

## Advanced Integrity Testing For Roofing And Water Proofing Membranes

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**ABSTRACT :** *Electronic Leak Detection (ELD) methods are used for determining ELD methods can also be used in forensic testing situations to locate. The roofing/waterproofing membrane must be electrically insulating to ensure the integrity of the roofing membrane during normal usage of the building. A solution to costly flat roof repairs: waterproofing integrity testing. One of the techniques, Electric Field Vector Mapping (EFVM) testing, is carried out by applying water on the surface of a roofing membrane to create an electric field and using the water as a conductive medium.*

*The concrete material of the structures is exposed to wet conditions for longer periods of time, which makes the proper adhesion of waterproofing membranes difficult. Joint movements from increased structural settlement, thermal expansion/shrinkage, and physical loads from external sources (e.g., vehicles) make securing durable waterproofing challenging. While ASTM Guides, Korean Codes, and BS Practice Codes on below-grade waterproofing stress the importance of manufacturer specification for quality control, ensuring high quality waterproofing for the ever-changing scale of construction remains a challenge. This study proposes a new evaluation method and criteria which allow for the selection of waterproofing membranes based on specific performance attributes and workmanship.*

**KEYWORDS:** *Waterproofing, Membrane, Testing, Chemicals, Roofs, waterproofing membrane; joint displacement; performance evaluation; dry and wet surface adhesion; overlap joint; concrete structure.*

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### I. INTRODUCTION

Integrity testing is the 'holy grail' of building envelope work. To have an assurance that the portions of a building that are expected to get wet due to weather are in a condition to prevent water transmission to the interior is the goal of every contractor, as well as every owner. As a result an entire industry, that of testing laboratories, has been created. Finding test methods to give that assurance has evolved over the decades, with each new advancement in testing providing either more accurate results, results in less time, or both. This document will provide information about the historical as well as state of the art testing methods available. This article does not discuss field testing of fenestration, louvers, or doors.

Historically there have been five widely used testing methods for testing of horizontal membranes: spray testing, flood testing, capacitance (impedance) testing, nuclear metering, and infrared (IR) thermal imaging. Within the last two decades, two new methods of testing have revolutionized the leak detection and integrity testing industry. These methods utilize electricity and a simple electric circuit to detect and identify problem conditions in roofing and waterproofing systems. These are generically referred to as 'Low Voltage Electrical Conductance Testing' and 'High Voltage Spark Testing'. To explain or address all the principles and subtleties of how each testing method should be done to provide accurate results would require more time and space than allowed. This document will focus on highlighting the testing methodologies, scientific principles, and their advantages and limitations. Special attention will be given to limitations. This is due in large part to the fact that it has come to the attention of the author that the abilities of the high and low voltage techniques are frequently overstated resulting in un-met expectations on the part of owners and contractors which lead to skepticism and possibly a bad reputation of an emerging technology.

As with most investigative tools, the test method selected is only as good as the experience of the person used to perform the test. Knowledge of all the test method options is only the first step. Knowing the benefits and more importantly the limitations of each system will assist a knowledgeable individual to quickly and cost effectively locate and repair all breaches within the membrane.

## II. IMPORTANCE OF INTEGRITY TESTING

Small punctures, membrane splits or mechanical damage to a waterproofing membrane will result in wet insulation, mould and costly interior damage. Leaks can go unnoticed and the water exit location might not correspond with the point of entry. Previously, lengthy and costly leak investigations were necessary to locate a membrane breach, especially in protected roof membrane assemblies, garden roofs, or parking and plaza decks. Vector mapping eliminates the dangers and potential damage inherent in traditional flood testing. Unlike the interpretive process of water, flood infrared, or nuclear testing, vector mapping detects membrane faults directly.

