CRITICAL EVALUATION ON WATERPROOFING PRACTICES IN THE INDUSTRY

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Degree of Master of Science

Department of Mechanical Engineering

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Sri Lanka

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Thesis/Dissertation submitted in partial fulfillment of the requirements for the degree of Master of Science in Building Services Engineering

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Declaration

"I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of our knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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…………………………………………….. ………………………………

Dr. L. L. Ekanayake Date

Abstract

Waterproofing is the process of rendering an object or surface resistant to water. Importance of waterproofing in construction cannot be overstated. It is essential for durability, hygiene and also for a pleasant appearance. Water tanks, reservoirs, ponds, planter boxes, sewerage plants, water treatment plants, swimming pools, basements, roofs, bathrooms, kitchens, floors, balconies, tunnels, silos, parking decks, bridge decks, ducts, parapet walls and foundations all require waterproofing to last longer and to secure its aesthetic appearance.

Also, there are several factors to be taken into consideration when selecting the most suitable waterproofing system for the required structure. The selected waterproofing system should be non-toxic, economical, permanent, easily applied, highly resistant to water, stable at a range of temperatures, compatible, resistant to bacterial & other growth and also provide a good texture.

There is a proper procedure to be followed before applying any waterproofing system on the surface. First of all, inspect the area and get accurate information about the site. Then measure the right area and calculate the correct material requirements. Next prepare the substrate effectively. Weak areas such as cracks, honeycombs and joints, etc. have to be repaired. Then seal around the pipes/protrusions. Lay a sloping screed (if required) and fillets at right angled edges. Now apply the waterproofing system strictly conforming to the manufacturer's specifications. Cure the waterproofing system as specified.

Various reasons may lead to failures in waterproofing. Some of them are application of an unsuitable waterproofing system, using incorrect application tools, incorrect mixing proportions, poor storage of waterproofing materials, poor substrate or surface preparation, bad maintenance practices, application under direct sunlight or during rain and failure to protect application from other sources.

(Keywords – waterproofing, consultants, applicators)

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1 Introduction

1.1 Background

Long term durability of buildings and its service quality depend on the quality of waterproofing done. However, it has very limited knowledge among building industry professionals. Due to this reason, many new and old buildings are causing huge money in waterproofing rectification works. This study will assess the necessity of waterproofing structural surfaces and the different industry practices and procedure of selecting the waterproofing solution.

1.2 Problem Identification

Waterproofing describes making an object or surface resistant to water. It is essential for durability, hygiene and a pleasant appearance. Water tanks, reservoirs, ponds, planter boxes, sewerage plants, water treatment plants, swimming pools, basements, roofs, bathrooms, kitchens, floors, balconies, tunnels, silos, parking decks, bridge decks, ducts, parapet walls and foundations all require waterproofing to last longer and to secure its aesthetic appearance.

There are several factors to be taken into consideration when selecting the most suitable waterproofing system for the required structure. The selected waterproofing system should be non-toxic, economical, permanent, easily applied, highly resistant to water, stable at a range of temperatures, compatible, resistant to bacterial & other growth and also provide a good texture.

There is a proper procedure to be followed before applying any waterproofing system on the surface. First of all, inspect the area and get accurate information about the site. Then measure the right area and calculate the correct material requirements. Next prepare the substrate effectively. Weak areas such as cracks, honeycombs and joints, etc. have to be repaired. Then seal around the pipes/protrusions. Lay a sloping screed (if required) and fillets at right angled edges. Then apply the waterproofing system strictly conforming to the manufacturer's specifications. Cure the waterproofing system as specified.

Even though, many agreed and followed general practices in the industry, many failures are observed. This has become a burden for the maintenance of such facilities. Therefore, this research is aiming to identify why the waterproofing application works fail in the industry by conducting a critical evaluation on waterproofing practices in the industry.

1.3 Aim & Objectives

1.3.1 Aim

The project's aim is to conduct a critical evaluation on waterproofing practices in the industry.

1.3.2 Objectives

- To study the manufacturer's literature about waterproofing materials and their recommended application procedures.
- To do case studies on selected waterproofing failures reported in University of Moratuwa and outside to understand the causes.
- To conduct a critical evaluation on waterproofing practices in the industry by conducting a survey on consultants and applicators in the industry.

1.4 Methodology

In-depth analysis of waterproofing failures was carried out. Their rectification works also studied together with repair materials and application procedures. The causes for the failures and the level of success of the rectification methods were analyzed and justified with industry experts and conclusions were made.

1.5 Key Findings

Key finding is that "wrong selection of waterproofing material and method" is the main caus for waterproofing failures and it is proposed to enhance the waterproofing knowledge among industry practitioners.

1.6 Structure of the Thesis

Chapter one introduced aim and objectives of this study. Then chapter two highlights various literatures on waterproofing and application. Then Chapter three highlights the methodology. Chapter four discusses data collection and analysis and highlights various case studies on waterproofing and rectifications. Conclusion and recommendations are given in final chapter five.

2 Literature Review

Waterproofing is the process of rendering an object or surface resistant to water. Importance of waterproofing in construction cannot be overstated. It is essential for durability, hygiene and also for a pleasant appearance. Water tanks, reservoirs, ponds, planter boxes, sewerage plants, water treatment plants, swimming pools, basements, roofs, bathrooms, kitchens, floors, balconies, tunnels, silos, parking decks, bridge decks, ducts, parapet walls and foundations all require waterproofing to last longer and to secure its aesthetic appearance. It is an essential requirement to protect a structure from potential damages due to water and other chemicals. Therefore, waterproofing can be termed as materials and systems combined together to prevent intrusion of water into a building's structural elements or its finished space.

2.1 History of Waterproofing

Waterproofing which came about from the urge to protect our shelters from the natural elements has been an essential part of human dwelling construction for more than 13,000 years now and it has seen vast improvements throughout the centuries.

The agrarian revolution saw the decrease of hunter-gatherers and the increased formation of larger social units who built their shelters in a single permanent location. This resulted in more productive agriculture, in turn resulting in an excess of produce. It was necessary to store this excess produce during the wet seasons, protected from the moisture. Hence, waterproofing became necessary for this purpose to store the excess produce without paving way for it to spoil.

A few thousand years later, the earliest forms of water transportation modes were discovered to facilitate explorations, fishing and trading. To ensure that these primitive boats were waterproofed, Neolithic men sealed these boats with bitumen emulsion from the surface of peat bogs.

The greatest monolithic structure of all-time, the Great Pyramid of Giza is sound evidence to prove the amazing waterproofing skills of the Egyptians who lived millenniums ago. The bitumen emulsion applied in coats with dry reed fibre applied in cross layers was capable of keeping the tombs completely dry despite of the floods that surrounded the pyramid every year. (Australian Institute of Waterproofing, 2014)

Even in ancient Sri Lanka, the necessity of waterproofing was recognized during the construction of tanks. Elephants were used those days to compact the soil as tightly as possible to prevent any sort of water infiltration or seepage. In those ancient times, clay was trampled on by elephants until the required level of compaction was achieved in the soil. Up to this day, this level is not known. A layer of granite was also used on top, to reduce the penetration of water.

Initially, metal sheets, GI sheets or PVC pipes were laid at joints to extend the path of water. Afterwards, oil-based bitumen was used to provide waterproofing for shorter periods of time. The use of that was discontinued when it was found out that it tends to become brittle when exposed to longer durations of ultraviolet radiation from the Sun. Later, polymer-modified oxidized bituminous soft materials were used. This was bitumen modified at high temperatures with synthetic polymers. They are two.

1. Atactic Poly Propylene (APP) plastomer
2. Sequenced Butadiene Styrene (SBS) elastomer

Bitumen modified with APP is normally stronger and stiffer than bitumen modified with SBS, which provides greater expansion flow and waterproofing. Both substances possess high forbearance for ultraviolet radiation. Therefore, they are preferred over hot mastic asphalt or bitumen.In cold countries, SBS modified polymer membranes or bituminous coatings are more effective while in hot countries, APP modified polymers are more effective. Also, it has to be noted that ultraviolet resistant polymers are highly expensive. If the surface is covered, ultraviolet resistant property of the waterproofing material is not needed.

2.2 Introduction to Waterproofing

Waterproofing is defined as the materials and system combined together to prevent the invasion of water into a building’s structural elements or finished space. The most likely methods of intrusion of water into building structures are through rainwater and groundwater above-grade and below-grade respectively. Other methods can be pointed out as melting snow, overspray, sprinklers and also from roof gutters and downspouts in the roof.

The existence of the above-mentioned sources in itself does not guarantee leaks unless these three conditions are satisfied.

1. The presence of water in any of its forms
2. Water must be stirred along the surface by a force (gravity, wind, hydrostatic pressure, capillary action, surface tension, etc.)
3. The presence of a breach or opening on the surface facilitating the entry of water into the spaces in the building

It is important to identify all the possible water sources likely to be encountered before finalizing the waterproofing system. Also, drainage from the structure must be facilitated as soon as possible as the faster the water is drained the lesser the chance for leakage. Some materials which are not waterproof themselves, succeed to maintain the interior areas dry simply because they shed or divert the water away from the surface as soon as possible.

It is also important to incorporate a standard slope in some structural components to prevent unnecessary infiltration of water. Sometimes, incorporating an adequate slope into the structure in itself is sufficient to prevent many of the leakage problems present today. For example commercial roofs which have a smaller slope have a greater incident rate of leakage problems than residential roofs which have a steeper slope even though materials that are expensive and normally of excellent performance have been incorporated in the construction of commercial roofs.

Surface tension occurs when water flowing under gravity passes across a change in building plane and sticks to the underside of the surface. Wind during a rainstorm increases susceptibility to infiltration of water. Apart from driving the water directly into the envelopes, strong winds are capable of creating sufficient air pressure to create hydrostatic pressure to force water upward and over envelope components. Small open spaces on the surfaces make them open to invasion of capillary water by creating a capillary suction force to draw in the water when still water is available. Sand is often used as fill material to prevent concrete structures from drawing in soil water through capillary action. The major areas of weakness in envelopes are terminations and transitions which enable leakage to a greater extent. Also, it is important to point out that below grade structures need to be more sheltered against infiltration than above grade structures.

Effective designs of waterproofing systems must be incorporated after taking all these factors into consideration. While the expected weather conditions in the considered geographical region will affect the above-grade envelope, the below-grade envelope is affected by groundwater tables which have to be determined by testing actual site conditions.

Designs of envelope components are prevent leaks by these three methods.

1. Barrier Systems

Barrier systems consist of barriers to prevent infiltration of water. They are capable of completely repelling water under all expected conditions.

2. Drainage Systems / Rain-Screen Systems

Drainage systems might let absorption through the surface to a certain extent but is successful in water collection and diversion before leakage. Rain-Screen systems use air spaces in cavity walls to stop air pressure from allowing the water into interior portions of the building.

3. Diversion Systems

Diversion systems convey water against components of the envelope and divert somewhere else before surface infiltration occurs.

Buildings usually contain a combination of systems to prevent water intrusion. To avert all cases of water invasion, enveloping a building from bottom to top with drainage systems or barrier systems with diversion systems included where needed to improve envelope performance. These systems interact and act in cohesion as a total-system to prevent leakages or else although the independent action of the systems is faultless, the system altogether might be a failure.

Enveloping the outer building skin is vital to prevent infiltration of water. The materials used in the envelope must all be waterproof without any exceptions.

If the correct product is not chosen or if other required materials for the necessary coverage are not obtained or if application is not done correctly, the system will fail.

At present, in most cases, application is not done by a person who has sufficient theoretical knowledge on the subject of waterproofing. Therefore, it is important to educate the applicators on the various application methods.

Initially the surface has to be prepared and structural failures have to be rectified. The waterproofing cannot bear any structural loads. Therefore, it is important to rectify structural errors such as cracks by repairing or sealing and the surface must be cleaned thoroughly. If water penetrates through the structure, blemishes will occur on the surface and the reinforcement will be subject to corrosion. (US, 2012)

Also it must be noted that nowadays superior waterproofing products are readily available in the market.

Another crucial aspect of waterproofing is the lack of publicity. Media coverage has to be provided about waterproofing as the general public including professionals is unaware of the critical importance of waterproofing. For example, a doctor is not exposed to any information about waterproofing in his/her daily routine.

A waterproofing system that satisfies all purposes can be manufactured at a very expensive price but all the properties of that waterproofing material are not essential in all situations so it is not economical. This is the reason why we have to choose the waterproofing system that possesses the needed properties.

In practical situations, most subcontractors will only undertake the waterproofing part. They do not do any required concreting or tiling part above the waterproofing they have laid so as to not bear any responsibility in that regard in case an error occurs during that stage.

An instance was noted where in Hambantota, a set of workers had forgotten to install the ladder inside an overhead water tank before the waterproofing was done. So they had covered it up by installing the ladder afterwards. When the test for water tightness was done, it appeared that the waterproofing had failed. Water was leaking from the nuts and bolts used which were fixed to install the ladder. This shows that care has to be taken to ensure water tightness by installing all required components before the waterproofing is done so that it does not damage the waterproofing afterwards.

There are standard codes of practice for waterproofing. Two of them are listed below.

- ASTM - American Society of the International Association for Testing & Materials
- BS - British Standard

2.3 Waterproofing Principles

2.3.1 The 90% / 1% Principle

"90 percent of all water intrusion problems occur within 1 percent of the total building or structure exterior surface area." (Kubal, 2008)

Workmen finishing the work are untrained and unsupervised in building enveloping. 1% of exterior surface area contains the terminations and transitions which often lead to breaks and ineffectiveness of building envelope. Manufacturers must provide appropriate details with their specifications. This principle explains that the actual manufactured waterproofing systems or envelope components do not leak but the terminations and transitions in the field construction details.

2.3.2 The 99% Principle

"Approximately 99 percent of waterproofing failures are due to causes other than material or system failures." (Kubal, 2008)

Inattention paid to detail is worsened by poor workmanship. Failure reasons are normally human errors, specification of the incorrect system, the erroneous or no primer being used, insufficient preparation, mismatched materials transitioned together in addition to inadequate material being applied. 1% of resulting failures can be attributed to the failure of substances used or the entire system.

Unfortunately, waterproofing is too often considered as an isolated requirement whereas it needs to be obviously identified that all constituents, including the soil backfilled to the mechanical rooftop are essential parts which are equally affected by the 99% / 1% principle and the 99% principle.

2.4 Benefits of Waterproofing

- Prevents water infiltration
- Prevents structural damage to building components
- Prevents concrete, masonry or stone spalling due to freeze thaw cycles
- Prevents rust or structural or reinforcing steel deterioration
- Prevents the passage of pollutants such as chloride ions into structural components
- Prevention of acid rain contamination and carbon acids
- Weather barriers against heat, cold and wind saving energy and providing environmental control
- Resistance to wind loading and wind infiltration
- Minimizes health concerns of occupants that are directly connected to formation of mold
- Increases durability
- Provides a pleasing aesthetic appearance

2.5 Structural Components that require Waterproofing

- Water tanks
- Reservoirs
- Ponds
- Sewerage plants
- Water treatment plants
- Planter boxes

- Swimming pools
- Basements
- Roofs
- Bathrooms
- Kitchens
- Floors
- Balconies
- Tunnels
- Silos
- Parking decks
- Bridge decks
- Ducts
- Parapet walls
- Foundations

2.6 Physical Factors to be considered when selecting the Waterproofing System

- The location that requires waterproofing(Rooftop, bathroom, pond, etc.)
- The condition of the substrate or surface(new, old, presence of cracks, even or uneven, inclination, etc.)
- The area of the substrate to be waterproofed
- Type of waterproofing according to exposure of the surface - exposed (No top layer) or covered (tiled etc.)

As an example, two separate locations have been analyzed in the table given below.

Table 2-1 : Analysis of physical factor of two locations

Property	Bathroom	Rooftop
Sunlight has an effect	No	Yes
Frequently gets wet	Yes	No

Tiling	Yes	No
Use	Single purpose	Multi-purpose

There are various methods of waterproofing that can be used for each situation after the necessary physical factors are analyzed. But it is very important that you select the most suitable method for the environment or situation involved.Some waterproofing materials may be suitable for several physical environments or situations (both rooftop and bathroom). But there can be complications. For example, even though, a waterproofing material used for the rooftop can also be used for the bathroom, but it might be more difficult to tile the bathroom floor with the said waterproofing system as it makes the floor smoother.

2.7 Types of Waterproofing Products Available in the Market

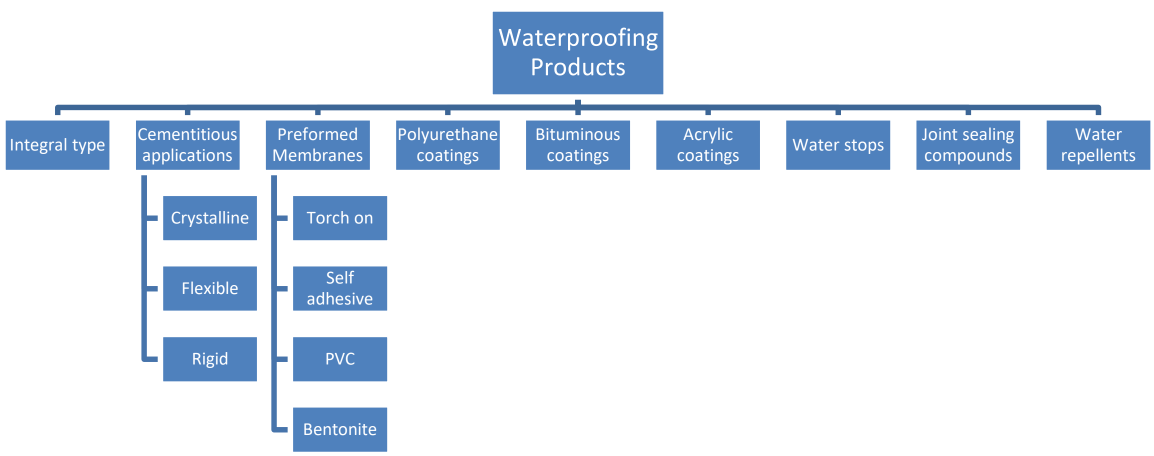

Figure 2-1: Types of Waterproofing Products Available in the Market

Adhesive types are not suitable for smaller areas like bathrooms because of the uneven places like gullies and joints. As an example, torch on membranes are suitable for rooftop surfaces (Duleeka, 2015) but not for bathrooms. They differ in their long-lasting abilities.

Some are effective for around 15 years while others only provide water resistance for around 5 years. Long-lasting ones are more expensive. It is not always essential to use the more long-lasting material. It has to be decided according to the situation and the required guarantee period should be decided by a specialist in waterproofing. These products vary according to these properties.

- Bonding Strength – higher bonding strength gives higher quality
- Water penetration ability – lower penetration ability of water gives higher quality
- Flexibility – Higher flexibility gives high quality. (Higher flexibility at low temperatures is needed mainly in cold countries)
- Ultraviolet Resistance
- Punching Resistance
- Elongation – higher elongation gives higher quality. (Polyurethane materials have higher elongation so they are resistive to cracking)
- Elongation at rupture
- Tensile Strength
- Specific Gravity
- Application temperature
- Service Temperature
- Chemical resistance
- Elasticity
- Dimensional Stability
- Durability
- Tear resistance – mainly important for adhesives and membranes
- Flow resistance at higher temperatures

Regions exposed to higher temperature ranges require waterproofing materials with higher elongation abilities because they are subject to expansion. For example, areas like Mannar which are exposed to temperatures as high as 38°C require materials with higher elongation abilities. On the other hand, regions exposed to lower temperature ranges do not require materials with very high elongation abilities. For example, areas like Nuwara Eliya which are exposed to subzero temperatures.

Some properties of waterproofing systems can only be compared if they are possessed by those materials. The following are some examples.

- Softening points of bituminous systems
- Elongation and bonding strength of cementitious systems

2.8 Different Selective Factors Considered according to the Target Market

Table 2-2: Selective Factors considered by different groups of the market

Group	Selective Factors
Customers	Cost, quality, ease of application
Applicators	Application method
Contractors	Cost, quality, application method
Consultants	Cost, quality, application method, specifications

2.9 Procedure of Selecting the Most Suitable Waterproofing System

- The purpose has to be identified.
- The condition of the surface and the usage has to be considered. For example, a rooftop which is frequently used for parties requires a protective coating while a one which is not used for such purposes does not need a protective coating (The effect of shoes, high heels on the surface). These factors might not always relate to the waterproofing problem but because of the other usages of the said surface. If a significant force is exerted on the surface on which the waterproofing membrane has been applied, the membrane might suffer severe distortion and the waterproofing system will fail thereafter. For example, if an outdoor AC unit is being installed on a rooftop. A real life instance can be pointed out as that when an outdoor AC unit was installed on the rooftop of the building of the Department of Mechanical Engineering in the University of Moratuwa. This resulted in a failure of the waterproofing system.
- Each situation has to be individually analyzed for its properties and the price of the waterproofing materials also have to be considered.

A cementitious waterproofing system has been applied to the exposed walls of the new building of Department of Textile Engineering of the University of Moratuwa even though cementitious (brittle) waterproofing systems are not suitable for surfaces excessively exposed to the sun's radiation as they are not adaptable to any sort of thermal movement whatsoever.

On the other hand, an acrylic waterproofing system was used to successfully waterproof the washrooms of the First Lane Hostel against a leakage from a septic tank of a nearby house.

These instances highlight why attention needs to be paid to detail when selecting a waterproofing system.

2.10 Deterioration of Concrete

Concrete is also prone to physical deterioration like any other material. Concrete made from naturally occurring cements has been found to be in excellent condition even after more than 2000 years. It can be believed that modern day Portland cement will also behave in the same manner under those prevalent conditions. However, it must be considered that today, the environmental conditions are aggressive to concrete and all other construction materials as well.

