The Application of Electromagnetic Waves in Monitoring Water Infiltration on Concrete Flat Roof: The Case of Malaysia

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Abstract

Roof leakages of high-rise buildings involving concrete flat roof design in tropical countries continue to be a serious problem. Currently, exiting methods of detecting potential leaks are mostly destructive to the building material. Although the method of detecting a defect using non-destructive measurement exists, current methods such as infrared thermography, metal detector and humidity meter have varying constraints in their application. This paper describes the potential use of microwave technology as an effective non-destructive tool to monitor and investigate leakage of concrete flat roof due to failure of membrane layer. This study was performed experimentally on flat room structures built for laboratory use and according to Malaysian flat roof concrete proportions standards. Experiments performed

utilized a sensor equipped with essential parameters that enable control to sensor angle, temperature and distance between object and sensor structure and designed to enable numerous measurements in real time. The study determined that microwave technology can be used to identify moisture content in concrete flat roof by analyzing properties of the concrete roof and water. This proves to be an effective non-destructive method of determining leakage problems in concrete flat roof in real time before the defects become critical.

1.0 Introduction

Building roof leakage problems had often been reported by owners of high-rise buildings, especially in the tropical countries. Almost all of the buildings involved have concrete flat roof design. The roof leaks have been disturbing activities and space planning up to affecting the income from the rental of building space. There are also buildings that had to be closed as a result of leaks that affect the safety of the user. Existing methods are not effective enough in detecting potential leaks. Most building owners taking a wait-and-see attitude until the building leaks occur. Thus, a method of effective monitoring is needed to address the issue. Non-destructive testing method is seen to have a potential to detect leakage problem at an early stage and other hidden defects before becoming critical. This paper describes the potential use of the microwave as a tool to monitor and investigate leakage of flatroof concrete due failure of membrane layer installed on the roof.

Many building defects reported involves the quality of building materials as well as materials that are embedded (Chong and Low, 2006). Although the method of detecting a defect using non-destructive popularity this time, existing methods is rather limited. Of those approach adopted are infrared thermography, metal detector and humidity meter, which, have certain constraints. Because of the limit, some destructive test methods had been used to detect any anomalies involving the hidden flaw. This destructive approach will damage the other components of the building. Hence, there is a pressing need to enrich the method and use of non-destructive testing more effective and not damaging part of the building to another. Inline with that, microwave applications in detection of different materials properties are seen as having great potential to meet these needs.

1.1 Flat Roof for Malaysia Building

Building materials identified as one of the factors that contribute to the defects in buildings. Interestingly, the building materials for a building consisted of a several of basic materials such as plastic, metal, stone, glass and composite materials. The materials chosen should be able to stand in line with the whole lifespan of a building. It is reported that although the installation method of building materials carried out as per manufacturer's instructions, it still had contributing to the occurrence of defects within a building. In addition, the quality of the building materials that sometimes does not reach to required standard or functioning properly while the fast paced changes of the weather caused the materials performance declined significantly. For instance, a flat roof construction, membrane layer even installed by legitimate manufacturers or trained contractor, building owners often faced the problem of building defect and unsatisfactory performance that resultant in leakage of the roof a few years later (Mailvagam and Collins, 2004). In the market, there is also a layer of membrane that require special mixing ratio with other materials such as cement, chemical, mortar and so forth, which will respond when it exposed to the effects of climate change and erratic temperatures. Other building materials also having the same problem such as peeling of paint and finishes like tiles installed will also be falling and face problems because of the tile itself least adhesive and porosity (Guan et al., 1997)

Some of the building materials mentioned are in composite and embedded, which cannot be seen physically. For example, PVC water pipe buried in the wall or floor, steel reinforcements in the concrete and etc. When there are defects resulting from composite materials, it is hard to determine the substantial cause. For water pipe leaks or clogged pipes in the walls or floors, it is hard to determine the actual location and cause of the potential problem. Most of the building defects occur after the building was occupied and method to get information about it is limited. Most defects were architecture and structure (Chong and Low, 2006). Seeley (1987) studied found that the problem of the defect caused by the workmanship is 35% while 12% come from the quality of materials used. Thus, there is a need for a non-destructive technique that is more efficient to be dealt with this problem, which is more effective and reduce costs.

It is the practice of concrete flat roof in Malaysia using rapid hardening concrete in-situ for ease of construction and maintenance in the future. Flat roof has gradient around 10 degrees in order to drain rainwater perfectly to tap in the gutter. This is important in order to avoid any water retention happens after rain, which could result in leaks. Obviously, the advantages of the use of concrete flat roof are it has a high compressive strength, thus it is suitable for rooftop access facilities as well as the ability to take the burden of life load. Reinforced concrete roof is also not easily suffering due to climate change. In Kuala Lumpur, the difference the weather throughout the day is rather significant and could achieve a difference of temperature above 10oC in a day (Talib, 2008). Thus, the concrete roof must be able to withstand the temperature difference and not easily cracked and damaged.

In order to avoid water infiltration into buildings through the flat roof for skyscrapers, a thin layer of bitumen or membrane layers used to cover the concrete roof. In many cases, installation of membrane depends on the manufacturer's instructions. In normal circumstances, within 24 hours the installation should be completed for the membrane layer to avoid any failure in the future (Talib, 2008). It is however depending on the weather conditions during the installation process performed. A layer of membrane needs to be installed on the roof of the concrete cleaning and free from any debris or foreign objects. If the membrane installed on the concrete that has not been completely dried will trap moisture, which in long term can cause the effects of rust on the reinforcement and cracks in the concrete.

In Malaysia, most flat roof for high-rise buildings used for the space of building services equipment. Usually, a roof area is more than adequate to provide spaces for services equipment such as cooling tower, domestic, fire and air-conditioning water tanks. Hence, the design and installation of the roof concrete need to absorb any vibration generated by the equipment; as well as membrane layer to avoid any leakage in the future.

