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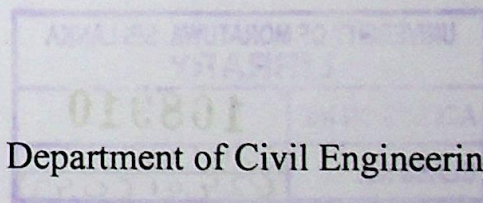
STUDY ON WATERPROOFING METHODS OF ROOF TOP SLABS

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Thesis/Dissertation submitted in partial fulfillment of the requirements for the degree
of MEng in Structural Engineering Design



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ABSTRACT

This research reports a study on waterproofing methods of roof top slabs in Sri Lanka. Waterproofing has become an essential component of a structure to protect its aesthetic appearance, prevent structural damages and for the safety of the occupants. Accordingly the type and the method of waterproofing required may vary with the location & exposure conditions. In the construction industry, many commercially available materials are used for waterproofing roof slabs.

Under this research, field surveys were carried out to identify the types of waterproofing material, different methods of applications & quality controlling measures related to waterproofing. Furthermore, issues related to waterproofing were studied to identify common problems, which can be arrived in a functioning building. Then the rectifying methods and their performance related to such issues were also studied. A laboratory test series was performed on commercially available waterproofing materials to check their suitability. For this both liquid applied waterproofing materials and admixture type waterproofing materials were used. Three specimens were prepared using each waterproofing materials. They were checked for water absorption under laboratory condition for 24 hrs. Two types of water absorption tests were done to study the effectiveness of the selected waterproofing materials. Furthermore specimens with integral admixtures were tested under compressive strength test to identify any increase in their compressive strength due to crystalline formation.

Finally from the experiment it is concluded that liquid applied waterproofing systems perform better than the integral waterproofing systems. Among the used waterproofing materials, K11 flex waterproofing coating showed better performance than the other materials. And also compressive strength has been slightly increased of specimens with admixtures.

ACKNOWLEDGEMENT

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1 INTRODUCTION

1.1 Problem Identification & Background

Many roofs throughout the world are constructed using poured concrete. These structures are usually made with reinforced concrete. They are inexpensive but require a great deal of maintenance to keep them from leaking. The root problem when using concrete as a roofing material is that concrete is porous and retains moisture. Water dampness flows from top floor to ground floor through walls. Leakage from roof top slabs results in:

- Dampness on walls
- Wet patches below the slab leads to staining and discolouration
- Water dripping
- Peeling of paint
- Fungus growth leading to unhygienic conditions, ill health and discomfort to people living in the lower floors
- Reducing the life of the structure
- Ingress of water into the walls causes electricity faults

It is often observed that small plants grow at the joints of vertical down take drainage pipe lines, resulting in choking of the pipes, leaking and sweating of pipes and damaging the plaster.

Due to not concerning the leakage in time, moisture and polluted atmosphere containing sulphate and carbon penetrates in building structure, resulting in corrosion of steel. Volume of corroded steel increases by more than three times its original volume. Due to expansion concrete cracks and spalls out. Durability of the structure is affected due to corrosion of steel.

Several measures have been tried to combat this problem and extend the service life of concrete structure.

By means of a suitable mix design, in theory concrete in new construction should be waterproofed, however this is not so in practice.

To avoid the ingress of rain water, moisture and aggressive environment in concrete surface it is imperative to make the outer surface impervious by coating with suitable

waterproofing compound, which could seal all the pores, crevices, hair cracks etc. The waterproofing compound should be resistant to atmospheric temperature, aggressive environment, and to the effect of ultra violet rays, Ozon etc. It should also be flexible enough to withstand the expansion and contraction of structures and resistant to normal abrasion.

So the main function of a waterproofing system is to prohibit water and any soluble salt from penetrating the concrete to cause corrosion, leaking and other problems. In addition waterproofing material can be very effective in minimizing the rate of corrosion once it has initiated by preventing access of moisture and oxygen to the steel surface.

Thus far, the selection of a waterproofing method for a building to overcome the various environmental condition of degradation has been centered on the selection of the waterproofing materials rather than the application of the concept of performance design. As such despite the fact that numerous waterproofing materials and construction techniques have been employed, the problem of the water leakage persists, a greater confusion regarding the design has arisen.

In industrial point of view, there are many commercially available waterproofing materials used for different purposes. However, the suitability and the performance of each and every product are yet doubtful. Some waterproofing products offer a warranty of 5 to 10 years, but there are situations where they have failed within the warranty period.

Therefore, this research was carried out to study the waterproofing materials and waterproofing methods for roof top slabs.

1.2 Objectives

To study the waterproofing methods in roof top slabs, three laboratory experiments were carried out. Experiments were done in order to find the effectiveness of commercially available waterproofing products. First experiment was done to find the water absorption of six waterproofing materials using a general method. Then the second experiment was done after oven drying process according to BS 1881-122: 1983. Third experiment was carried out to find the compressive strength of specimens which were cast with crystalline admixtures. This test was carried out to

check whether the compressive strength has been increased due to the crystalline formation.

1.3 Methodology

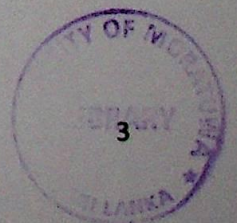
1.3.1 Introduction

Literature survey was done to identify further supportive information for the particular project. This consists of referring past research articles and method statements. Field survey was also done by visiting waterproofing companies interviewing occupants, visiting major construction sites, interviewing industrial professionals and visiting buildings with waterproofing issues. Then laboratory experiment was done by preparing waterproofed specimens and checking their effectiveness. In addition compressive strength of specimens was also checked for specimens for which crystallization admixtures were applied. Finally, compared the effectiveness of each waterproofing product by performing calculations.

1.3.2 Description of methodology

Literature survey was done covering four main areas regarding waterproofing in building slabs. Initially literature explaining available waterproofing methods was studied in order to narrow the study area of the research. Waterproofing is a wide topic covering different areas in the construction sector. Therefore, initial stage of the literature survey helped to narrow down the research only to the waterproofing methods for roof slabs. Then the methodologies for the application of different kinds of waterproofing materials were referred. This was done by studying relevant method statements and product brochures. After that literature regarding quality controlling and standard testing of waterproofing was also studied. Finally the literature regarding rectifying methods was studied in order to get an idea about how the repairing works should be done when issues are found in a building.

Field survey was carried out in order to observe the waterproofing materials and application methods in building slabs. Quality controlling measures and standard testing methods were also observed during the field survey. Apart from that, industry professionals from different waterproofing companies were interviewed to get an



idea about the common issues, which can occur in building slabs. Rectifying methods regarding to such issues were also discussed during the field survey.

In order to check the effectiveness of different waterproofing materials, a laboratory test was carried out. 150 mm x 150 mm x 150 mm concrete specimens were used to check the effectiveness of each waterproofing product obtained from different companies. Effectiveness of each waterproofing material was found by measuring the amount of water absorbed when specimens are immersed in water for 24 hours. Under this test six different waterproofing products were checked for their effectiveness. Three cubes were cast for each product and there were 21 cubes including control samples. Initially the dry weight of each sample was measured and all the cubes were immersed in water at the same time. Then the weight of each cube was measured at specific time intervals to check their effectiveness. Second experiment was carried out to find the compressive strength of the waterproofed specimens with crystallization technology. Some product brochures have mentioned that the compressive strength will be increased by this crystallization technology. Therefore, 12 cubes including the control samples were tested using the compressive strength testing machine to obtain the compressive strength.

1.4 Outline of the report

In this report, the methods currently adopted for waterproofing roof top slabs of buildings in Sri Lanka are introduced with their features and benefits in Chapter Two. In addition under field survey, common issues related to waterproofing, solutions, reasons for waterproofing failures are discussed in Chapter Three. The details of the samples tested in the present study together with the test results are given in Chapter Four. In Chapter Five the results from Chapter Four are discussed before concluding the report with the outcomes of the current research and the recommendations for future works is in Chapter Six.

2 LITERATURE REVIEW

In this chapter essential properties of waterproofing materials, various waterproofing systems use in industry, merits and demerits of the mentioned materials and systems and how they are developed to suit to the modern construction sector have been discussed. Furthermore, information of waterproofing materials that were used in this research with their application methods were presented. Also to check the effectiveness of waterproofing materials, test for water absorption of concrete according to BS 1881-122:1983 was discussed. Finally, related research studies to investigate the different aspects of waterproofing were discussed in this chapter.

2.1 Introduction

Waterproofing is an essential requirement of a structure to protect itself from potential damages caused by water and other chemicals. Waterproofing system is necessary for:

- A durable structure
- Hygienic environment
- Pleasing aesthetic appearance

History of waterproofing dates back to biblical times, where liquid bitumen coatings were used to waterproof boats. However, in early 19th century, certain methods were developed by mixing various materials with bitumen to obtain waterproofing materials. Mainly these types of materials were used to waterproof roofs in those days. After that certain developments were made to improve the effectiveness of waterproofing in order to meet the industrial requirements. Then in the 1940s a membrane type waterproofing material was developed by introducing reinforcing fibers. Meantime, liquid type waterproofing materials were also developed in Europe with various developments. Crystalline waterproofing method was also found in 1940s, creating a whole new industry in waterproofing. And in the late 20th century, flexible waterproofing systems were introduced to the market. This technology enhanced the durability of waterproofing liquids greatly.

So it can be seen that the waterproofing industry has changed vastly during last decades while introducing many products to the construction industry. Lots of

innovations have been introduced to the industry, which can be used for different applications. Therefore, suitability & effectiveness of various waterproofing products are yet questionable when their performance is measured. Essential properties of waterproofing materials must possess the following properties:

- They should minimize the absorption of water by substrate.
- They should exhibit sufficient bond strength with the substrate to resist the outward thrust caused by hydrostatic pressure.
- They should be sufficiently elastic to avoid cracking and leaking.
- Puncture resistance
- Dimensional stability
- Durability when exposed to the environmental agents of degradation (wind, rain, temperature and UV radiation).
- Waterproof but not vapour proof
- Elongation at rupture
- Tear resistance
- Flow resistance for high temperature
- Good flexibility (especially for low temperature)
- Water tightness

In this literature review, reader can get an idea about the various waterproofing methods which are used in the industry. Furthermore, suitability and the functionality of each product are also discussed under this literature review.

2.2 What is waterproofing?

Waterproofing can be defined as the formation of an internal or external membrane which is capable of preventing water from entering or escaping through a permeable layer. There are many different means to provide internal or external membranes in the construction industry. Internal membranes are provided via waterproofing admixtures which are added to the concrete during the mixing process. External membranes are provided using sheet membranes and liquid coatings on the concrete surface.