Deterioration can be due to chemical attack on or between the various materials of which the structure is built, or from climate changes, damage from high speed water, friction, fire, impact, explosion, failure of foundation or overloading which cause physical deterioration. (Perkins, 1986)

A very high percentage of the defects in concrete structures arise from the corrosion of the reinforcement. Therefore, special attention must be paid to ensure long term protection of the reinforcement when designing and constructing new concrete structures. Unless stainless steel is used, or the rebars are given a complete, durable and impermeable coating such as heavy galvanizing or special powder epoxy, the concrete surrounding the rebars must be as impermeable as possible. (Perkins, 1986)

A durable structure fulfills its intended purpose for the entire design life with the minimal maintenance. Portland cement concrete has an almost unlimited life if it is not subjected to chemical attack by an aggressive environment or physical damage. Cracking, deep carbonation and spalling owing to materials or workmanship of substandards, and reinforcement corrosion will also result in lowering the durability of concrete. On the other hand, weather staining and similar discolouration are not signs of lack of durability. Concrete structures include reinforcement, joint sealants, fillers, thermal and sound insulation, metal fixings, pipe connections, waterproofing and decorative layers apart from concrete. These other materials may also contribute to reducing the lifetime of the concrete structure. Especially joint sealants, fillers, waterproofing and decorative layers which require periodic renewal. Also certain parts of the structure may be subject to physical deterioration such as abrasion caused by steel wheeled trolleys on a floor, a stream of high velocity water containing grit impinging on a concrete wall or floor, spalling and surface flaking due to freeze-thaw cycles and damage by wave action abrasion by sand and shingle in the case of marine structures. (Portland Cement Association, 2002)

Concrete should possess low permeability for durability. The permeability of concrete depends on the size, distribution and continuity of the pores. Permeability is tested by measuring the rate at which a fluid passes through the test specimen under an applied head. The rate of flow of water under pressure through dense, good quality concrete is extremely slow. The main factors involved with the permeability of concrete are those given below. (Portland Cement Association, 2002)

- Quality of the cement and aggregate
- The quantity of the cement paste and its quality (The quality is based on the water/cement ratio, amount of cement, and degree of hydration)
- Bonding between the cement paste and the aggregate
- The concrete’s degree of compaction
- Presence or absence of cracking
- Standard of curing
- Properties of the admixture used

Atmospheric carbon dioxide’s effect on Portland cement is carbonation. When calcium hydroxide in cement converts to calcium carbonate by the absorbing this carbon dioxide, it seals the pores on the surface provided that the concrete is dense and impermeable. Carbonation lowers the pH of the pore water in concrete from around 13.5 to around 9. This may result in corrosion of the reinforcement. Therefore, it can be concluded that the deeper the carbonation, the higher the risk of corrosion of the steel. A phenolphthalein test can be done to determine the extent of carbonation. Phenolphthalein turns pink colour at the presence of an alkaline. Therefore, the carbonated part will remain without any colour change while the uncarbonated part will turn pink. Good quality dense concrete carbonates very slowly. Low quality cast stone products are particularly prone to carbonation. The indirect detrimental effect of carbonation on the steel rebars is what makes the carbonation process undesirable to all. Sulphur dioxide and sulphur trioxide in rainwater will also react with the alkalis in concrete. In cases of deterioration of concrete, it is not always that the concrete itself suffers significant chemical attack.

The following can cause chemical attacks on concrete.

- Aggressive substances in solution in the sub soil or groundwater
- Aggressive chemicals in the surrounding atmosphere
- Aggressive chemicals stored in, or in contact with
- Chemical reaction between constituents of concrete (alkali – aggregate)

Chemicals which attack concrete can be divided into four main categories.

a) All acids

All acids react with alkalis and Portland cement is highly alkaline. They will also attack calcareous aggregates such as limestone. If the acid penetrates the concrete through cracks down to the rebars, then the steel will corrode and spall the concrete. Likewise, the deterioration of concrete will be largely due to the corrosion of steel rather than the direct attack on the concrete as mentioned earlier.

b) Some ammonium compounds

Most ammonium compounds, especially those in chemical fertilizers such as ammonium nitrate, ammonium sulphate and ammonium super phosphate are harmful. In warm, humid conditions, their attack can be severe. It is worth mentioning that there have been instances of sever attack by ammonium nitrate resulting in no corrosion of the rebars whatsoever.

While ammonia liquid is only harmful to concrete, if it contains ammonium salts, ammonia vapors are likely to attack moist concrete slowly. Dilute solutions of ammonium chloride and ammonium nitrate attack Portland cement concrete. The action of ammonium sulphate solution causes disintegration, which in this case is due mainly to the expansion caused by the formation of calcium sulpho-aluminate. High alumina cement concrete is much less affected by solutions of ammonium salts than Portland cement concrete.

c) All sulphates

All solutions of sulphate will attack Portland cement concrete up to different extents. The sulphate reacts with the tricalcium aluminate in cement to form the compound ettringite. The degree of attack by sulphates depends on various factors.

i. Percentage of tricalcium aluminate present in cement
ii. Permeability of the concrete
iii. Solubility of the sulphate
iv. Whether the cations in the sulphate react with the compounds in the cement.

Although, in most cases sulphates are external to the concrete, in some parts of the world like the Middle East, sulphates are present in significant concentrations in the aggregate for concrete. The result is expansive disintegration of the concrete. If saline water is used for mixing concrete, the concentration of sulphate in that must also be taken into account. It must be noted that Portland cement itself contains sulphate as gypsum (calcium sulphate) used during manufacturer for setting the concrete. While the acceptable concentration of sulphate in concrete is about 4% by weight, the weight of sulphate in gypsum accounts for like 3%.

d) Other aggressive compounds

Brine, calcium hypochlorite, caustic soda (sodium hydroxide), distilled and demineralized water, ferrous sulphate, fruit and vegetable juices, hydrogen sulphide, sour milk, petroleum oils, sea water, sewage, sugar, urea and sodium chloride are some other compounds which are aggressive to concrete under certain conditions.

Also, for an attack to take place, the compounds must be in solution.

These reasons can cause physical aggression to concrete.

- Freezing and thawing of outside structures in severely cold climates. When surface layers are penetrated by moisture that causes this. The consequent freezing and expanding of water absorbed in the concrete will cause disintegration of the surface layers. Hydraulically pressed precast precast concrete products have proved their ability to resist the disintegrating effects of this freeze-thaw cycle.
- Thermal shock caused by a sudden and severe drop in the temperature of the concrete, such as spillage of liquefied gases can cause thermal shock. This is rather rare compared to the other causes.
- Abrasion to concrete, such as wheeling steel trolleys in industrial buildings. The abrasion resistance possessed by the concrete is dependent on the compressive strength of concrete. The finish of the surface is also important. If the quality of the aggregate is exceptionally good or bad, that will also show some influence on abrasion resistance. The use of certain limestones can result in polishing and slipperiness.
- Damage from high velocity water can be due to friction from grit in water, cavitation, and impact from a high speed jet of water.
- Abrasion in sea structures caused by sand and shingle from gale force winds

Metals that are used for reinforcements and fixings in concrete are namely, mild and high tensile steel, stainless steel, phosphor-bronze, gunmetal, aluminum and copper.

A basic principle highlights that when dissimilar metals are in contact, one of them is likely to suffer from corrosion. One will act as the anode while the other will act as the cathode. The anodic metal is subject to corrosion. This problem can arise with fixings and anchors kept in contact with the steel reinforcement. It is of crucial importance to find out which metal is vulnerable in these cases. A couple of examples are steel being anodic to copper and phosphor-bronze and gunmetal being anodic to stainless steel. Accordingly, steel reinforcements in contact will be caused to be subjected to corrosion. The extent of corrosion is determined by the content of moisture in the concrete and the amount of oxygen at the surface of steel. Building designers must be mindful of this during designing and construction.

Although steel embedded in concrete is sheltered against corrosion, high alkalinity of pore fluid in hydrated cement paste can passivate the steel. However the small the corrosion of steel maybe, it can still be measured as it is an electrochemical process. If the alkalinity of the concrete in contact with the steel is reduced, for example by carbonation, then in the presence of oxygen and moisture corrosion will occur. Also it must be noted that the presence of chlorides in the concrete can stimulate corrosion even at high alkalinity. A high percentage of chloride ions in concrete reacts with tricalcium aluminate to form compounds which effectively prevents the chloride ions from attacking the steel. But the remaining chloride ions remain freely in the pore water of concrete. These free chloride ions attack the steel. Due to this, it has been designated that, the chloride ion concentration in reinforced concrete made with ordinary or rapid hardening Portland cement should not exceed 0.4% by weight of cement. In concrete made with sulphate-resisting Portland cement, the permitted concentration of chlorides is reduced to 0.2% by weight of cement. For prestressed concrete and structural steam cured concrete, the concentration is further reduced to 0.1% by weight of cement. (Sika, n.d.)

Normally exposed concrete inside a building is more deeply carbonated than the external concrete but that corrosion of the rebars on the inside is less severe than the outside. It must also be noted that cracks in concrete, especially those which extend down to the reinforcement, will stimulate and hasten the corrosion process. In the short term, crack width is of importance to the rate of corrosion. The deterioration of concrete due to the corrosion of the reinforcement may be described in the following stages.

i. Passivation after the placing of concrete
ii. Reduction and final destruction of the passivation
iii. The initiation of active corrosion and formation of rust
iv. The expansion of the rust resulting in the cracking of the concrete cover to rebars
v. As the rust continues to form, the cracks are extended in width and length and pieces of concrete become unstable and eventually result in spalling

Stainless steel, phosphor-bronze and gunmetal are used for fixings and anchors in reinforced concrete and are usually very resistant to corrosion in the normal building environment. But expert advice needs to be obtained about fixings and anchors in structures used for holding aggressive liquids and in industries where aggressive vapors are generated. The coefficient of thermal expansion of steel is about 40% greater than that of concrete. (Sika, n.d.)

Aluminum and copper are often embedded in concrete or are in direct contact with it. If aluminum which is in direct contact with concrete is not properly anodized or coated, it should always be protected unless it can be ensured that no moisture will be present at the contact surfaces. This protection can be easily given by bituminous paint or another paint which is alkali-resistant. The objective of this protection is to form a barrier between the highly alkaline concrete and the aluminum. Copper is not usually attacked by concrete unless the concrete contains chlorides or ammonium compounds from certain organic based adhesives that can gain access to copper ions. The coefficients of thermal expansion of aluminum and copper are much greater than that of concrete.

Another issue that must be addressed is the use of brackish or saline water for mixing concrete and mortar. Although in most countries, drinking water is used for mixing concrete, in some countries where drinking water is scarce, saline water and sea water have to be used more often than not with salt contaminated aggregates. In all cases where normal freshwater is not available for mixing concrete, the manufacturers of the cement should be consulted. The chlorides can also be effective in accelerating the setting and hardening of the cement. Even then, sodium chloride is very aggressive to ferrous metals, and therefore a detailed consideration of the effect of chloride ion concentration is deemed necessary. It has to be noted that in those areas where sea water is used for mixing of concrete, there is a considerable quantity of salt in the aggregates, particularly sand. From this it can be concluded that there is a serious danger of corrosion of the reinforcement if sea water is used to mix concrete. It is advised to maintain the chloride ion concentration under the recommended limits and to undertake any practical steps to ensure the reduction of the chloride ion concentration back to that level in case of an unexpected rise. Also high sulphate content is also a complication as it will be in solution with the pore water and therefore will be in close contact with cement particles. It is generally accepted that the maximum sulphate concentration should not exceed 4% by weight of ordinary Portland cement. This can be increased to 6% for sulphate resisting Portland cement where the tricalcium aluminate content is within 3%.

2.11 Types of Waterproofing

2.11.1 Below-grade Waterproofing

Below grade waterproofing substances are subjected to more severe hydro conditions than above-grade waterproofing materials. Below-grade structural components are open to hydrostatic pressure due to groundwater table which rises considerably in seasons of heavy rain. It must be noted that below-grade components are not affected by harsh environmental conditions such as ultraviolet weathering, rain due to wind and acid rain. Below grade waterproofing system manufacturers can improve characteristics of the waterproofing systems by taking these factors into consideration. For example, below-grade membranes can have substantial elongation properties, as manufacturers do not need to enhance the product with ultraviolet resistance that limits elongation. (Kubal, 2008)

Below grade waterproofing consists of barrier systems and diversion systems. Below-grade structures are affected by two sources of water; groundwater and surface water. Surface water from sprinklers, rain or snow should be diverted away instantly to prevent percolation of water. A preliminary step taken to do so is grading and sloping the soil adjacent to a building. As a standard, minimum slope should be 0.5 in/ft for natural areas, sidewalks and paved areas. Also downspouts, roof drains and trench drains direct large amounts of water away from the building. In the case of groundwater, besides providing protection from normal groundwater tables, sufficient allowance has to be made for temporary rises due to rain accumulation and natural capillary action of soil as well. (Mapei, 2011)

Below-grade waterproofing systems should address issues related to collection, drainage and discharge of water away from the envelope. Foundation drains are good means of collecting and discharging. They must be put next to and somewhat above the bottom of the foundation to prevent soil washing under the foundation. Coarse gravel around and the piping prevents percolation and water collection. Meshes are put above the gravel to stop building up of soil. (Kubal, 2008)

Below-grade waterproofing systems can be categorized as positive and negative systems. Positive systems are those that are applied to sides with direct contact to water or hydrostatic head. Negative systems are applied to the opposite side from which water contact occurs. Allowing water to enter a concrete substrate, facilitating active curing and corrosion and deterioration of reinforcement if chlorides are there are the principle advantage and disadvantage of negative systems respectively. Positive systems do not allow curing of concrete but protects reinforcing steel and substrate. Advantages with disadvantages of positive and negative systems are summarized in table 1 given below.

Table 2-3: Advantages and Disadvantages of Negative & Positive Systems

	Positive Systems	**Negative Systems**
Advantages	Prevention of water into the surface	Accessible after installation
	Protection of substrate from freeze-thaw cycles	Concrete substrate is allowed to moist cure
	Protection of substrate from corrosion	Prevents need for sub slabs and well pointing for waterproofing in the foundation
Disadvantages	Concrete does not cure properly	Limited to cementitious systems (see 3.6.1)
	System inaccessible for repairs after installation	No protection from freeze-thaw cycles
	Sub slabs and well pointing needed for waterproofing the foundation	No protection of surface or reinforcement from chemicals in groundwater

Positive systems and negative systems are of five types.

2.11.1.1 Cementitious Systems

Cementitious systems contain a Portland cement base, with optional sand and an active waterproofing agent. Cementitious system is effective in both positive and negative applications. These systems are mainly used for large concrete components which make it relatively easier to specify and install without any compatibility issues. Cementitious system is mainly used in;

- Tunnels
- Underground vaults
- Water reservoirs
- Water and sewerage treatment facilities
- Elevator and escalator pits
- Below grade concrete structures
- Swimming pools
- Cooling tower basins

Cementitious system is cost efficient as they do not mandate a completely dry surface and as it isn't needed to completely cure the concrete before applying eliminating well pointing and control of water during construction. Also, they are applicable to both walls and floors. Additionally, no subslabs are required. Furthermore, in elevator pits, waterproofing can be done at any time during construction. All cementitious system is similar in their unified application after which protection board is not needed but they deter water differently according to the additive used. In disadvantages, these systems lack crack-bridging abilities or elastometric properties. This has no considerable issue when applying to below-grade areas with no thermal movement but if subjected to freeze thaw cycle and structural settlement, it can make the cementitious system to crack leading to the infiltration of water.

Before application of cementitious systems, the surface must be clean of laitance, dirt, form release agents and other alien materials. The surface is normally required to be lightly sandblasted, acid etched or bush hammered. Tie holes, honeycombs and cracks must be filled. It is critical that changes in planes are formed and grooved to form 1 in x 1 in coves and these coves must be filled.If a cove is not formed, a cant of materials has to be placed.

Although, priming is not required, it is mandatory to wet the concrete using water. Substances are mixed according to the manufacturer's recommendations, using water that is clean. Normally application of two coats is carried out, of which the first is the proprietary materials and the second is the chemical or metallic materials. A third coat is applied if additional protection is necessary. Application of these systems is done by spray, brush or trowel. They usually require a wet cure of 24 – 48 hours. Negative cementitious mixtures should be installed after the structure is completely built to allow structural movement. A water stop can be installed at intersections to improve detailing.

Table 2-4: Advantages and Disadvantages of Waterproofing Systems that are Cementitious

Advantages	**Disadvantages**
Application on positive or negative surfaces	Unable to move
Application as remedial measures	Necessity to mix at job site
Lack of necessity of well pointing or sub slabs	Unsuitability for areas subjected to high traffic

Cementitious systems are also of four types.

2.11.1.1.1 Metallic Systems

A combination of cement and sand along with iron aggregate or fillings that is finely graded make up these systems. These materials expand in the formation of slurry due to the oxidation of iron at the presence of water which seals the surface and prevents further movement of water through the solid. Application of two or three coats, followed by a cement and sand mix applied along with the final coat. Leaching and oxidation are then prevented due to the sealing of the metallic coats. Also concrete toppings can be installed above all this to prevent excessive wear.

2.11.1.1.2 Crystalline / Capillary Systems

Sand and cement mixtures with dry or liquid registered chemical derivatives form these systems. Application is done using spray, brush or trowel. The advantage of these systems is the “dry-shake” application or applying the dry mix directly over concrete that is not yet gotten to final set or has been cured. The chemical additives used enter the concrete to react with calcium hydroxide to form crystalline structures which block water transmission through the substrate increasing water repellency. This process begins immediately upon application but can take up to 30 days to reach maximum repellency at which it is able to endure high hydrostatic pressures up to 400 ft of water head. Advantages also include not needing a protection layer, ability to seal hairline cracks that occur after installation and not being harmed by chemicals and acids. It is critical to cure the system to allow sufficient crystalline growth. Curing is to be carried out for 24 to 48 hours after it is installed. Coating installation should be protected in interior applications that are exposed.

2.11.1.1.3 Chemical Additive Systems

A mix of cement, sand, organic or inorganic chemicals make up these systems which provide a watertight substrate after chemical action. These chemicals typically include silicate or siloxane. This system requires a relatively thin application. Also they do not require a dry substrate or curing.

2.11.1.1.4 Acrylic Modified Systems

Cementitious systems that are acrylic modified include an acrylic emulsion in addition to the primary sand and cement mixture. Two applications using the trowel are needed. A mesh of reinforcement is added in the first layer soon after applying it. Certain crack bridging abilities are thus obtained to the system while eliminating the need for a protective covering. However, movement is limited. Substrates can be damp during application, but curing is necessary for proper bonding. It has to be noted that alkaline substances deter the performance of acrylic modified systems.

2.11.1.2 Fluid-applied Systems

Solvent based mixtures with rubber, plastic, urethane, vinyl or polymeric asphalt bases. Curing is done to create a seamless sheet after liquid application. It is critical to control the thickness and uniformity during application because of the fluid nature. When solids percentage of uncured material is equal to 75% or less, it may shrink in size, resulting in pinholes, splits, inadequate millage. These systems are positive applications and therefore require a layer of protection. Proper concrete curing, dry and clean substrate and proper millage are necessary for application of fluid systems. Fluid systems can be applied on horizontal and vertical surfaces consisting of concrete, masonry, metal or wood substrates. Substrate preparation is very important before the application of fluid-applied systems.

Table 2-5: Advantages and Disadvantages of Fluid Applied Systems

Advantages	**Disadvantages**
Easy to apply	Does not withstand UV weathering
Seamless curing	Does not withstand foot traffic
Adaptability to difficult detailing	Wet, damp or uncured substrates will cause the fluid system to not adhere and blisters will occur
Allow both above-grade and below-grade applications	Horizontal applications require a subslab
Excellent elastometric properties enable to bridge substrate cracking	Difficulty in controlling a undeviating 50 – 60 ml in field applications
Self-flashing installation capability	Contain hazardous and toxic chemicals requiring protection during installation and disposal

These derivatives of fluid applied systems are available.

2.11.1.2.1 Urethane

One or two component material systems are available. Substrate needs to be completely dry as they are solvent based materials. This will prevent membrane blistering. Highest elastometric properties and good resistance to all chemicals as well as alkaline conditions are shown by these systems.

2.11.1.2.2 Rubber Derivatives

Butyl, neoprene or hypalon compounds on a solvent base. These materials are flammable and toxic. These systems possess slightly lower elastometric properties than membranes that are urethanes. These systems also show resistance to environmental chemicals normally found below grade. Safety training during usage and disposal is needed due to the toxicity of the materials.

2.11.1.2.3 Polymeric Asphalt

The material qualities of asphalt can be improved by chemical polymerization enabling it to be used as a waterproofing material below grade. Drying or curing of masonry surfaces is not needed with asphalt compounds while some can even be installed over concrete that has not been cured yet. But asphalt systems do not show resistance to chemicals like other fluid-applied systems. Their life cycle is limited and used only less frequently.

2.11.1.2.4 Coal Tar or Asphalt Modified Urethane

They are cost effective systems which have limited elastometric capabilities and chemical resistance. They present difficulties in installing in confined spaces due to the toxicity of coal tar. Irritations and burns are a result of coal tar being exposed to skin. Necessary precautions need to be taken to protect against the hazards of the material.

2.11.1.2.5 Polyvinyl Chloride

These systems are commonly used as membrane sheets on the roof. They have lower elastometric properties and higher material costs and resistance to chemicals.

2.11.1.2.6 Hot-applied Fluid Systems

Rubber derivatives are added to an asphalt base to improve performance, chemical resistance and crack-bridging abilities. While solvent based products lose their use in 6 months to an year, these systems have an extended life. Since they are applied hot, they can also be applied in cold temperatures where other fluid-applied systems cannot be used.

2.11.1.3 Clay Systems

Montmorillonite clay is primarily found in Bentonite. This is used commercially in a range of products including toothpaste. Bentonite waterproofing systems have about 85% to 90% of montmorillonite clay and 10% to 15% natural residues like volcanic ash. When water is added after the clay system is installed in a dry state, the clay swells and becomes impervious to water. Swelling and water resistance depends on the composition and grading of the clay. Clay swells up to 10% to 15% of its volume when dry with maximum wetting. This shows the importance of selecting a system with a higher amount of montmorillonite clay and a minimum amount of natural residues. Bentonite is an outstanding waterproofing material if hydrated properly. Hydration must be done right after installation and backfilling to make the material watertight. Swelling and hydration must happen within an adequate enclosed region for effective waterproofing. If inadequate space is provided, the swelling may elevate floor slabs or cause cracks in the concrete. The most important advantage of clay systems to be highlighted is that it can be installed in various stages during construction. Also clay waterproofing systems can be adhered to the excavation lagging system and installed before the concrete or against similar foundation support. They can be applied on the inside surface of concrete framework. These application methods permit the contractor install the waterproofing without having to delay the schedule. The ability to lay clay panels directly on compacted soil before concreting without a working or mud slab saves not only the construction time but also allows to cut down on associated costs. Clay systems require no curing time and minimal substrate preparation, and they are also the least harmful and toxic. Also they are usually self healing. Installation is considerably simple, but clay is extremely delicate to severe weather conditions at installation. If it rains or groundwater levels are raised and wet the material prior to backfilling, premature hydration can occur resulting in loss of all waterproofing capability because hydration occurred in an unenclosed area. Polyethylene coverings are used to protect the material against water before backfilling. These systems should not be installed in conditions where constant wetting and drying occurs or in conditions where free-flowing groundwater is present, as that will cause the clay to deteriorate and lose the capabilities of waterproofing or it will get washed off from the surface. Bentonite clay is not resistant to chemicals such as brine, acids or alkalines. At present, bentonite derivatives are also used in other waterproofing systems.

Of all below-grade systems, clay systems require the least preparatory work. Concrete substrates does not need curing other than rubberized asphalt combos. Damp concrete does not hinder installation, but it cannot be wet. Large voids, honeycombs and minor irregularities should be filled with clay gel. Applications will vary considerably. Bulk clay is applied like fluid membranes (see 3.6.2). Chalk lines can be used to ensure straightness of vertical applications and to avoid fish mouthing of material.

Table 2-6: Advantages and Disadvantages of Clay Systems

Advantages	**Disadvantages**
Self-healing characteristics	Clay may be subjected to premature hydration
Ease of application	Not resistant to chemicals in soil
Range of systems and packaging	Must be applied in enclosed conditions for proper swelling to occur.

2.11.1.3.1 Bulk Bentonite

Bulk bentonite is sprayed with an adhesive that seals it to the surface. They can be directly installed to the framework or lagging before completion of foundation. Although installations are seamless, care must be taken to guarantee that sufficient material is applied uniformly. Polyethylene covering is required to protect materials after installation.

