounding building materials. This is necessary to achieve cost effectiveness, meet construction detail requirements and maximise the product advantages.

4.1 Positive and negative side membranes

Positive side membranes are applied on the side of applied hydrostatic pressure, preventing water from entering through the wall/surface [10]. It is the main line of defence to stop the water from infiltrating into the building; protecting the concrete and reinforcement from any chemical attack and controls the humidity within the structure [12]. Waterproofing additives can also be placed in concrete as a secondary line of defence.

Negative side waterproofing on the other hand, refers to membranes that are applied on the opposite side of applied hydrostatic pressure so that water cannot leak into the building once it permeates through the substrate. It is commonly applied to areas that are inaccessible on the positive side such as existing structures and commonly include lift pits and basement walls. Negative side waterproofing can also be used in conjunction with positive side waterproofing to areas where there is a high risk of water ingression. Deciding on whether the location requires positive and negative side waterproofing should be the first design step in creating a waterproofing system.

4.2 Sub-grade and above-grade waterproofing

Sub-grade waterproofing are areas in which the membrane is applied externally below the ground surface level of the building. Typical areas include building under-slabs, lift pits, tunnels and retaining walls. Under-slab and retaining walls require different waterproofing techniques, where under-slabs require the waterproof system to be installed before the concrete is poured on to it, often referred to as blind-side waterproofing whereas membrane to retaining walls can be applied directly to the wall once it is constructed. Sub-grade membrane selection should consider its ability to withstand constant contact with moisture and its root resistance properties.

Above-grade waterproofing refers to areas that are above the ground surface and require waterproofing and can be further classified into internal and external works. It is required to the areas where climate conditions and water usage can cause damage to the structure. Typical above-ground locations that require waterproofing include balconies, internal wet areas, podium areas above basements, planter beds on suspended slab and in some instances, roof areas. Membranes to these areas can be applied by roll/brush, trowel, sheet or spray applied unit systems.

4.3 Exposed and non-exposed system

Waterproofing coating systems can be divided into two categories; exposed systems and non-exposed systems. Exposed membrane systems refer to membranes that are directly exposed to the elements such as pedestrian and/or vehicular traffic, ultraviolet light, spillage, rain and chemicals [13]. These systems will require a maintenance program to ensure longevity during its operational life. Non-exposed membrane systems otherwise known as protected systems are usually below-grade or are between slab-floor finish applications where the waterproof membrane is hidden from view after the project is finished. In this instance, application of the system must be robust and durable enough to function without maintenance for decades of the structure’s design life.

5 Extent of waterproofing

Identifying the extent of areas to waterproof in a structure is simple. Any surface area that is in contact with water, or has the opportunity for water to come in to contact with it or has the risk of creating water ingress into a building needs to be waterproofed. Waterproofing can be termed as high-risk or critical when the waterproofing area is over a habitable space. Any waterproofing membrane failure will cause a leak into the structure, which can cause collateral damage to expensive plant and equipment, priceless artworks and possessions to name a few. The waterproofing areas in buildings can be classified into three main categories such as internal, external and sub-grade works.

5.1 Internal works

Internal wet areas (bathrooms, amenities, and laundry) are the most common locations where rectification and defect works are performed as they are subject to constant wear and tear, thus, increasing its likelihood of water damage. The extent of membrane to internal wet areas includes the entire floor area, 150mm up floor/wall junctions, membrane detailing around all waste water outlets and fittings, vanity splashbacks, a minimum 1800mm up shower walls (in some instances 2100mm may be required) and 800mm up bath walls. Common membrane systems used for internal wet areas are two-part reinforced systems, acrylic or polyurethane membrane systems. Compatibility between the membrane and adhesives used should be considered as some ceramic tile adhesives may not adhere directly to the membrane system. Timing also plays a factor as some membrane systems require tiling to be done within 24 hours of membrane curing for optimum adhesion. Waterproofing is not required to residential kitchens.

The standard AS3740 [1] recommends that general floor areas require a minimum fall to waste of 1:100, with hob-less shower areas requiring a minimum fall of 1:80. The use of toppings graded to falls and shower trays offer an effective system to divert water to discharge outlets. A secondary membrane application over shower floor toppings can also be executed for protection and to reduce efflorescence.