1.2 Malaysia Climate

The weather in Malaysia is categorised as equatorial and located in tropical areas. Various conditions of temperature and rainfall throughout the year in which indirectly effect on the durability of materials used in a building. Malaysia has an average rainfall of 2500mm to 3500mm per annum with the Sabah recorded the highest reading. The annual average temperature readings recorded between 20^{o}C to 30^{o}C with relative humidity between 78%-90%. The weather was much depends on the wind direction from the southeastern and southwest monsoon during the year. The humid condition throughout the year as well as the quantity of rainfall is likely to contribute to the occurrence of roof leaks, especially for buildings that using a flat roof. If there is a leak in a flat roof, an effective method to detect the exact location of the leak is necessary so that repairs can be carried out effectively.

1.3 Condition-Based Maintenance

1.3.1 Infrared Thermography

Infrared thermography used to detect the infrared energy generated by an object. The temperature difference between the normal and the condition with a defect, it will give an indication that the object has a problem. Tsang (1995) and Li et al. (2000) defined infrared thermography as a method to measure the emissions of infrared energy or radiation from objects and display them in the form of visual heat image, which is also as a mean to determine the operating condition of plant machinery and system. Jadin and Taib (2012) highlighted that infrared thermography is the science of obtaining and analysing thermal information from non-contact thermal imaging devices. Through these devices, infrared energy is detected and converted into electronic signals from which a thermal image is produced and displayed on a video monitor to perform temperature calculations. Infrared thermography however, used mostly to detect malfunction on the mechanical and electrical equipment. Applications of infrared camera to detecting faulty in building components usually carried out for damp proof layer, damaged timber caused by termites or exposed clogged pipes. However, this application requires a significant difference in surface temperature of an object for the infrared thermography to detect any anomalies.

1.3.2 Moisture meters

This is a useful tool for detecting any presence of moisture in an object (Burkinshaw and Parrett, 2002). Usually, moisture meter used to check moisture condition of an object surface before more detailed investigations could be carried out. By using two pins of probe, which context on an object, the moisture meter will give a reading on the moisture level up to 100 percent. Reading the percentage of moisture objects could be read directly from the moisture meter screen. The reading could be categorised into dry, moderate and damp. Type moisture meter is of the type resistant electric meter with 2 electrodes or probe pins could be pressed in a material to check the moisture content. However, it depends on the depth of the probe reading penetrated. The voltage applied to the two pins, the electrical conductor increases when the moisture content increased at objects (Ralph, 2002). Among the advantages of this meter is that it is easy to carry to test the moisture conditions in building materials. However, the use of this tool would slightly damage the surface of the material being tested because the probe pin prick. Moreover, this equipment is only effective if both probe pins touching to the object surface that containing the moisture. No readings can be detected on an object that has no direct context on it. Ralph (2004) describes the use of a moisture meter to monitor the humidity level in the building component. The moisture meter considered effective to monitor the humidity level for wood, tile, concrete and brick wall in a period of time and easily operated.

1.3.3 Metal detection meter.

Metal detector nowadays is widely used in various sectors such as archeology, industry, security and building to detect any presence of metal components in a building wall (Syatos et al., 2011). Metal detector used to detect substances that are installed in the wall such as electrical cables, metal pipes and reinforcement steel bar. Usually this meter can detects material embedded in walls up to 70 mm. There are also detection meter that capable to detect reinforcement steel bar up to 400 mm depth available in the market. This tool has become one of the popular tools for building owners in building maintenance especially when identifying the position of reinforcement bar, metal pipes and etc., which important for refurbishment works (Feng et al., 2014). Similarly, this tool also normally used to assist the contractor or consultant in decision to create openings or demolishing part of a building. However, this tool could only detect metal related only. Presence of other elements such as water, waterproof layer and physical changes of material are undetectable clearly.

2.0 Microwave Technology in Monitoring Concrete Flat Roof

The use of electromagnetic waves for the purpose of detecting anomaly for some objects is the approach that is being actively investigated (Mukhopadhya and Yunus, 2011). Microwave is a technology that used wave that is not harmful to the user and this technology has been successfully applied in several industries such as environmental pollution monitoring, wastewater quality monitoring, carbon emissions levels, for the purpose of monitoring human health and so forth (Korostynska and Al-Shamma'a, 2014). The advantage of using microwave spectroscopy is the ability to real time monitoring the interaction of electromagnetic waves with and tested object. As a result it is possible to observe changes of microwave spectrum due to the different dielectric properties and texture of measured objects.

There are different types of antenna that can be used to transmit and receive microwave signal such as: Wire Antennas, Aperture Antennas and Microstrip Antennas. In this paper aperture antenna will be reviewed. There are different types of aperture antennas such as pyramidal horn, conical horn or rectangular waveguide. Compared to waveguide, microwave horn antennas generate a phase front of the same pattern with larger aperture and greater directivity. A horn antenna is made up of a flaring metal tube in the shape of a horn, closed at the narrowest end, and opened at the widest end. The microwaves are let into the waveguide by a coaxial cable connected to the horn antenna (Vijayakumar, Wylie, Cullen, Wright and Al-Shamma'a, 2009).