2.2.1 External waterproofing membranes

External waterproofing membranes can be divided into two categories as Liquid-applied membranes and preformed membranes

1. Liquid Applied Membrane
 - 1.1 Cementitious applications
 - 1.1.1 Crystalline
 - 1.1.2 Flexible
 - 1.1.3 Rigid
 - 1.2 Polyurethane coatings
 - 1.3 Bituminous coatings
 - 1.4 Acrylic coatings
2. Preformed Membranes
 - 2.1 Torch-on membrane system
 - 2.2 Loose-laid system
 - 2.3 Self-adhesive system

1. Liquid Applied Membrane
 - 1.1 Cementitious application:
 - 1.1.1 Crystalline Application

Crystalline application is a type of liquid applied system and can apply as cementitious coating. When mixed with water and applied as a cementitious coating, the active chemicals cause a catalytic reaction which generates a non-soluble crystalline formation of dendritic fibres within the pores and capillary tracts of concrete. Thus the concrete becomes permanently sealed against the penetration of water or liquids from any direction. Figure 2.1 shows Crystalline application and Figure 2.2 shows how the pore blocking occurs inside the concrete.

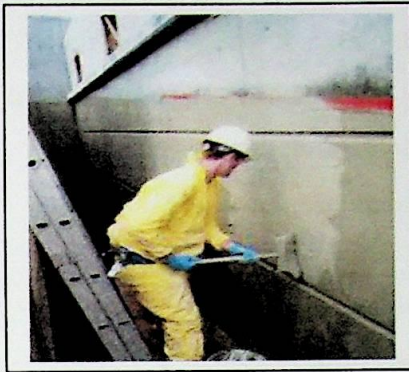


Figure 2.1: Crystalline Application
(www.mar-flex.com)



Figure 2.2: Pore Blocking
(www.hycrete.com)

Not only will these chemical reactions take place at the surface of the concrete or immediate adjacent area, but will continue deep into the concrete structure. The extent of the penetration and the time factor involved depend first of all on the presence of the moisture and the concrete ingredients. Furthermore, it would depend on the physical properties of the concrete such as cement content, density and compaction.

Although these crystalline complexes form as a result of reactivation of the cement, they eventually block the capillary systems from passage of water but will allow the passage of vapour, and in this way water which has not been bound in crystal form is allowed to evaporate during the course of the crystallising process until it is halted altogether with a minimum of internal pressure. If there action is denied water it will cease until wetted and the remaining capillaries take up free water thus completing crystallisation. It is vital to keep the concrete surface wetted during reactivation and hydration.

The products comprise mineral based hydraulically setting products, which when applied to concrete as cementitious slurry react with concrete to form a crystalline structure deep within the capillary and pore structures, blocking voids and producing waterproofing effects. Cement and sand used in the product are used as a carrying agent for the chemicals.

The types of products require moisture to produce the crystalline formation. Therefore, concrete that is moisture or green is ideal for the treatment. The advantages of this system are;

- Becomes an integral part of the substrate
- Allow concrete to breathe
- Non-toxic
- Doesn't require dry weather or a dry surface
- Cannot puncture, tear or come apart at the seams
- Doesn't require costly surface priming or leveling prior to application
- Doesn't require sealing, lapping and finishing of seams at corners, edges or between membranes
- Vapour breathable

The main limitation of this system is this application has less flexibility.

1.1.2 Cementitious flexible application

The conventional cement based coatings are very hard, brittle and do not bridge the hairline cracks occurring due to the environmental changes in the concrete surfaces. The cement based waterproofing coating developed contains a special polymeric additive and hence possesses good flexibility, high elongation at break and low permeability.

Cementitious flexible application is a type of liquid applied system consists of sand, cement, water and an acrylic polymer dispersion, and various additives. They are applied on to wetted concrete. The bulk of the water evaporates and the polymer forms a tough, rubbery film, which bridges fine cracks and waterproofs the concrete without impeding water vapour diffusion-drying of concrete. Concrete coated with such waterproofing system practically no longer carbonates and chloride penetration is considerably suppressed.

Various manufacturers of construction chemicals supply cementitious flexible waterproofing coatings usually in two components already measured out for mixture. The powder component contains fine sand (maximum grain size: 1mm), cement and various additives. The liquid component contains the polymer dispersed in water.

The two components are mixed together, with addition of recommended quantity of clean water at site.

The colour of the coating obtained can be adjusted from white to dark grey depending on the cement and fine sand used.

Features and benefits of this system are:

- Polymer modified – Improved bond strength on a variety of substrate.
- Permeability to water vapours – Allow surface to breath, preventing buildup of vapour pressure.
- Flexible – Can stand moderate movements of hair line cracks.
- Resistant to weathering – Suitable for use in exposed conditions.
- Brushable consistency – Easy to apply by brush or spray.
- Nontoxic – Can be applied on surfaces in contact with drinking water.

Figure 2.3, Figure 2.4 and Figure 2.5 show the mechanical mixing of the two components and Figure 2.6 shows its application at a site.

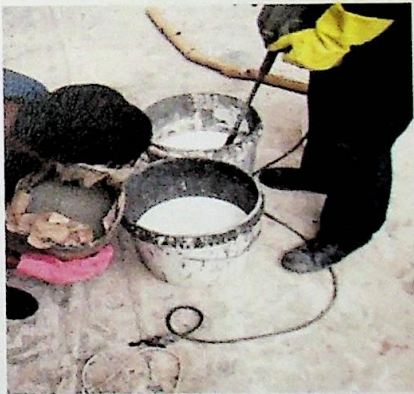


Figure 2.3: Mechanical Mixing-i



Figure 2.4: Mechanical Mixing-ii

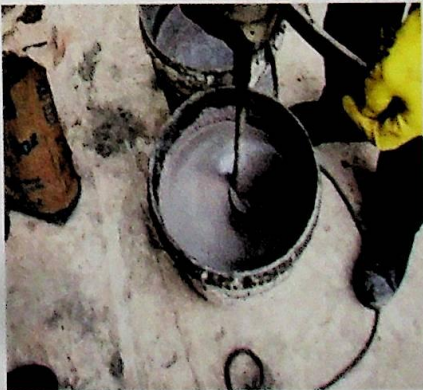


Figure 2.5: Mechanical Mixing-iii



Figure 2.6: Application at a site

1.1.3 Cementitious Rigid application

Standard, rigid waterproofing slurries are polymer-modified, prepacked, drymix mortars which are gauged with water before being applied as a slurry by brush, roller or airless spraying, or, if less gauging water is used, by trowel. Standard or rigid waterproofing slurries can only be used for mineral substrates which are stable, sound and solid, and if there is no risk of crack formation, movement or dimensional change (e.g., shrinkage). Dispersible polymer powder is used as a polymeric binder to improve the adhesion of the waterproofing membrane to different substrates, to improve its cohesive strength, its flexibility, its abrasion resistance and toughness and, last but not least, the water impermeability and density of the membrane. Such polymer modified cementitious waterproofing membranes can withstand water pressure, not only from the positive side, but also, to a limited extent, due to their excellent adhesion and cohesion, from the negative side, if this is necessary for a special application. A dispersible polymer powder, which confers a hydrophobic effect is the preferred type of polymer which should be incorporated in the dry mix mortar.

1.2 Polyurethane coatings:

Polyurethane coating of proper grade when applied has good adhesion on concrete surface. It forms an impervious membrane over the surface and has no effect of mild acids and alkalis. It has flexibility to withstand the expansion and contraction of structures. However, it has an adverse effect of ultra violet rays hence not suitable for surface exposed sun. If required to be used in areas exposed to sun, the top surface must be coated with material having resistance to ultra violet rays. Polyurethane compounds are good for internal surfaces, water tanks, basements, effluent treatment plants, water retaining structures etc.

1.3 Bituminous coatings:

Bitumen is the residue of petroleum and/or mineral asphalt with the advancement in petroleum refining technology, high value solvents are extracted, which has reduced the bonding property of Bitumen. Bitumen is generally heated on the terrace before laying due to which the concrete of the slab decays with fire. Bitumen is heated on

ground below, it cools down by the time it is brought on terrace, hence cannot be applied properly. It is a good material for areas where temperature does not exceed 25°C. In places where temperature exceeding 25°C, the tar felts crack due to the effect of solar radiation, heat and atmospheric oxidation, resulting in volatile of solvents and brittleness. Entrapping of air while lying tar felt, different values of thermal expansion between tar felt and terrace results in blister formations. Moisture and rain water penetrates through such blisters causing cracks and leakages.

However, the original waterproofing coating for concrete still in use today is hot applied bitumen. The method is relatively laborious, unpleasant and time consuming, particularly for small areas. Therefore emulsion based bitumen coatings have been developed. These are easier to apply and may be applied to damp or dry concrete.

1.4 Acrylic coatings:

These coatings are easy to apply and have excellent elasticity and elongation. These coatings reflect more than 90% of the Sun's radiation.

Generally, Liquid applied membranes can be easily applied on the surface by spraying, rolling or using a hand brush. These liquid type membranes are easy to apply, conform to the surface texture and irregularities of the concrete and do not contain any seam compared to sheet applied membranes. However, liquid membranes require a correct termination and sometimes reinforcing may be required at the edges. It is difficult to control the thickness of the coating during the application. Therefore, two coats are applied perpendicular to each other to ensure an even thickness over the applied area. If the coating is too thin, it can be damaged easily. On the other hand if the coating is too thick, cracks can occur. Therefore, controlling the thickness is a must in liquid-applied membranes. Typically, these membranes cannot resist abrasion and can be damaged when exposed to direct sunlight. Therefore, a protection screed should be applied as soon as the curing process is finished.

2. Preformed Membranes:

2.1 Torch on membrane system:

These are prefabricated sheets reinforced by polyester or glass fibre fabric. The reinforcement is impregnated and coated on both sides with bitumen. These prefabricated polymer modified bitumen membranes are designed for economy and easy application.

The underside of the membrane should be torched just enough to superficially melt the bitumen to bond to the substrate. The special consideration in this system is proper lap at edges and ends should be maintained.

Figure 2.7 shows the application of the torch on membrane on a substrate with melting the underside of the sheet membrane. Figure 2.8 shows the preparation of the joint in between two sheet membranes by maintaining a proper seam to avoid leakages through the joints.



Figure 2.7: Application of Torch on membrane

(www.solico.com)



Figure 2.8: Preparation of Joints
(www.nuralite.com)

Outstanding features of this system are:

- Totally impermeable
- Good bondability
- Stability at high temperature
- Good flexibility
- Compatible with all normal roofing and building components

Main disadvantage of this system is leaking can occur through the seams between two layer of adjacent membrane if the joint is not maintained well. These overlaps should be reheated from the top and resealed with a trowel to ensure seam integrity. Figure 2.9 shows the path of the leaking through a traditional waterproofing sheet membrane.