2.11.1.3.2 Bentonite Sheets

These sheets are manufactured by applying bentonite clay to a layer of chlorinated polyethylene. Polyethylene provides temporary waterproofing until the clay is hydrated and it also protects the clay from premature hydration and adds chemical resistant properties. If subjected to constant wetting and drying, the clay gets deteriorated and then the waterproofing depends entirely on the polyethylene layer.

2.11.1.3.3 Bentonite Mats

Clay is applied to a textile fabric. The coarse fabric allows for immediate hydration of clay after backfilling unlike with the fabricated paper panels. Adhesives or nails are required when installing to vertical substrates. A polyethylene protection is laid to avoid premature hydration. This is effective in horizontal applications because it eliminates unnecessary seams. Installation costs are lowered and errors in seaming and prevented.

2.11.1.4 Summary of Below Grade Waterproofing Systems

Table 2-7: Summary of below-grade waterproofing systems

Property	Cementitious	Fluid applied	Clay
Elongation	None	Excellent	Fair - good
Chemical and weathering resistance	Good	Fair to good	Fair to good
Difficulty of installation	Moderate	Simple	Simple
Thickness	Thick	Average	Thin
Requirement of horizontal subslab	No	Yes	No
Positive or negative system	Both	Positive	Positive
Areas requiring inspections	Coves and cants at changes in plane, control joint detailing	Millage at turnups, detailing and priming at penetrations	Laps, penetration detailing, changes in plane
Repairs	Simple	Simple	Moderate

Requirement of protection	No	Yes	No

2.11.2 Above-grade Waterproofing

Above grade waterproofing is the deterrence of water intrusion into exposed structural elements or components by one or more of the following methods. (Kubal, 2008)

1. Natural gravity

Gravity has the greatest effect on horizontal or slightly sloped surfaces as they can easily succumb to ponding water or still water. Surfaces need to be sufficiently inclined to drain water away to overcome the effect of water on above-grade waterproofing.

2. Capillary action

Capillary action is the natural upward movement which absorbs water in ground sources into above grade structural components. For example, balcony walls can be subjected to the effect of capillary action if standing water is present in the balcony.

3. Surface tension

Surface tension in water lets it to stick and move across the underside of an envelope. This water may be absorbed into the surface by gravitational forces or differences in air pressures.

4. Air pressure differential

If the interior air pressure is extremely lower than that of the exterior, then water gets sucked into the interior.

5. Wind loads

Wind loading at heavy rains can lead to forcing water to the inside of a surface if the surface is not made water-resistant.

Although above grade structures are not subjected to hydrostatic pressure etc, they are still open to damaging environmental conditions like Ultraviolet radiation.

Above-grade waterproofing can be successfully done in three methods.

1. By using the façade material itself.
2. By applying waterproofing materials to the surface.

3. Channeling water that has passed through the surface, back into the outside by using flashing, weeps and dampproofing.

Most above-grade waterproofing systems nowadays are an appropriate combination of all these three methods.

In early constructions, outer load bearing walls were made up to 3 feet thick which ensured shear impregnability. However, at present, high rise buildings do not have such thick walls to allow lighter weight systems, to lower building costs and to provide greater aesthetics. But, various issues arise in these systems regarding waterproofing.

The need for aesthetics is important in above-grade waterproofing. Dampproofing, wall flashings, sealants, weeps, deck coatings, wall coatings and the natural water tightness of architectural finishes all act cohesively to provide waterproofing and the required aesthetics to above-grade structures. (Pringle, 2007)

Some differences between below-grade waterproofing and above-grade waterproofing are given as follows.

Table 2-8: Differences between above-grade and below-grade waterproofing

Above-grade Waterproofing	**Below-grade Waterproofing**
Breathable coatings to allow negative vapor transmission which is the passing of moisture condensation from the interior to the exterior caused by the sun and pressure differentials. Non-breathable (vapor barriers) coatings may cause spalling during freeze-thaw cycles, disbonding from the substrate and deterioration of structural reinforcement and other internal wall components.	Does not allow negative vapor transmission. If present, will cause the material to blister and become unbounded.
Ultraviolet resistant	Not ultraviolet resistant

Capable of withstanding thermal movement	Incapable of withstanding thermal movement
Subjected to wear such as foot traffic	Not subjected to wear
Does not withstand hydrostatic pressure	Withstand hydrostatic pressure

2.11.2.1 Vertical Applications

2.11.2.1.1 Clear Sealers

These are used when surface aesthetics are needed. They can be applied over natural stone, precast architectural concrete, brick, exposed aggregate or masonry. They are not entirely waterproof. They deter the rate of absorption by the surface simply repelling the water off the surface. Therefore, wind loads and large amounts of water will ultimately cause leaks through a clear sealer. Flashings, dampproofings and sealants have to be used along with clear sealers to overcome this issue.

It has to be noted that clear sealers do not bridge surface cracks. Therefore, it is essential to properly prepare the substrate initially before application of the waterproofing to ensure the effectiveness of the clear sealer used. Also, control joints and expansion joints can be used to alleviate cracking problems.

Although older structures had thick exterior envelopes, at present exterior envelopes are relatively thinner requiring additional protection. This is where clear sealers come in handy. Clear sealers are available as penetrating sealers or film-forming sealers.

Table 2-9: Clear Sealant Types

Penetrating Sealers	**Film-Forming Sealers**
Siloxanes	Acrylics
Silanes	Silicones
Silicone rubber	Aliphatic urethane

Siliconates	Aromatic urethane
Epoxy modified siloxane	Silicone resin
Silane – siloxane combination	Methyl methacrylate
Siloxane – acrylic combination	Modified stearate

Sealers that form films are sufficiently viscous to stay atop the surface unlike sealers that penetrate which penetrate into the substrate. The penetration of the sealer depends on the molecule size of the resin. Some penetrating sealers are mass-produced to chemically react with the materials of the substrate and form a chemical bond repulsive to water. Sealers with a higher solid percentage provide better waterproofing than those with a lower solid percentage. The reason is that they fill open pores and fissures. On the other hand, this high solid percentage will cause sealant to darken or create a glossy, high sheen appearance. They are also not the most effective in weathering or abrasive wear. But the opaque stains help to cover repair work in substrates. On the other hand, penetrating sealers can withstand ultraviolet weathering and abrasive wear. But they can cause damage to adjacent surfaces, especially glass and aluminum, and natural environment like plants and shrubs. Painting over penetrating sealers is not advised. If needed, it is better to use an elastometric coating to achieve the desired quality of waterproofing and the required colour. It has to be said that penetrating sealers are not suitable for previously painted surfaces, wood surfaces, exposed aggregate finished and glazed terra cotta. It is better to use film-forming sealers on these abovementioned substrates. (Conservation Solutions Inc., n.d.)

Penetrating sealers are breathable coatings. The breathability of film-forming sealers depends on the quantity of solids in the sealant. If an impermeable coating is applied to a masonary substrate, the moisture absorbed by capillary action from the ground will cause spalling inside the substrate.

Although penetrating sealers have low coverage rate and higher cost per gallon, they call for lower labor costs as they require only a single coat of application.

Also, another major reason for failure of waterproofing sealants is due to their lack of resistance to the alkalinity of concrete and masonary.

Penetrating and film-forming materials are effective in protecting surfaces from the detrimental effects of acid rain. They also prevent worsening from air, water pollutants, dirt and other contaminants by repelling those pollutants as well from the substrate.

When selecting the most appropriate repellent for the purpose, the basic characteristics should be taken into consideration first. Mainly adequate water repellency and extended life-cycling under alkaline conditions should be considered. It is mandatory for the repellent to possess both these characteristics because even though the repellent has excellent water repellency, it is useless if it cannot last against the alkalinity of the concrete and masonary. Concrete in particular has the ability to cause complete loss of repellency capability. Therefore, it is not considered wise to depend solely on the initial repellency rates. In addition, if reinforced steel is embedded into the substrate, attention has to be paid to the resistance to chloride ion infiltration. Although chlorides cause major structural damage to reinforced steel, many sealers possess very poor resistance against chloride ions.

The effective repellency must be on the substrate surface. Penetrating capability is an important factor for UV protection. When the active compounds are found deeper in the substrate they have better protection against the sun's UV radiation. Uniform Gradient Permeation (UGP) assesses the penetration of the active ingredient rather than the solvent carrier. Most alcohol carriers have a tendency to penetrate deeper than petroleum-based carriers.

Although smaller molecules penetrate deeper, larger molecules enable higher water repellency. In contrast to common myths, excessive amounts of solids in the sealer will not contribute to increasing the water repellency significantly. 10 to 20 percent of active solids in the sealer will provide the maximum water repellency without any major issue. Also film-forming repellents require a higher solid content than penetrating repellents because they have to directly repel the water from the surface itself. In this case, the closer to 100 percent of solids, the higher the capability to repel water from the surface effectively.

Sealers can be tested before selection. The weight gain of the surface can be measured by measuring water absorption into a test cube submerged after treating with a selected water repellent. (British Standard Institution, 1983)

It is important for repellents to possess weathering characteristics as most masonry substrates on which they are applied are alkaline which makes them capable of destroying the water repellent characteristic of the repellent. Apart from that, UV degradation also removes the water repellent characteristic from the repellent. Therefore, it is important to test the repellent under accelerated weathering conditions. Also it is important to test if the sealant is compatible with the other components of the envelope and on the very surface on which it is applied to certify that no staining occurs and also to ensure that the sealant will sufficiently penetrate into the surface.

Acrylics and their derivatives have minimal penetration and are therefore considered to be film forming repellents. They are available as both water based and solvent based derivatives. For surfaces such as wood, exposed aggregate panels and dense tile, penetrating sealers cannot be used. Acrylics come in handy in these instances. Also they are useful in extremely porous surfaces where it is necessary to build up a film to repel water continuously. Acrylics simply create a film over the substrate which acts as a barrier to water as is the case with paint. In most cases, at least two coats are necessary to provide the required coverage and uniformity of the film on the surface. This depends on the surface and its porosity. Care must be taken not to apply acrylics on wet surfaces as this can result in solvent based materials turning white. Also application cannot be done in freezing temperatures or on a frozen surface. They show excellent adhesion to the surface if applied under proper conditions onto a well-cleaned and prepared substrate. It has to be noted that the main disadvantage of acrylics is that they cannot withstand any thermal or structural movement. An advantage is that their application in itself reduces dirt buildup, mildew, atmospheric pollutants and salt on the applied surface. The availability of transparent and opaque forms allow hiding or blending of substrate repairs with the patching compounds. They maintain existing surface textures and do not oxidize or peel off the surface like paint does. They can be applied on limestone, all masonry substrates, wood, stucco and aggregate panels if they have not been sealed or painted before. Very porous surfaces such as lightweight concrete blocks are not very effective surfaces on which acrylics can be used on as these coatings cannot displace the air trapped in the thousands of gaps and holes on the surface.

Table 2-10 : Advantages and Disadvantages of Acrylics

Advantages	Disadvantages
Can fill minor substrate cracks	Poor weathering resistance
Stain colours that are compatible with patching materials are available	May pickup dirt particles during curing
Breathable coating allows vapor transmission	Poor crack-bridging abilities

Silicone water repellents are made by mixing silicone solids (resins) in a solvent. Most silicones are considered to be film-forming repellents. The solvent lets the solid particles to pass through the surface but not to very large depths like penetrating sealers. The solids in the repellent effectively fill in the pores on the surface forming a solid film that repels water. The base raw material is silane for all silicone based water repellents. A wide range is produced by reacting this base raw material with different compounds including siliconates, silicone resins, silicones and siloxanes which mainly differ due to their different molecular sizes. Silicones repel water by penetrating the substrate and reacting with moisture in the atmosphere or by the evaporation of solvents or by reacting with carbon dioxide in the atmosphere to form silicone resins which repel water. It is a mandatory requirement for silica to be present in the surface for the necessary chemical reactions to happen. Therefore, silicones are inappropriate for natural stone, metal or wood surfaces. The main disadvantage of silicones is their lack of opposition to weathering. They easily deteriorate and lose their water repellency when exposed to intense ultraviolet radiation. Also, they are not resistant to abrasive wearing. Therefore, they cannot be used on horizontal surfaces. It must be noted that they are also inappropriate for marble or limestone surfaces and precast concrete panels as the application of silicones might end up causing discolouration of the surface. Therefore, it is always better to test the substrate for staining before application. A solution for the staining can also be provided by using a silicone with a lower solid concentration (1% - 3%). But also, these formulations are only effective on denser surfaces like granite which allow proper silicone penetration. Another drawback of using silicones is that they turn yellowish after application with aging and weathering. As with most other sealers, silicones should also not be applied in wet conditions. They do not possess crack-bridging abilities. Very porous substrates and lightweight or split face concrete blocks are also unsuitable surfaces for application of silicones. Also, care must be taken to protect adjacent windows and vegetation from overspray during application.

Table 2-11: Advantages and Disadvantages of Silicones

Advantages	**Disadvantages**
Breathable coating allows vapor transmission	Poor ultraviolet resistance
Ease of application	Can stain or yellow certain substrates
Cost	Other materials cannot be applied over the silicone due to the risk of contamination of the substrate

Urethanes are derivatives of carbonic acid. Clear urethane sealers are utilized for horizontal and vertical applications. They have some ability to fill and span immobilized cracks in the substrate owing to their high solid content (40%). On the other hand, this can also act as a disadvantage. If any moisture or vapor drive happens in the surface, it may cause coating blistering. Urethanes are film-forming sealants which do not yellow upon aging. They also give a high gloss finish to the surface upon application. They can be applied on almost any substrate including wood or metal surfaces after performing adhesion testing. Adhesion failures may occur due to concrete curing agents if the surface is not prepared by acid etching or sandblasting. They can be applied on other well-matched coatings such as urethane paints for supplementary protection from weathering. Another advantage of urethanes is that they are resistant to many solvents, acids and chemicals. They are most commonly used on horizontal and vertical seating sections on stadiums etc. Another major drawback of urethanes is their excessive cost.

Table 2-12: Advantages and disadvantages of Urethanes

Advantages	**Disadvantages**
Applicable on wood and metal surfaces	Poor vapor transmission

Horizontal and vertical applications	Blisters occur if applied on wet surfaces
Resistant to chemicals, acids and solvents	Higher material cost

Of all silicone based materials, silanes have the smallest molecular structure which allows them to penetrate deeper into the substrate. They also require the presence of silica in the substrate for chemical reactions to happen for water repellency. Therefore they cannot be used on surfaces with no silica such as limestone, metal and wood. Also, silanes require the most difficult application procedure out of all silicone-based products. Substrates must be sufficiently alkaline and moisture must be present for the required chemical reaction to happen and form silicone resins. Also a lot of the silane material evaporates before the chemical reactions take place due to its high volatility. Also if the substrate gets wet too soon after application the silane might be washed away making it incapable of repelling water completely. If applied in extremely dry conditions, the substrate is wetted to provide the required moisture for the chemical reactions to happen. Care must be taken to do this wetting before all the silane evaporates. Proper application results in the silanes forming chemical bonds with the substrate and showing 99% water repellency from the surface. The other factor that limits their use is their cost.

Table 2-13: Advantages and Disadvantages of Silanes

Advantages	**Disadvantages**
Ability to penetrate deep into the substrate	High evaporation rate during application
Forms a chemical bond with the substrate resulting in excellent water repellency	Dry substrates must be wetted before evaporation occurs
Good resistance to weathering	High cost of material

Siloxanes are used more frequently for horizontal applications. Two types of siloxanes polymeric (longer chain molecular structure) alkylalkoxysiloxanes and oligomerous (short chain molecular structure) are present. Oligomeroussiloxanes are the most common at present. They are more common because polymeric products can stay wet or tacky on the surface drawing dirt and they have poor alkali resistance. On the other hand, oligomeroussiloxanes are highly resilient to alkalines and can be successfully used on high alkaline surfaces like cement rich mortar. As with silanes, siloxanes also react with moisture to create the water repellent silicone resin. They also form chemical bonds with the substrate. Siloxanes are preferred over silanes due to their lower volatility which results in lower evaporation rates. Therefore labour productivity can be increased by applying using high-pressure sprays. The cost is also lower because the percentage of solids is also comparatively less. The need for wetting is eliminated as the chemical reaction time is achieved faster. Water repellency can be achieved within 5 hours of applying the siloxane. There are formulations now available that do not require alkalinity to form silicone resins. Chemical reactions take place even in a neutral substrate if the moisture is present. Therefore, siloxanes can be applied on wet masonry substrates without making the surface turn white. Testing of the substrate before application is necessary to safeguard compatibility and its effectiveness. Siloxanes do not affect the pores of a surface allowing the moisture to leak without harming the repellent or the building materials. Siloxanes should not be used on natural stones such as limestone or gypsum products or plaster or on painted surfaces.

Table 2-14: Advantages and Disadvantages of Siloxanes

Advantages	**Disadvantages**
Not susceptible to alkali degradation	Not applicable on natural stone substrates
Forms chemical bonds with the substrate	May cause damage to adjacent substrates and vegetation
Excellent water repellency	Cost

Silicone rubber system is a mixture of silicone based film forming and penetrating sealers. The solvent carrier carrying the silicone solids penetrate into the substrate and form a solid film that is a part of the substrate. The percentage solids create a film in the substrate thick enough to bridge minute hairline cracking. These materials are capable of sealing only existing cracks and new cracks will not be bridged as the material is a part of the surface and cannot move like film forming membranes do. These materials are UV resistant owing to their chemical designs and their penetration into the surface. As there are no reactions occurring, these systems can be applied on wood, canvas and terracotta surfaces. Silicone rubber systems are suitable for horizontal and vertical applications. Also their formulation does not allow another material to bond to it directly. Therefore, after sealing a substrate using silicone rubbers it cannot be painted over without removing the sealer using caustic chemicals such as solvent paint removers. These materials possess excellent water repellency characteristics. Extra precautions must be taken when applying silicone rubber systems near glass or aluminium surfaces as it is almost impossible to remove the material from these substrates in case of an overspray.

Table 2-15: Advantages and Disadvantages of Silicone Rubbers

Advantages	**Disadvantages**
Applicable on a wide range of substrates	Cannot be painted over
Bonds integrally with the substrate	Overspray may damage other glass and aluminium components
Can fill minor cracks in the substrate	

2.11.2.1.2 Elastometric Coatings

Elastometric coatings are paints with a high content of solids capable of producing high millage coatings when applied to the required surface. They have three basic elements in their formulations. They are the pigment, binder and solvent. Also they might contain special additives to achieve various purposes. The binder and the solvent together are known as the “vehicle”. The binder portion of the formula provides the characteristics unique to that material. Owing to that, waterproofing coatings are classified according to their binders. Sometimes, solvent is added to lower the viscosity of the material. The binder is either dispersed in the solvent forming an emulsion or dissolved in the solvent. The chemical polymer used during manufacture decides the manner in which the solvent leaves the binder after application. While thermoplastic polymer coatings cause the solvent to evaporate, in thermosetting polymers the solvent reacts with the binder and becomes part of it. Therefore, thermosetting polymer coatings are more chemically resistant than thermoplastic polymers. So, they are also able to contain a higher solid content than thermoplastic polymers.

Water-based elastometric coatings are easier to apply and not as sensitive to moisture as solvent based elastometric coatings.

The use of resins in elastometric coatings make them breathable. The resins used must allow the formation of a watertight, elastic and breathable film on the surface. It is the thickness of the coating that makes the film waterproof and elastic. Elongation is the minimal ability of a coating to expand and afterwards come back to its original shape with no cracking and spalling. Elastometric coatings show excellent elongation properties.

The variance between clear sealers and elastometric coatings is that the sealers do not have the colour pigments. They completely cover and eradicate any natural surface aesthetics. Also, they may add a texture to the surface, depending on the amount of sand in the coating. For effective waterproofing from an elastometric coating details such as patching cracks and spalls in the surface, thermal movements and installations of flashings must be addressed.

Elastometric coatings are extensively used on stucco, exterior insulation finish systems, masonry block, brick, concrete, wood, metal and sprayed urethane foam roofs. Formulations for asphalt substrates are available with asphalt primers. Also, elastometric coatings can be successfully applied on previously painted surfaces after proper surface preparation. The existing surface must be cleaned and prepared by repairing cracks and priming.

Considering the aesthetic aspect, coatings are available in a variety of textures and a range of colours. However there are limitations of these as well. Dark colours tend to fade sooner. Heavy textures limit the elastometric capabilities of the coating. Also they tend to pickup airborne contaminants easily and thus lighter colours may get dirty quickly. The application of elastometric coatings is extremely labor-sensitive as uniform thickness of the coating is important to ensure crack bridging and allow for thermal movement of the substrate.

Table 2-16: Advantages and disadvantages of Elastometric Coatings

Advantages	**Disadvantages**
Elastometric and crack-bridging capabilities	Difficulty in maintaining a uniform thickness during application
Availability in a wide range of colours and textures	Relatively shorter life cycle
Breathable	Cannot be used below-grade
Applicable on wood and metal surfaces	Major repairs may be needed on masonry substrates before application
Resistant to acid rain and pollutants	May fade with time

As with most products, successful application of elastometric coatings also depend solely on proper surface preparation. These should not be directly applied over voids, cracks and deteriorated materials as it will deter cohesive waterproofing of the envelope. Also it is essential to choose coatings that are compatible with the existing coatings. Coating manufacturers have now produced patching, sealing and priming materials specific for a selected waterproofing material so that no compatibility issues will arise during any stage of the application process. Also, application of elastometric coatings must be necessarily done by a trained applicator with the necessary experience and knowledge. Pressure-cleaning equipment can be used to properly clean the substrates fre of dirt, mildew, grease, oil and other contaminants. If necessary, the removal of mildew must be done using chlorine as well. In some instances, chemical cleaning is essential to get rid of mismatched curing agents. If that is done, the surface must be washed completely afterwards to ensure that none of the incompatible chemicals will remain on the surface and interfere with the adhesion process of the coating when it is applied. A duct tape test can be done to ensure that previously painted substrates are compatible with the coating to be applied. The coating should be applied on a portion of the substrate and sealed firmly before swiftly pulling it off. If any of the coating rips off with the duct tape, the existing materials on the substrate are not compatible with the coating materials. If that’s the case, all existing materials must be removed and the substrate must be effectively sealed using a primer.

Masonry substrates must be tested for their pH before application and if the pH is greater than 10 specific manufacturer's guidelines must be followed before application. Aid washing and extending the curing time are effective methods of reducing the pH of the substrate. This will also cause shrinkage and the development of cracks on the substrate which need to be repaired before application. Sealant installation at joints and crack bridging should also be done before application of the coating. Care must be taken not to apply the coating over moving joints as elastometric coatings do not have the ability to withstand movement. Brick and block masonry substrates must be checked for lose or unbonded mortar joints and they must be sealed with a compatible sealant before applying the coating. Block filler should be applied on split-face blocks to gain the additional waterproofing protection necessary for such porous surfaces. An acrylic block filler must be used on previously painted split-face blocks. If proper curing is not done after applying the sealants and patching compounds, the formation of mildew will occur beneath the coating after it is applied. For metallic surfaces, all rust must be removed and a rust inhibitor must be applied and then the surface must be primed. Newly galvanized metal must also be primed. Attention must be paid to seal all laps and joints on wood surfaces. Special wood primers are available in the market for priming wooden surfaces. Priming is a very important part during application, because the success of an elastometric coating an solely depend on whether the surface has been properly primed or not.