2.1 Dielectrics Properties of Building Fabrics at Microwave Frequency

Electromagnetic waves and dielectric properties has received growing interest in the investigations of material and structural assessment. With a direct relationship with other materials characteristics, dielectric properties could be used to establish properties such as moisture content, bulk density, bio-content and chemical concentration (Buyukozturk, Yu and Ortega, 2006). Microwave imaging for building fabrics detection is based on the contrast in dielectric properties of different types of materials and moisture contents. These properties allow finding the source of the leak in the roof, location of the reinforcement in the concreate and the level of the moisture content in the roof (Fear, Li, Hagness and Stuchly, 2002). Dielectric properties of materials are the relationship between the applied electric field strength E (V/m2) and the electric displacement D (C/m2) in the material. Dielectric properties of material can be characterized by the use of a scalar effective complex permittivity denoted as ε_{e}^{*} to account for EM dielectric losses and conductivity of the material (Buyukozturk, Yu and Ortega, 2006).

$\varepsilon_e^{*}=\varepsilon_e^{'}-j\varepsilon_e^{''}=\varepsilon^{*}+\sigma^{''}/j\omega=(\varepsilon^{'}+\sigma^{''}/\omega)-j(\varepsilon^{''}+\sigma^{'}/\omega)$ (Buyukozturk, Yu and Ortega, 2006)

Where $\varepsilon_{e}^{'}$ is the real part of ε_{e}^{*} and represents the ability of a material to store the incident EM energy through wave propagation, $\varepsilon_{e}^{''}$ is the imaginary part of ε_{e}^{*} and represents the degree of EM energy losses in the material, j is the imaginary number. $\varepsilon^{*}= \varepsilon^{'}-\varepsilon^{''}$ Is the complex permittivity (F/m), $\sigma^{*}=\sigma^{'}-j\sigma^{''}$ is the complex electric conductivity (Ω/m), and $\omega=2\pi f$ is the angular frequency (rad/s) (Buyukozturk, Yu and Ortega, 2006).

2.2 Current Methods

Currently, there are many methods for obtaining the moisture content of the building fabrics, although most of those techniques are destructive for the material. There are three groups of measurements: Radiological, Electrical and Mechanical Property.

Radiological measurement has two main methods for obtaining the level of the moisture content. First method is Neutron Method where the interaction of neutrons mainly with hydrogen nuclei provides a direct measurement of water content by volume (Wittman, Zhang, Zhao, Lehmann and Vontobel, 2008). Second Method is Gamma Scattering Method. The interaction of gamma rays and orbital electrons happens in three ways. Firstly, the photoelectric effect in which the whole of the energy of gamma ray is absorbed occurs at low energies. Second is the compton effect, which is the scattering of gamma rays by electrons at medium energies, and finally the creation of positron-electron pairs, becomes important at high energies. Measuring the weakening of gamma radiation enables to determine the density of material (Vijayakumar, Rajasekaran and Ramamurhy, 2002).

Three Electrical Measurements that are commonly used are electrical resistance measurement, LTCC Sensor and Time Domain Reflectometry. Electrical resistance is based on the fact that each material has electrical resistance capabilities and water content has a direct effect on the electrical resistance of material. More water means less resistance. Needle-shaped electrodes are used for measuring electrical resistance. Two measuring detectors are driven into a building element and electrical resistance as a function of the electrical conductivity is measured. High conductivity and lower electrical resistance is present in wet materials. Results are indicated on the measuring device according to construction materials type, which can be converted into percentages of moisture (Maksivomic, Stojanovic, Radovanovic, Malesev, Radonjanin, Radosavljevic and Smetana, 2012).

Low Temperature Co-Fired Ceramic (LTCC) sensors can be utilized by burying them in the plaster during construction, and in already constructed walls, can be imbedded through small cuts. An antenna coil that tracks changes in the sensor resonant frequency is used to measure variation of water content in tested specimens wirelessly. This sensor has two dielectric layers. There is a screen-printed LC structure on the first layer and the second layer has a window over capacitor’s electrodes. The sensor is exposed to moisture through this window causing change of its dielectric constant and total capacitance and as a result the resonant frequency of the LC sensor. Between 0% and 70% detection range in width of water absorption with high linearity and fast response is exhibited by the sensor (Li et al., 2000).

The Principle of Time Domain Reflectometry (TDR) used for moisture measurement is to transmit an electromagnetic signal down parallel electrodes of a waveguide inserted into the dielectric material under investigation. The time taken for the signal to return after reflecting off the end of the waveguide is measured. This gives a direct measure of the permittivity of the surrounding material along the length of the waveguide (Phillipson, Baker, Davies, Galbraith and McLean, 2008).

Moisture content can be detected by Mechanical Property Measurements. One of the methods is thermal method. This involves supplying a probe that determine the thermal conductivity in the material with a known heat input, and measuring the rise in temperature at a preset distance from the heat source with the use of thermocouples or thermistors. Being independent of the salt content of the porous body is one benefit of measurements using thermal conductivity. However, thermal conductivity is dependent on environmental temperature, which can be compensated for, and also upon material density which necessitates several calibration curves for different densities of the measured material. One disadvantage of the thermal conductivity method is that it presents difficulty in obtaining calibration curves that could be reproduced, and for every material density, only one calibration curve is valid. IR Thermography can be used to monitor moisture content of the buildings by scanning the entire surface of building and comparing with the image of interested area. Comparison between the temperature of the dry and moist surfaces enables identification of the areas affected by dampness (Griinzato, Bison and Marinetti, 2002). One of the thermal techniques is a ‘pad’ Sensor (Davies and Ye, 2009). It is a non-destructive technique for the measurement of moisture content within a material. It uses thermal diffusion to provide heat into a surface wherein the resulting temperature increase is detected at a distance from the injection point. Both the heater and temperature sensor are attached at the surface of a thermal insulation material block (the ‘pad’). The device offers the benefits of the traditional dual probe, but with the important advantage of not requiring any invasive holes to be drilled into the material (Davies and Ye, 2009).