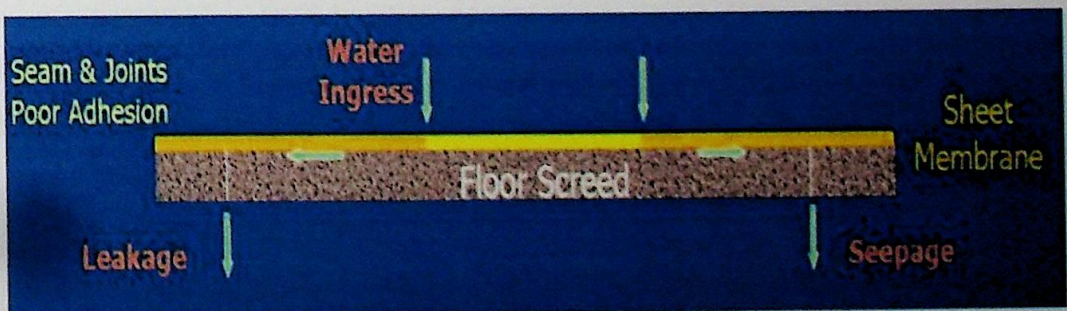


Figure 2.9: Path of leaking

This weak seam is a result of poor lapping joints between sheetings and also as a result of incompatibility of adhesive and substrate. This poor adhesion leads to leakage. The other disadvantages of this system are aging and degrade of the membrane under ambient air, ultra violet radiation and heat. And also because of the Bitumen based, leading loss of elasticity, disintegrate cracks etc.

2.2 Loose laid system:

For this system, flexible PVC synthetic membrane is normally used. With comparing the torch on system loose laid system offers the following advantages.

- Fast application because only joints are hot welded.
- Less dependence on substrate preparation.
- Reduced (or eliminated) membrane splitting risk
- Less sensitivity to climate condition

Less dependence on substrate preparation is an obvious benefit of loose laid system. To assure high bond strength at the membrane – substrate interface of an adhered system requires not only smoother more uniform finish, but also a much cleaner and drier surface than a non-adhered system.

Reduced splitting risk is the other advantage compared to the full adhere system. Adhered membranes carry a greater splitting risk because substrate cracking is propagated directly up into the membrane.

Comparing with a full adhere system like torch on system, there are some draw backs in loose laid system too. Leak detection is not easy in loose laid system. When water leaks through a crack in a slab with an adhered membrane, it can be reasonably assumed that the membrane rupture closely coincides with the cracks location.

The other beneficial of the full adhere system comparing to the loose laid system is less probability of membrane slippage during back filling operations or subsequent settlement of poorly compacted fill.

2.3 Self-adhesive system:

These membranes are produced with special multilayer design with a glassfibre or polyester reinforcement which is impregnated and coated on both sides with a

uniquely formulated elastomeric bitumen compound which provides high adhesive properties. Due to the self-adhesive properties, torching is not necessary which makes the application safe and easy for handling. Figure 2.10 shows the application of the self-adhesive system.



Figure 2.10: Application of Self Adhesive system
www.huiyuanchem.en.alibaba.com

It is advisable to avoid using torch-on membranes on heat-sensitive surfaces and thermal insulation materials. Yet even if a naked flame is not used, there must be no compromises when it comes to waterproofing. For that instant self-adhesive systems that can be installed simply, quickly and safely.

Generally speaking like in liquid-applied membranes, a protection screed is required for sheet membranes to prevent any damages. Common problem with both liquid applied & sheet membranes is that they are vulnerable to damages. Therefore, if membrane is damaged, it will allow water to penetrate through the structure. On the other hand finding and repairing such damage is also difficult during the functioning of the building.

2.2.2 Internal waterproofing

Using a sufficient low water cement ratio in the mix, a concrete should be produced of such a low porosity that it is effectively waterproofed. Alternatively, several

proprietary chemicals often termed "Integral waterproofers" are available as admixtures for use in concrete mixtures.

These are liquid, powder or concrete admixture, which are designed to significantly reduce the permeability of concrete. This waterproofing admixture is a combination of admixtures that have the ability of producing concrete with reduced permeability. These are specifically designed for new constructions and are added to the concrete mix at the time of batching. This is a best option for water retaining structures and basements where in any case the outer surface is not accessible for coating applications.

The advantages of this system are;

- Low cost
- Easy to use
- No surface preparation
- Instant and complete dispersion resulting in uniform waterproofing throughout the concrete
- Impermeability
- Improved workability
- Dense concrete minimize porosity and honey combing

There are some limitations when using the above waterproofing type.

- Use is difficult to control
- Rigid
- Effectiveness doesn't depend on waterproofing product only, but much more on other factors (concrete quality).
- Generally, it needs more than one admixture for complete waterproofing system.
- Difficult to ensure waterproofing at construction joint.

All the above materials have their own advantages as well as limitations. One has therefore to select a suitable material as per the environment and the area where the same is required to be applied.

2.3 Available waterproofing products

There are many commercially available waterproofing products which can be used for different type of applications. However, under this research only two main types of waterproofing products are studied for their effectiveness. They are liquid-applied membranes and integral waterproofing compounds namely. Sheet membrane type was not studied under this research study due to complexity of its testing.

2.3.1 Tamseal Admix

Tamseal admix is a commercially available waterproofing material which falls under the crystalline technology. This can be added to the concrete at the time of batching and formation of crystals will waterproof the concrete. Addition rate of Tamseal admix is between 0.8% and 1.2% by weight of cement. Addition of Tamseal admix to the concrete can be done in three ways.

1. Dry Batch Operation – Adding Tamseal powder to the drum of ready-mix truck
2. Central Mix Operation – Mixing Tamseal powder with water and adding it to the concrete at ready mix plant
3. Pan Mixer – Mixing Tamseal powder with aggregate and then mixing with cement and water

Tamseal Admix can be used for basements, marine applications, reservoirs, water tanks, water retaining structures and civil substructures.

2.3.2 Xypex Admix C-1000 NF

Xypex Admix is a chemical treatment for the waterproofing, protection and improvement of concrete. Xypex Admix C-1000 NF is added to the concrete mix at the time of batching. This consists of Portland cement and various active proprietary chemicals. These active chemicals react with the moisture in fresh concrete and with the by-product of cement hydration to cause a catalytic reaction. This reaction generates a non-soluble crystalline formation throughout the pores and capillary tracts of the concrete that permanently seals the concrete and prevents the penetration of water and other liquids from any direction. The Xypex Admix C- Series has been specially formulated to meet varying project and temperature conditions. This

product is recommended for reservoirs, sewage and water treatment plants, swimming pools, roof decks, tunnels and subway systems, basements, foundation and parking structures.

The advantages of this product are:

- Resists extreme hydrostatic pressure from either the positive or negative surface of the concrete slab.
- Become an integral part of the substrate.
- Highly resistant to aggressive chemicals.
- Can seal hair line cracks up to 0.4mm
- Allow concrete to breathe
- Non toxic
- Permanent
- Added to the concrete at the time of batching and therefore is not subjected to climatic restraints.
- Increase flexibility in construction scheduling.

2.3.3 Penetron Admix

Penetron admix also can be considered as an integral waterproofing admix which is added to the concrete at the time of batching. Penetron admix also contains reactive chemicals which react with the moisture in concrete to generate a non-soluble crystalline formation throughout the pores and capillaries inside the fresh concrete. Dosage rate of Penetron admix will vary between 0.8% and 1% by weight of cement. Addition of Penetron admix can also be done using the same three ways which are mentioned in section 2.3.1. Penetron admix is recommended for reservoirs, water treatment plants, tunnels, foundations, swimming pools and precast products.

2.3.4 Xypex Concentrate

Xypex Concentrate is a liquid applied chemical treatment which can be used for waterproofing and concrete repairing. Even though this is applied as a surface treatment, with time chemicals penetrate to the concrete and generate a crystalline formation to block the pores and capillaries.

This product can be applied on the surface by using a brush or by spraying. For normal brush application, 5 parts of Xypex powder can be mixed with 2 parts of water to obtain a thin slurry. Then depending on the specifications, single coat or double coats can be applied on the surface. It should be noted that the second coat should be applied after the first coat has reached the initial setting time. Then the curing should be done by a misty fog spray of water three times per day for two to three days. This product is also recommended for reservoirs, water treatment plants, foundations, swimming pools & roof decks.

2.3.5 Brushbond

Brushbond is an acrylic polymer modified cementitious coating product which can be used for concrete and masonry surfaces. This is a liquid-applied flexible waterproofing material which can be used to waterproof reservoirs, tanks, toilets, kitchen, basement, retaining walls and concrete gutters. For normal brush application 3.5 parts of powder are mixed with 1 part of liquid to obtain a thin slurry and addition of water should be avoided. To get the best results two coats which are perpendicular to each other should be applied on the prepared surface. Then the curing should be carried out according to the site practices and a protection screed should be applied prior to any other construction work.

2.3.6 K11 Flex

K11 Flex is also a flexible two part acrylic polymer modified cementitious coating system which can be applied on the surface of concrete and masonry. This liquid-applied waterproofing material can be used for slabs, swimming pools, kitchens, toilets, balconies and water tanks. Surface should be well prepared and wetted down prior to the application. For normal site application 1.5 powder parts are mixed with 1 part of liquid to obtain a thin slurry which can be applied on the surface. Two coats which are perpendicular to each other should be applied to obtain the best results. Then the curing should be carried out according to the local practices. In order to commence other construction works, a protection screed should be applied on top of the coating.

2.4 Test methods for waterproofing products

There are many test methods to check the quality of the waterproofing products which can be used to determine the various properties of waterproofing materials. There is no specific test developed to measure the water absorption of waterproofing materials. However, to check the effectiveness of waterproofing materials, test for water absorption of concrete (BS 1881-122:1983) was adopted in this research. Test procedure to determine the water absorption of concrete is as follows:

- 1). Specimens should be placed in a drying oven which the temperature is controlled at $105 \pm 5^{\circ}\text{C}$ such that they are not less than 25 mm from any heating surface or from each other, so that air can access all their surfaces.
- 2). Let the drying process to be continued for 72 ± 2 h and after the removal, specimens should be cooled for $24 \text{ h} \pm 0.5 \text{ h}$ in a dry air tight vessel.
- 3). Then weight (dry weight) of each specimen should be measured immediately after the cooling process so that they can be immersed in a tank with its longitudinal axis horizontal and at a depth so that there is $25 \pm 5\text{mm}$ of water over the top of the specimen.
- 4). All free water shall be removed after the removal of specimens by shaking and drying processes prior to measure the mass.
- 5). After measuring the mass, water absorption of each cube can be calculated as the increase in mass due to immersion expressed as a percentage of dry weight.