## III. QUALITY CONTROL CHECKLIST

- Developers recognises that the roofing contractor may wish his personnel to test the roof, as part of their own quality procedures, but recommends that the final test and certification should be provided independently of the contractual parties (i.e. by a Third party member test house).
- The test service provider must submit a job-specific method statement for approval prior to the test. This must demonstrate that the technique to be used is effective for the roof specification and the construction circumstances. If there is any doubt as to the efficacy of the method, a sample test should be considered.
- Prior to the test, a co-ordinate system should be agreed between client and test service provider based upon a roof drawing, which can also be used to identify the location of defects / breaches / leakage pathways.
- For the electrical conductance/resistance ('Wet') test method, a healthy supply of water at roof level must be available to enable full wetting of the roof.
- All points of potential leakage must be marked on the roof surface with a waterproof marker (e.g. wax crayon), which can be subsequently cleaned off if necessary once repairs are complete.
- The roofing contractor should be in attendance to conduct repairs to the waterproofing, during (or immediately following) the test. Therefore, services required for repairs (e.g. power supply for welding single-ply) must be available.
- The test service provider can then re-test the repairs, so that a final certificate of integrity can be issued. If this is not the case, then a second visit to re-test will be required.

## IV. DESCRIPTION

This Resource Page discusses several methods of integrity testing and moisture detection, as follows:

### **Integrity Testing:**

1. Low Voltage Testing
2. High Voltage Testing
3. Flood Testing
4. Spray Testing

### **Moisture Detection:**

1. Capacitance Testing
2. Infrared Thermography
3. Nuclear Meter

## V. LOW VOLTAGE TESTING

Low voltage testing is a definitive test in that once false positives are excluded the testing provides definitive locations of breaches in the membrane tested. The equipment shows where current is following water through the membrane to the substrate below.

Low voltage is a viable testing option when a non-conductive membrane is installed over a conductive deck assembly. This configuration yields a simple electrical circuit whereby the membrane is an electrical isolator and any breach in the membrane closes the circuit path and allows current to flow. (See Diagram 1)