Although elastometric coatings can be applied by spray, roller or brush after apt mixing of the coating, roller application is recommended by manufacturers as it fills crevices and voids on the surface well. Long nap rollers can be utilized for this purpose. Elastometric coatings must be applied in two coatings where the second must be applied after the first is completely dried which is normally within 3-5 hours after application. Spray application must be done by a correctly skilled mechanic as per the crosshatch method. In this method, the coating is sprayed vertically and then again horizontally to guarantee proper coverage. Even then, it is advised to apply a coating on top of that using a saturated nap roller to fill crevices and voids completely. Although brush application is necessary around windows and protrusions, it is not the recommended application method for significant wall areas. It is extremely important to pay careful attention during application if a textured elastometric coating is being applied. Textured coatings must not be rolled over twice or too much pressure should not be applied during application. These errors during application will ruin the texture of the coating.

Especially water-based coatings must not be applied during freezing conditions or highly humid conditions and should be stored properly before application. Elastometric coatings must not be applied on extremely wet substrates although it is necessary to mist too hot or dry substrates before application. Coverage rates of elastometric coatings depend on the nature of the substrate and the porosity of the surface.

Also it must be noted that elastometric coatings have not been designed for below-grade application or for application on horizontal surfaces exposed to traffic or ponding of water.

2.11.2.1.3 Cementitious Coatings

Cementitious coatings also cover substrates completely. As with below-grade waterproofing, the main drawback is that they do not allow any substrate movement whatsoever which will lead to cracking of the surface and allowing water to infiltrate. Therefore, fitting sealant joints for movement and crack preparation should be done before applying cementitious coatings.

Patching materials are used with all vertical applications to ensure water tightness. They range from brushable sealants for small cracks to high strength, quick set cementitious compounds for spalled surfaces.

They are cement based products comprising of finely graded nonmetallic siliceous aggregates, colour pigments and proprietory chemicals added for integral waterproofing. An integral bonding agent is added to the dry mix or a separate bonding agent liquid is provided to be added to the dry packaged material during mixing. Their composition allows them to be used on both above-grade and below-grade applications.

Cementitious products are resistant to freeze thaw cycles by eliminating water penetration that might freeze and end up spalling the substrate. They are non-chalking, retain the colour well and become part of the substrate. Colours like white increase the material cost due to the requirement of white Portland cement.

Cementitious coating require job-site mixing done under careful supervision to ensure that each batch is mixed uniformly because different mixing quotients affect the finished colouring.

They have excellent compressive strength after curing. Waterproofing capabilities of cementitious coatings is slightly lower than that of elastometric coatings. They are resistant to weathering and salt. However, sulphates in acid rain have a detrimental effect on cementitious coatings.

They are breathable coatings which eliminates the need for completely drying the substrate before application. They are most suitable for exteriors of planters, undersides of balconies, walkways, swimming pools, tunnels, retention ponds, water reservoirs and water treatment plants. They are widely used to protect exposed concrete in bridges and roads from road salts which can damage the reinforced steel in the structure by chloride attacks. (Xypex, 2016)

In masonry substrates, when the substrate is wet the bricks swell and relax when dry. This cycle of swelling and relaxing causes damage to the mortar joint. The application of cementitious coatings prevents the said water infiltration and therefore the resulting deterioration as well. However, clients may not readily accept cementitious coatings as the solution because the coatings may alter the original façade aesthetics.

Cementitious coatings can only be used on masonry or concrete substrates unlike elastometric coatings. The suitable substrates include precast concrete, poured-in-place concrete, concrete block units, stucco, brick and cement plaster surfaces. Once applied, cementitious coatings have to be considered as an integral part of the substrate as it bonds so well to the substrate.

An advantage of cementitious coatings is that they fill voids, cracks and honeycombs in concrete and masonry substrates, thereby effectively waterproofing the substrate.

When complete coverage of the substrate is required, bag/face grouting of the masonry is also an alternative which means the application of a cementitious coating using a brush on the entire masonry wall. Afterwards the cementitious coating is removed to expose the brick and mortar joints leaving only the coating material left in the voids and cracks. Although this can be costly, it is a very effective method in making the substrate water repellent.

Complete cementitious applications result in an impermeable surface and therefore are used to repair masonry walls that have been sandblasted to remove existing coatings and severely deteriorated walls. They preserve a façade while making it waterproof. Coloured cementitious products can be used to give a desired to existing walls while making them watertight.

In mask grouting, existing masonry units are carefully taped over, so as to expose only the mortar joints. The coating material is then applied to these exposed joints using a brush and then curing is done. When the tape is removed, it leaves behind a repaired joint surface with no change in wall colour. Recessed joints require thicker coatings. This method is applicable only if the substrate masonry units are non-deteriorated and watertight.

Texture of a cementitious coating applied varies according to the coarseness of the aggregate added or the method of application such as roller, brush, spray, hopper gun, sponge or trowel.

In floor-wall junctions, it is better to first apply the cementitious coating to the substrate and then to fill the joints with a matching sealant material. It is recommended to use cementitious coatings on masonry substrates rather than other sealers because cementitious coatings have better bonding strength, a longer life cycle, lower maintenance and less attraction of airborne contaminants. Cementitious coatings will function effectively provided that means for structural and thermal movement are provided.

Table 2-17: Advantages and Disadvantages of Cementitious Coatings

Advantages	**Disadvantages**
Excellent bonding with substrate	No movement capability
Applicable for both above-grade and below-grade applications	Difficult to control uniform colour and texture during application
Excellent resistance to weathering	High expertise required during installation
Availability of a range of colours and textures	Not resistant to acid rain and other contaminants
Does not require tuck-pointing	Not applicable on wood and metal substrates

Surfaces must be cleaned free of contaminants, dirt, efflorescence and residues. Previously painted surfaces must be sandblasted to remove all the paint. It is recommended that all holes and gaps are filled with non-shrink grout. Although the concrete substrates need not be cured before application, the concrete must be set past the green stage of curing which is within 24 hours after laying the concrete. Smooth concrete finishes may require priming before application while some might require a mild etching and proper rinsing afterwards. Voids in mortar joints should be filled. Existing cracks can be filled by sponging in a small quantity of dry mix of cementitious material. Large cracks should be sawn out using a non-shrink material. Moving joints can be prepared using a sealant that allows thermal movement and differential movement. The cementitious material should not be applied directly on these places as it will crack for the slightest movement of the surface. If cracks are already infiltrated by water, the pressure must be relieved before application. Relief holes can be drilled in the substrate to relieve this pressure. They can later be filled with a non-shrink hydraulic cement material after application of the coating. Just before application, the substrate must be dampened to enable bonding with the substrate during application. The amount of water needed depends on the weather and substrate. When mixing cementitious coatings, strict adherence to the manufacturer's guidelines is a must. Cementitious coatings may be applied using stiff, coarse or fiber brushes, trowels and sprays. Brush applications require the finish being applied in one direction to obtain uniformity. Competent applicators are capable of obtaining acceptable finishes and water tightness even with spray applications. Trowel applications are most suitable for the second coat. In certain instances, the misture for the second coat requires the addition of silica sand in accepted proportions to obtain a suitable thickness of the material. Also it must be noted that the second coat must be applied within 24 hours of applying the first. Improper bonding and spalling will result if it is attempted to obtain the required thickness from just one single coat. Spraying or brush applications are the only feasible methods for textured masonry units. If the applied cementitious coating is seen to be rolling or pulling off the surface, that is an indication of the surface being too dry. Redampening the substrate with clean water will help to overcome this issue. Also it must be kept in mind that the mix proportions should be kept constant throughout, or else uneven coloring of the substrate will occur. After application, curing of the coating must be done accordingly (i.e. not too soon). Although typically primers are not required for cementitious applications, a bonding agent is applied as a primer in case of a smooth substrate or one which had a previous coating removed off it. It is crucial to remember that cementitious coatings must not be applied on substrates other than masonry substrates, wood, metal or plastic.

2.11.2.2 Horizontal Applications

2.11.2.2.1 Surface Coatings

Surface coatings which are directly applied to exposed areas are available in mainly two types.

2.11.2.2.1.1 Clear Siloxane Types

They do not change existing substrate aesthetics. However, they are not completely waterproof. They are specified to provide chloride ion penetration into concrete surfaces. These chloride ions cause spalling and structural deterioration of reinforced steel.

2.11.2.2.1.2 Solid Coatings of Urethane or Epoxy

They change the aesthetics of the surface but have elastometric properties such as crack-bridging abilities. These coatings usually have a silicon sand or carbide coat which allows vehicle or foot traffic while protecting the waterproofing base coat. Foot and vehicular wear require continuous maintenance at a regular frequency. The frequency and repairs depend on the type and quantity of traffic on the surface.

2.11.2.3 Above-grade Exposure Problems

Above-grade building envelopes require resistance from many detrimental conditions. (Builder's Engineer, 2013)

- Ultraviolet weathering
- Wind loading
- Structural loading
- Freeze thaw cycles
- Thermal movement

- Differential movement
- Mildew and algae
- Chemical and pollution from chloride ions, sulphates, nitrates and carbon dioxide

Chemical and pollution attack are becoming the most difficult to deal with.

Chloride ions are extremely corrosive to reinforcing steel present anywhere. Even if steel is protected by an encasement of concrete, if water containing chloride ions penetrate into the substrate, corrosion will occur. When subjected to corrosion, steel increases greatly in size which will in turn cause spalling and structural cracking. This is a severe case in coastal areas as salt spray is concentrated and spread by the wind. Although not in Sri Lanka, in countries around the world in winter this scenario takes a toll for the worse.

Acid rains which bring sulphuric and nitric acids affect all building components. Acids attack the calcium compounds in substrates and cause deterioration.

Within masonry or concrete substrates, carbonation occurs to unprotected or unwaterproofed surfaces. Carbonation is the deterioration of cementitious compounds when exposed to atmospheric carbon dioxide from automobile exhaust etc. Carbon dioxide mixes with water to form carbonic acid. Carbonic acid is what causes deterioration of cementitious compounds and also corrosion of reinforcing steel by changing the substrate alkalinity. Reinforcing steel is normally protected by the high alkalinity of concrete but begins to corrode when carbon dioxide lowers this alkalinity.

Algae attacks mainly affect roofing systems. Thermal transfer causes cracks in the building envelope resulting in failure of the waterproofing membrane. Also an envelope must be able to withstand structural movement. This means that all constituents of the waterproofing should be resistant to all these elements, if it is to effectively protect the structure.

2.11.2.4 Application of Water Repellents

All clear water repellent applications must be done on a clean and dry substrate except siloxane applications which can be done on slightly damp surfaces and silanes which require the presence of moisture for chemical reactions to occur. All release agents, oil, tar, asphalt stains, efflorescence, mildew, salt spray and other surface contaminants must be removed. Application over wet substrates will cause discolouration of the substrate, formation of a white film or water repellency failure. If the moisture content of the substrate is doubtful, a moisture test can be done using a moisture meter or a mat test using visqueen taped to a wall, to check for condensation.

It is important to repair cracks in the substrate before applying the repellent. Non-shrink grout or a sand-cement mixture can be used to repair small cracks whereas large structural cracks need to be epoxy-injected. If a crack is expected to continue to move, it must be sawn out to a minimum and sealed with a compatible sealant.

Also it must be noted that joint sealers must be installed first as repellents can cause contamination at joints and result in failure of bonding of the sealant. All curing of concrete surfaces must be done at least 28 days before applying the sealer.

Care must be taken to protect all adjacent structures such as window frames, glass and shrubberies from overspray. Special formulations are available for substrates such as limestone which get stained when certain sealers are applied.

Sealers should never be diluted. It is recommended to apply these sealers by low-pressure spray, using a Hudson or garden-type sprayer. Brushes and rollers reduce coverage rates and high-pressure sprays must only be used if recommended by the manufacturer.

Applicators must wear protective clothing and proper respirators during application. Application areas must be well-ventilated due to the solvents used in most sealers. It is recommended to evacuate building occupants during application or intake ventilation areas must be covered to prevent the interior areas from being contaminated with the sealer fumes.

Application should be done from the bottom of a building, working upwards. Application should be done to produce a rundown of about 6 inches of material below the application point for sufficient application. If required, the second coat must be applied in a similar manner. Coverage rates will increase for the second coat.

Prior testing of the substrate can ensure that saturation does not cause darkening or add sheen to substrate finishes.

Dense concrete finishes that contain admixtures such as integral waterproofing or form-release agents, will end up absorbing insufficient repellent. These situations require acid-etching or pressure cleaning to ensure that the substrate absorbs sufficient repellent. Also priming is not required with any clear repellent.

2.11.3 Waterproofing of Civil Structures

It is deemed necessary to apply waterproofing on civil structures such as bridges and highway overpasses for the mere protection of the substrate and the reinforcing steel embedded within the substrate rather than to prevent water infiltration into any underlying spaces. Waterproofing is necessary for these structures to provide protection against freeze-thaw cycles, road salt intrusion and chemical contamination through water infiltration into the substrate. These detrimental effects have the substantial capability to reduce the life cycle of these structures. Typically, cementitious coatings and clear repellents are used to provide waterproofing for these structures. But sometimes elastometric coatings and sheet systems are also used.

Both above-grade and below-grade waterproofing systems are suitable for structures like tunnels and water reservoirs. While negative-side cementitious coatings are suitable for above-grade water retainers, positive-side systems such as clay, liquid membranes or sheet goods are effective for below-grade water retainers.

Landfills, pond linings, earthen reservoirs and other environmental protection projects require waterproofing to provide protection from erosion in ponds, leaching from contaminants in landfills and other nonconventional uses. Sheet systems are used as pond liners while drainage matting helps to collect the discharge from a landfill.

Vapor barriers prevent moisture vapor transmission between the interior and exterior of above-grade constructions. In countries like ours with a tropical climate, the difference in vapor pressures cause the moist and warm outside air to travel into the cool and dry interior areas which is known as positive vapor drive. Negative vapor drive is when warm and moist interior air is drawn outside to the drier outside air due to the difference in vapor pressures.

Vapor barriers are also known as retarders. They are not essentially waterproofing systems but are used as part of the wall to prevent vapor transmission and to let it condense into a liquid. Vapor barriers are most useful for structures located in tropical climate where vapor transmission into air conditioned areas can be so severe that mold and mildew form frequently on exterior walls. This problem is more often misunderstood as water leakage or infiltration when that is not the case. Therefore, attempting to address this issue by applying breathable coatings like elastometric coatings will never properly solve this problem. The application of a non-breathable coating will only worsen the problem by causing blistering and disbonding of the coating when negative vapor drive occurs.

When negative vapor drive occurs, vapor barriers or retarders are required to be applied on the interior or warm side of the envelope. On the other hand, in tropical areas, where positive vapor drive occurs, the barrier must be placed on the exterior to prevent the condensation from wetting the insulation.

Retarders are available in polyethylene sheets or aluminum foil sheets on laminated reinforced paper. When applying these sheets, the seams must be lapped and sealed to prevent any possible breaks in the barriers.

The performance of a vapor barrier is related to its permeability. This means the permeability of the vapor transmitting through the particular envelope material or component. Polyethylene materials show low permeability while materials like masonry block are highly permeable. Glass is a barrier on which moisture collects and condenses as it cannot pass through. In negative vapor drive conditions, it is necessary to use permeable materials to allow the moisture to pass without damaging the waterproofing material by causing blistering and disbonding.

2.11.4 Interior Waterproofing Applications

The waterproofing systems discussed earlier are applicable for interior areas such as showers, kitchens, steam or locker rooms, laboratories and mechanical rooms.

Liquid applied membranes and sheet-goods are the most commonly used systems. Although clay systems are not practical for interior areas, cementitious coatings are extremely suitable as there is no risk of most internal areas being subject to thermal movement.

Shower and bath areas require mandatory waterproofing. It must be noted that the waterproofing material is applied over a concrete substrate. It is recommended that sheet or cementitious systems be used in these instances. This is effective for any other interior space where a finished floor capable of acting as a layer of protection for the waterproofing is present. This finished floor is usually a tile surface that is most effective in wet areas. If deemed necessary, these waterproofing systems can be used to completely envelope a room.

Specific guidelines for application in interior areas can be requested by most manufacturers for their waterproofing products. Although a thin set tile directly set on a waterproofing membrane inhibits movement, most manufacturers will allow it as these interior areas are not as prone to experience as much movement as the exterior areas.

A major complication that occurs when it comes to waterproofing such interior areas is the effect of the traffic on the waterproofing membrane before the finished floor is laid on it. For example, after the waterproofing membrane is installed, various electrical and mechanical work must be done before the finished floor is laid. During this stage, the waterproofing membrane is exposed to a considerable amount of traffic. Therefore, it is imperative to provide the required protection to the waterproofing membrane until the finished floor is applied properly over the membrane.

The waterproofing membrane must be checked to verify that it functions properly before laying the finished floor because this will prevent costly repairs of removal and replacement of the finished floor in case of any damage to the membrane before application of the finished floor. A flood test can be done to ensure this. In this test, all drains in the room are temporarily blocked and the room is flooded to around one inch of water and it is allowed to stand for 24 hours to ensure that membrane is capable of holding the water.

2.11.5 Residential Waterproofing

It is evident that most homebuilders do not pay the required amount of attention when it comes to waterproofing residences although residential waterproofing practices are not different from any of the commercial practices discussed earlier. Homebuilders wind up using material from the local building supply store without any prior investigation of the surface and compatibility with the selected material. Or in the worst case scenario, they use no waterproofing at all for their residence. Most contractors and subcontractors do not even consider waterproofing to be an essential part of residential construction. Due to this, it is very uncommon to find a home without any traces of water or moisture infiltration whatsoever. Unfortunately, local building codes and regulations also ignore the necessity of waterproofing for residential constructions. Also this results in most homeowners believing that waterproofing related issues are maintenance issues rather than ones that could have been addressed during initial construction stages and resolved.

Residential constructions are relatively simpler and uniform because contractors, subcontractors and building code inspectors are not prepared to handle very unique designs and finishes. This is also why architects who design larger and somewhat complicated residential homes advice the client to employ a commercial contractor to complete the work as they are experienced in addressing all related issue including waterproofing in commercial structures. They pay attention to detail and whereas contractors and subcontractors usually make due with materials available in the local building supply store whether it is suitable or not. Although sometimes, unfortunately even commercial contractors misjudge the importance of waterproofing and act similar to most contractors and subcontractors. (Kubal, 2008)

Below-grade waterproofing in residential homes is mainly for basement structures. Very often, residential contractors substitute damp proofing for waterproofing even though most damp proofing materials are not even intended for below-grade application. They are intended for areas subjected to the pressure of moisture only. Not areas subjected to hydrostatic pressure which is the case in below-grade structures. Residential contractors will try to limit the so-called waterproofing to the application of visqueen, a damp proofing system from the local building supply store.

Even though residential basements are not located at very low elevations, they must also possess a high-strength to receive waterproofing treatment. Most residential concrete mixes are of low-strength making it insufficient to apply a quality waterproofing system.

Substrate preparation and application is similar to as discussed earlier for each separate waterproofing system.

As with commercial below-grade applications, it is mandatory that the groundwater present is drained away from the structure as much as possible and the surface water that permeates through the soil is also managed. This simply can eliminate most of the water infiltration problems faced. French drain systems used for this purpose involve a perforated pipe in loose gravel near the foundation to allow the water to percolate into the piper before being drained away. The problem with this is that by the time the construction is complete, this drainage system will be damaged and deteriorated by improper backfilling over the drains during construction. Installing prefabricated drainage systems can help overcome this issue as they are designed to withstand these inflexibilities during construction including poor backfilling. Also these prefabricated systems relatively simpler to install that even an inexperienced residence contractor can successfully install it by following the manufacturer's guidelines. Also it is of crucial importance that above-grade water drainage is installed properly diverted from the below-grade structures. The main concerns here are roof drains and downspouts which should not be positioned to drain directly above the below-grade structures. This will prevent the water from draining down immediately and causing a considerable increase in hydrostatic pressure.

It is widely accepted that negative applications (dry side) are the more appropriate choice for below-grade waterproofing. Negative cementitious mixtures are relatively easier to install where the only thing to be mindful about is placing a cove at the wall-floor joint and packing it with negative waterproofing material to prevent leakage at this critical junction. Residential contractors who use these negative cementitious waterproofing systems must advice homeowners to avoid any penetration of the waterproofing system by nailing or screw driving.

All in all, for the typical residential basement, installing a preformed drainage system beneath the slab and adjacent to vertical applications followed by the installation of a negative waterproofing system with proper cove placement will provide a substantially long-term protection against water and mold infiltration.

Any of the above-grade waterproofing systems presented earlier are applicable for above-grade waterproofing in residential homes as well. On the plus side, most above-grade waterproofing systems are simple enough to be applied by your average homebuilder. Even then, regardless of how simple the installation may be you cannot overlook the detailing at terminations and transitions mostly at windows and siding joints.

However, customarily, actual above-grade waterproofing systems are not incorporated in homes most of the time. Instead, they depend on the finish materials such as paint to act as barriers and add water repellency to the surface.

Vinyl siding, wood siding and cement-board siding products are common envelope finish systems which offer the required protection against water infiltration. Of these products, wood siding and cement-board siding require painting while vinyl siding does not. As sealing the seams will trap the moisture and make it unable for the moisture to escape directly or evaporate, it is advised not to seal the seams. Sealing will not cause water infiltration, but it will directly contribute to mold formation in interior areas and the substrate. Additionally, trapped moisture can cause wood rot from the wood siding and wood framing portions of the structure. When using siding, it is best to use plastic or vinyl building wrap applied to the entire substrate, carefully sealed and flashed around door and window openings. This building wrap is capable of providing protection from moisture and mold penetration and even minor cases of water infiltration. Even here, it is critical to pay attention to transition detailing near doors and windows to ensure that water is diverted out at the window or door joint rather than travelling directly into the interior. Building wraps are the most optimal choice as they are readily available at most local building supply stores and as they save energy by eliminating the air currents that enter the house usually.

Although many builders avoid elastometric systems and instead use regular paint for finishing, it is not recommended. Sidings do not require elastometric coatings but stucco finishes do. Brick or stone finishes also do not necessarily require the application of a sealer but the application of such will prove its worth in cold climates by protecting the brick and stone surface from being subjected to freeze-thaw cycles which would otherwise result in spalling of the brick and stone surface.

2.12 Procedure of Waterproofing

A surface can be successfully waterproofed upon three steps.

- Selection of the most suitable material
- Accurate and detailed specification
- Installation by an experienced and competent applicator

Ensuring all three elements will successfully improve performance and durability of the final surface.

2.12.1 Material Selection

Selection of the correct material can only be done when the demands placed on the surface are known and detailing is done. The list of requirements given below detail what the surface will be subjected to avoid costly omissions or errors.