2.5 Related researches

Many research studies have been carried out to investigate the different aspects of waterproofing. A collaborative experimental program has been carried out by Dias (2007) with an industrial partner to test the effectiveness of concrete waterproofing systems in Sri Lanka. In this experiment both admixture & coating waterproofing systems have been tested to check their suitability for water retaining structures. After preparing specimens using grade 40 concrete, permeability and sorptivity tests have been carried out to check their effectiveness. Two waterproofing products namely Xypex admix and Xypex coating have been tested with control specimens with added silica fume under this experiment. It has been found that Xypex admix

gives the best performance against a considerable water head implying that it is suitable for water retaining structures. Specimens with silica fume have given the best performance for the resistance against water penetration into unsaturated concrete. And according to the test results Xypex coating has not performed as well as expected.

The research by Walter et al (2003), presented a classification system for current flat roof bituminous membranes waterproofing systems with regards to inspection, diagnosis & pathology. Anomalies which can be occurred in bituminous membranes in flat roofs have been identified and listed. After, possible causes for defects in waterproofing methods have been identified and given a specific rating system for those defects according to the gravity of defects. A correlation matrix has been derived for the anomalies & possible causes to diagnose the defect when it is detected. Furthermore the study has been extended to identify the interrelation between defects & also correlation matrix for defects & repairing techniques. Then sample repair form has been provided for repairing defects with flat roof bituminous membrane waterproofing systems. Through an objective description of each of these entities, complemented with the so-called anomaly and repair forms and the correlation matrixes, it is possible to drastically decrease the subjectivity of judgment and reporting of the pathological symptoms detected during the inspection and to help the decision maker in selecting the maintenance/ repair works to be performed afterwards, always within a limited funds perspective.

Al-Zahrani et al (2002), conducted a study to evaluate reinforcement corrosion and some physical properties of concrete specimens coated with two polymer-based, a cement-based polymer-modified, and a cement-based waterproofing coatings. The coated and uncoated concrete specimens have been subjected to accelerated corrosion to determine the time taken to initiate corrosion. The physical properties were also evaluated by subjecting the concrete specimens to wetting/drying cycles and heating/cooling cycles for five months. The physical properties such as water absorption, water permeability, chloride permeability, and adhesion were also evaluated. The accelerated corrosion test results have clearly showed that the specimens coated with the polyurethane elastomer-based waterproofing material performed better than concrete specimens coated with other waterproofing materials.

This has been followed by the specimens coated with cement-based polymer modified, epoxy-based, and cement-based coatings in descending order. The two polymer-based coatings have shown better performance than the cement-based polymer-modified and cement-based coatings in terms of the evaluated physical properties.

Jorge Lopes et al (2010), conducted a study to Dimensional stability of waterproofing bituminous sheets used in low slope roofs. Lap joints between waterproofing bituminous sheets, applied in either single or multiple layers, are one of the most critical areas of roofs, especially when the waterproofing system comprise only a single sheet. In fact, the way how lap joints are executed is highly associated with the occurrence of anomalies in such systems. With this regard, the dimensional stability of the sheets is one of their most important characteristics. As it can strongly influence the performance of the lap joints and the details on roof up stands. The paper presented results of an experimental study on the dimensional changes suffered by bituminous sheets when subjected to temperature variations. Different types of traditional and non-traditional sheets, with various types of bituminous mixtures and reinforcements were tested according to EN 1107-1 standard. The results of these experimental investigations confirm that sheets with polyester reinforcement are much less stable than sheets reinforced with glass fibre.

As it is mentioned earlier most of the flat roofs of the buildings are waterproofed by using the bituminous membranes with a self-protection constituted by mineral granules. These granules constitute the barrier against the fundamental environmental agent of degradation, the UV radiation. Marques et al (2010), have presented an experimental study on the behaviour of the self-protection granule of bituminous membranes when subjected to environmental agents of degradation. Different types of bituminous membranes, with different finishing systems have been exposed to the effects of elevated temperature and water for up to 24 weeks and 4 weeks respectively. Following accelerated ageing, specimens of the different types of membranes were subjected to brushing tests in order to evaluate the adhesion of the self-protection granules. Experimental results have shown that the higher loss of self-protection granule of bituminous membranes occurs in membranes modified by

Atactic polypropylene polymers. In addition, it has been concluded that the effect of water is much more severe than that of the elevated temperature.

3 FIELD SURVEY

This chapter discusses common issues related to waterproofing and solutions with some figures. And also listed some reasons for waterproofing failures and considerations when selecting a suitable waterproofing system. Some proper detailing methods to be followed to achieve the best results from the particular system are also included in this chapter. Finally, after selecting a suitable waterproofing system, the chapter discusses some considerations before and after applying a waterproofing system for a particular area.

3.1 Introduction

Waterproofing is perhaps the most common problem encountered in the construction industry. Both old as well as new construction may leak. The causes of water seepage are mainly due to:

- Faulty construction
- Improper compaction
- Uneven settlement
- Improper slope

Prolonged water seepage in a building may damage reinforcement or other building materials and spoil the aesthetic look.

3.2 Background of the problem

If the construction is made perfect, ie zero defect, then no waterproofing system is required. In practice it is not possible as even the slightest defect may cause leakage/seepage. Even after construction, sometimes hairline cracks develop on the roof that may also cause water seepage.

There are some common failures without having any waterproofing system. Figure 3.1 and Figure 3.2 show spalling of concrete, which usually caused by moisture, corroding bar causing breaking away of concrete.

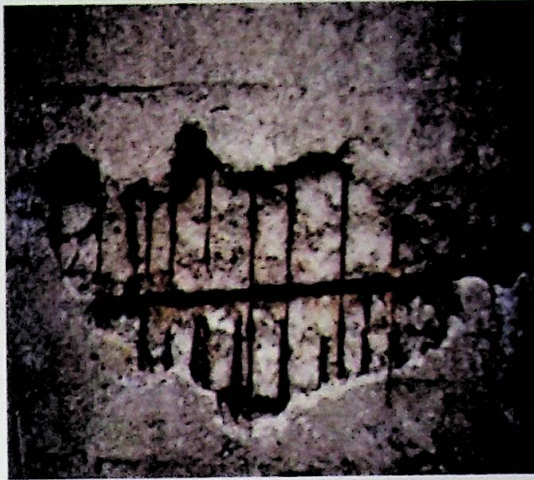


Figure 3.1: Spalling of concrete

www.civildigital.com



Figure 3.2: Spalling of concrete

www.quest-cp.com

Figure 3.3 shows biological growth on a roof top, since concrete roof are porous and absorb moisture, which supports fungal growth.

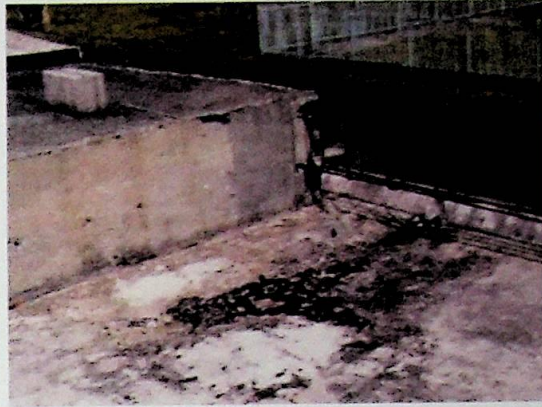


Figure 3.3: Biological growth on a roof top

www.quest-cp.com

3.3 Common issues related to waterproofing and solutions

Most of the time, waterproofing in roof slabs is done using bituminous membranes. This is a popular method for waterproofing slabs with long spans including roof slabs and ground slabs. With time these bituminous membranes will lose the bond with the surface due to the temperature especially when they are placed in roof slabs. Therefore, once the water is entered through a damaged part of the membrane, water can flow anywhere under the membrane. This water can leak through the concrete to create water patches on the slab soffit. So, when a leakage occurs, it's hard to find a location to treat in such case.

It can be seen that, this type of a leakage is hard to find because water does not leak just below the damaged membrane. Even the point of leakage is treated, after a while water can leak from another point. Therefore, whole membrane should be removed and repaired in such a case.

Figure 3.4, Figure 3.5, Figure 3.6, Figure 3.7 and Figure 3.8 show some common waterproofing failures.



Figure 3.4: Water seepage



Figure 3.5: Drips along cracks



Figure 3.6: Weak adhesion



Figure 3.7: Water seepage via loose seam



Figure 3.8: Cracked membrane

Another problem that can occur in roof slabs is leakage of water due to the leakages from the parapet wall. These kinds of leakages are hard to identify, because ponding test would not detect cracks in the parapet wall. An actual crack which has appeared in a parapet wall is shown in the figure 3.9.

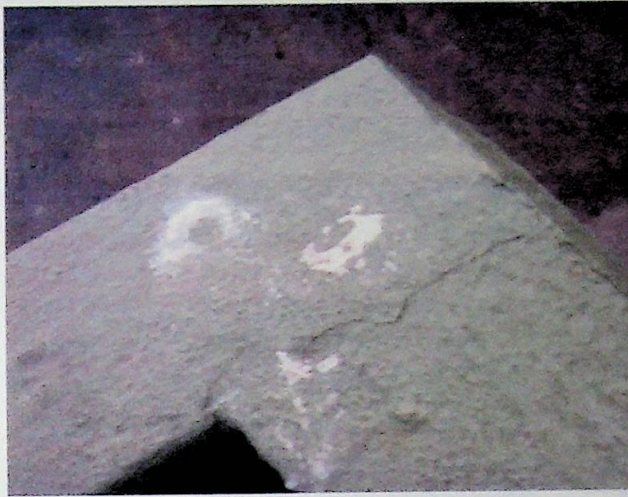


Figure 3.9: Crack appeared in a parapet wall

In this case, crack should be sealed by using a fibre glass mesh and a binder in order to stop the water flow.

Another problem that can occur in roof slab is the leakage occur from the edge of the slab. If the leakage is severe, slab soffit can also be damaged due to the water patches. This will destroy the aesthetical appearance of the building and reinforcement corrosion could also occur in severe exposure conditions. Figure 3.10 and figure 3.11 show the consequences of this kind of a leakage occurred in a roof slab.