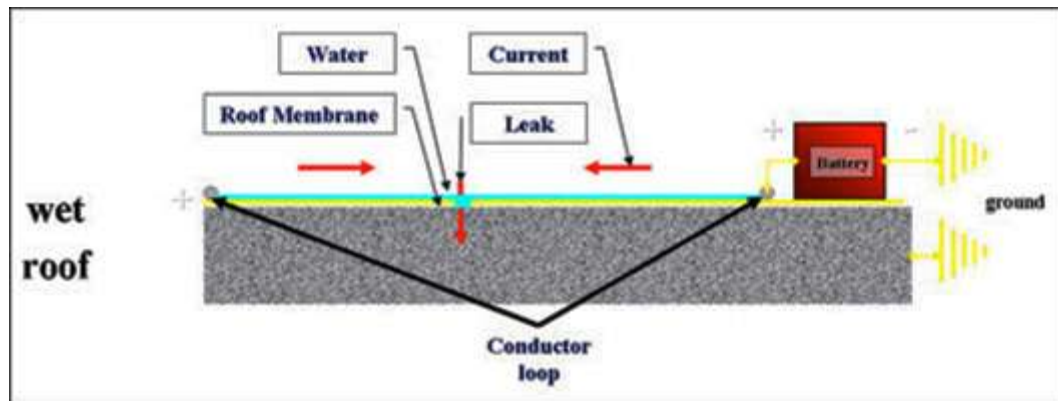


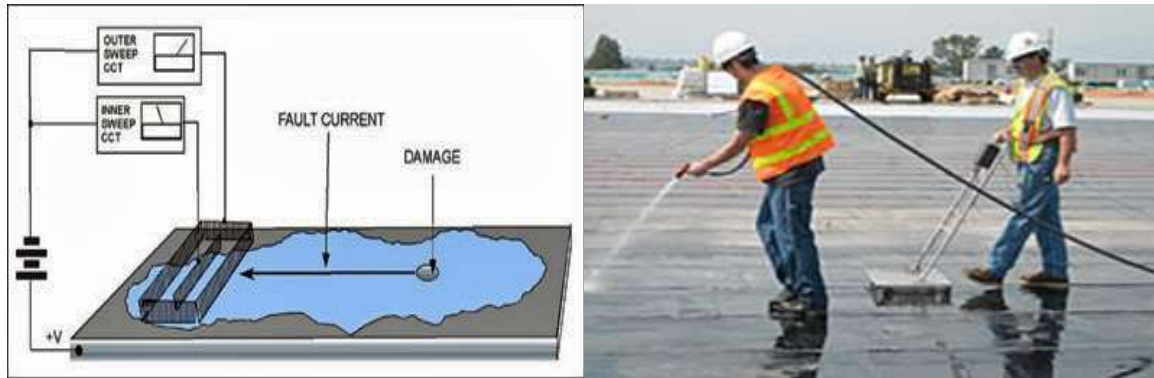
Figure 1: Low voltage electrical circuit

The electric circuit is developed via a conductive deck such as concrete or steel, to which a ground lead from the testing equipment is attached. An exposed metal wire is then placed in a circle/loop on the membrane and attached to the positive side of the testing equipment. The entire roof area is then wetted with water which creates an electrical plate at the entire top side of the membrane when charged by the test unit. In this electrical circuit, the membrane acts as an isolator between the positively charged electrical plate on the membrane surface and the conductive deck which is considered the ground. If there is a breach in the membrane the circuit is completed and current will flow to the breach and ultimately to the ground/deck. A sensitive meter connected to two probes can detect the direction of current flow, directing the test operator to the pinpoint location of the breach. (See Figure 2) Once a breach is found, it must be electrically isolated out of the test area by placing a circular loop around it with a twisted wire connected to the loop that affectively removes this area from the area that is being tested.



Figure 2. Low voltage test equipment

Newer low voltage test equipment available does not require a separate loop and testing probe. A testing configuration similar to that described above only in miniature is created by a scanning platform that is approximately 18" x 24". (See Figure 3 and 4) This platform contains a perimeter loop made from metallic chains hanging from the edges of a scanning platform and an additional line of chains in the center which are both connected to the power source. Meters are attached to the two chains and when a breach is within the limits of the platform there is a potential difference between the two chains that creates a current flow which activates an audible tone to alert the test technician.



**Figure 3. Low voltage test platform** **Figure 4. Low voltage platform in action**

As with all testing methods, there are limitations. The most important part of this and any testing protocol is the test technician. The number of years of experience does not guarantee a qualified technician and unfortunately there are no courses or certifications for this type of testing. The test equipment is 'dumb', providing the technician with audible tones and numerical or gauge readings. It is the job of the technician to decipher these readings and act accordingly. If the technician does not understand the principals of the test procedure, they will not be able to understand the readings in the event of a unique field condition, or in the unlikely event of an equipment malfunction.

Other limitations include:

- Conductive membranes, such as black EPDM and foil-faced modified bitumen membranes cannot be tested.
- If the breach is below a large amount of overburden/soil, the signal read by the meter will be faint and is easy to miss.
- If in the case of a membrane covered with overburden there are electrically insulative materials between the membrane and overburden surface (i.e. foam insulation, plastic drain mats, polymer sheets for physical protection or root barriers, etc.), the accuracy of the testing will be limited to half the smallest dimension of the barrier around which the current must travel
- If water has not found its way from the breach to the deck, such as if the breach is new and/or has not been exposed to the weather, the circuit will not be completed and the breach will not be identified.
- If a vapor retarder is present below the membrane and is not penetrated by mechanical fasteners, the deck is electrically insulated and no breaches in the exposed roof membrane will be detected.
- If multiple penetrations exist in close proximity to each other, it can become physically impossible to isolate out known breaches and retest areas immediately adjacent to breaches.
- Some accumulated debris, particularly on gravel surface built-up roofs, effectively repels water and does not create a continuous electrically charged plate on top of the membrane. Any area that is not wet cannot carry current and therefore is not tested.
- Vertical flashings are extremely difficult to keep wet and therefore are difficult to test.