- **Design life** – The surface finish must be selected and specified to meet the required life expectancy of the intended maintenance free period.
- **Application** – There are two main methods in use.
  - **Monolithic** – This is where the system is applied as a dry shake procedure and then trowelled into the surface to form an integral part of the concrete slab. These dry shake products can only be applied immediately after the concrete slab has been poured and cannot be applied on to existing surfaces
  - **Granolithic** –This is where the system is applied as a screed or topping to an existing concrete slab and a bonding agent is used to maximize the level of bond. It is recommended to use concresive epoxy resin based bonding agents to provide additional safety.
- **Thickness** – The thickness of the intended surface finish must be considered. This is necessarily true in existing premises where an increase in the surface thickness may cause problems with door thresholds etc.
- **Structural Loading** – The static and dynamic loads imposed on the surface during construction, production refitting and maintenance should be considered. The substrate must be capable of enduring the demands.
- **Traffic and Mechanical Wear** – The frequency, type and location of wear must be considered along with the physical requirements for resistance to impact and abrasion caused by traffic.
- **Chemical Spillage** – Chemicals that may be spilled on the surface, their spillage concentration, temperature, the possibility of the formation of mixtures, the actions taken after spillage. All these must be considered.
- **Slip resistance** – Slip resistance can be varied by the trowelling action.
- **Hygiene** – Surfaces that must be totally dust free without cracks or angled corners and easily cleanable yet chemical and mechanical resistant

- **Crack-bridging ability** – This is related to dynamic loading, vibration and traffic on the floor.
- **Temperature** – Temperature of the area must be considered as thermal shock can be a major cause for premature surface failure. Special attention must be given to areas adjacent to extremely hot or cold areas
- **Colour / Aesthetics** – Lighting, descent, taintless, beautiful, attractive and pleasant surfaces increase efficiency and productivity. Colour allows easy and quick identification of danger areas, wet areas or chemical exposure risks
- **Ease of cleaning** – A system must be installed after detailing the cleaning procedure as well.
- **Cleaning** – The cleaning chemicals to be used on the surface during cleaning are also to be considered.
- **Drainage** – Drainage must be designed and finalized so as not to allow any cracking or leaking
- **Conductive, Antistatic** – The demand for antistatic surfaces is rapidly increasing to prevent electrical interference with sensitive electronic equipment and buildup of static electricity.
- **Repair and Maintenance** – Allowance for repairs and maintenance should be given during installation.
- **Impact** – The occurrence and frequency of impact damage must be considered

2.12.2 Specification

The requirement and type of material can now be specified. Alternate proposals must also be reviewed with care. The same criteria must be used to assess all alternatives. Paying major attention to short term cost savings will result in failure of the surface to achieve the required design life, abrasion, chemical attack or impact. Only materials approved and guaranteed by the manufacturer should be used. Long term costs of refurbishment must also be considered.

2.12.3 Installation

The role of the applicator is important to the overall success, not just in terms of his expertise but also the ability to manage resources to ensure that the required finish is achieved. Unlike resin based floors, on which the application is done after the main construction work, abrasion resistant floors must cater for all complications in the construction site. For this, the rate of application and methodology must be closely monitored. The size of slabs and positioning of joints are important in minimizing the possibility of cracking. It must also be ensured that any addition to the concrete mix does not have an adverse effect on the adhesion of the system.

Surface preparation involves several key elements interdependent on each other. They are cleanliness, porosity, profile, contamination, level, coving, movement joints and relative abrasion resistance. Their level of requirement varies according to the waterproofing system.

2.13 Technical Drawings of Waterproofing of Selected Surfaces

2.13.1 Rooftop

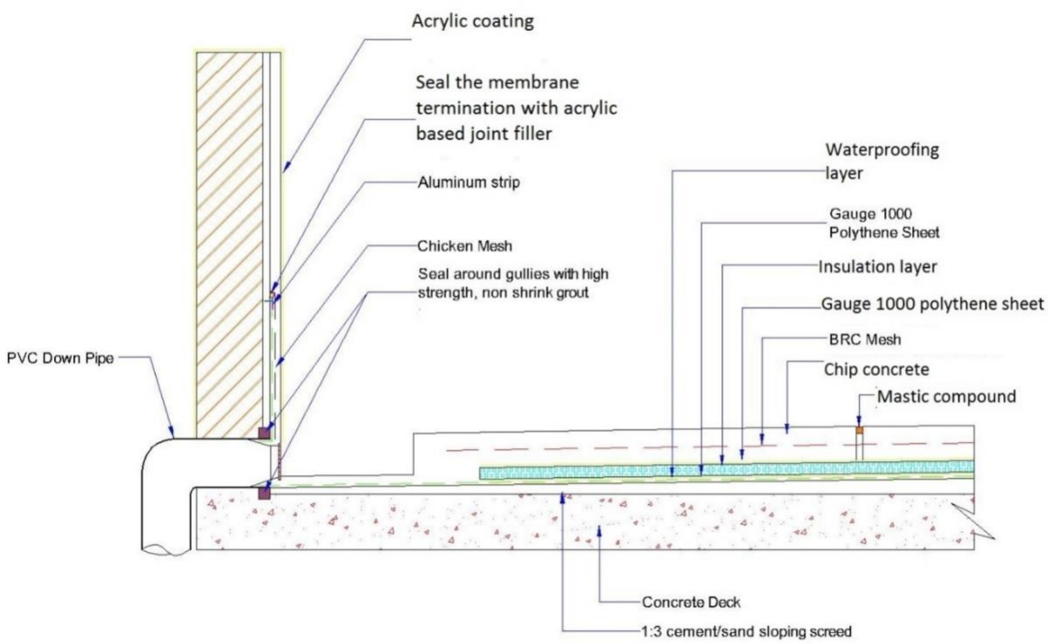

Figure 2-2 : Rooftop Waterproofing

2.13.2 Sealant Details of Walls and Floors

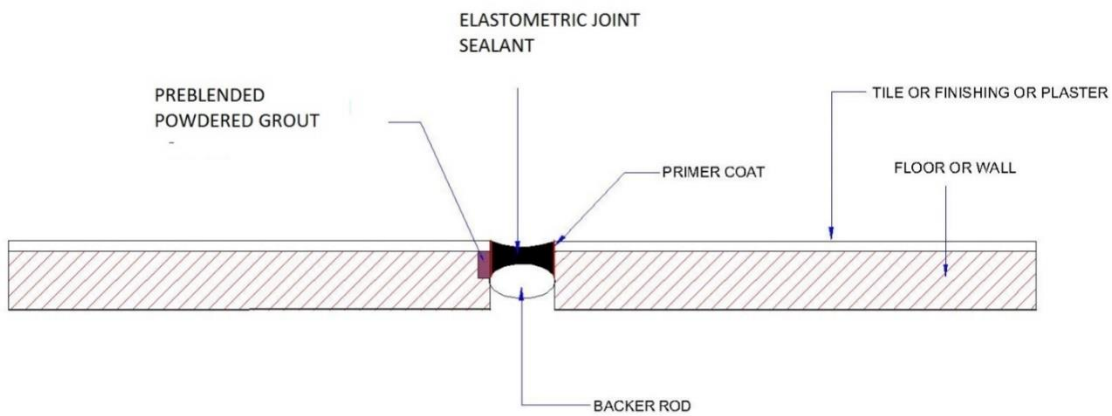

Figure 2-3: Sealant Details of Walls and Floors

2.13.3 Waterproofing of Bathrooms and Toilets

2.13.3.1 Single Layer System

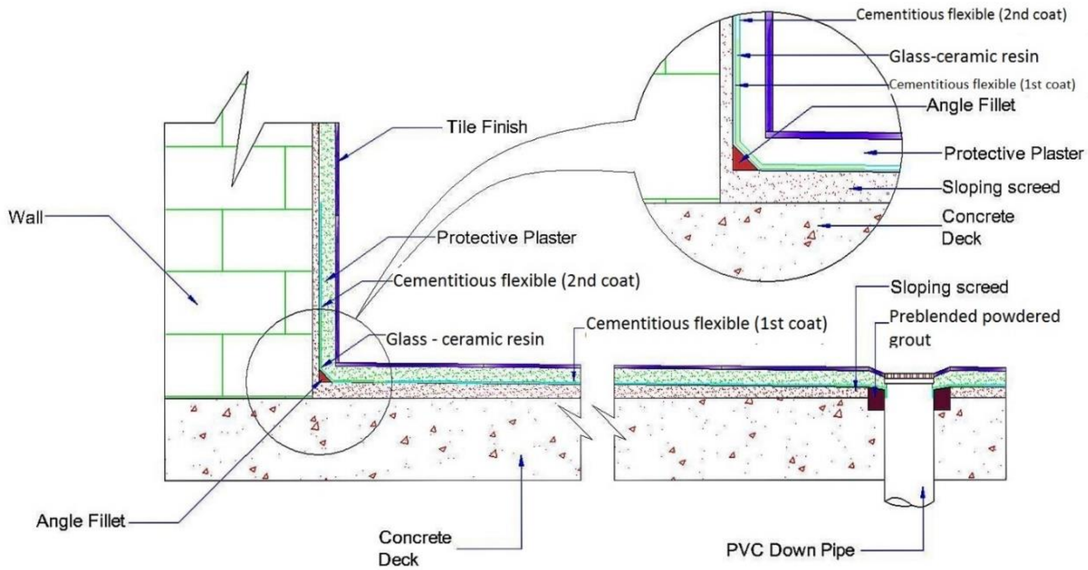

Figure 2-4: Waterproofing of Bathrooms and Toilets (Single Layer System)

2.13.3.2 Double Layer System

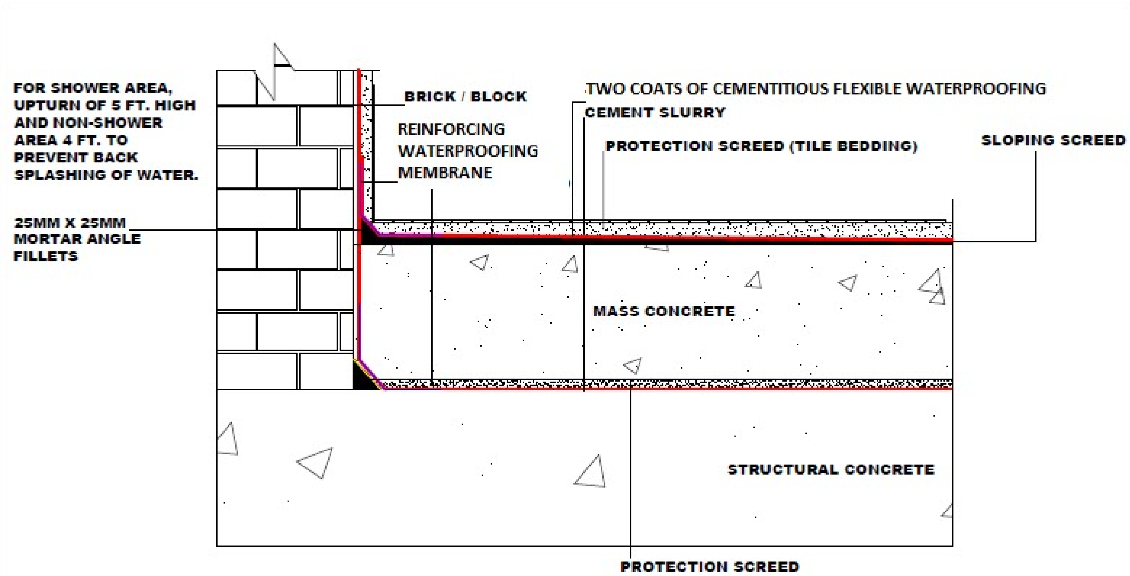

Figure 2-5: Waterproofing of Bathrooms and Toilets (Double Layer System)

2.13.4 Waterproofing of Exposed Driveways and Ramp Slabs

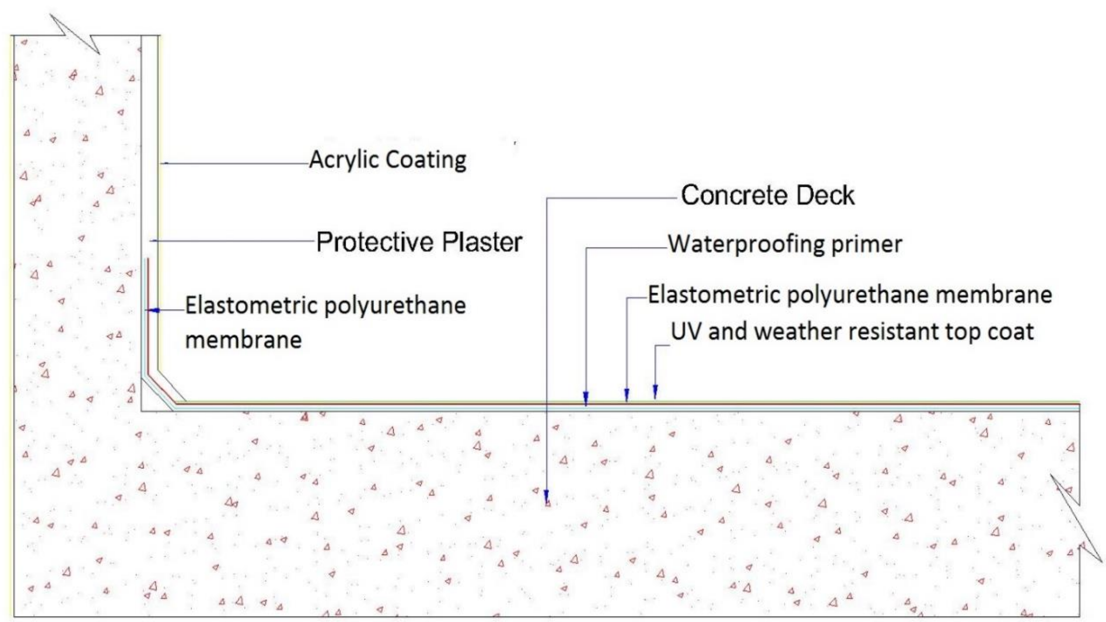

Figure 2-6: Waterproofing of Exposed Driveways and Ramp Slabs

2.13.5 Waterproofing of Basements, Underground Sumps, Swimming Pools, Lifts, Tanks & Reservoirs

2.13.5.1 External

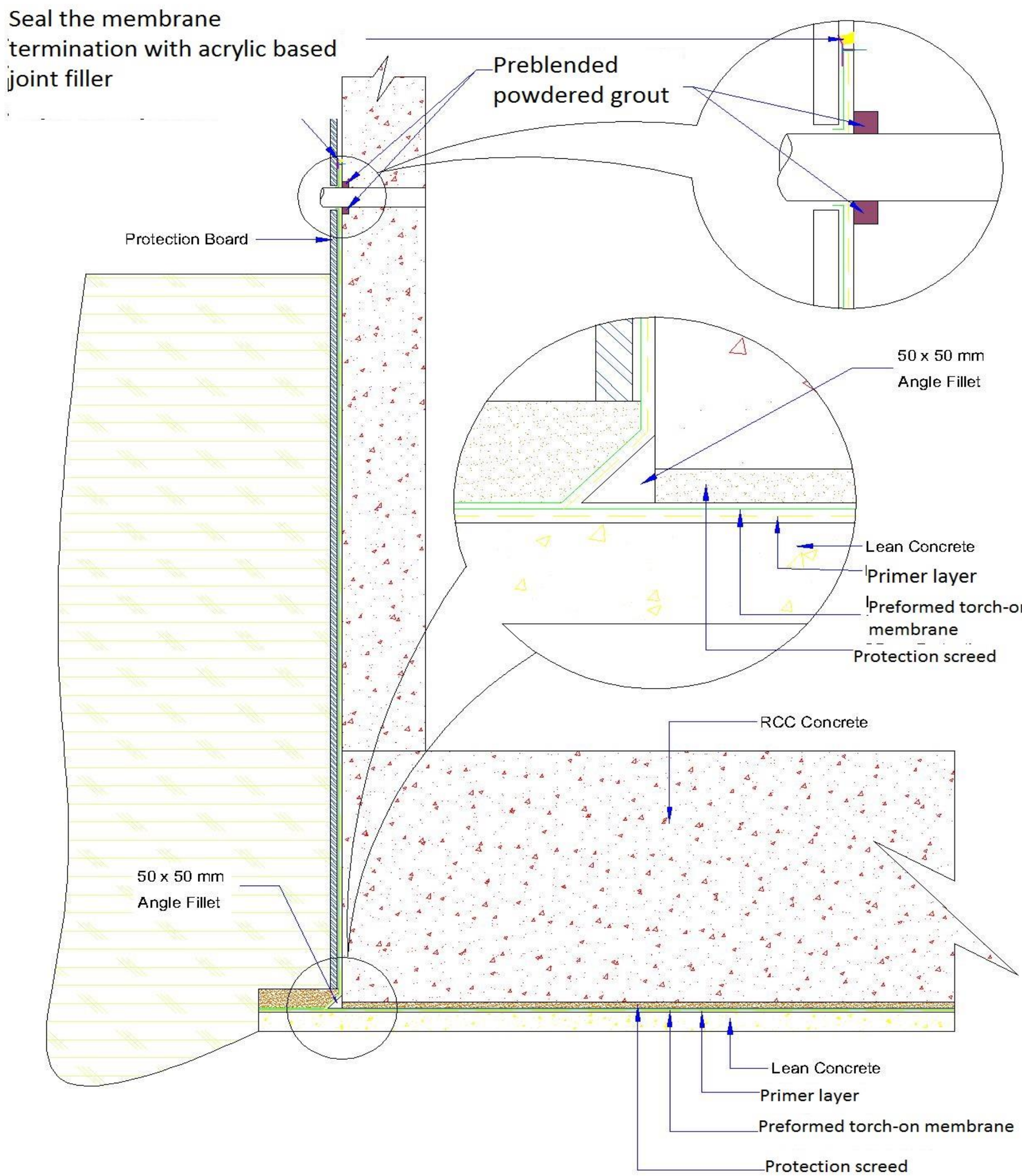

Figure 2-7: External Waterproofing of Basements, Underground Sumps, Swimming Pools, Lifts, Tanks and Reservoirs

2.13.5.2 Internal

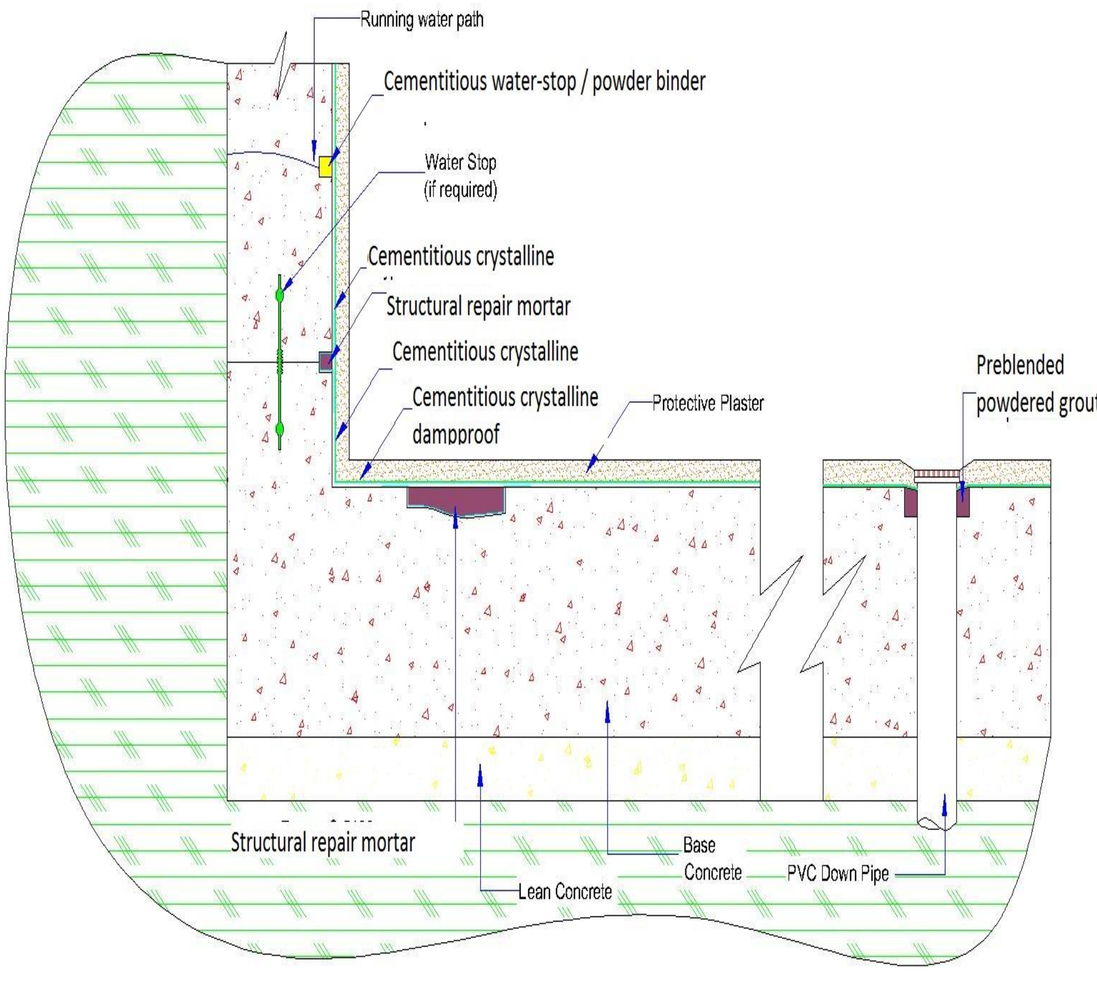

Figure 2-8: Internal Waterproofing of Basements, Underground Sumps, Swimming Pools, Lifts, Tanks and Reservoirs

2.13.6 Sealing of Expansion Joints

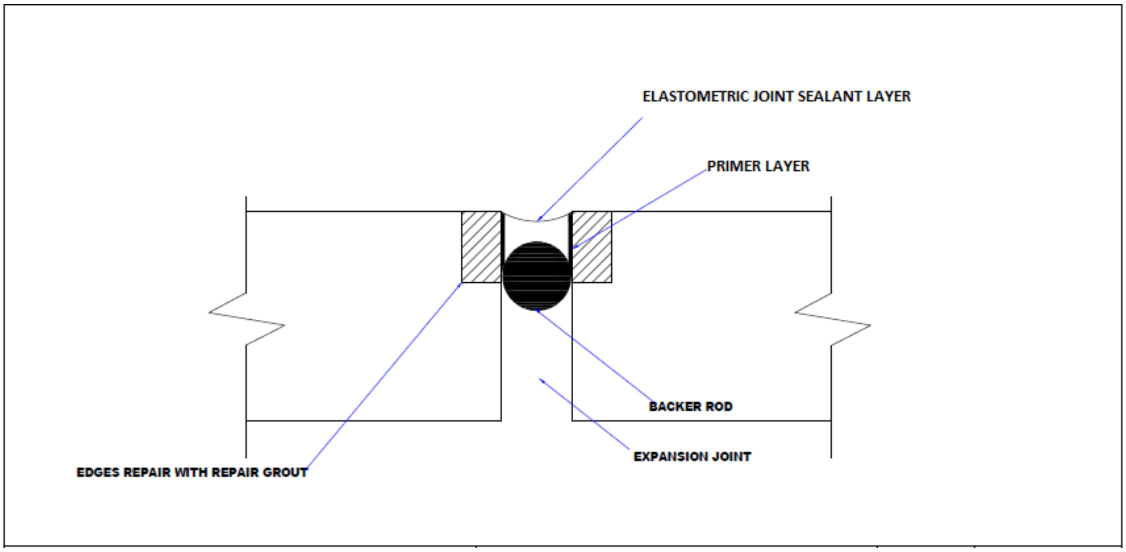

Figure 2-9: Sealing of Expansion Joints

3 Methodology

The main objective of this research project is to conduct a critical evaluation on waterproofing practices in the industry. Those include assessing the necessity of waterproofing, determining a procedure to follow in selecting the most suitable waterproofing solution for the purpose, laying out the steps to be followed when applying the selected waterproofing system while conforming to the manufacturer's standards and also to conclude the root causes for failures in waterproofing.