Figure 3.10: Leakages along the edge of the slab

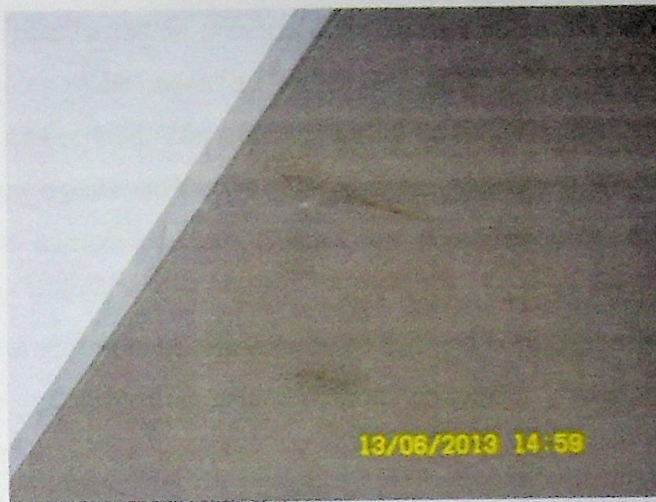


Figure 3.11: Leakages appeared on the slab soffit

These types of leakages occur due to the poor workmanship and damages in the waterproofing membrane. Waterproofing companies always ask to provide a barrier (concrete step) if a parapet wall is not provided along the edges of the slab, so that the membrane can be continued up to some height to avoid water leakages.

Following are some reasons for such common waterproofing failures:

1. Wrong waterproofing system

It is important to choose a correct/suitable waterproofing system to achieve a durable and impermeable concrete structure, which can last more than its anticipated life. It is important to consider that all systems are not the same although most of the datasheets look alike. It is important to remember that waterproofing accounts for less than 1% of the total budget foreseen for the building, but 75% of possible damages to the same building could be caused by incorrect waterproofing systems and their short term durability.

2. Wrong application tools

3. Wrong mixing proportions

4. Wrong storage of waterproofing materials

5. Poor substrate / Surface preparation

All surfaces have to be prepared before they receive a waterproofing layer. In most cases the substrate preparation determines the quality of the system.

Surface preparation in waterproofing cannot be overestimated. Usually the surface has to be taken off or cleaned until a solid substrate is reached, leveled and primed. The substrate has to be sound, solid, and free of bonding inhibiting agents such as grease and oil, separating substances and loose parts. In corners concave fillets have to be installed. Preparation to the substrate surface is essential for optimum long term waterproofing.

The main objective of a primer is to facilitate bonding between the substrate and the waterproofing layer. Without primer, a waterproofing layer may separate from the substrate. Therefore, in many cases the primer is an essential part of the waterproofing system.

6. Tight schedule at site

Make sufficient material, plant and labour available to ensure that application is a continuous process.

7. Bad maintenance practices

8. Application under direct sun

Sun and high temperatures can result in shorter reaction times of any liquid waterproofing material and thus reduces the pot life and the time available for application. In that case less material is mixed at once in order to apply the waterproofing before curing. The sun can also prematurely dry out cementitious materials so that wetting becomes necessary. It is always preferable to work in the shade. In extreme cases the work has to be carried out before sunrise or after sunset. Try to avoid application during the hottest times of the day, arrange temporary shading as necessary.

9. Application during rain

Rain may wash away liquid waterproofing materials. Especially waterproofing materials that are based on bitumen emulsions need the evaporation process for curing and therefore have to be protected from rain.

10. Failure to protect application from other services

After providing a waterproofing layer, a protection layer should be provided. Protective layers ideally combine two functions: mechanical protection and drainage. On concrete slabs, a protection layer of screed is often used to prevent mechanical damages from subsequent building activity.

Whichever waterproofing system is used, proper detailing should be followed to achieve the best results from the particular system. Figure 3.12 shows typical detailing of waterproofing membrane at flat roof with parapet wall. To avoid the sharp edge, mortar fillet is formed at the edge of the wall and the roof slab interface.

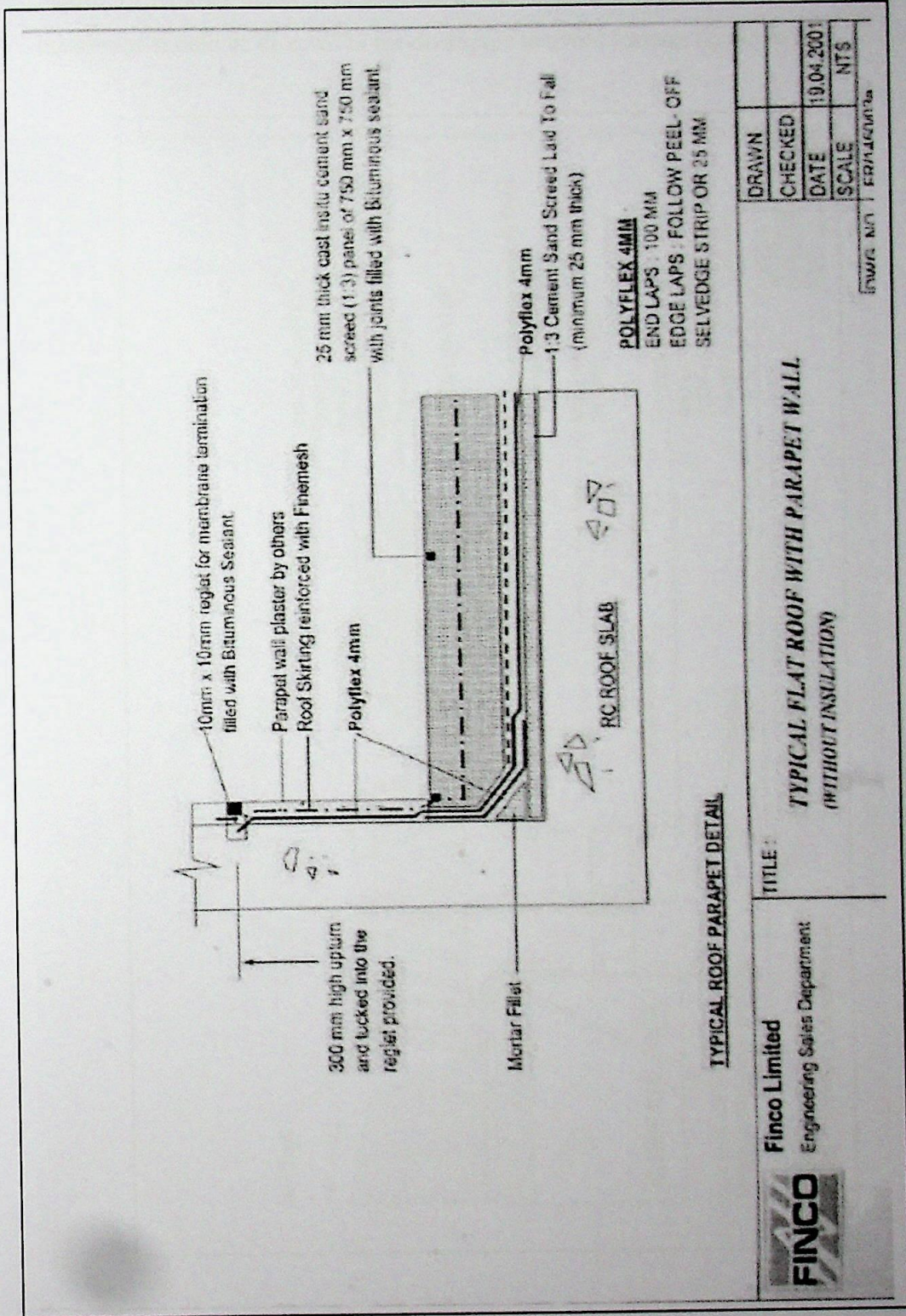


Figure 3.12: Typical detail at flat roof with parapet wall.

Figure 3.13 shows the typical detail at terrace with down pipe. The waterproofing membrane should be directed to the downpipe to avoid leakage on the terrace.

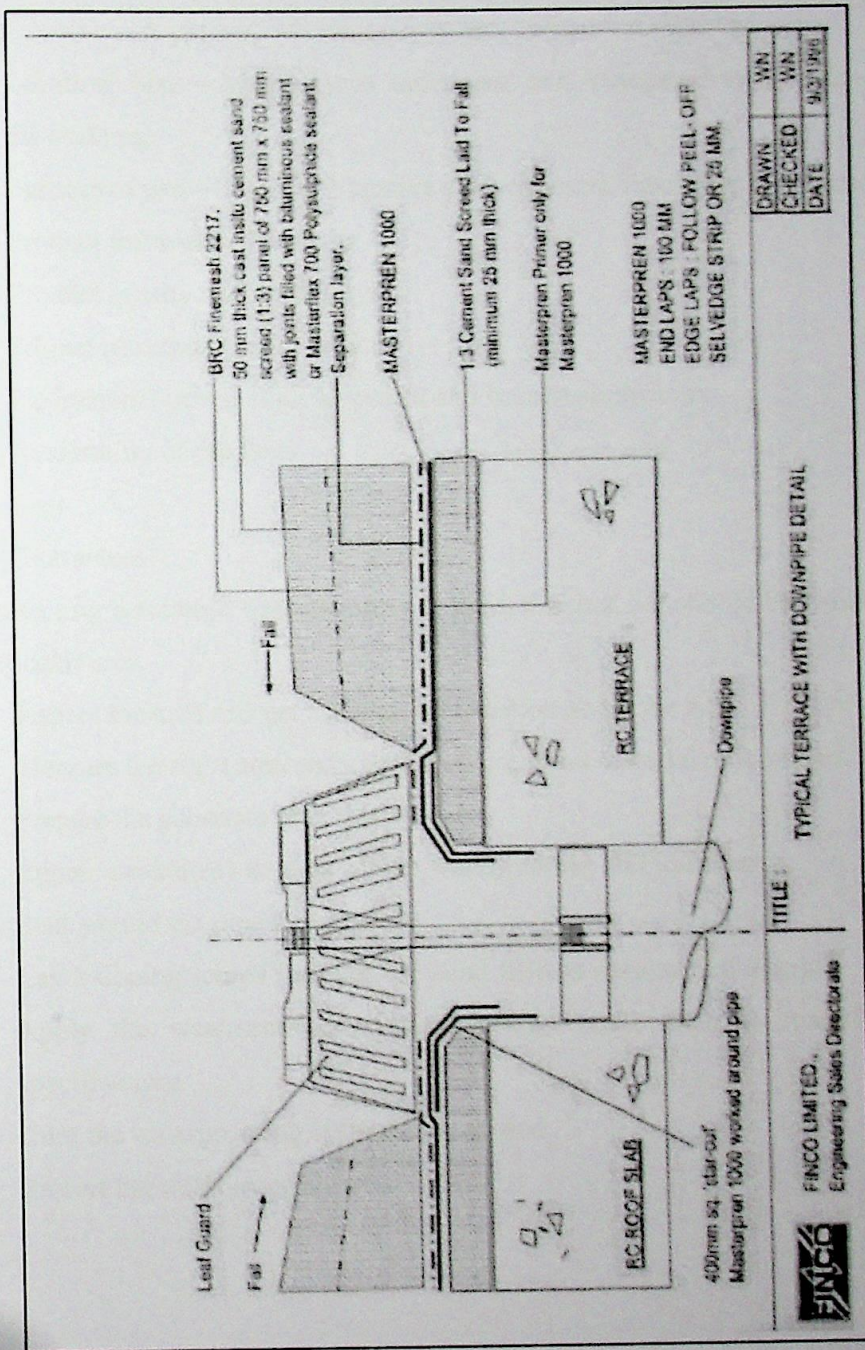


Figure 3.13: Typical detail at terrace with down pipe

Even though there are various types of waterproofing systems available in the market, it is essential to select the suitable product or service to a particular situation. Following are some considerations, when selecting the suitable waterproofing system.