## VI. HIGH VOLTAGE TESTING

The concept of high voltage testing is similar to that of the low voltage and is depicted in Diagram 3. The high voltage testing utilizes a charged metal broom above the membrane rather than an electrical plate of water to create the electrical potential difference. (See Figure 5 and 6) The power source is again grounded to the conductive deck and creates a high potential difference with an extremely small current. When the metallic broom head is swept over a breach in the electrically insulative membrane surface, the circuit is completed allowing current to flow. This current flow is detected by the test unit which turns off the power to the broom and emits an audible tone to alert the test operator. The area where the broom head was located when the tone was heard is then carefully swept again at ninety degrees to the original sweeping direction to pinpoint the exact location of the breach. This process is continued until all areas of the membrane have been tested, including vertical base flashings and penetration flashings.

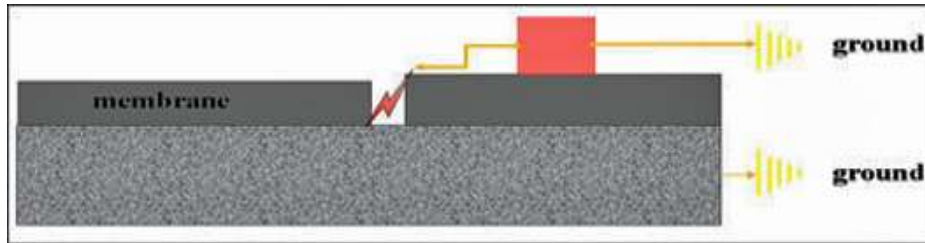


Figure 5.High Voltage electrical circuit



Figure 6.High voltage test equipment

The lack of water, as well as the relative speed and simplicity of high voltage testing makes it preferable to low voltage in most conditions. When temperatures are very high, keeping the membrane wet for the low voltage testing is often impossible. When temperatures are very low, working with water can be dangerous, or sometimes impossible. High voltage testing will identify the precise location of breaches in the membrane and, because no water is used, allows their immediate repair and retesting.

A unique advantage of this test procedure is that for liquid applied membranes, it can detect locations where membrane thickness does not meet minimum requirements. If the electrical insulating properties of the membrane (i.e. dielectric constant) are known, the equipment can be set to the proper voltage where current will flow through the membrane and activate the audible alarm unless a predetermined minimum thickness of material is present. This precision is typically not required for building envelope projects; however this equipment is routinely used in pipelines where interior coatings and their thicknesses are tested.

Again, the test method has limitations. Being a relatively new technology, the same caution about qualified testing technicians applies. Other limitations include:

- Membrane must be dry, possibly delaying testing a few hours if dew occurred the night prior.
- Membrane must be exposed (cannot test through overburden).
- Due to the higher voltage, more 'false positives' are possible, making the test technicians skill important.
- It is possible to burn a very thin liquid applied membrane if the test voltage is set too high.
- Electrically conductive membranes such as black EPDM and foil faced modified bitumen membranes cannot be tested.

## VII. FLOOD TESTING

Flood testing is the simplest and most basic of testing methods available. It can also be one of the most effective. An in-depth knowledge and understanding of structural systems and their safe load carrying capacity is imperative prior to considering or employing this method. The drainage system is temporarily sealed or blocked and the area in question is covered with water typically for a time period of between 12-48 hours. Simultaneously during this period the underside of the test area is inspected for any evidence of water infiltration. The depth of the water can vary, however a minimum of 2" is common to provide a sufficient hydraulic head to force the water into any small breaches that may occur within the timeframe of the test. (See Figure7)



**Figure 7. Flood testing in progress**

Difficulties with flood testing are the time required to fill, test, and then drain the sometimes tens of thousands of gallons of water required to properly test an area. When the area to be tested has a slope greater than 1/4" per foot, the depth of the water needed to test that area increases dramatically. On occasion, the depth of the water required can exceed the safe load carrying capacities of the structural frame or deck and may require that the area be broken down into multiple smaller sections by the construction of water retaining dams. Once the test is complete, the water must be safely removed from the membrane. If the water depth is sufficient and the drains are simply opened completely to drain the area, catastrophic results such as blowing out elbows in drain piping can cause all of the test water to enter the building interior causing significant damage. Another major limitation of this type of testing is that if a leak occurs using testing, it must be found at the top side either by visual inspection or one of the other methods described in this article.