3.1 Literature Survey

Initially a comprehensive literature survey was done to gather a deeper understanding on the research topic. This included reviewing articles and other content published by intellectuals throughout the years. It also enabled to gather knowledge on the various waterproofing products available to date and their effectiveness. Product brochures published by various manufacturers of waterproofing solutions were also reviewed to gain a practical understanding. In addition, the application methodologies were also studied.

3.2 Field Study

Field studies were conducted by visiting various sites relevant to waterproofing to gather a practical understanding on the aspect including application procedures and methodologies. Also, the importance of addressing waterproofing during the initial stages of construction was noted. The variations of remedial action taken to mitigate waterproofing issues that may arise later was also highlighted during these field visits.

3.3 Field Survey

After gathering an understanding on the topic of waterproofing in a deeper level, field surveys were conducted. Various manufacturers, contractors and consultants were approached to identify the waterproofing solutions available in the market today. The field surveys were beneficial in providing a practical insight into how these waterproofing products were selected and applied on structural surfaces. Also, discussions with manufacturers gave an insight into how the chemical formations of these waterproofing solutions proved effective in the applied environment.

In order to overcome this issue, it was decided to conduct a survey. A questionnaire was prepared to be given out to separate entities of selected groups. For this purpose, it was decided to conduct the survey on consultants and applicators. The justification of the selected class sizes are as follows.

Table 3-1: Justification of class size

Category	**Selected Number**	**Received Number**
Consultants	40	32
Applicators	40	32
Total	80	64

A sample questionnaire from each has been attached as Appendix 1 and 2.

The entities were contacted by visiting construction exhibitions held annually in BMICH and also by visiting sites.

The questionnaires were emailed or given in person to consultants of projects relevant to waterproofing. The completed questionnaires were then emailed by the consultants. The applicators at waterproofing sites were approached in person and the questionnaire was filled by them or by me according to the verbal responses they provided during the in-person discussion at site.

Although a class size of 80 was initially expected to respond with their completed questionnaires, only 64 completed questionnaires were able to be collected.

The data thus collected were analyzed by various means to come to the conclusions stated later on in this report.

4 Data Analysis

4.1 Field Study

In view of gaining knowledge and understanding on the practical aspect of waterproofing, areas with diagnosed issues with regards to waterproofing were identified and inspected. The following premises were identified within the University of Moratuwa as such areas. These numerous instances were actually a leading cause for selecting this field of specialization for further studies.

- Washrooms of First Lane hostel due to adjacent land filling on higher ground. The First

  Lane Hostel was located in a lower ground level and therefore was subjected to infiltration of water. Initial planning and adequate steps during land filling would have helped to prevent this.
- Rooftop of the new building of the Department of Mechanical Engineering. It is believed that the waterproofing must have been damaged during the finishing activities and when fixing AC outdoor units etc. Therefore, these crevices are subjected to be open to water stagnation. Proper precautionary measures would have helped to avoid this issue.

Figure 4-1: Deteriorated surface of the rooftop of the Mechanical Engineering Department new building - 1

Figure 4-2: Deteriorated surface of the rooftop of the Mechanical Engineering Department new building - 2

- Rooftop and washrooms of Goda Canteen

In this case, ponded water collected beneath the floor surface was removed by breaking into the surface. This is a good example of addressing the root cause itself. Other measures would not have sufficed here.

Figure 4-3: Deteriorated surface of Goda Canteen rooftop - 1

Figure 4-4: Deteriorated surface of Goda canteen rooftop - 2

Figure 4-5: Deteriorated surface of Goda canteen rooftop - 3

Figure 4-6: Deteriorated surface of Goda canteen rooftop - 4

Figure 4-7: Deteriorated surface of Goda canteen rooftop - 5

Figure 4-8: Remedial action taken on Goda Canteen rooftop - 1

Figure 4-9: Remedial action taken on Goda Canteen rooftop - 2

In the following figure, the remedial action needed was very simple. That included only the placement of a covering, in this case a piece of slab over the location which leaked water into the canteen located beneath this surface.

Figure 4-10: Remedial action taken to prevent water leakage

- Staffroom of the Department of Electrical Engineering - This case required mould treatment to be done by application of paint.
- Washrooms and water tank of Prof. Patuwathavithana Hostel. Here the issue of waterproofing was only around 5% but the rest of work required for the remedial activities (including demolishing and finishing) makes up the remaining 95%. Here, the remedial measures need to be instated in a top-down approach.
- Canteen rooftop, washrooms and Staff Quarters in Hostel Village. Ponding of water and the requirement of a slope for water drainage were the issues to be remedied here. This was addressed appropriately.
- Washrooms of the old building of the Department of Textile Engineering. Cracks had surfaced that were then open to water ponding. This required chipping, waterproofing and finishing off the surface.
- Upper floors of the new building of the Department of Textile Engineering. Here the problem identification took more than two to three tries by the contractor. Then a specialist in the field was recruited to find the root cause and address the issue. The design itself had not provided for sufficient drainage. Stagnant water ponds on the rooftop was the cause for the issue in the whole building. Remedying that fixed the issue completely.

Figure 4-11: Deteriorated surface of the new building of the Textile Engineering department - 1

Figure 4-12: Deteriorated surface of the new building of the Textile Engineering department - 2

Figure 4-13: Deteriorated surface of the new building of the Textile Engineering department - 3

Figure 4-14: Deteriorated surface of the new building of the Textile Engineering department - 4

Figure 4-15: Deteriorated surface of the new building of the Textile Engineering department - 5

Figure 4-16: Deteriorated surface of the new building of the Textile Engineering department - 6

Figure 4-17: Deteriorated surface of the new building of the Textile Engineering department - 7

Figure 4-18: Deteriorated surface of the new building of the Textile Engineering department - 8

- Slab on top of the Main Board Room of the Vice Chancellor’s Office. Due to the age of the structure, a few failures in finishing had occurred and the finishing was chipped off, waterproofed and refinished to address the issue.
- Roof drains of the Library Building. Lack of maintenance of the storm water drains due to lack of proper access to the drains was the cause of this problem. Proper cleaning and application of waterproofing was the recommended option.

- Washrooms and rooftops of the old building of the IT Faculty. The waterproofing component was not addressed by the contractor after the building was handed over to the client. Therefore, the issue was left for the client to address.

Figure 4-19: Deteriorated surface of the rooftop of the IT faculty old building - 1

Figure 4-20: Deteriorated surface of the rooftop of the IT faculty old building - 2

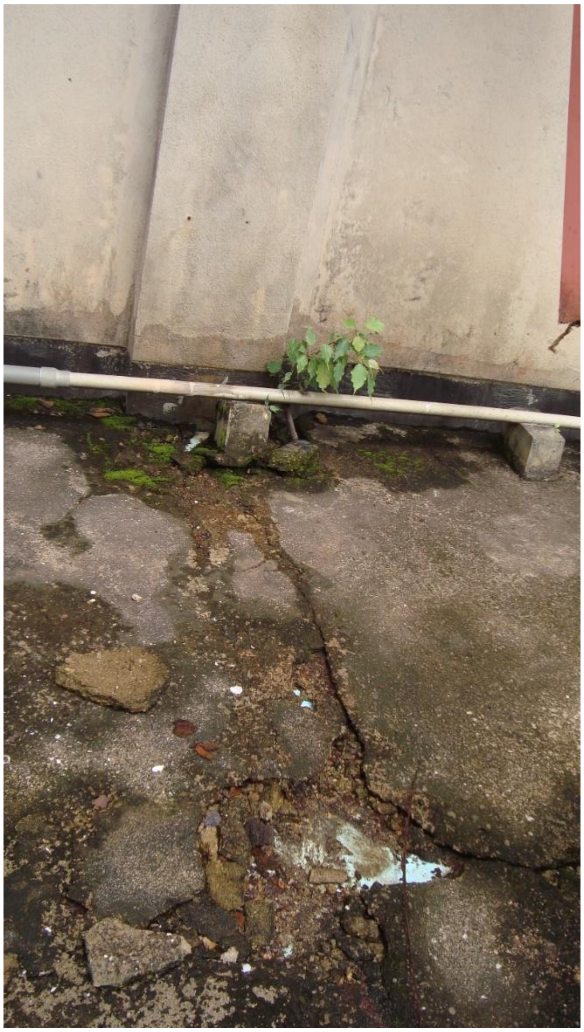

Figure 4-21: Deteriorated surface of the rooftop of the IT faculty old building - 3

- Gutters and washrooms of the L Block Building. Damaged areas in washrooms and gutters were not maintained routinely. The damaged areas had been prone to water leakages and resulted in persistent issues of water leakage. Routine maintenance is recommended to avoid such issues.
- Washrooms of A, B and C Hostel. Locating the root cause required a considerable amount of effort, time and money as the components had to be removed, waterproofing done and then refinished.
- Washrooms of female hostels located within the university premises. Locating the root cause required a considerable amount of effort, time and money as the components had to be removed, waterproofing done and then refinished.

- Rooftop slab of Health Centre. Due to the age of the structure, a damage in the slab caused the problem. After chipping off, waterproofing and reconcreting the problem was addressed.
- Washrooms of Sumanadasa Building. Locating the root cause required a considerable amount of effort, time and money as the components had to be removed, waterproofing done and then refinished.
- Top floor washrooms and sides of columns of the labs of the building of the Department of Electronic Engineering. The outlet pipes were not jointed properly. Thus causing leaks in from the washrooms along the columns. The pipes were re-laid, waterproofed as needed and finished.
- Washrooms above the Maintenance Division. The required areas were identified without having to demolish or remove considerably. Addressing the minor issues properly would have helped to avoid this.
- First floor washrooms of the Union Room and Physical Education Division. Ignoring minor issues had caused the problem to spread far and wide. Addressing minor issues during routine maintenance is the recommended approach.

Waterproofing is a mandatory component in the design and construction of swimming pools, bathrooms and exposed rooftops, etc. But in most other cases, the need for waterproofing has arisen due to design faults which have resulted due to neglecting the ability of structures to retain water. Also, it may even be due to poor workmanship.

Apart from the above areas, several case studies were conducted to further the understanding on the necessity and process of waterproofing.

4.1.1 Case Study I

For Case Study 1, a residence situated in Wijethunga Mawatha near the University of Moratuwa was selected. The waterproofing issue in this case was the leakage of water into the house through a wall located on one side of the house. The entire area is subjected to the effects of a high water table as it is low ground. But waterproofing was done on the area to prevent leakage of water before constructing this residence in question. But a house that was built before the construction of this house was then demolished and removed afterwards. While the house was standing, that area in which the house was located was not subjected to any waterproofing as the surrounding areas. So when the house was demolished, the water level rose in that area in which the house was initially located. Now, the wall in question of the residence is located right on the boundary of the house that was demolished. Hence, the issue of leakage of water came into light through that wall.

Identification of the root cause and initial investigation would have helped to avoid the issue completely.

In this situation, negative side waterproofing was the proposed remedial action. Negative side waterproofing is the application of waterproofing products onto the dry or inside surface. The goal here is to keep the water out by preventing it from entering into the surface.

The remedial action taken in this case can roughly be summarized into the following steps.

1. The deteriorated plaster was chipped off.
2. Catch up plaster was applied for inspection.

Figure 4-22: Initial surface with the deteriorated plaster chipped off and catch up plaster applied

3. Surface preparation was done by applying a thin plaster to prepare the surface for waterproofing.

Figure 4-23: After surface preparation for waterproofing

4. The waterproofing product was applied.

Figure 4-24: After application of waterproofing

5. Cover plaster was applied over the waterproofing product as finishing.

Figure 4-25: After application of cover plaster - 1

Figure 4-26: After application of cover plaster - 2

4.1.2 Case Study II

For Case Study II, an inaccessible, open area within the Information Technology faculty building was considered.

Figure 4-27: Open slab area in the IT faculty building of University of Moratuwa considered for case study II

Figure 4-28: Open slab area prone to collection of rainwater

Figure 4-29: Another problematic inaccessible narrow strip of slab area

Figure 4-30: No proper means of access to the area

The open slab area above tends to retain water after a heavy rain or such as proper means for drainage have not been allocated initially. Due to this holding of water, the collected water leaks on to the labs situated under that area.

Figure 4-31: Labs onto which water leaks from the considered area

Moreover, a health hazard also comes to play due to the breeding of mosquitoes in the retained water.

Figure 4-32: The area poses a health issue by being a breeding ground for mosquitoes

It must be noted, that a passive waterproofing design could have been utilized at the design stage itself. But in this case, the Consultant has not made use of passive waterproofing designs initially. In this situation, a structural solution can even be implemented over a waterproofing product. By covering the area in question using a roof structure, the issue of water being collected on the surface can be addressed while the area can also be taken into use as a study area for students or such. This would have been an appropriate passive waterproofing action during initial design and construction stages itself.

On another note, waterproofing of the surface can also be done to protect the structural integrity of the surface and also to keep the water from seeping in to the lower floors.

4.1.3 Case Study III

In case study III, the basement area of the Civil Engineering department building was considered. This area is located below the structural labs and the area is being used to adjust machines in the laboratory easily. The ground water table being above the level of this basement area and the well nearby is a reason for the flooding of this area.

Figure 4-33: Flooding of the basement in the Civil Engineering Department building including the staircase - 1

Figure 4-34: Flooding of the basement in the Civil Engineering Department building including the staircase - 2

Figure 4-35: Flooding of the basement in the Civil Engineering Department building including the staircase - 3

Figure 4-36: Flooding of the basement in the Civil Engineering Department building including the staircase - 4

Figure 4-37: The basement of the Civil Engineering Department building prone to flooding

In this situation, the application of specialized waterproofing products was required to deal with the problematic situation. The waterproofing product was injected into the walls to completely fill up the insides and thus block out the water trying to seep inside.

Figure 4-38: Non-return nozzles fixed to inside walls for the injection process - 1

During this injecting process, the injected product seeps out from another location. Care must be taken here to be on the lookout for such.

Figure 4-39: Non-return nozzles fixed to inside walls for the injection process - 2

Figure 4-40: Injection Process - 1

Figure 4-41: Injection Process - 2

Figure 4-42: Injection Process - 3

Figure 4-43: Injection Process - 4

Figure 4-44: Injection Process - 5

4.1.4 Case Study IV

Case Study IV was conducted at Flower Court House apartment complex comprising of ground plus seven floors located in Colombo 07. A waterproofing issue was brought to light in the building when water from the rooftop started to leak through the walls to the lower floors. Here, passive waterproofing design at construction joints at initial stages would have prevented this issue from occurring.

Figure 4-45: Construction joint line in floor level of 7th floor

Figure 4-46: Water seepage from construction joint line at slab level of 7th floor - 1

Figure 4-47: Water seepage from construction joint line at slab level of 7th floor - 2

Figure 4-48: Water seepage from construction joint at floor level of 7th floor

Figure 4-49: Water seepage along the wall of the ground floor

Figure 4-50: Water seepage along the walls from the duct line in the ground floor

Figure 4-51: Rooftop deteriorated tile skirting expelled

In the following figure, the area is waterproofed using applicatory methods and apart from that as an additional precaution another drainpipe is put in place to drain out any water that may otherwise turn stagnant after years of collection. This is a good example of passive waterproofing in practice.

Figure 4-52: Rooftop location of water meters prone to collection of water

Figure 4-53: Rooftop location prone to collection of water - 1

Figure 4-54: Rooftop location prone to collection of water - 2

Remedial measures taken in terms of waterproofing involved draining the collected water beneath the tile surface by causing a slight slope to facilitate such drainage into the drains and then discarding that water likewise. Afterwards a waterproofing solution was applied on the surface before finishing it by laying tiles.

Figure 4-55: Passive waterproofing mechanism on rooftop drains into which water gets drained beneath the tile surface - 1

Figure 4-56: Rooftop drains into which water gets drained beneath the tile surface - 2

Figure 4-57: Remedial action taken to prevent collection of water at rooftop level using passive waterproofing design

Figure 4-58: Rooftop surface to be finished

Figure 4-59: Post application of waterproofing solution at rooftop level

Figure 4-60: Finished surface and unfinished construction joint line of rooftop

Figure 4-61: Rooftop drainpipes to facilitate proper drainage

Also, another location was noted where the water had seeped in from a crack in the floor and ponding of water has occurred. In such cases, even the best of waterproofing solutions being applied on the top surface will not prevent the ponded water from leaking through the bottom surface. Here, the solution is to find the root cause, in this case the pond of water by removing the floor surface and then extracting the ponded water and then taking usual remedial measures in terms of waterproofing.

The construction was in two stages and the issue laid with the construction joint. Ponding of water had occurred within the construction joint. The ponded water had to be removed first and foremost before applying waterproofing.

4.1.5 Case Study V

The tallest dam in Sri Lanka, Victoria Dam was selected for as the fifth case study. This goes on to show that waterproofing issues can even affect the largest of structures. This arch dam is located 209 km upstream of the mouth of Mahaweli River and 6 km from Teldeniya. Victoria Dam has proven to be extremely useful in terms of irrigation purposes and hydroelectric power production.

The sluice gates are a crucial part of a dam structure. Any waterproofing issues to the sluice gates must be addressed immediately. The sluice gates located at the far left corners in the figure below were affected by waterproofing issues that may have been a threat to the structural integrity of the sluice gates of the dam. These affected surfaces were quickly patched up with waterproofing solutions to prevent such damages from reaching the light of day.

Figure 4-62: Sluice gates located at the far left were affected by waterproofing issues

The cause has been identified as a leak that sprung up due to the high pressure that the structure is being subjected to. These minor leaks were addressed by injection moulding.

Figure 4-63: Affected surfaces were injected with waterproofing solutions - 1

Figure 4-64: Affected surfaces were injected with waterproofing solutions - 2

The following figure shows the surface at ground level of an underground control room located within the premises of the dam. Water seeps in from the corners of the surface into the underground control room and this required an immediate remedial measure in terms of waterproofing as well.

Figure 4-65: Top surface of the underground control room from which water leaks in

Figure 4-66: Bottom surface through which water leaks in

Several locations of the machine rooms with water leaks and waterproofing issues were also noted and are mentioned below. The location has not been decided with proper consideration for water drainage at ground level which is above the control room. The regulation of the slope for water drainage will help address the issue of leaking through the joints.

Figure 4-67: Water seeping in from puddle collar - 1

Figure 4-68: Water seeping in from puddle collar - 2

Figure 4-69: Surface injected with waterproofing solutions - 1

Figure 4-70: Surface injected with waterproofing solutions - 2

Figure 4-71: Surface injected with waterproofing solution from top level - 1

Figure 4-72: Surface injected with waterproofing solution from top level - 2

Figure 4-73: Water leaks to be injected with waterproofing solutions

It must also be noted that this case is a good example for why waterproofing must be done as a design and build contract instead of measure and pay. Only that way can consultants recommend appropriate and suitable solutions with regard to waterproofing.

4.1.6 Case Study VI

The Galle Town Hall was selected for the sixth case study. Due to its coastal location and owing to the age of the building, this site proved to be truly challenging. Being part of the Dutch Fort which was built nearly 423 years ago, the building itself requires more frequent maintenance and renovation activities to be carried out. Apart from that several locations were noted with leaks and requiring waterproofing solutions and other remedial actions. Also, structural deterioration was also noted as part of lack of waterproofing.

Figure 4-74: Water leaks in the front wall of the Galle Town Hall

Figure 4-75: Water leaks - 2

Figure 4-76: Water leaks - 3

Figure 4-77: Structural deterioration of ground floor slab level due to lack of waterproofing - 1

Figure 4-78: Structural deterioration of ground floor slab level due to lack of waterproofing - 2

Figure 4-79: Structural deterioration of ground floor slab level due to lack of waterproofing - 3

Figure 4-80: Structural deterioration of ground floor slab level due to lack of waterproofing – 4

The case must be studied thoroughly and Consultants need to gain sufficient knowledge on materials, application and applicators. Separate parts of the work can be done as design and build by obtaining proposals or as a whole even.

4.2 Questionnaire Survey

The completed questionnaires were obtained from the selected entities and grouped according to their categories. Afterwards, the results obtained from each party were analyzed together with the other parties in the category to derive a better understanding of their views on this topic. The discussion of the results of the analysis are presented next.

Apart from general questions, a few specialized questions were included in the questionnaire. Out of those specialized questions, the answers received from the 32 consultants and the 32 applicators were analyzed as follows.

Consultants

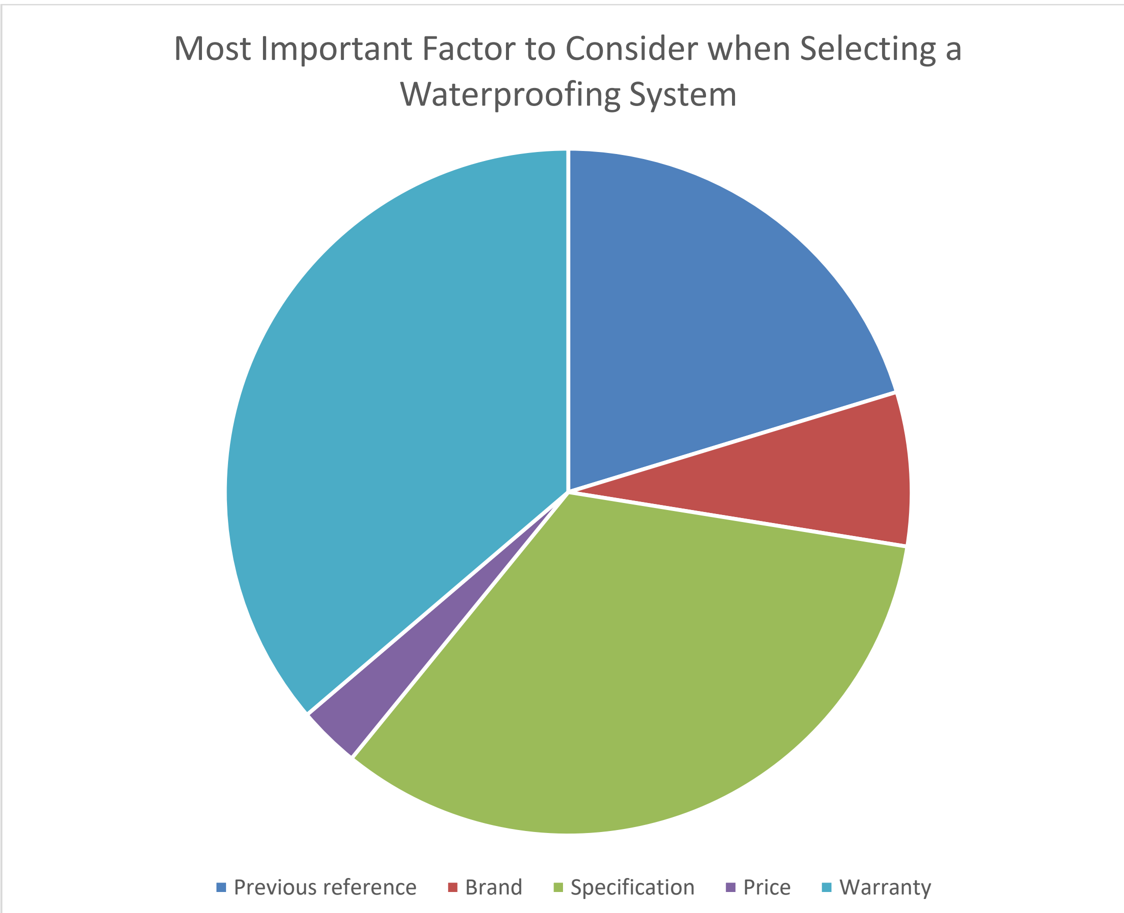

Figure 4-81: Most Important Factor to Consider when Selecting a Waterproofing System

According to the responses received from Consultants, the most important factor to consider when selecting a waterproofing system is shown in Figure 4-81 above. According to that, warranty and specifications are the two most important factors to consider when selecting a waterproofing system.