Vapour pressure technique enables measurement of the equilibrium relative humidity of air in contact with a porous body. It enables the determination of the water tension of the porous body, which can be correlated with the moisture content. Converting water tensions to moisture content through individual calibration for each porous material type is an unreliable procedure. Precise measurements of the equilibrium relative humidity between the porous body and the surrounding air are required for vapour pressure method (McCullough, Kwon and Shim, 2003).

2.3 Building Pathology

Pathology of the building is a method of investigation to find the source of a defect or damage occurred. Investigation of damage within a building started when there are symptoms of a defect, which indirectly interfere with the function and activities in it. For example, a building that uses compound materials such as concrete and mortar exposed to give a response when there is high-water content in the long run. There are also some compound materials, which less flexible by products to react with other composite materials. Byproducts are usually short-lived and will disappear slowly in the long term as a result of temperature and environment changes around (William, 1995). Flat roof that built from a concrete mixture are exposed to weather and the environment continuously. Environment and weather such as acid rain and extreme heat caused a reaction occurs to the composite materials. This reaction causing expansion and contraction, which in turn contributed to the cracking on the surface of the concrete roof structure. This inevitably will speed up the process of water seepage through the concrete roof of a building. Many construction researchers reported the problem to the absence of as-built drawings as an issue also to the problem of accuracy of information in carrying out the investigation on building components. Many of the buildings have drawings for construction; however, it is lacking in term of accuracy and does not reflect the latest changes to the buildings (Dias and Jayanandana, 2003). In concrete structures, information such as the position of steel-reinforced concrete, grade and size of the thickness of the roof that¬ were built to be re-tested before any decision on the structure can be made.

This includes the use of destructive test methods that indirectly damaging other building components in order to obtain accurate information. Therefore, it is improper if a method more suitable and cost-effective as using non-destructive testing implemented to address this issue.

David and Dane (2005) stated the results of their study on the defects in the roof of the building especially water absorption is due to the other factors of environmental problems. The study uses actual data for defect roofs of buildings that show 75% of the problem stems from a layer of membrane that does not function properly as well as the workmanship and the design of the roof itself. The process for determining the actual cause of roof components of disability is rather difficult due to it requires accurate information in detail. Detailed analysis of building materials such as concrete composition, method of installation and implementation of maintenance should be refined to determine the cause of defects occurred. The analysis process will be easier if there is equipment that could help in providing the information needed for these purposes. Problems of humidity absorption at concrete roof can occur in several ways such as condensation and liquid seepage process. This occurs due to temperature and pressure differences at the two surfaces in contact. In many circumstances this process happens both at the same time where there are changes in temperature and environment (De Freitas et al, 1996)

A layer of membrane installed on the roof of flat concrete exposed to problems of durability in the long term. Durability of membrane layer will be affected by environmental conditions such as excessive heat, biological agents, radiation Ultra Violet (UV) and chemical reactions as a result of illness rapport he had built-up material for roof construction (CIB and early 2007). Therefore, the choice of which meet the needs and membrane specification as well as regular monitoring is needed to ensure that it works as expected.

3.0 Methodology

Currently, numerous flat roofs getting damaged during high amount of rainfalls in Malaysia due to faults of waterproof membrane, which lead to high repair costs and potential consequential damage with the building. The novel microwave technology will allow non-destructive measurement to determine damages to concrete roof structure caused by membrane failure in real time measurement. Sensor also will enable to identify the location of the reinforcement in the roof structure.

The sensor has been designed to enable numerous of measurements in real time without concern about displacement. Sensor has been equipped in essential parameters that will enable to control sensor angle, temperature and distance between object and sensor structure. The sensor design as presented in Figure 1.

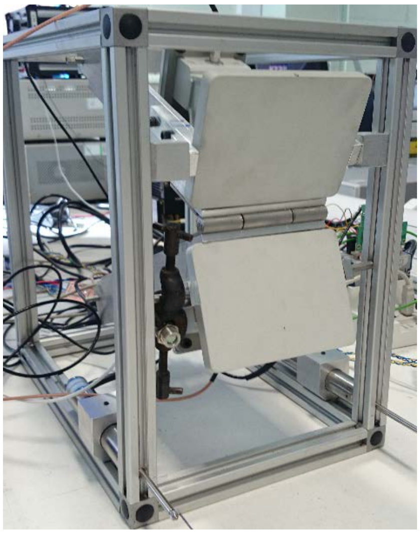

Figure 1: Sensor Design.

It was critical to design and build flat roof structures which would enable multiple test to be undertaken in laboratory environment. One structure has been built without reinforcement (Figure 2) and second structure has been built with reinforcement (Figure 3).

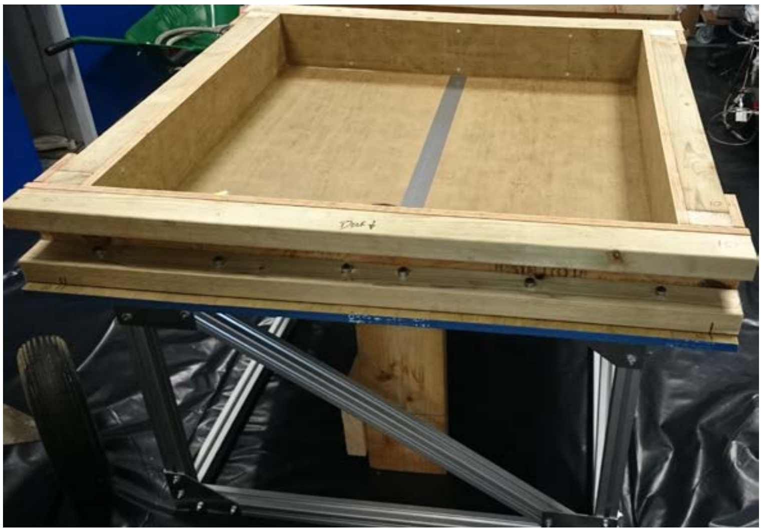

Figure 2: Roof structure frame without reinforcement.