1. Location/ Size – Maintenance and repair cost, compared to the life-span of the building
2. Purpose of use – Positive, Negative side, exposed, flexibility requirements
3. Product features and benefits
4. Product quality and durability
5. Project references in Sri Lanka
6. Professional personal involvement and trained applicators
7. Availability of products
8. Cost
9. Guarantees

After selecting a suitable waterproofing system, a check list should be followed for the particular area.

1. Inspect the area and get accurate information about the site
2. Measure the right area and calculate the correct material requirement
3. Prepare the substrate effectively
4. Repair weak areas such as cracks, honey combs and joints etc.
5. Seal around the pipes/ protrusion
6. Lay a sloping screed (if required) and fillet at right angled edges
7. Apply the waterproofing system, strictly conforming to manufacturer's specifications
8. Cure the waterproofing system as specified
9. Protect the waterproofing area

4 LABORATORY EXPERIMENTS

In this chapter laboratory experiments were discussed including materials used for the experiment, methodology, mix detail for concrete, mix detail for integral waterproofing product and mixing proportion of liquid applied waterproofing membranes. Also this chapter contains test results of first water absorption test, second water absorption test and compressive strength test.

4.1 Introduction

Laboratory experiments were carried out in order to identify the effectiveness of the commercially available waterproofing materials. There are many waterproofing materials which are commercially available in the industry. Depending on the field survey data, waterproofing materials which are commonly used in the construction industry were selected for the test. Following waterproofing methods are commonly used for roof top slabs of buildings according to the field survey.

1. Cementitious coating type waterproofing system
2. Internal waterproofing by crystallization
3. Bituminous membrane type waterproofing system

However, for these particular experiments only the first two types were selected due to the application difficulties and difficulties in sample preparation found in the third waterproofing type on specimens. i.e. bituminous membranes.

4.2 Materials

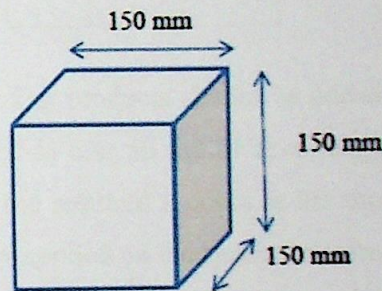
It was decided to use grade 30 concrete to prepare concrete specimens for the test. As most of the building slabs are constructed using grade 25 or 30 concrete, results would demonstrate the actual site conditions if grade 30 is used. Waterproofing materials given in the table 4.1 were tested under this laboratory test series.

Table 4.1: Selected Waterproofing materials

Admixture type waterproofing	Cementitious coating type waterproofing
Xypex Admix C-1000 NF	Brushbond
Tamseal Admix	Xypex Concentrate
Penetron Admix	K11 Flex

4.3 Methodology

Tests were carried out using 150 mm x 150 mm x 150 mm concrete specimens of grade 30 concrete as shown in figure 4.1.

**Figure 4.1: Dimensions of the specimen**

For each waterproofing product, three cubes were cast and three control specimens were also cast separately. Therefore, altogether 21 cubes were tested under this test. Nomenclature used for each cube is given in table 4.2 for future references.

Table 4.2: Details of the specimens

Product name	Number of cubes	Nomenclature
Tamseal Admix	3	TA-1,TA-2,TA-3
Xypex Admix	3	XA-1,XA-2,XA-3
Penetron Admix	3	Pe-1,Pe-2,Pe-3
Xypex Concentrate	3	XC-1,XC-2,XC-3
Brushbond	3	B1,B2,B3
K11 Flex	3	K-1,K-2,K-3
Control cubes	3	C-1,C-2,C-3
Total = 21		

Admixture type waterproofing products should be added to the concrete when it is batched. So, it was decided to cast all the 21 specimens on same day, and add the admixtures separately for the required 9 cubes at the time of batching. Cementitious coating type materials were applied on the specimens after 14 days.

Initially concrete which was enough to cast 12 cubes was batched without adding any admixture. All specimens were prepared as a standard mixture with calculation of concrete mix design. Water was added while mixing as per the water cement ratio of 0.50. The cement used was Tokyo Super. The fine aggregate had 35 % passing the 600 μm sieve. Mix details for the normal concrete batch are given in Table 4.3.

Table 4.3: Mix details per 1m^3

W/C ratio	Cement	Water	Sand	Gravel
0.5	410 kg	205 kg	808 kg	987 kg

Then 3 cubes were cast separately for each integral waterproofing product by adding the admixtures during the batching process. Mix details for the cubes cast with integral waterproofing products are given in Table 4.4.

Table 4.4: Mix details for integral waterproofing products

Product	Tamseal	Xypex	Penetron
Cement (kg)	5.535	5.535	5.535
Water (kg)	2.767	2.767	2.767
Sand (kg)	9.693	9.693	9.693
Gravel (kg)	14.539	14.539	14.539
Admixture	Powder - 55.35g	Powder - 55.35g	Powder - 55.35g
	Water - 79.07g	Water - 102.79g	Water - 69.80g

It should be noted that all the admixtures were added to the concrete by mixing the powder with water. This is called as the central mix operation in the construction industry in which the powder is mixed with water to form thin slurry and added to the batching plant. Then the mixing is continued for 3-5 minutes to ensure that admix is evenly mixed with concrete.

After casting all the 21 cubes, they were cured by immersing in a water tank for 14 days prior to the test. Then the cubes were taken out and kept under laboratory conditions until laboratory experiments are carried out.

Then the next step was to apply the cementitious coating type waterproofing on 9 cubes which were cast without adding any admixture. Mixing proportions which were used to prepare coating slurry for each product are given in table 4.5. Mixing of liquid and powder was done by using a paddle mixer.

Table 4.5: Mixing proportions of liquid-applied waterproofing membranes

Product	Mixing ratio (Powder: Liquid)
Xypex concentrate	5 : 2 (Liquid is water)
Brushbond	3.5 : 1
K11 Flex	1 : 1.5

After preparing the slurry coats for each product, they were applied on the 9 cubes. Slurry coats were applied using a brush in two coats according to the product specifications. Figure 4.2 shows the brush application of liquid-applied waterproofing on a specimen during the laboratory experiment. Then the curing was carried out for 3 days by spraying water as it is required prior to testing.

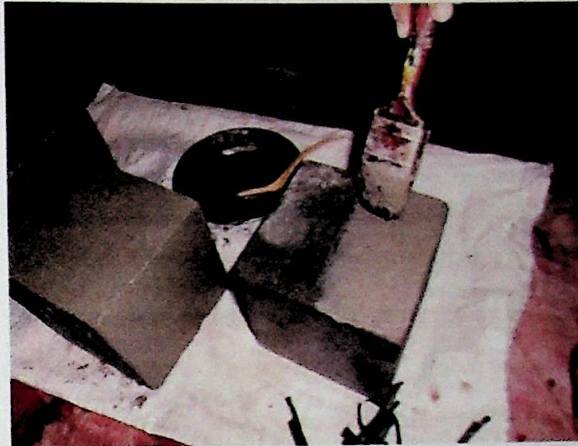


Figure 4.2: Brush application of liquid-applied waterproofing system

4.4 Testing

4.4.1 Water absorption test 1

After preparing and curing the specimens, first water absorption test was carried out on all the samples without oven drying them. It is assumed that the water absorption test can be used to determine the effectiveness of waterproofing products. Since the roof top slabs won't experience a very high water head during its lifetime, a pressurized test was not required under this research. Figure 4.3 shows the apparatus used to immerse the cubes in water.

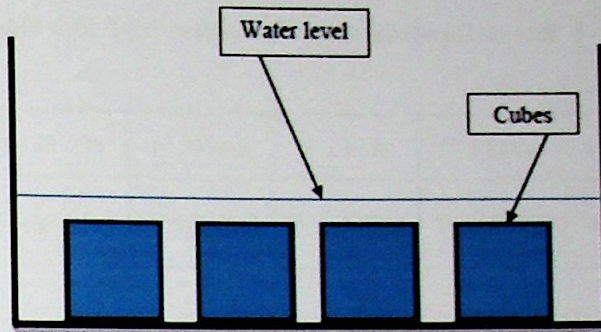


Figure 4.3: Apparatus used to immerse cubes

Initially, the dry weight of each specimen was measured before they were immersed in water. Then all the cubes were completely immersed in the water tank at the same time. First set of readings were taken at the 15 minutes time interval by measuring the weight of cubes after removal from water tank and wiped the surface of the cube thoroughly. Then the cubes were immersed again in the water tank to continue the test at 30 minutes, 1 hour, 3 hours, 7 hours & 24 hours time intervals. Table 4.6 gives the test results of the first water absorption test.

Table 4.6: Test results of water absorption test 1

Cube Name	Initial Weight (kg)	t= 15 min	t= 30 min	t= 1 hour	t= 3 hours	t= 7 hours	t= 24 hours
		Weight(kg)	Weight(kg)	Weight(kg)	Weight(kg)	Weight(kg)	Weight(kg)
TA-1	8.440	8.450	8.450	8.455	8.475	8.475	8.475
TA-2	8.450	8.450	8.450	8.450	8.465	8.475	8.485
TA-3	8.620	8.630	8.630	8.635	8.640	8.655	8.655
XA-1	8.520	8.535	8.535	8.535	8.535	8.550	8.550
XA-2	8.380	8.400	8.400	8.400	8.400	8.400	8.420
XA-3	8.465	8.470	8.470	8.470	8.480	8.485	8.490
Pe-1	8.605	8.615	8.615	8.615	8.620	8.630	8.640
Pe-2	8.470	8.470	8.475	8.485	8.485	8.495	8.500
Pe-3	8.490	8.495	8.505	8.505	8.505	8.515	8.520
XC-1	8.685	8.700	8.700	8.700	8.700	8.700	8.710
XC-2	8.900	8.905	8.905	8.905	8.905	8.910	8.920
XC-3	8.780	8.785	8.785	8.785	8.785	8.795	8.805
B1	8.710	8.715	8.715	8.715	8.720	8.730	8.745
B2	8.925	8.930	8.930	8.935	8.940	8.950	8.965
B3	9.145	9.145	9.150	9.150	9.155	9.165	9.180
K-1	8.935	8.935	8.935	8.935	8.935	8.940	8.955
K-2	9.055	9.055	9.055	9.055	9.060	9.065	9.070
K-3	8.960	8.960	8.960	8.960	8.960	8.970	8.975
C-1	8.560	8.570	8.590	8.590	8.590	8.600	8.615
C-2	8.315	8.330	8.335	8.340	8.345	8.350	8.360
C-3	8.565	8.580	8.585	8.585	8.605	8.605	8.610

4.4.2 Water absorption test 2

One cube from each product was selected to commence the second experiment according to test for water absorption of concrete (BS 1881-122:1983). In this second experiment, cubes were oven dried before immersing them in the water. Figure 4.4 shows the oven drying process carried out prior to the test. Then the same test was carried out again to check the water absorption of each cube by immersing them in the water tank as shown in figure 4.5. Test results of the second water absorption test are given in table 4.7.