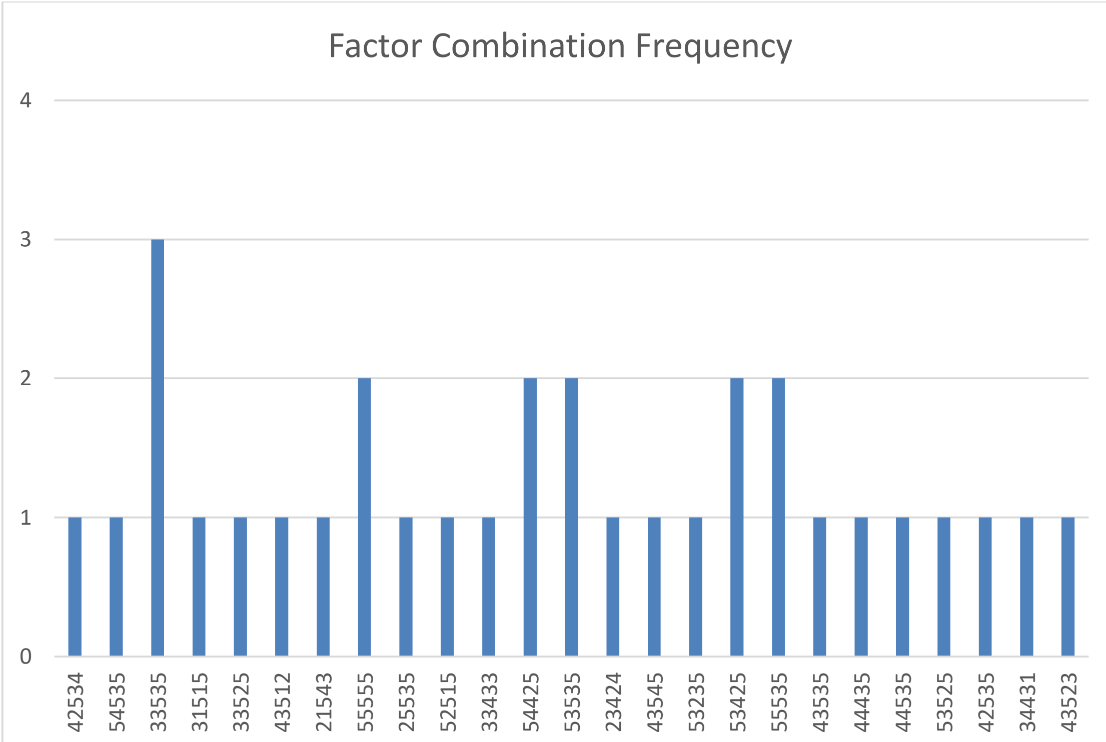

Figure 4-82: Factor Combination Frequencies for importance of factors

The above graph shows the frequency distribution of the importance of factors to be considered when selecting a type of waterproofing system. The factors that were considered are as follows.

1. Previous product application reference
2. Brand of the product
3. Product specification
4. Product price
5. Warranty offered

From the above results the most common combination for the importance of factors is as follows.

Table 4-1: Most Common Combination for Importance of Factors to be considered for selecting a Waterproofing System

		5 – Most Important	4 – More Important	3 - Important	2 – Less Important	1 – No importance
1.	Previous product application reference			√		
2.	Brand of the product			√		
3.	Product specification	√				
4.	Product price			√		
5.	Warranty offered	√				

As per the most common combination shown in the above table, the highest level of importance has been given to the two factors of Product Specification and Warranty. The other three factors of previous application reference, brand and price are given importance of an average level.

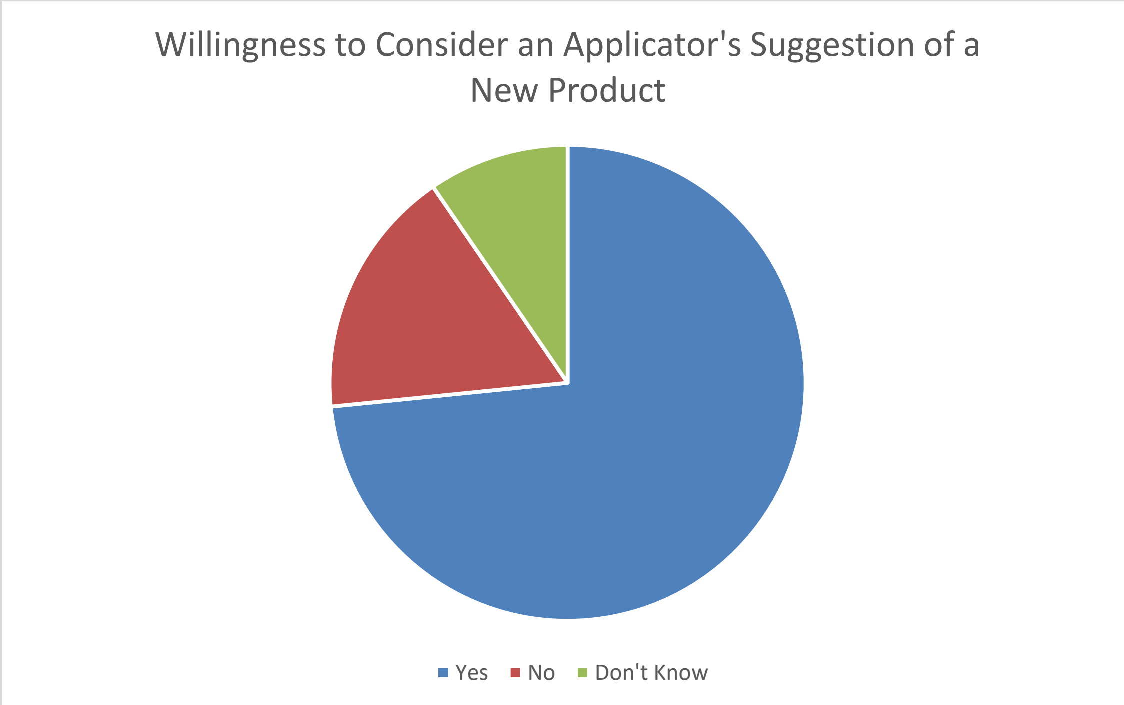

Figure 4-83: Willingness to Consider an Applicator's Suggestion of a New Product

Figure 4-83 above gives the willingness shown by Consultants to consider an applicator's suggestion of a new product. As seen from the graphical representation given above, a majority of consultants are willing to consider an applicator's suggestion of a new product. The reasons suggested by some consultants for this are as follows.

- The product will be considered after considering composition, engineering proportion, specification and warranty offered.
- The product will be considered based on new technology and to promote more efficient products.
- The product will be considered based on factors given in the previous question such as previous product application reference, product brand, product specification, product price and warranty offered.
- The product will be considered if it brings about an improvement in quality and/or reduction in price.
- The product will be considered to encourage more innovative products in the market.

- The product will be considered based on cost benefit ratio, characteristics and behavior of site condition.
- The product will be considered based on new material compliance.
- The industry improves with time and the introduction of new products maybe more efficient.
- The product will be considered based on brand name specification, warranty and source of material.
- The product will be considered based on properties, durability and cost.
- The product will be considered for improved performance due to improved research technology related to the specification.

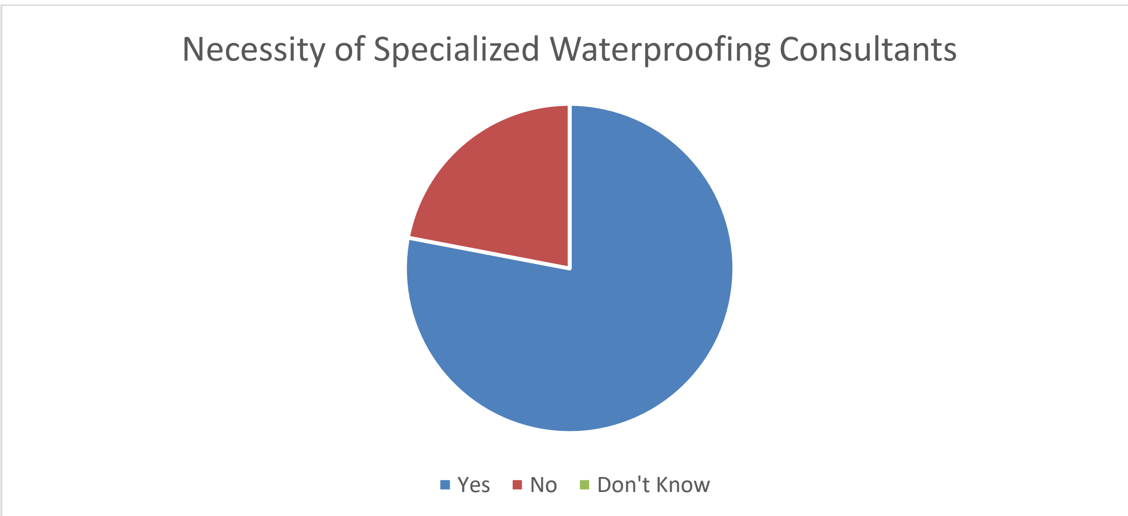

Figure 4-84: Necessity of Specialized Waterproofing Consultants

The Consultants' views on the necessity of specialized waterproofing consultants is shown in Figure 4-84 above. A considerable majority of consultants are on the view that a specialized waterproofing consultant is necessary.

The following noteworthy suggestions were also given by consultants to improve waterproofing practices in the industry.

- Proper training should be given to applicators.
- Establishment of an efficient mechanism to control the quality of material

- Use easy to use, cost effective, ecofriendly material for reinforced concrete structures
- Educate the general public regarding the importance of waterproofing practices in the industry and include more professionals in waterproofing practice.
- Substandard waterproofing applications have caused considerable damages to the buildings and it leads to maintenance at a higher cost. Therefore, if we can achieve better waterproofing work at first instance, it is economical and this can be achieved through a professional approach.
- Introduction of a proper testing methodology
- Educate construction industry stakeholders on the purpose of waterproofing
- Research and development needs to be approached for waterproofing
- Performance based contracts can be awarded for waterproofing
- Follow standard and technical specifications properly
- Civil engineers and technicians should be made aware of waterproofing methods and techniques as any building may need some sort of waterproofing.
- Establish a control body to collect performance data from applicators in the industry.
- Evaluate and categorize on the performance and the cost.
- Make available of the information to the users.
- Certification of skilled personnel for the application.
- There are a lot of products available in the market. Therefore, we need consultants who have good experience in such fields to select suitable material for different locations that suit the site conditions.
- Waterproofing is specialized work and it is very difficult to find skilled persons for these works. It would be better if organizations take action to train persons in this regard.
- Waterproofing should be done under strict supervision of experts by professional contractors according to the specifications. It is very important to identify correct waterproofing method for various locations to achieve our task without any doubt.

Applicators

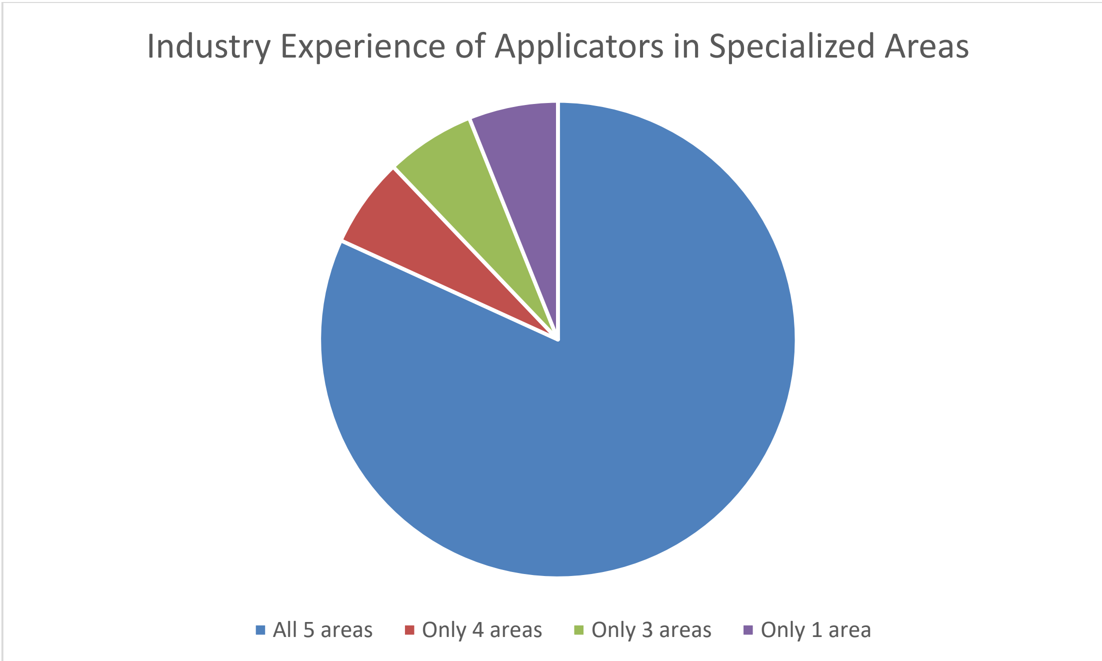

Figure 4-85: Industry Experience of Applicators in Specialized Areas

Bathroom waterproofing, roof slab / balcony waterproofing, water tank / sump waterproofing and basement waterproofing were considered as the five specialized areas of waterproofing in the industry. 81% of applicators possessed experience in all 5 specialized areas while 6% knew about 4 specialized areas, another 6% knew about 3 specialized areas and a final 6% knew about only 1 specialized area.

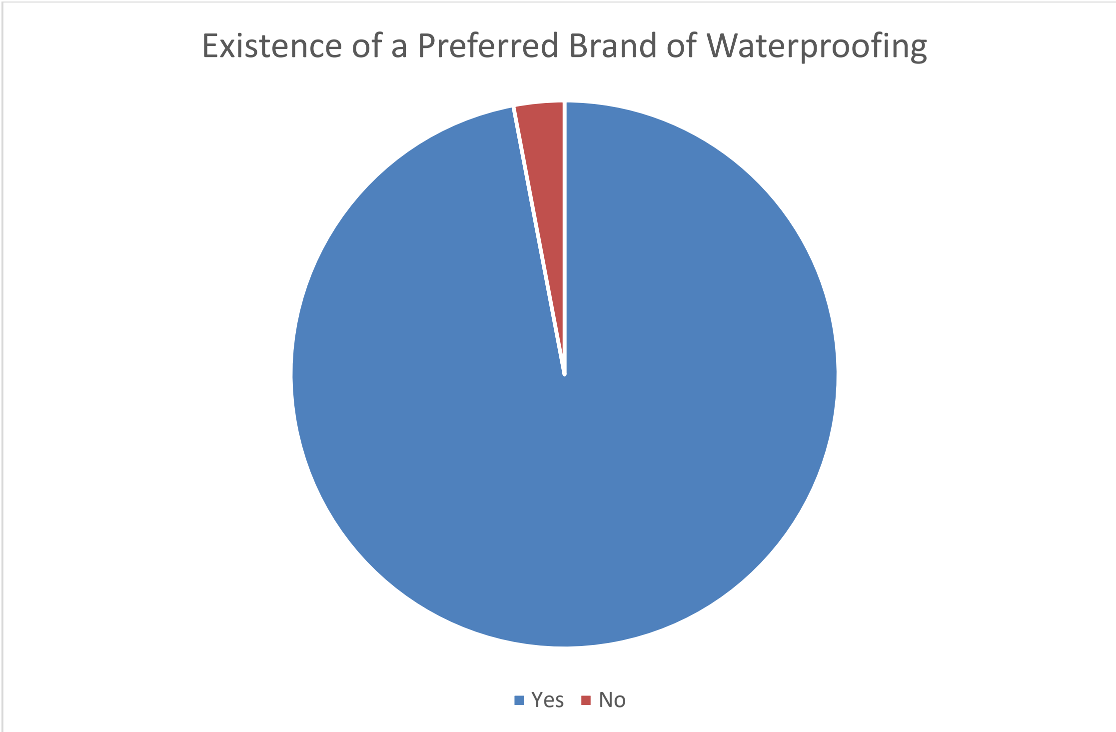

Figure 4-86: Existence of a Preferred Brand of Waterproofing

Figure 4-86 above shows the preference shown to a specific brand of waterproofing by applicators in the field. As is evident from the graphical representation above, almost all applicators have a certain bias towards a specific brand of waterproofing products.

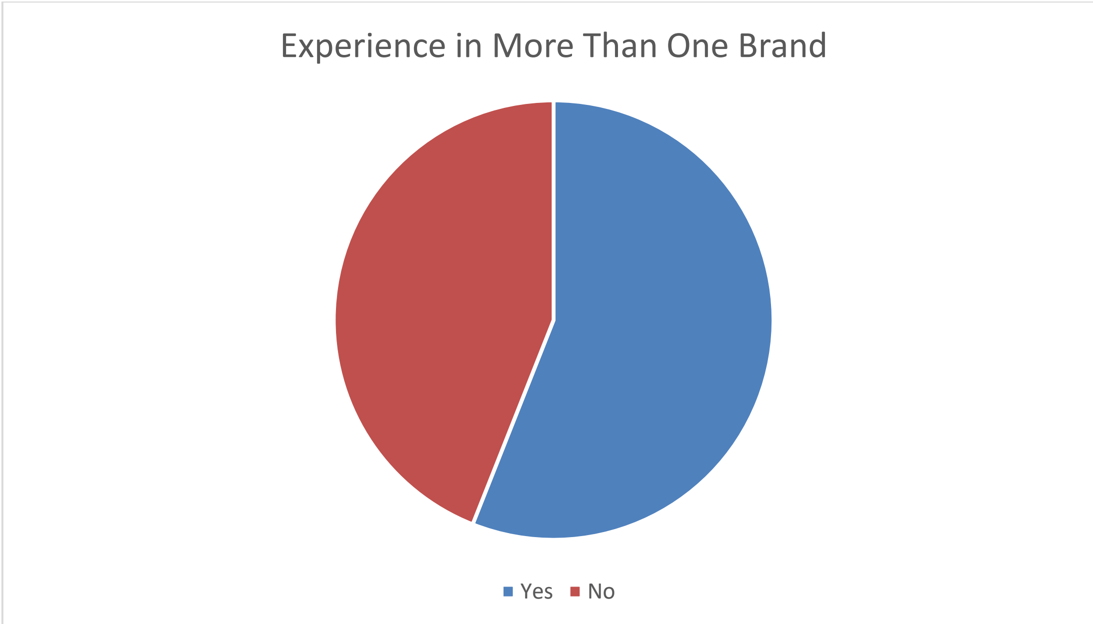

Figure 4-87: Applicators Experience in More than one Brand of Products

The applicators' experience in more than one brand of products is shown in Figure 4-87. The results showed that more than half of the applicators did possess experience in more than one brand of waterproofing product in the field. Combining these results with the previous results in Figure 4-86 shows that applicators still prefer a specific brand even after working with multiple brands of waterproofing products.

Figure 4-88: Selection of Specific Products for Each Area

The above Figure 4-88 shows that all applicators selected specific waterproofing products that are suitable for each area based on the area subjected to waterproofing.

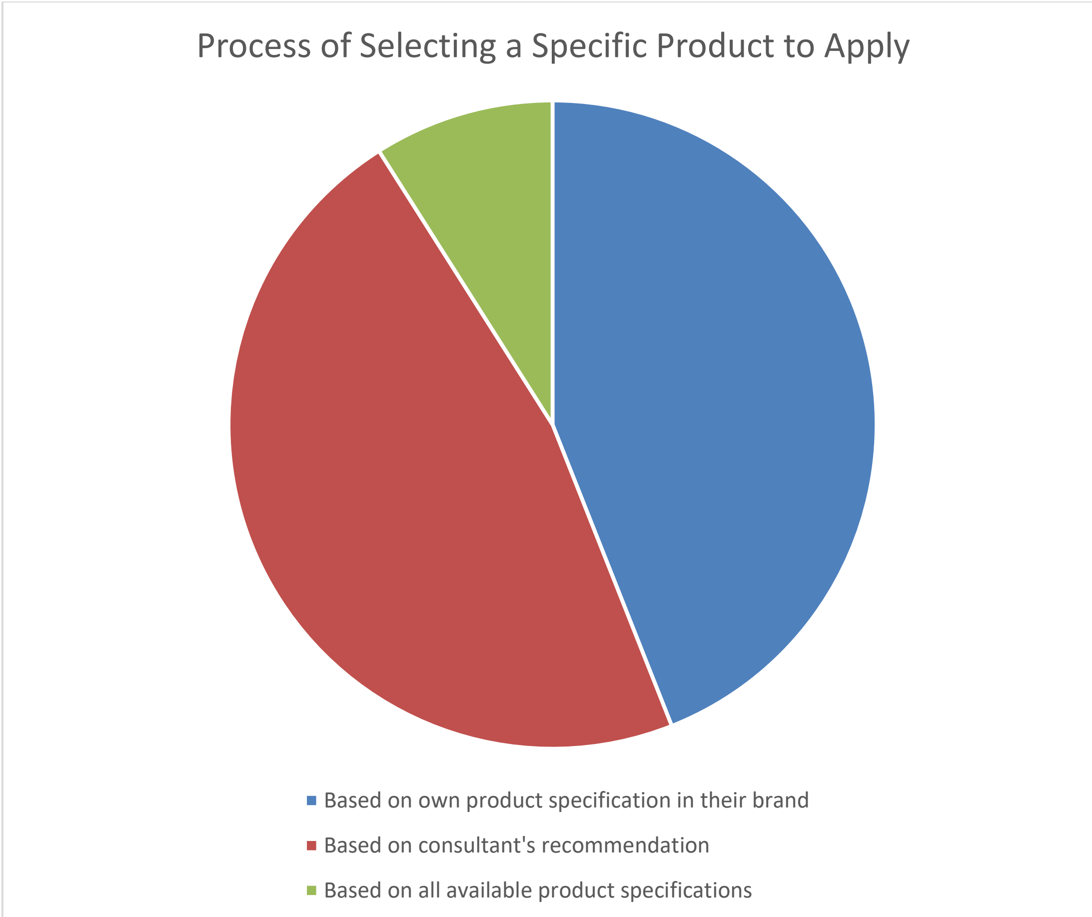

Figure 4-89: Process of Selecting a Specific Product to Apply

As per Figure 4-89 while some applicators selected a specific product to apply based on consultant's recommendations, others selected the waterproofing product based on own product specifications of their brand. A minor group of applicators also preferred to select the waterproofing product based on all available product specifications. A group of applicators selected the system based on both consultants' recommendations and their own product specifications. A similar group of applicators selected the system based on consultants' recommendations and all product specifications. Of all these groups, it can be noted that the group that selects the system based on consultants' recommendations and all product specifications can be considered to be the most knowledgeable in the field.