Roof structure without reinforcement has dimension 100cm x 100cm x 23cm and is created to Malaysian flat roof concrete proportion standards.

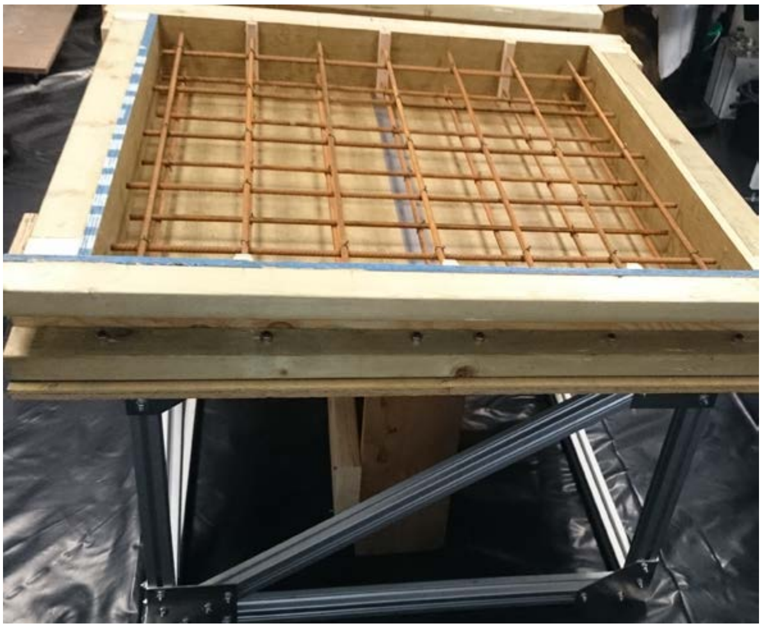

Figure 3: Roof structure frame with reinforcement.

Roof structure with reinforcement has dimension 100cm x 100cm x 23cm and is created to Malaysian flat roof proportion standards. Therefore, it has rebar located at the same distance as suggested in Malaysian roof structure.

Flat roof structure has waterproof membrane between the screed layers. Waterproof membrane rubber sheet has been used to determine if it is possible to detect any faults. Figure 4 presents roof structure with a membrane without any faults,Figure 5 presents roof structure with a membrane with a fault.

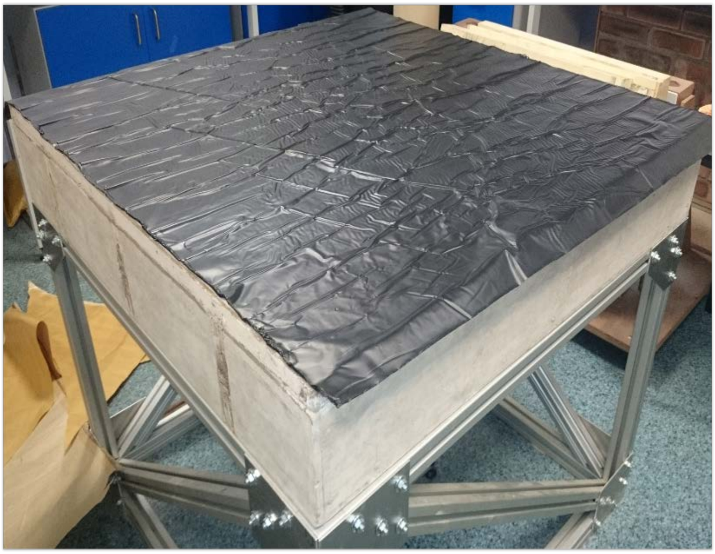

Figure 4: Roof with a membrane layer

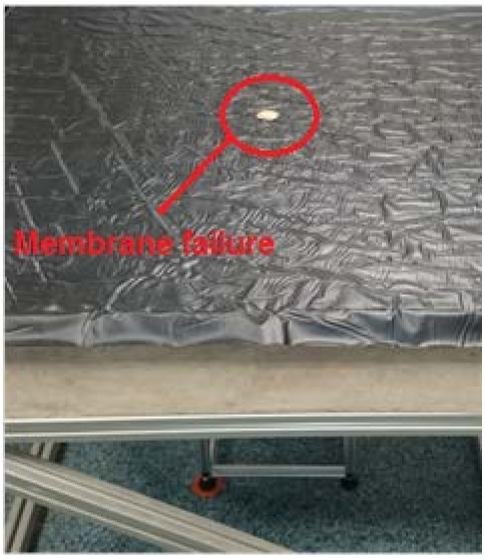

Figure 5: Roof with damaged membrane layer.

Linear traverse has been used to monitor the movements of the horn antenna (Figure 6). Antenna has been mounted 5 mm above the roof surface. Special software created to control linear traverse enable to control movement distance. Each measurement has been taken every one cm.

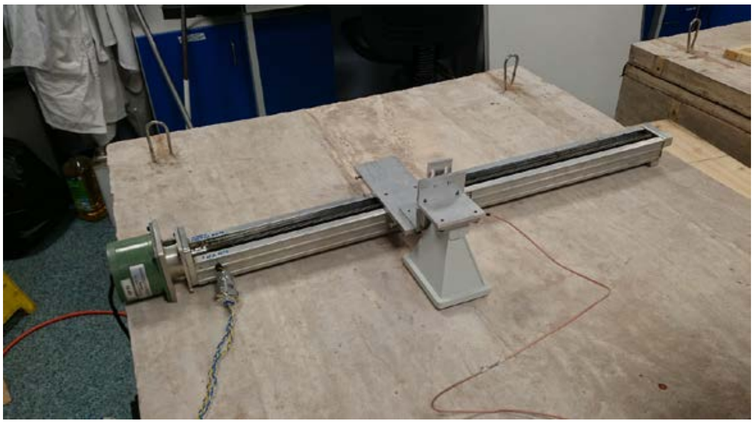

Figure 6: Linear traverse setup.