Figure 4.4: Oven drying process

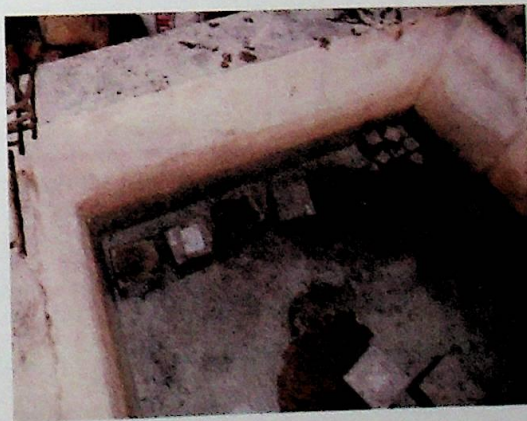


Figure 4.5: Cubes immersed in water tank

Table 4.7: Test results of water absorption test 2

Cube Name	Initial Weight (kg)	t= 15 min	t= 30 min	t= 1 hour	t= 3 hours	t= 7 hours	t= 24 hours
		Weight (kg)	Weight (kg)	Weight (kg)	Weight (kg)	Weight (kg)	Weight (kg)
TA-2	8.130	8.280	8.320	8.350	8.420	8.445	8.460
XA-3	8.160	8.310	8.345	8.385	8.435	8.460	8.470
Pe-2	8.195	8.330	8.365	8.395	8.430	8.450	8.465
XC-2	8.560	8.720	8.765	8.805	8.855	8.858	8.890
B-1	8.350	8.465	8.510	8.545	8.620	8.685	8.730
K-2	8.740	8.790	8.810	8.825	8.865	8.905	8.970
C-1	8.245	8.410	8.460	8.505	8.550	8.575	8.595

4.4.3 Compressive Strength Test

Final experiment was carried out to check the compressive strength of specimens in 21 days which crystallizing admixtures were added. This was done to see whether the compressive strength has been increased due to the crystallization effect. All the specimens with admixtures were tested using the compressive strength testing machine. Control samples were also tested to compare with the specimens cast using admixtures. After measuring the weight and the dimensions of each specimen, they were tested for compressive strength using a calibrated compressive testing machine. Figure 4.6 shows the testing of compressive strength of a specimen.

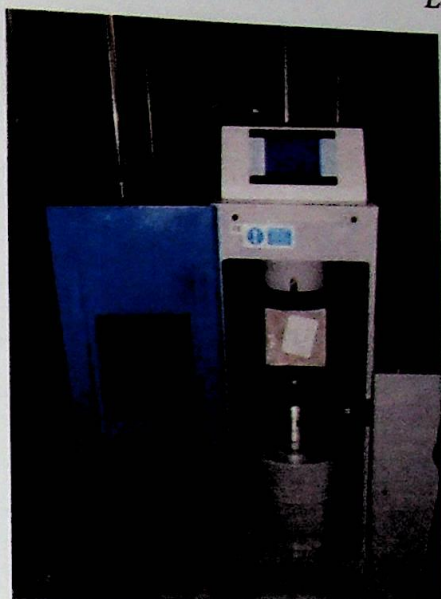


Figure 4.6: Compressive Strength Test

Loading was applied at a constant rate of 6.8 kN/sec during the test. Test results of the compressive strength test are given in table 4.8. It should be noted that the specimens which were oven dried before were also tested under this experiment. According to the test results, specimens which were oven dried gave lesser compressive strength than the specimens which were not oven dried.

Table 4.8: Compressive Strength Test results for 21 days strength

Cube Name	Weight (kg)	Dimensions (in mm)	Crushing Load (kN)
TA-1	8.40	151x152x150	1174.5
TA-2	8.40	150x150x150	800.8
TA-3	8.60	150x149x151	996.7
XA-1	8.50	152x149x150	861.6
XA-2	8.35	150x150x150	1066.3
XA-3	8.50	150x150x150	765.4
Pe-1	8.60	152x152x152	1174.2
Pe-2	8.45	151x151x151	746.2
Pe-3	8.50	150x151x152	912.6
C-1	8.75	155x153x150	891.5
C-2	8.30	150x149x149	886.0
C-3	8.55	152x151x152	937.9

5 RESULTS AND DISCUSSION

Three laboratory experiments were done under this research project in order to find the effectiveness of commercially available waterproofing products. First experiment was done to find the water absorption of six waterproofing materials using a general method. Then the second experiment was done based on the results of the first experiment. Therefore, specimens which gave the best results were selected for the second experiment. Then the water absorption test was done on the selected specimens by oven drying process according to BS 1881-122: 1983. Third experiment was carried out to find the compressive strength of specimens which were cast with crystalline admixtures. This test was carried out to check whether the compressive strength has been increased due to the crystalline formation.

5.1 Water absorption tests

Two types of water absorption tests were done to check the effectiveness of available waterproofing products. In the first experiment specimens were tested without the oven drying procedure. This was done to avoid any damages caused by the oven drying prior to the test. Then in the second experiment selected specimens were oven dried prior to the test.

5.1.1 Water absorption test 1

Test results of the first test are given in table 5.1. Table 5.2 shows the average percentage of water absorption of each waterproofing material. According to the results it can be seen that all the specimens which were waterproofed have performed better than the control specimens. Among them K11 Flex specimens gave the best results compared to other specimens. However, it can be seen that the liquid-applied waterproofing materials have given the better results compared to integral waterproofing compounds. Graphical representation to compare cementitious coating type & integral waterproofing type with control specimen are given in figures 5.1.

Table 5.1: Water absorption test results -1

Cube Name	Initial Weight (kg)	Water absorption (%)					
		15 min	30 min	60 min	180 min	420 min	1440 min
TA-1	8.440	0.12	0.12	0.18	0.41	0.41	0.41
TA-2	8.450	0.00	0.00	0.00	0.18	0.29	0.41
TA-3	8.620	0.12	0.12	0.17	0.23	0.40	0.40
XA-1	8.520	0.18	0.18	0.18	0.18	0.35	0.35
XA-2	8.380	0.24	0.24	0.24	0.24	0.24	0.48
XA-3	8.465	0.06	0.06	0.06	0.18	0.24	0.29
Pe-1	8.605	0.12	0.12	0.12	0.17	0.29	0.41
Pe-2	8.470	0.00	0.06	0.18	0.18	0.29	0.35
Pe-3	8.490	0.06	0.18	0.18	0.18	0.29	0.35
XC-1	8.685	0.17	0.17	0.17	0.17	0.17	0.29
XC-2	8.900	0.06	0.06	0.06	0.06	0.11	0.22
XC-3	8.780	0.06	0.06	0.06	0.06	0.17	0.28
B1	8.710	0.06	0.06	0.06	0.11	0.23	0.40
B2	8.925	0.06	0.06	0.11	0.17	0.28	0.45
B3	9.145	0.00	0.05	0.05	0.11	0.22	0.38
K-1	8.935	0.00	0.00	0.00	0.00	0.06	0.22
K-2	9.055	0.00	0.00	0.00	0.06	0.11	0.17
K-3	8.960	0.00	0.00	0.00	0.00	0.11	0.17
C-1	8.560	0.12	0.35	0.35	0.35	0.47	0.64
C-2	8.315	0.18	0.24	0.30	0.36	0.42	0.54
C-3	8.565	0.17	0.23	0.23	0.46	0.46	0.52

Table 5.2: Water absorption test results -1 (Average)

Cube Name	Avg. initial weight (kg)	Avg. water absorption (%)					
		15 min	30 min	60 min	180 min	420 min	1440 min
TA	8.50	0.08	0.08	0.12	0.27	0.37	0.41
XA	8.46	0.16	0.16	0.16	0.20	0.28	0.37
Pe	8.52	0.06	0.12	0.16	0.18	0.29	0.37
XC	8.79	0.10	0.10	0.10	0.10	0.15	0.26
B	8.93	0.04	0.06	0.07	0.13	0.24	0.41
K	8.98	0.00	0.00	0.00	0.02	0.09	0.19
C	8.48	0.16	0.27	0.29	0.39	0.45	0.57

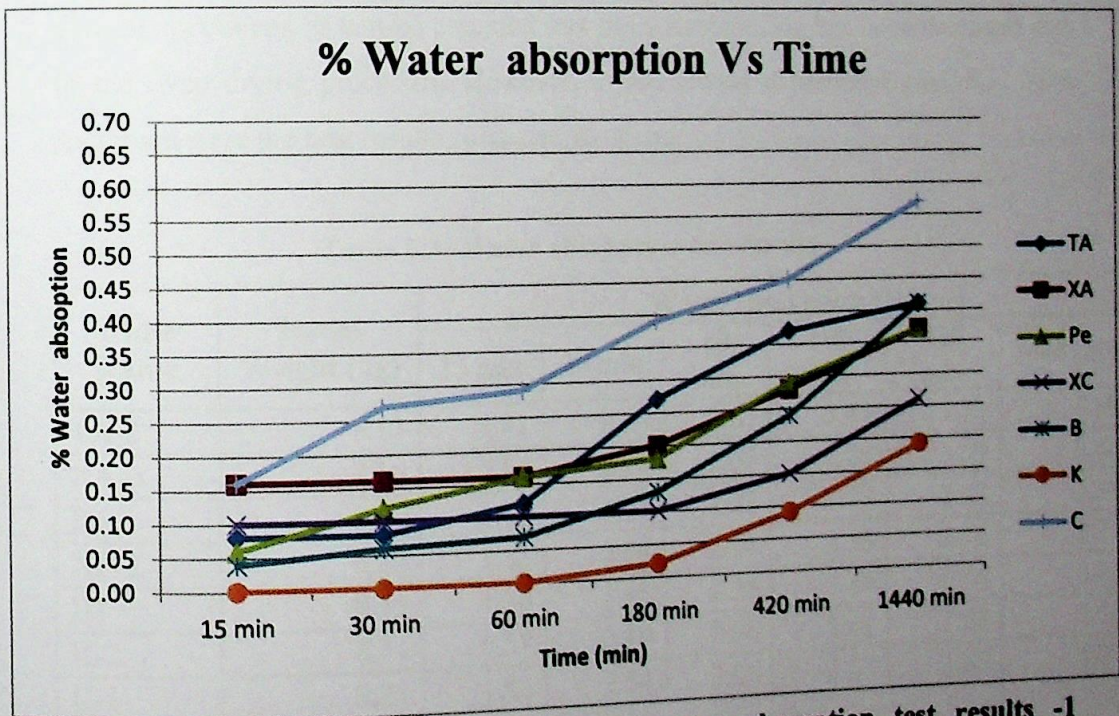


Figure 5.1: Graphical representation of water absorption test results -1 (Average)

5.1.2 Water absorption test 2

This test was carried out based on the method for determination of water absorption of concrete (BS 1881-122: 1983). So based on the results of first experiment, cubes which gave the least water absorption were selected from each product including control samples. Then they were tested using the same procedure to find out the water absorption of each cube. Test results of the second experiment are given in the table 5.3. And a graphical representation of the test results is also given in the figure 5.2.