### **VIII. SPRAY TESTING**

Spray testing is the use of controlled water flow deposited on building components in a manner that simulates normal to severe weather conditions. ASTM E1105 and AAMA 501.2 test methods are good overall methods commonly used to test exterior walls, sloped glazing, and shallow pitched roofs to help identify leak sources. This ASTM testing procedure utilizes a calibrated spray rack with specific water pressures, nozzles, and distances to wet a wall with water at the rate of five gallons per square foot per hour. A pressure differential that simulates wind is created between the interior and exterior of the building and the interior is inspected for any leaks. The AAMA testing involves a calibrated spray nozzle that applies water at a known rate and pressure to very limited and specific areas.

Less formal hose testing can be done on horizontal and vertical areas with similar results provided the water spray is controlled to wet only the areas intended to be tested. The spray testing is started at the point of lowest elevation below an area of suspected leakage. The drainage path of test water on lower areas of roof or walls must be tested to be certain they do not contain the leak location. If a higher elevation area is tested and lower wash areas were not tested to assure they are watertight, it is impossible to determine where the water was entering. After testing the lowest areas, the spray is directed at progressively higher building components with the wash water running over the components at a lower elevation that have already been tested. With this methodology, it is possible to pinpoint the location of water entry. After the location is found, it is good practice to make the leak start and stop several times by isolating and spraying only the suspected breach, with little or no wash water running down the wall or roof. This decreases the potential that lower building components contain a breach that allows water entry and if a delay in seeing the leak exists may erroneously appear to indicate a component higher in elevation that is tested a few minutes later in the test process is allowing the water to enter.

This type of testing can be particularly effective when testing by any of the other methods is difficult due to access or assembly composition limitations. These might be when ponding water for a flood test is not practical or the presence of multiple metal penetrations make electrical testing difficult. (See Figure 8) Also, spray testing is ideally suited for fast and easy results as the materials and techniques are quite basic and can be learned fairly quickly.



**Figure 8. Areas suited for spray testing**

The most critical limitation of spray testing is that it may take hours for a leak to wet the entire path, prior to being observed at the interior. Additionally, activating the leak may cause more damage to interior components/finishes that may not be acceptable to the building owner. Other limitations of spray testing are that during periods of cold weather the use of water may be impractical and spray testing may not replicate all the conditions, i.e. direction, pressure differential, etc., necessary in order to re-create a leak.

### IX. CAPACITANCE TESTING

Capacitance testing utilizes an electric field to determine the relative moisture content of a membrane assembly. An electric field is created and a sensor then reads the strength of the electric field when the meter is placed over the membrane. The strength of the field and sensitivity of the sensor can be changed based upon the substrate being tested in order to obtain readings that provide greatest variation while staying within the limits of the analog read-out or digital display. This type of meter calibration at each job site provides the most accurate survey the equipment will allow.

Readings are generally taken in a grid pattern with a hand-held unit and recorded although it is possible to take continuous readings with some meters that are mounted with wheels. (See Figure 9)



**Figure 9. Tramex Capacitance meters**

This testing method is interpretive and not definitive in that it does not specifically identify the location of the membrane breach, rather it locates areas of elevated moisture content, which in most instances can be assumed to indicate the presence of a breach. However that breach could already be corrected or repaired, or it could be water incorporated in the system during construction. The equipment does not indicate the presence of, nor locate a leak. It simply indicates that water is below the membrane. Once the metering of the test area in question is complete, test cores should be taken at the high and low reading locations and their moisture content precisely established by laboratory measurement after controlled drying. This technique will provide a correlation between the meter readings and the absolute moisture content of the assembly. Removing additional samples at locations of intermediate meter readings will provide more precise correlations from meter reading to actual moisture content.