Software has been developed in LabVIEW program (Figure 7). This program enables to control linear traverse and Vector Network Analyser. It is possible to configure VNA parameters, program will display real time measurement and will record the data.

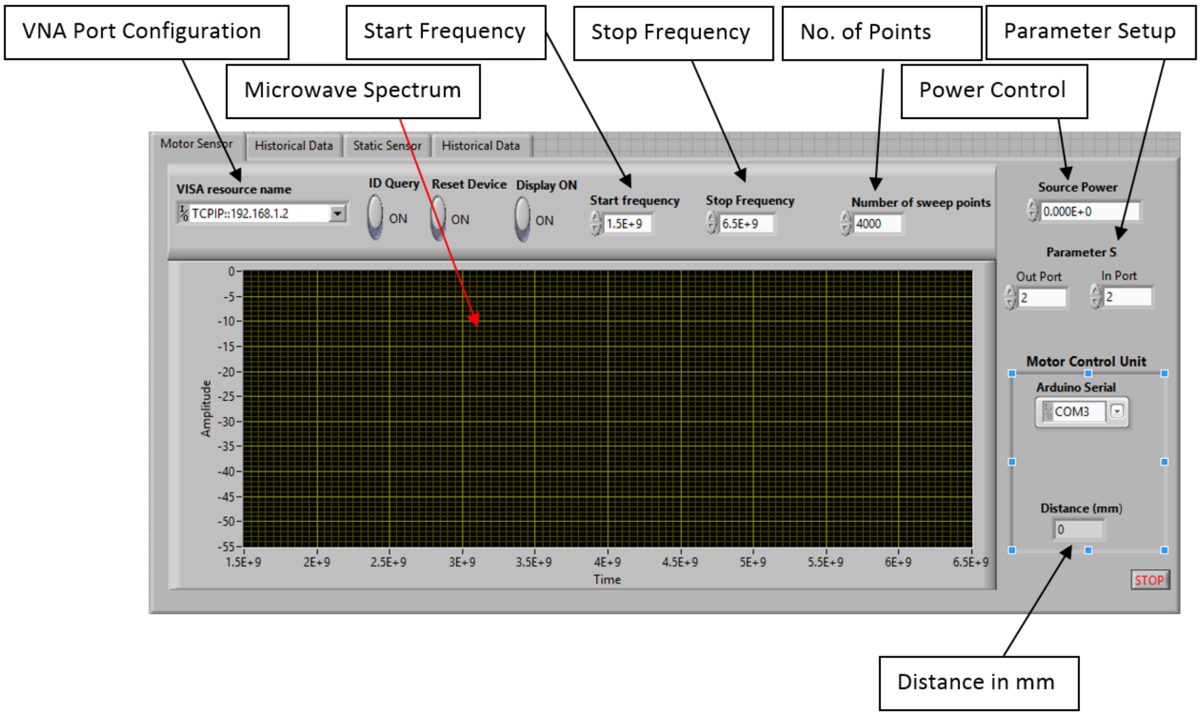

Figure 7: LabVIEW Graphical User Interface.

4.0 Finding and Discussion

Firstly, it was significant to collect the microwave spectrum signature to be able to identify uniqueness of flat roof structure. Measurement has been provided on roof structure without reinforcement, shown in Figure 8. Sensor has been situated 5mm from measured area and data has been collected across 38cm of the roof structure and recorded at every 1 cm of sensor movement. Antenna has been configured to S11 parameter, which allows antenna to transmit microwave signal through concrete and to receive reflection signal from the object which had been under monitoring. Data presented in Figure 8 enables to observe that microwave spectrum does not change for that roof structure at every 1cm of measurement. This confirms that specific spectrum is unique for flat roof structure without reinforcement.