5.2 External works

Balconies are one of the most common areas to membrane in residential buildings and require waterproofing as they form an integral part of the building. They are considered high risk areas when they are located over habitable space. The correct membrane detail and drainage solution is critical to avoid water leaks. Drainage outlets are usually located in the centre or at the lowest point on the floor, whichever is lowest. Detailing to all outlets and membrane termination plays a role to provide a good waterproofing system. Membrane to hobs, penetrations and plinths in balconies, podiums, wet areas, plant rooms and roof areas are required so that these areas do not create a potential spot for water ingress.

Balconies, roofs or podium areas containing built-in planter boxes and landscaped areas could be waterproofed in two instances. The first situation occurs when the slab is poured, walls are built and the area is waterproofed. The second being when the concrete slab is poured, waterproofed and the planter walls are installed at a later date when all other trades have used the area during construction. Hence, it is best practice to membrane the entire podium slab and planter bases in one continuous system to create a seamless finish.

Construction joints and movement joints differ in the way the concrete is installed. With construction joints being tied to connecting slabs, whilst movement joints are joints that can withstand structural movement. Construction and movement joints that run through areas that will be waterproofed need special detailing and protection before the application of the waterproofing system. Typical locations where construction and movement joints will need waterproofing treatment include podiums and roof areas.

Construction joints are subjected to less movement than expansion and movement joints hence, they require different treatment. This can be achieved by either placing a bond breaker tape or a double detail to the joint. To reduce the likelihood of leaks occurring, landscaped areas should not be placed to areas which have movement, expansion and construction joints.

Roof plant rooms are commonly waterproofed to prevent the water leaking to the below levels. The only difference between waterproofing an external and internal roof plant room is that external roof plant rooms require a UV resistant membrane. Membrane systems applied to these areas should be slip resistant, durable to traffic, abrasion resistant and UV resistant. It is critical that all roof areas are watertight to prevent the infiltration of water into the structure. In situations where roof areas are paved, exposed or is a green roof, it is recommended that a membrane system be in place.

There are three types of trafficable surfaces a roof could be subjected to: (a) vehicular; (b) maintenance; and (c) pedestrian (AS4654.1) [2]. The type of membrane used is dependent on this finish and usage of the roof. Exposed trafficable roof areas require a UV resistant membrane with a non-slip finish. The membranes used on exposed trafficable roof areas should take into consideration the membrane's UV resistance capability and its ability to withstand traffic and environment conditions.

6 Waterproof defects and risk minimization strategies

Four main signs of waterproof failure are: (a) bubbling of membrane; (b) wet walls and/or floors; (c) water ponding; and (d) mould growth. A good waterproofing system is designed to drain water away from the area and has the correct waterproofing system installed. Ponding of water can lead to waterproof failure over a period of time, with any points of weakness in membrane areas increasing the risk of water penetration.

The waterproofing failure occurs due to one or a combination of following factors: (a) inadequate surface preparation; (b) poor applicator skills and competence; (c) poor product selection; (d) expiration of product material; (e) incompatibility of membrane system to location; (f) not taking into consideration the environment conditions; (g) insufficient membrane detailing; (h) inability of the membrane to withstand the structural movements; (i) inadequate quality control including inspection and testing; and (j) poor maintenance of membrane. These factors cause the membrane failure, causing areas of blistering, bubbling and pin-holing when air bubbles or water vapour are trapped between the substrate and membrane. Fig. 2 shows a typical membrane failure with the formation of bubbles on a deck application. Membrane has to be stripped and reapplied with adequate surface preparation.

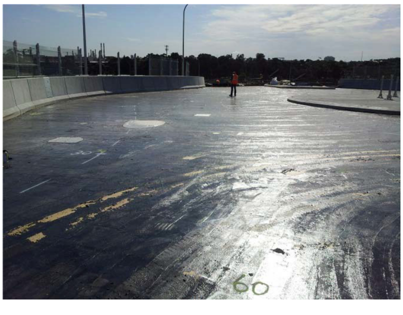

Fig. 2. Membrane failure in a deck area with the signs of bubbling.

Pinholes and blisters often form due to the application thickness of the membrane, the temperature during application and the rate of polymerization of the membrane and substrate [14].

The build-up of moisture is a tell-tale sign that there is a water ingress problem. This could affect the integrity of the structure. The delamination of adhesive seals at joints also plays a major factor in membrane failures as it allows water ingress. Adequate adhesive and termination details should be implemented before the membrane application to ensure all points are made watertight.

The application of membranes in thicker coats instead of several coats to achieve the recommended dry film thickness (DFT) is highly discouraged as it increases the risk of air bubbles being trapped between membrane and substrate.