The preparation and calibration required for the testing described above may seem lengthy and cumbersome with the survey results not available until after laboratory moisture content results are provided. However, a skilled technician can quickly calibrate the electric field and sensor in order to get relative readings

that provide information to allow areas with elevated moisture content to be mapped out before leaving the test location. Knowing the areas of elevated moisture content provides areas that should be inspected with the purpose of finding the breach in the membrane.

There can be instances in which the capacitance testing will provide elevated readings that are not due to leakage. Condensation within a roof insulation system is a typical example in which the capacitance meter readings will be elevated with no associated roof leak as a cause of the elevated readings.

This testing technique requires that the test membrane be dry, the assembly be uniform in its materials and their thicknesses, and that water be in the system to provide differential readings at relative dry and wet areas.

#### X. INFRARED THERMOGRAPHY (IR)

Infrared thermography is an interpretive testing method that is based upon the principle that wet and dry building components have differing rates of heat gain and retention. Wet materials have significantly more mass and have slower rates of heat transfer, meaning that they gain and lose heat more slowly than a dry sample of the same material. This physical characteristic is used in the same manner as in the Capacitance Testing described earlier in order to quantify the location of wet building components. The testing equipment used is generally a hand-held IR camera with the ability to have recording devices connected or contained within the unit to allow the information to be retained and presented at a later time in a report. (See Figure 10)



Figure 10. FLIR ThermoCAM ES IR camera and IR photo

The most common use of IR imaging is in the evening hours after a sunny day when the exterior of a building that is exposed to the sun gets warmer than the surrounding air temperature due to solar radiation. The amount of this temperature difference has a direct relationship to the color and reflectivity of the surface with the darker and less reflective the surface the greater the temperature difference; or the lighter in color and greater the surface reflectivity the less the temperature difference will be. As described above, the rate of thermal gain upon initial exposure to the sun and the rate of thermal loss upon setting of the sun will vary between two areas of the same material that have different moisture content. If the IR imaging is done after sunset, exposed roof and wall areas that have elevated moisture content will retain significantly more heat than surrounding dry areas. This temperature difference can be readily detected in the IR scan. Areas of elevated temperature within a homogeneous roof and wall assembly are assumed to be due to the presence of moisture. Laboratory drying of test cuts removed from areas with low, medium, and high temperatures will allow calibration of the IR image to absolute moisture content of the building materials.

As with capacitance scanning, a skilled investigator can utilize the areas of elevated temperature detected by the IR equipment, assume it to be due to elevated moisture content and thereby concentrate detailed visual inspections in these areas in order to isolate the source of the leak.

As with the capacitance meter, an IR scan will outline areas of wet insulation that could be due to condensation or problems other than a roof membrane breach.

The obstacles to the use of IR in the location of leaks are that the scans are typically done at dusk or in the early evening and should be done when weather conditions are favorable. Once the areas of suspected elevated moisture have been identified, the visual inspection for the membrane breach must be done the following day in the daylight hours. Also, assumptions must be made with respect to items such as the homogeneity of the materials, thicknesses, and interior building temperature of the scanned areas. As with capacitance testing the IR equipment does not indicate the presence of, nor locate a leak. It simply assumes temperature differences to be caused by water below the membrane are present.



## XI. NUCLEAR METER

Nuclear meter testing is also an interpretive test method that utilizes relative readings that are interpreted to locate areas of identical substrate materials with differing moisture contents.

A nuclear meter emits a stream of high velocity neutrons that collide with hydrogen atoms and give up some energy and then rebounds to the metering device at a slower speed. One point to remember is that each molecule of water is made of two hydrogen and one oxygen atom. The meter then records these slower speed neutrons and provides a digital reading on a pre-set calibrated scale. Readings generally take from seven to sixty seconds each and are done in a grid pattern that varies from three feet to ten feet on center. (See Figure 11.)