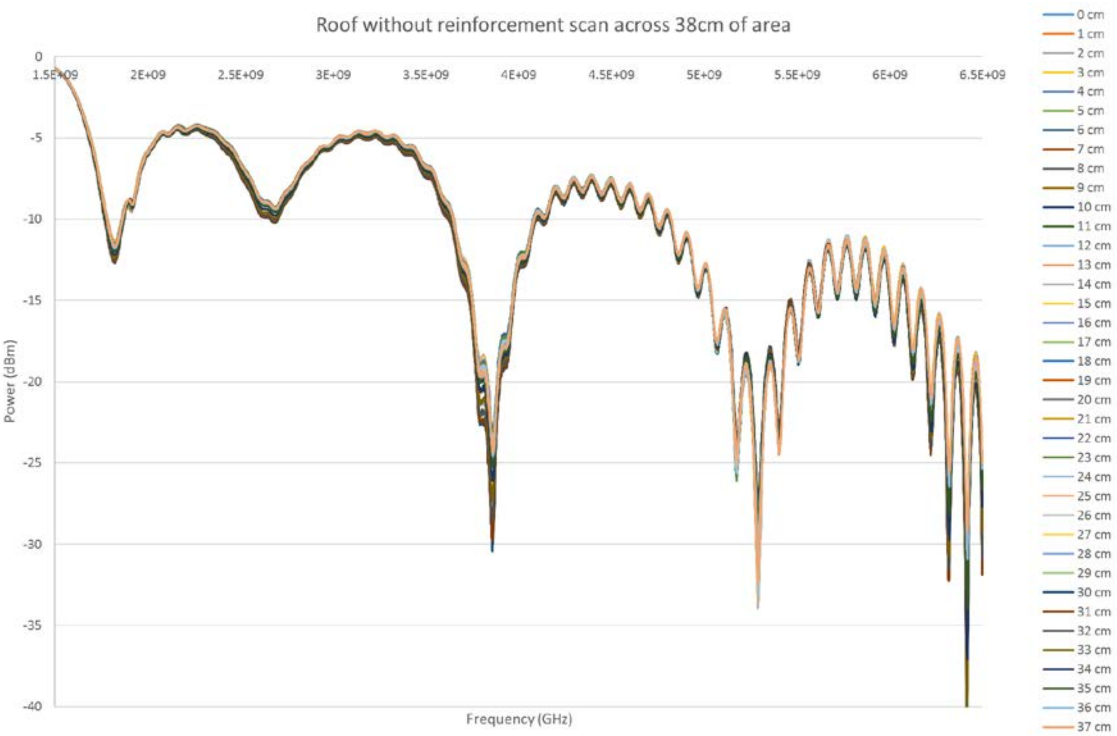

Figure 8: Roof scan without reinforcement.

Second experiment has been provided on roof structure with reinforcement and data has been collected across 38cm of roof area. Every 1cm movement has been recorded and analysed. Figure 9 presents results from the sensor. In this experiment antenna has been setup in the same configuration S11 and it was located at the same distance from the object. Unique concrete signature stays the same at the location between the rebar until sensor will change its location closer to the reinforcement bars, then the unique signal is changing due to dielectric properties of steel rebar which enables to identify that material inside of the concrete structure. Microwave spectrum identifying rebar by shifting the signal amplitude due to the fact that steel reflect high amount of the microwave energy. Developed algorithm allows to provide the distance between the sensor and the reinforcement.

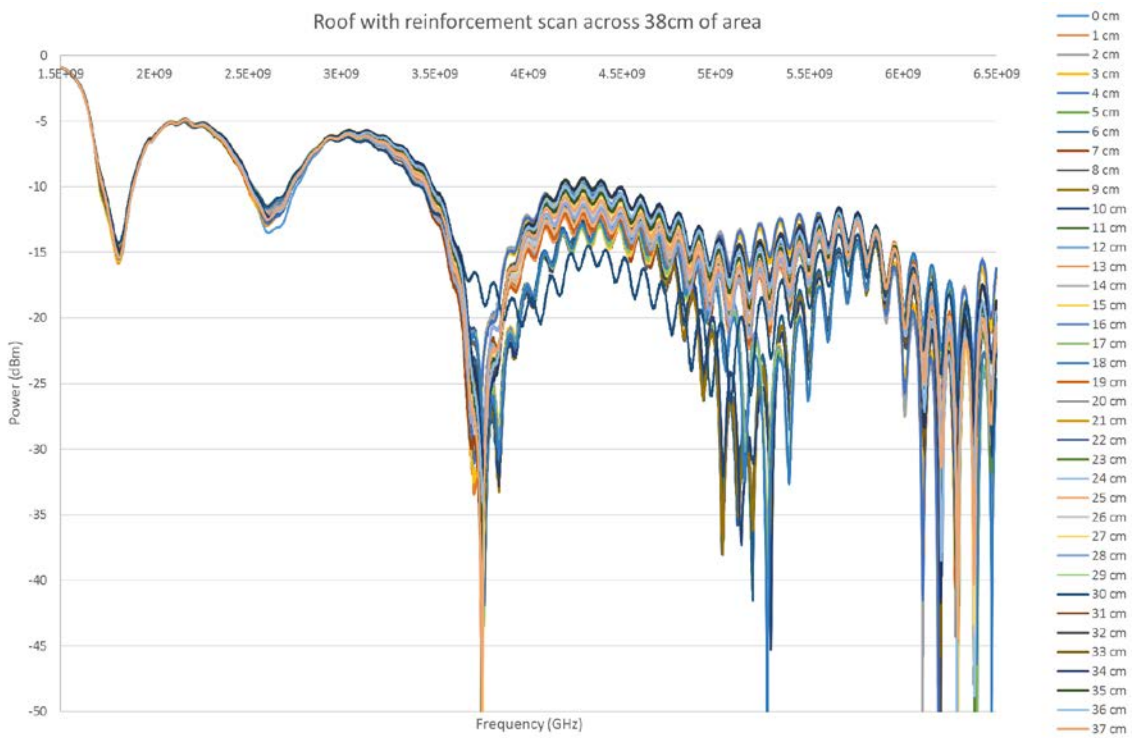

Figure 9: Roof scan with reinforcement.

Comparison between two roof structures has been presented on Figure 10. Sensor has been placed at specific location (7cm) from the beginning of the measurement where the rebar is in the middle of the sensor and it has been compared with the measurement at the same location from the roof without the reinforcement. Unique microwave spectrum for concrete roof is shifted left and also there is amplitude shift due to the visibility of steel rebar which reflects different amount of the microwave energy than concrete roof itself.