The risk of water infiltrating the structure could be minimised during the design, construction and post-completion phases of the project. At the design stage the following considerations should be made: (a) waterproofing areas on top of each other (i.e. balconies over balconies) to reduce the risk of water ingress into the habitable area; (b) designing landscaped areas around movement joints; (c) avoiding the use of inferior/incorrect membrane systems; and (d) avoiding under-priced tenders. Construction phase considerations are: (a) assessing the extent of waterproofing required; (b) designing a waterproofing system; (c) selecting the correct products suitable to the service and exposure conditions; (d) scheduling waterproof membranes installation; and (e) selecting qualified and experience water proofers to supply and install membranes. Post-completion phase consideration is to perform proper inspection and maintenance to detect the defects.

7 Design techniques

The design of the waterproofing system should consider the drainage system, compatibility of membranes with other building materials, exposure conditions of membrane during and after application, finishing of the membrane, detailing of the membrane, consideration of expected movements in the membrane and the loads on the membrane.

The key design aspect in a waterproofing system is the drainage system to reduce the risk of water ingress. This includes constructing substrates to falls and allocating a point of water drain holes. Topping screeds should be used, if concrete is not laid to falls, preferably installed above the membrane to protect the membrane from damage. However, a slip sheet is recommended in between the membrane and topping so that less pressure is placed on the membrane when the topping shrinks over time.

The waterproofing membrane system should be compatible with the concrete substrate, any screed/topping types (placed below or over the membrane) and any adhesives used. Membrane products selection should consider its appropriateness to the location and exposure conditions. This includes its chemical and physical properties of resistance, elongation and its application on previous projects. Flexibility of membranes should be taken into consideration for movement in the structure, as well as the expansion and shrinkage of concrete. Flexibility becomes a critical factor when designing for movement and construction joints that run through waterproofed areas.

For slabs that are below the water-table, waterproofing to the under-slab is recommended. For basements that are above the water-table, a vapour-proof membrane could be used [12]. Other service conditions include rain, wind and chemical factors.

Membranes that are not exposed are generally cheaper as a UV resistant membrane is not required. However, in some cases, an exposed membrane system can end up being cheaper than a non-exposed membrane system due to the cost of installing the finishes.

The design details of membranes should be simple. Overdesigned and detailed membrane details can prove to be ineffective and costly. Detailing of membrane around penetrations and up-stands, over movement joints, floor/wall junctions should be taken into consideration, as these are the critical areas in which water leakages can occur. Proper attention to these areas is required such as a backing rod installed with a polyurethane sealant and bond breaker.

Cold joints require less detailing of membrane as the slabs are tied in when poured since there is minimum movement. If it was a movement joint, then installation of bond-breaker tape or double detailing of membrane is usually required to these areas to avoid the failure of waterproof membrane. The bond breaker should be compatible with the substrate and the membrane. The compressive strength membranes can withstand stresses from pedestrian or vehicular traffic. These membrane systems must be resistant to the constant wear and tear.

8 Concrete surface preparations

Careful consideration and proper installation techniques involve concrete surface preparation, caulking, membrane application and membrane protection. Hardening concrete requires different surface preparation techniques to ensure proper adhesion of the membrane to the substrate. Waterproofing to concrete up to 28 days old is not recommended as high moisture content in concrete often causes the membrane to blister or bubble.

Concrete over 28 days old is suitable for membrane application. However, with time constraints on projects, it is not uncommon for lift pits or similar building components to be waterproofed at this stage. Hence, the appropriate waterproofing products must be used to ensure the substrate does not fail. In these cases, a water-based membrane or epoxy system is most commonly used in conjunction with the membrane which allows water vapour to escape from the system, yet providing moisture barrier.

The moisture content of matured concrete, which depends on the concrete thickness and environment condition, should be below 4% of the weight of the concrete [15]. The moisture content of the substrate should be measured using a dewpoint meter and the substrate should be free of any contaminants such as dust, oil, grease, moisture, latencies or any foreign matter. Oil and grease should be removed from the surface by using a detergent or solvent. All areas should be thoroughly rinsed before waterproofing to remove any chemical and detergent residue. The curing compound is to be compatible with the membrane to ensure optimum adhesion or not used at all [13].

Honeycombed concrete and any feathered edges should be rectified prior to any application of membrane. Patching to these areas may be required to ensure surface is in good condition. Depending on the surface profile required the proper surface preparation can be achieved by various grinding techniques including vacuum grinding, sandblasting, shot blasting, captive shot blasting or abrasive blast cleaning. The type of surface preparation should be judged by experienced water proofer.