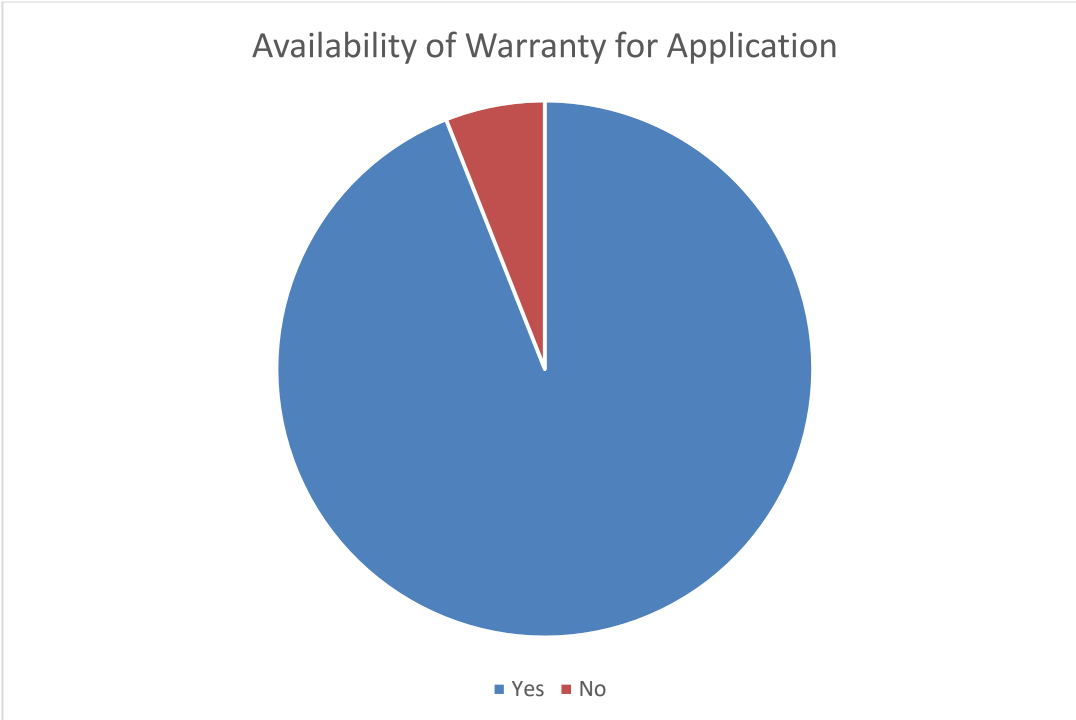

Figure 4-90: Availability of Warranty for Application

As shown in Figure 4-90, most of the applicators have responded that warranty is available for the application of their brand of waterproofing products.

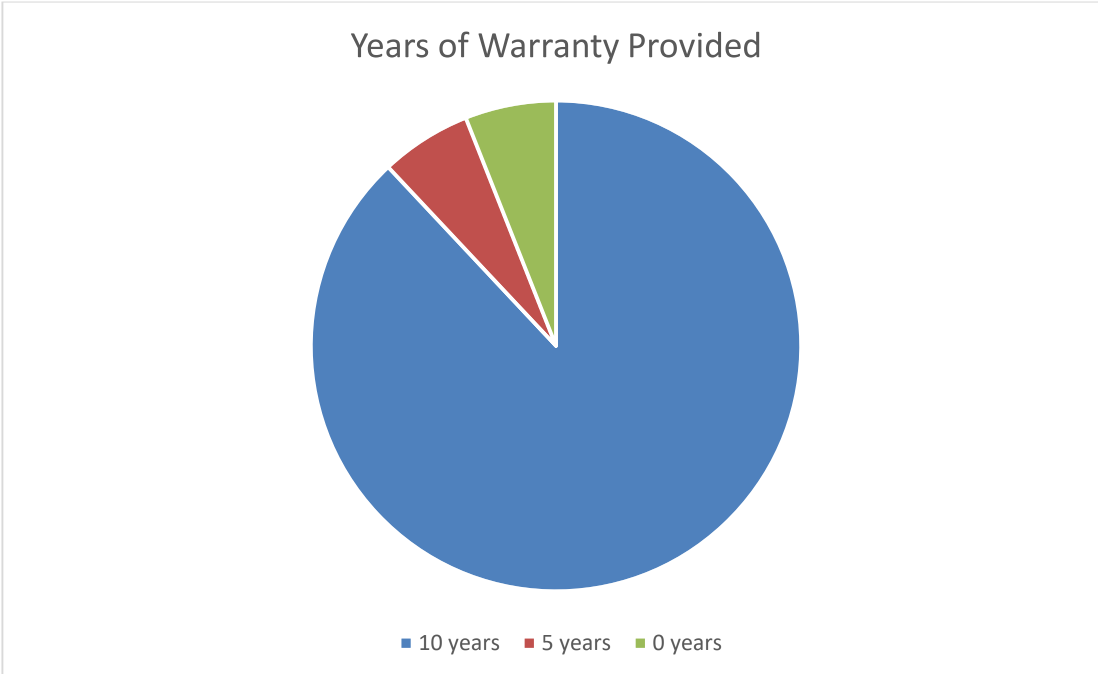

Figure 4-91: Years of Warranty Provided by Applicators

A majority of waterproofing products provide 10 years of warranty for their system while some provided 5 years of warranty. Yet there are some for which no warranty of sorts is provided. One applicant provided 5 years of warranty for old areas and 10 years for new areas and 2 years for blind walls or any other painted surface.

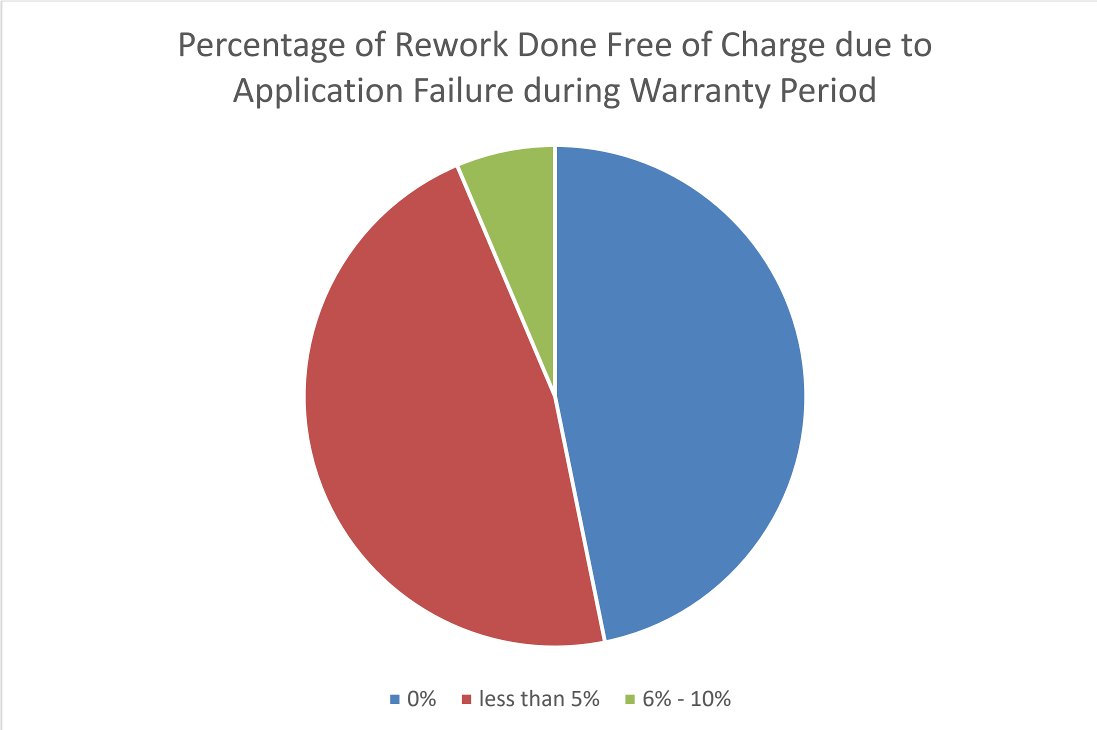

Figure 4-92: Percentage of Rework Done Free of Charge due to Application Failure during Warranty Period

The above figure shows the percentage of rework done free of charge due to application failure during warranty period. In most cases, it was either 0% rework done free of charge or less than 5% rework done free of charge due to application failure during warranty period. A minority actually provided 6% - 10% rework done free of charge due to application failure during the warranty period.

Noteworthy recommendations from applicators will be highlighted here.

- An applicator emphasized that finishing work contractors like plumbing and tiling need to inform the waterproofing applicators if any damage occurs by their hand on the waterproofing envelope so that the applicators can rectify it again before handing the project over.
- Another emphasized that pipes need to be cut at concrete level to prevent damages to the envelope from projected sections. Pipes can be fixed externally so that no structural disturbance needs to be done for repairs, etc. These are methods of implementing passive waterproofing design practically.

- Some applicators also noted that the Consultants sometimes recommend the same system to all locations as well although it is unsuitable ignoring the applicators' recommendations. They noted that the Consultants knowledge must be improved.
- There was one applicator who has had no issues during his 5 years in the industry as he himself carries out the full scope of finishing works including tiling and plumbing works in addition to waterproofing. Therefore, he can ensure the envelope remains intact and can also confidently provide his warranty of 10 years.
- Improvement of product awareness among applicators was another suggestion.
- Honeycomb repairing must be done properly with construction grout was another recommendation.
- Improvement of awareness regarding weather shield paint and their uses and limitations.
- One applicator informed that he had not encountered any problems as he covers the waterproofed surface with a plaster finish within one day of ponding and therefore can give the warranty with confidence.
- Plumbers and tilers engaging in waterproofing work will not ensure a high-quality workmanship or finish.
- Also, changing pipelines after waterproofing is done should be avoided as it damages the waterproofed surface.

During the study and based on discussions it was revealed that most of the waterproofing failures have occurred due to the lack of proper knowledge when selecting the waterproofing system, preparing the substrate and application of the waterproofing system. On the other hand, it is the manufacturers' who possess wide knowledge on waterproofing solutions because it is their field of expertise and it is they who govern the decision making in selection. This is further proven because other parties have limited knowledge on the topic.

The applicators engage in their practice according to the advices and recommendations provided by the engineer in charge. That included the contractors, consultants and also the manufacturers of the waterproofing solution that was being applied.

The clients choose to partake in waterproofing as recommended by the contractors and consultants of the respective project. The views of this category can also be used to gain further insight into the general public opinion on this topic. Their knowledge in this topic was quite limited.

The contractors follow the recommendations of the consultant of the project as supposed to. Similarly, for waterproofing, analyzing and selecting the suitable waterproofing system lies within the role of the consultant. Otherwise they are at the mercy of suppliers' knowledge in making recommendations.

Finally, the consultants' views on this topic were on par with the manufacturers' ideals. The consultants convey the message of the manufacturer regarding their waterproofing products according to the situation presented. The manufacturer presents the scope of the solutions available and the consultant finalizes the decision accordingly as seen fit.

5 Conclusion & Recommendations

5.1 Conclusion

Passive waterproofing is the act of obtaining the results of an effective waterproofing system without utilizing waterproofing materials. That involves the inclusion of suitable design aspects and remedial measures in the design and construction stages itself to avoid the need for any additional waterproofing during the latter stages. The following passive waterproofing design aspects can be implemented.

- Sloping bed formation at initial stages
- Formation of kickers in parapet walls etc. to stop water leakage from joints
- Covering open areas with an architectural roof or such
- Certain acrylic coatings that are used for insulation can provide waterproofing properties as well and vice versa
- Avoiding embedded conduits and instead placing pipe joints, etc externally
- Certain chemical reaction formations can help block openings and prevent leaks.

Accordingly, it can be concluded that when selecting a waterproofing system attention must be paid to the location, cost and exposure of the substrate. It is mandatory to pay attention to detail when selecting the most suitable waterproofing system during a new structural construction. Following reasons were revealed as failures in waterproofing.

- Improper detail specifications
- No allowance for structural or thermal movements
- Improper selection of materials
- Use of substitutes that do not integrate with other components of the envelope
- Insufficient standard details provided for terminations and transitions
- Inadequate training for installers of materials
- Insufficient testing for compatibility with other envelope components
- Improper installations
- Inattention to details

- Use of untrained mechanics to complete the work
- No scheduled maintenance programs
- Use of untrained personnel to make repairs
- No scheduled inspection programs
- Postponement of repairs until further damage is caused to the envelope and structural components

Although there is a minimal chance of errors occurring during the construction stage, any errors during application and installation will prove their existence later.

Also, in most cases the issue was with identifying the root cause that resulted in the problem. This may even take some time but it is extremely important to address the root cause instead of short-term remedies if the need is to eliminate the problem entirely.

Most errors occur during waterproofing due to the lack of quality workmanship and due to lack of proper knowledge in selecting the most appropriate waterproofing system for the structure. Erroneous substrate preparation can also result in full and ultimate failure of the most suitable waterproofing system as well. Therefore, it has to be noted that special attention must be taken during each and every stage from the selection of waterproofing to finishing the application so as to prevent the occurrence of any errors in any stage.

The survey results also concluded that the manufacturers' views are the most prevalent in the field as those recommendations are passed on from each entity to entity. Manufacturers of waterproofing solutions possess a wide knowledge on the topic as it is their field of expertise while other parties have comparatively limited knowledge on the topic. Thus the manufacturers can be concluded as the experts in the field.

Also, it was concluded that more often than not the budget allocated for waterproofing proved to be insufficient for the purpose. That is because the actual waterproofing cost was only around 5% of the full cost while the remaining 95% was needed for the other preliminary actions such as demolition etc. or finishing such as retiling etc. In most cases, failure to regard the costs of these preliminaries and finishing costs resulted in the actual cost being immensely higher than the estimate.

Ultimately, it can be said that the incorrect selection of waterproofing materials and methods is the main cause for waterproofing failures and therefore, it is advisable to enhance the knowledge pertaining to waterproofing among industry practitioners.

5.2 Recommendations

It was evident that most of the waterproofing failures have occurred due to the lack of proper knowledge when selecting the waterproofing system, preparing the substrate and application of the waterproofing system. Therefore, it is recommended that proper awareness in this regard is created among the public to overcome this issue.

Also, it is recommended that application of all waterproofing systems to be always done by a trained and qualified applicator to minimize errors during application. In selecting the suppliers, it is better to demonstrate the performance of their products by practically demonstrating by showing the location where the product is in operation. Also the training of laborers to do the job according to specified guideline should be the role of the supplier in case they do not have capacity for installation.

In addition, from the above conclusions derived, it is also recommended to follow the manufacturers' advice and recommendations while complying with their standards as fully as possible. Their expertise can be made use of from selecting a waterproofing solution to application and finishing itself.

Since waterproofing, analyzing and selecting the suitable waterproofing system lies within the role of the consultant. Therefore in case they do not have that know how they should hire required expertise without depending solely on manufacturers' ideas.

Also, it is advisable to always prepare estimates for waterproofing under three components such as;

1. Preliminaries
2. Waterproofing
3. Finishing
4. Unforeseen provisional sum

Likewise, the estimate can be prepared much closer to the actual cost rather than just being a minute fraction of it.

Also, it is best if waterproofing work can be awarded as design and build contracts where the contractor is required to identify the underlying root cause, then propose the most suitable and economical solutions and then undergo implementation of the selected solution.

The following are recommendations to be given to the general public with regards to waterproofing of rooftop, water tank and blind walls.

Recommendations to the General Public

1. **Rooftop**
    - Due to sunlight and high elongation, a flexible waterproofing system needs to be used always. Cementitious rigid ones are not suitable as they do not facilitate expansion. Therefore, it is more suitable to use a system that is more flexible like acrylic based or electrometric based.
    - For preparation and final finishing follow the relevant waterproofing guideline and data sheet to make sure that the system remains intact.
    - Work needs to be done by a good applicator.
    - Follow quality control procedures as per above points.
2. **Bathrooms**
    - As tiling can damage the waterproofing, make sure to lay a protective screed over the waterproofing before laying tiles. If the thickness is not sufficient, tiling must be done without damaging the waterproofing system.
    - Electrometric based systems with a smooth finish that are used for rooftops are not suitable here. Instead cementitious systems are suitable as tiling can be done on top of that.
    - Work needs to be done by a good applicator.
    - All pipes and joints must be securely sealed using construction grout or similar material before doing the waterproofing.

- Crystal forming materials are not suitable as of now as they are only suitable for cement surfaces and not brick surfaces. This can cause problems at cement-brick joints.
- Obtain previous reference from good waterproofing practitioners.
- Always stick to the relevant guidelines and product data sheets when engaging in the activities.

3. **Water Tanks**
    - Make sure that the waterproofing system is suitable for drinking water storages by referring data sheets before applying any waterproofing on internal surfaces.
    - Crystal forming materials are suitable if the whole tank is concrete. But it is best to identify honeycombs and repair any leaks before applying the waterproofing system.
    - Lay a protective layer on top of the waterproofing system as it may be damaged during cleaning activities afterwards.
    - All pipes and joints must be securely sealed using construction grout or similar material before doing the waterproofing.
    - Work needs to be done by a good applicator.
    - Follow quality control procedures as per above points.
4. **Blind Walls**
    - It is recommended to avoid blind walls if possible.
    - Waterproofing admixture can be added to the plaster and plastering can be done on the blind wall.
    - Paint the surface using a single component like an acrylic coating.
    - Even better if a two component system such as polymer modified can be used as it will provide insulation in addition to the waterproofing. Also, it can help to prevent cracks developing in the plaster due to excessive heat.

5.4 Future Works

Further studies can be done while expanding the sample collection further and analyzing the results obtained. The study area can be widened by considering additional case studies to deepen the knowledge and exposure in the field. In addition, the questionnaire can be developed further as separate questionnaires for each class like contractors, clients, consultants and applicators.

5.5 Summary

This project started with an extensive literature review on the topic of waterproofing and waterproofing of structures.

The research related to the project was done in two parts as the field study and the field survey. The field study focused on real world examples of waterproofing needs and issues. It also focused on locating the root cause and identifying the appropriate remedial measure in such cases.

The other part of the research included the field survey. In this survey, questionnaires were handed out to four parties engaged in the field of waterproofing, those four parties being contractors, clients, consultants and applicators. Their expertise was obtained in the form of filled questionnaires to collect data to be analyzed for the project. The collected questionnaires were thoroughly analyzed to depict the conclusions thus obtained in this project.

During the study it was revealed that most of the waterproofing failures have occurred due to the lack of proper knowledge when selecting the waterproofing system, preparing the substrate and application of the waterproofing system. It is the manufacturers' who possess wide knowledge on waterproofing solutions because it is their field of expertise and it is they who govern the decision making in selection. This is further proven because other parties have limited knowledge on the topic.

It was evident that most of the waterproofing failures had occurred due to the lack of proper knowledge when selecting the waterproofing system, preparing the substrate and application of the waterproofing system. Therefore, it is recommended that proper awareness in this regard is created among the public to overcome this issue.

Also, it is recommended that application of all waterproofing systems to be always done by a trained and qualified applicator to minimize errors during application. In selecting the suppliers, it is better to demonstrate the performance of their products by practically demonstrating by showing the location where the product is in operation. Also the training of laborers to do the job according to specified guideline should be the role of the supplier in case they do not have capacity for installation.

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Appendices

1. Sample questionnaire for Consultants
2. Sample questionnaire for Applicators

Questionnaire for Consultants

I am (I.K.A Bandara) a post graduate student at the University of Moratuwa. Please kindly spare a few minutes of your valuable time to fill out my M.Sc research questionnaire. All your valuable inputs will be used only for academic purpose to help my M.Sc research works. Thank you in advance.

1. Your Name (Optional) :
2. Your Organization (Optional) :
3. What is your Profession/ Designation :
4. Postal Address (optional) :
5. Telephone no. (optional) :
6. Is it ok to call you on the above number given, if I need any further clarification regarding waterproofing work? Yes/ No
7. How many years of industry experience, do you have in waterproofing works? ………..
8. As a consultant, please indicate how much relative importance do you like to consider into each factor given below when you have to select a type of waterproofing system? (5 – Most important, 1- No importance)

		5-Most Important	**4-More Important**	**3-Important**	**2-Less Important**	**1-No Importance**
(a)	Previous product application reference					
(b)	Brand of the product					
(c)	Product specification					
(d)	Product price					
(e)	Warranty offered					

9. If the waterproofing applicator suggests a new waterproofing product/brand to replace your recommended product/brand, will you consider the above request to approve the applicator's new suggestion?
    a) Yes
    b) No
    c) Don't know

10. Please indicate below the reason in details for your above answer.

    ……………………………………………….

    ……………………………………………….

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11. Do you think that, there is a need in the industry for a specialized waterproofing consultant?
    a) Yes
    b) No
    c) Don't Know

12. Please give your suggestions to improve waterproofing practices in the industry.

    ………………………………………

    ………………………………………

………………………………….

Sign

Questionnaire for Applicators

Please spare a few minutes of your valuable time to fill out this questionnaire.

13. Name :
14. Organization :
15. Profession/Designation :
16. Address :
17. Telephone no. :
18. How many years of field experience do you have related to waterproofing work? -------
19. Please indicate below an appropriate waterproofing area that you have specialized? you may cross one or more appropriate box/es.

(a)	Bathroom waterproofing	
(b)	Roof slab / balcony waterproofing	
(c)	Blind walls waterproofing	
(d)	Water tank/ sump waterproofing	
(e)	Basements waterproofing	

20. Do you have any specific preferred brand of waterproofing?
    a). Yes
    b). No
    c). Don't know

21. Do you have experience of more than one brand of products?
    a). Yes
    b). No
22. Do you select specific waterproofing products to apply in each different areas of waterproofing?
    d) Yes
    e) No

23. How do you select a specific product to apply on a given waterproofing area?

a) Based on my own product specification in our brand
b) Based on consultant recommendation for that particular project.
c) Based on all available products specification in any brand in the industry

24. Do you give warranty for your waterproofing application?

a) Yes
b) No

25. How many years of warranty do you give for your waterproofing application?

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26. What is the approximate percentage of works completed by you that have failed during the warranty period requiring you to rework free-of-charge?

a) 0% b) less than 5% c) 6% - 10% d) 11% - 15% e) more than 15%

27. Please indicate how to improve quality of waterproofing applications in the industry?

…………………………………

Sign