When compared with the test results of the first experiment, it can be seen that the water absorption has significantly increased in the specimens of the second experiment. This is due to the oven drying procedure carried out prior to the test. Oven drying was done in order to obtain a constant mass of the specimens. However, according to the test results some specimens have absorbed more water than the control specimens. It can be assumed that the waterproofing has been damaged due to the oven drying procedure. However, in the second experiment also, K11 Flex specimen gave the best results compared to others.

Table 5.3: Water absorption test results -2

Cube Name	Initial Weight (kg)	Water absorption (%)					
		15 min	30 min	60 min	180 min	420 min	1440 min
TA-2	8.13	1.81	2.28	2.63	3.44	3.73	3.90
XA-3	8.16	1.81	2.22	2.68	3.26	3.55	3.66
Pe-2	8.20	1.62	2.03	2.38	2.79	3.02	3.19
XC-2	8.56	1.83	2.34	2.78	3.33	3.36	3.71
B1	8.35	1.36	1.88	2.28	3.13	3.86	4.35
K-2	8.74	0.57	0.79	0.96	1.41	1.85	2.56
C-1	8.25	1.96	2.54	3.06	3.57	3.85	4.07

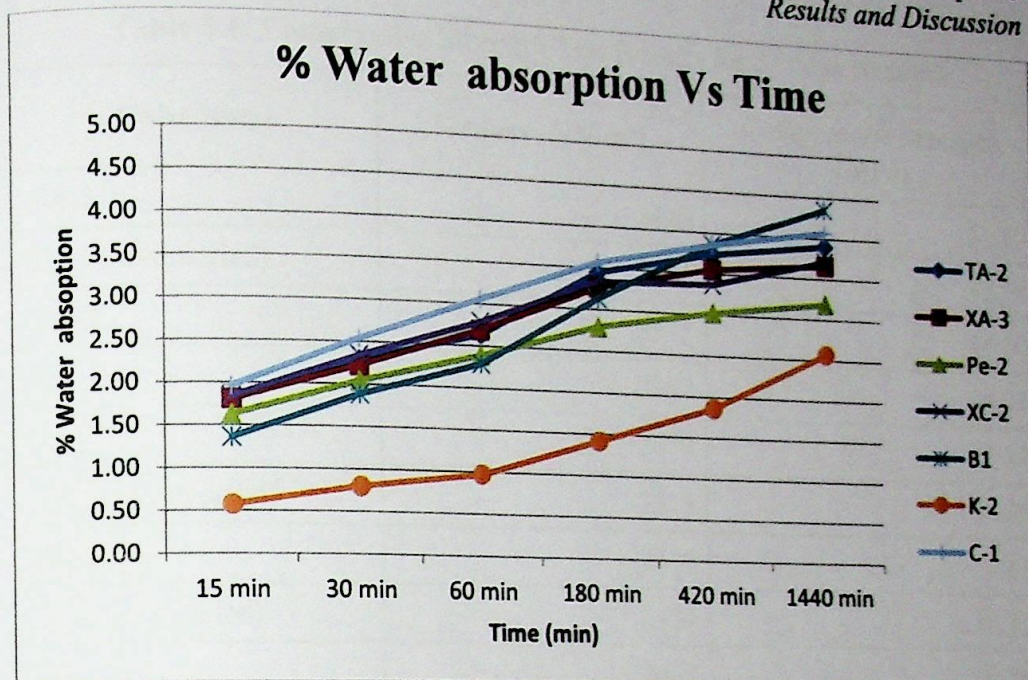


Figure 5.2: Graphical representation of water absorption test results -2

5.2 Compressive Strength Test

This test was carried out on the specimens, which were prepared with integral waterproofing admixtures to find the compressive strength. Results of the compressive strength test of each cube are given in the table 5.4.

Table 5.4: Compressive Strength Test Results for 21 days strength

Cube Name	Density (kN/m ³)	Compressive Strength (MPa)
TA-1	2440	51.17
TA-2(oven dried)	2489	35.59
TA-3	2548	44.60
XA-1	2502	38.04
XA-2	2474	47.39
XA-3(oven dried)	2519	34.02
Pe-1	2449	50.82
Pe-2(oven dried)	2454	32.72
Pe-3	2469	40.30
C-1(oven dried)	2460	37.60
C-2	2476	39.38
C-3	2451	40.86

According to the test results it can be seen that the compressive strength of specimens with admixtures has been slightly increased compared to control samples. Average compressive strength of each set of specimens is given below.

- 1). Tamseal Admix - 47.89 MPa
- 2). Xypex Admix - 42.72 MPa
- 3). Penetron Admix - 45.56 MPa
- 4). Control samples - 40.12 MPa

It should be noted that the compressive strength of the oven dried samples were not considered to calculate the average compressive strength of specimens. And a comparison of the average compressive strength of each product is given in figure 5.3.

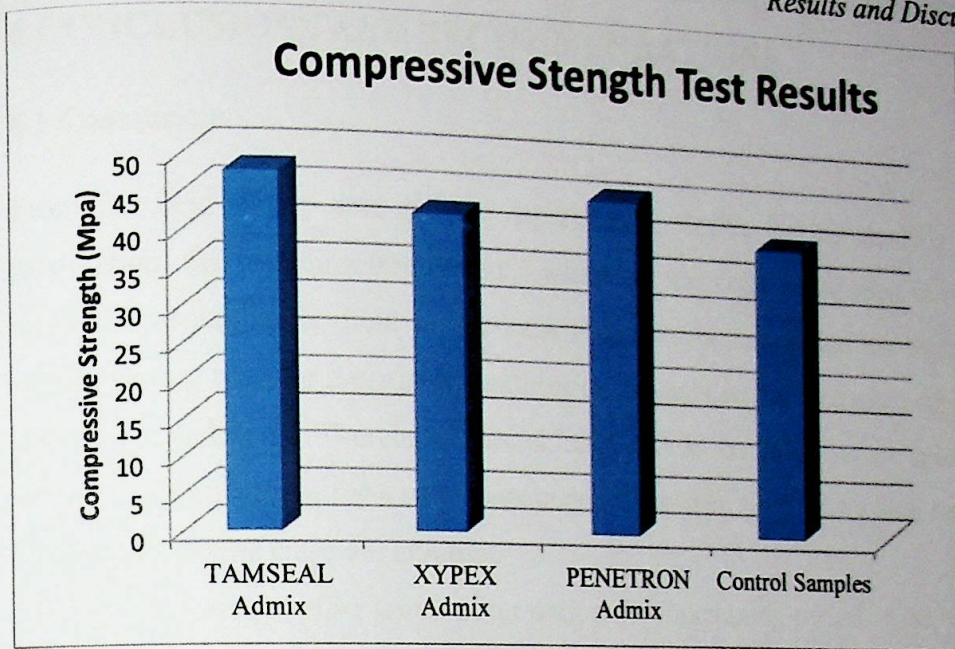


Figure 5.3: Comparison of Compressive Strength Test results

From the comparison it can be seen that the average compressive strength of specimens with Tamseal Admix has been increased by 20% compared to control samples. Penetron Admix has given a 14% increase in compressive strength while Xypex Admix has given a 6.5% increase in compressive strength compared to control samples.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

From the field survey data and the experimental results, few conclusions can be made about the waterproofing methods which are currently being used in roof top slabs. According to the field survey data, it can be concluded that the selection of waterproofing type for a particular application depends on the location, cost and the exposure conditions. Therefore, special care should be taken when selecting a waterproofing material for a new construction. However, problems which can occur in the construction stage are minimal.

Most of the waterproofing issues occur during the functioning period of the building. These issues occur due to poor selection of waterproofing materials and poor workmanship. Therefore, it is difficult to guarantee the efficiency of waterproofing system just by selecting a good quality waterproofing material as long as poor workmanship is involved.

Bituminous membranes are widely used to waterproof roof slabs in high rise buildings. But with time these membranes tend to lose the bond with slab causing water leakages which are hard to repair. Liquid-applied membranes are the most common waterproofing systems which can be used to waterproof bathrooms, kitchens and balconies. Integral waterproofing admixtures are widely used nowadays to waterproof ground slabs, sump areas and lift cores. From the above mentioned waterproofing systems, integral waterproofing system is considered as a one-time treatment. However, the performance of integral waterproofing systems compared to other two types is yet questionable.

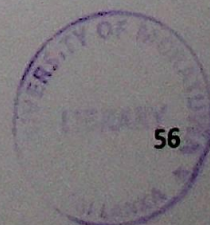
According to the laboratory experiments, liquid-applied waterproofing systems perform better than the integral waterproofing systems. Among the methods considered in the present study, K11 flex waterproofing coating showed better performance compared to the other methods. However, this conclusion is based on the water absorption test carried out on waterproofed specimens. More comprehensive tests should be done to check the effectiveness of waterproofing systems under different exposure conditions.

6.2 Recommendations

Bituminous membrane type waterproofing materials were not tested under the laboratory experiments in this research. Therefore, it is recommended to perform a laboratory test on small slab panels so that bituminous membranes can also be tested with other waterproofing materials.

Integral waterproofing materials are capable of self-sealing cracks up to 0.4 mm in concrete. Therefore, a laboratory test can be carried out by inducing cracks on specimen slab panels to check the self-sealing ability of different integral waterproofing materials. However, a method to induce a crack should be determined in order to check the self-sealing ability.

According to the water absorption test results, oven drying procedure can damage the waterproofing membrane. Therefore, it is recommended to suggest a suitable test method to find the water absorption without damaging the waterproofing materials.



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