Figure 11. Nuclear meter (yellow) and grid pattern on roof

As with the other interpretive test methods, the testing equipment should be calibrated at each individual job site as well as for different roof assemblies and thicknesses within a single site for accurate results. The relative readings can again be utilized by a skilled investigator to locate areas of suspected wet materials to limit the bounds of a detailed visual inspection to determine the source of the leak.

Unlike the IR scanning method, the nuclear testing can be done in the daytime hours to allow immediate inspection, identification, and repair of the suspected leak source(s).

The difficulties with this testing technique are that the transportation of radioactive materials contained within the meter has become much more difficult and overhead intensive since September 11th, 2001 and the use of a metering device that contains radioactive material can be troublesome due to perceived danger on the part of the public and building occupants. As with IR and capacitance testing, the source or sources of the leak must be found visually within the area determined to contain the elevated readings after the nuclear testing is completed.

Again, the equipment does not indicate the presence of, nor locate a leak. It simply highlights locations of irregularities in the quantity of hydrogen atoms at distinct locations, which are assumed or interpreted to be water

## XII. APPLICATION

The testing techniques described above are best suited for integrity testing, or testing to be done immediately after installation of roofing or waterproofing membranes. These test methods can also be used to find leaks. However in the case of waterproofing covered with overburden, the process becomes less precise and more difficult, and therefore more expensive.

## XIII. RELEVANT CODES AND STANDARDS

I have all standards License copies. Described above. They include, but are not limited to:

- AAMA 501.2 Quality Assurance and Diagnostic Water Leakage Field Check of Installed Storefronts, Curtain Walls, and Sloped Glazing Systems
- ASTM C1153 Standard Practice for Location of Wet Insulation in Roofing Systems Using Infrared Imaging
- ASTM D4787 Standard Practice for Continuity Verification of Liquid or Sheet Linings Applied to Concrete Substrates
- ASTM D5957 Standard Guide for Flood Testing Horizontal Waterproofing Installations
- ASTM D7240 Standard Practice for Leak Location using Geomembranes with an Insulating Layer in Intimate Contact with a Conductive Layer via Electrical Capacitance Technique (Conductive Geomembrane Spark Test)

- ASTM D7877 Standard Guide for Electronic Methods for Detecting and Locating Leaks in Waterproof Membranes
- ASTM E1105 Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls, by Uniform or Cyclic Static Air Pressure Difference
- ASTM G62 Standard Test Methods for Holiday Detection in Pipeline Coatings

#### XIV. HEALTH AND SAFETY CONSIDERATIONS

- Prior to commencement, the test service provider must submit a Risk Assessment for approval.
- None of the methods described presents a significant health and safety risk in respect of the electrical output. Nonetheless, care is required with the 'Dry' (high voltage) method.
- Normal health and safety procedures as regards edge protection and/or fall arrest facilities, (in compliance with HSE Regulations), must be fully operational prior to the test. If an electrically conductive edge protection system is removed temporarily, another means of fall restraint must be provided in the interim.
- Some membranes may be slippery when wet, especially if soap solution is used during testing to extend drying times. Appropriate footwear is essential.
- Testing must not be carried out in frosty conditions.
- Whether or not other works are in progress, use of suitable head protection should be considered, since testing frequently involves access to areas with restricted height or width clearance.
- Some testing equipment (e.g. large-model electrical capacitance) is heavy and requires extra care when being passed up through access hatches, etc.

#### XV. CONCLUSIONS

As with most investigate tools, the test method selected is only as good as the experience of the person used to perform the test. Knowledge of all the test method option is only the first step. Knowing the benefits, and more importantly, the limitations of each system will assists a knowledgeable individual to quickly and cost effectively locate and repairs all branches within the membrane.

The thermal imaging method is the most advanced technique to trace the leakage path. This technology is available in india and is being used by many consultants to detects water leakages as well as many other common defects in buildings.

The EFVM test method is the most advanced technique and precisely pinpoints the leakages points in a waterproofing system. Though the technology is rarely available in india at present, once introduced, sooner or later, it will be most preferred system for leakage detection.

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