When preparing matured concrete, any existing coating should be removed; the concrete substrate should be free of any contaminants. Surface preparation to old and existing concrete requires more considerations to repair the concrete to make it sound for suitable membrane application [16]. If possible, a test patch on the old concrete surface could be performed to ensure the membrane is compatible with the substrate.

9 Testing and quality assurance

9.1 Testing

The tests that could be performed in membranes include flood testing, adhesion testing, dry film thickness (DST), atmospheric and substrate temperatures and pinhole and porosity detection. Flood testing involves blocking all water outlets with a plug and filling the waterproofed area with water at a minimum water depth of 50mm. The area is then left for a minimum of 12 hours. If the water level has dropped, the problem area must be found and rectified. Another flood test must be conducted after the area is rectified to ensure it is watertight. Flood testing is also a good indicator if the drainage system works well, as no water should pond in areas after the water is drained.

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Fig 3. Adhesion test from membrane applied under controlled conditions – Elcometer Adhesion Tester, dolly, adhesion test result and mode of failure

Adhesion testing is carried our using an Elcometer Adhesion Tester and metal dolly as shown in Fig. 3. The dolly is adhered to the membrane surface using the required adhesive. The elcometer is then placed on the metal dolly. A tensile force is then applied to the metal dolly and increased until the dolly is removed from the surface. The pull off force is then recorded. It is recommended that the adhesion test be performed three times in large waterproofed areas to ensure reliable results are obtained. The typical benchmark adhesion pull-off strength is 0.7mPa.

Dry film thickness (DFT), the thickness of the fully cured membrane, is determined using an ultrasonic or destructive test. The application should meet the minimum DFT recommended. Typical DFT is around 2 mm. Case studies had indicated that the thicker the applied membrane system, the higher the adherence between the membrane and the substrate [17]. The dewpoint meter is used to measure the atmospheric temperature, the relative humidity and the dewpoint temperature.

Pinhole and porosity detection otherwise known as spark testing in a membrane system can be tested using a high voltage detection technique otherwise known as the holiday detection unit system. The holiday detection unit discharge a high voltage current through the membrane system. Any defect located in the membrane causes sparking and send a detection signal to the unit. However, this technique can only be used on insulating coatings and conductive substrates such as moist concrete.

9.2 Quality assurance

A quality assurance system should be administered on major projects to ensure quality waterproofing membrane application. Quality assurance testing includes five main components, namely moisture content, applied film thickness, membrane adhesion, watertightness and membrane repair. The air temperature, humidity and substrate temperature should be monitored before the membrane application. Depending on the membrane used, the membrane application should be done within the moisture content limits according to the recommended of the manufacturer.

Testing for the applied film thickness (AFT) involves direct measurement of the adhesion test dollies removed during the testing of membrane adhesion. The other method is achieved by keeping a log book of the quantities used for the membrane location. The applied film thickness can then be calculated by using the manufacturer's technical data sheet, using the coverage rate and quantity to achieve the required dry film thickness (DFT).

The adhesion of the membrane to the substrate can be tested by conducting a pull-off test. Any adherence results that are less than the benchmark should be further tested to find the underlying cause of failure and repaired accordingly. The watertightness of a membrane area is tested using flood test. Another method to test the watertightness of a membrane is by using the electronic pinhole detection test. These tests are discussed in Section 9.1.

10 Conclusions

Waterproofing is a vital building component in structures that should be looked at with more care in the construction industry. With the proper waterproofing system in place through adequate design and installation techniques and the implementation of adequate maintenance procedures, the rate of waterproofing failures and remedial costs could be significantly reduced. This paper reviewed the waterproofing membrane systems, standards and codes, inspection, failures, testing and quality assurance.

Waterproofing failures affect all who are involved in the project and the users of the buildings. Financial factors should not be the overall deciding component when letting waterproofing contracts out to subcontractors. Consideration of the quality of membrane and waterproofing applicator's capability should be the major factors of decision-making. When assessing the applicator's reputation, capability to undertake the works, the water proofer's past history of installing the membrane system on similar projects, their financial position, the human resources available, the ability to meet all the environmental, safety, quality, statutory and government requirements and regulations, and lastly their ability and confidence to warrant the product and application are to be considered seriously.

When assessing the suitability of the membrane system, it is important to consider its compatibility to the location, physical and chemical properties, ease of installation and the compatibility of the membrane system with other building materials. Design and application skills and substrate preparation are the contributing factors to the successful and durable performance of the waterproofing membrane system. The correct waterproofing system maintains the integrity of the building's intended design life.

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