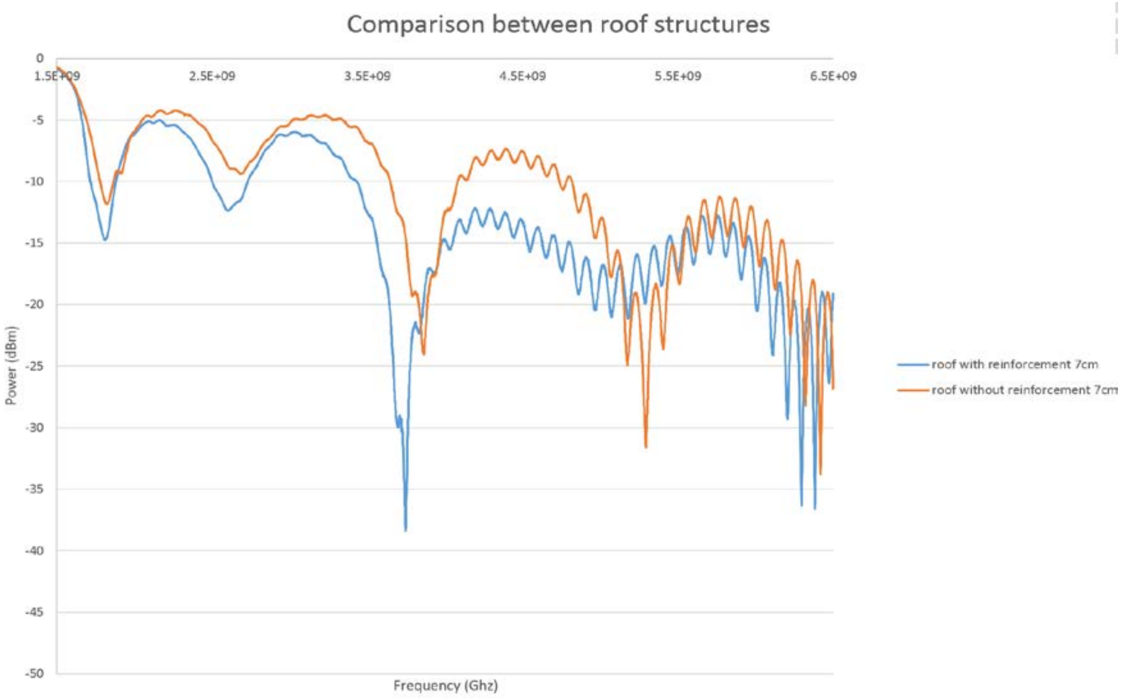

Figure 10: Comparison between roof structures 7cm distance.

It was essential to repeat experiment at different location where another rebar is placed (26cm) to make sure that the results that been achieved at first location will be repeatable at any place where rebar is located and to make sure that the microwave spectrum will act in the same manner when it will locate a rebar. Figure 11 proves that the microwave spectrum acts in the same manner by shifting signal frequency and its amplitude at 26 cm of the measurement due to the rebar location.

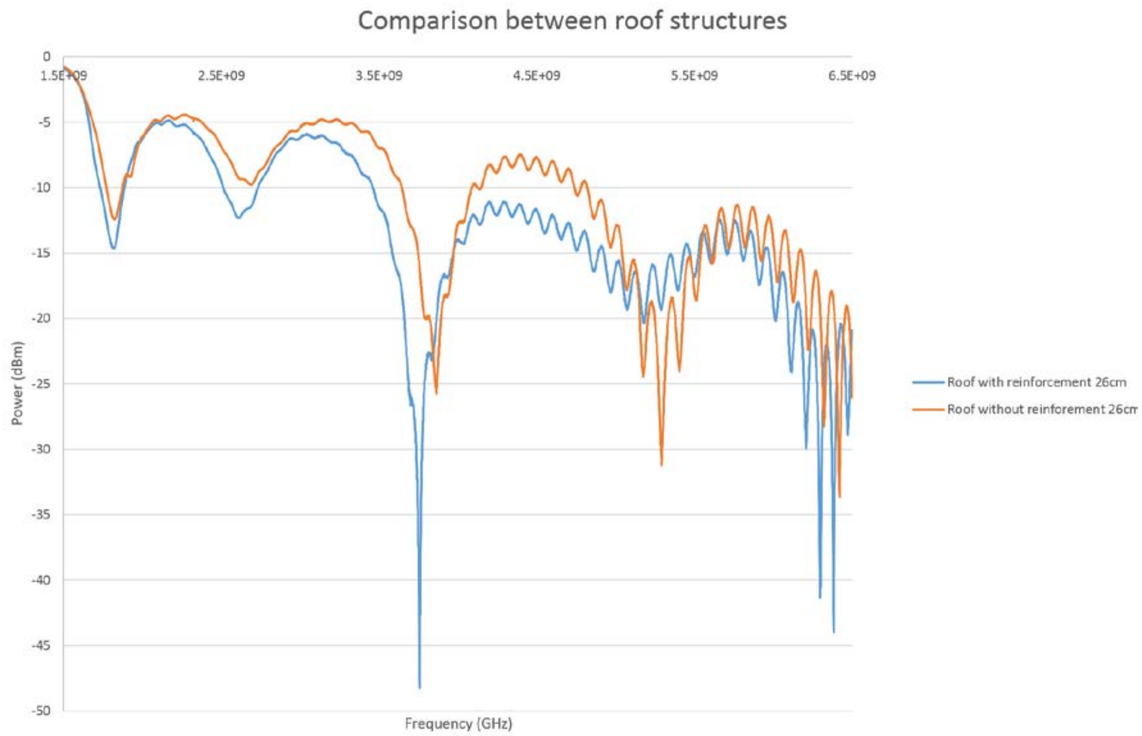

Figure 11: Comparison between roof structures 26cm distance.

Another experiment that has been undertaken identifying the membrane failure of the flat roof structure is with and without the reinforcement. Sensor has been placed on the top of the flat roof structure just above the membrane layer. Data has been collected at every one centimetre and results are presented on Figure 12. There are four measurement presented on the graph. Firstly, microwave spectrum of concrete roof without reinforcement and membrane, concrete roof without reinforcement with a membrane, concrete roof with reinforcement without the membrane and concrete roof with the reinforcement and membrane. Microwave spectrum is different for all examples due to the dielectric properties of membrane and steel rebar. Those materials absorb and reflect different amount of the energy which allows microwaves to identify changes that appearing to the signal. Microwave Signal can be analysed by developed software to recognise current status of the membrane.

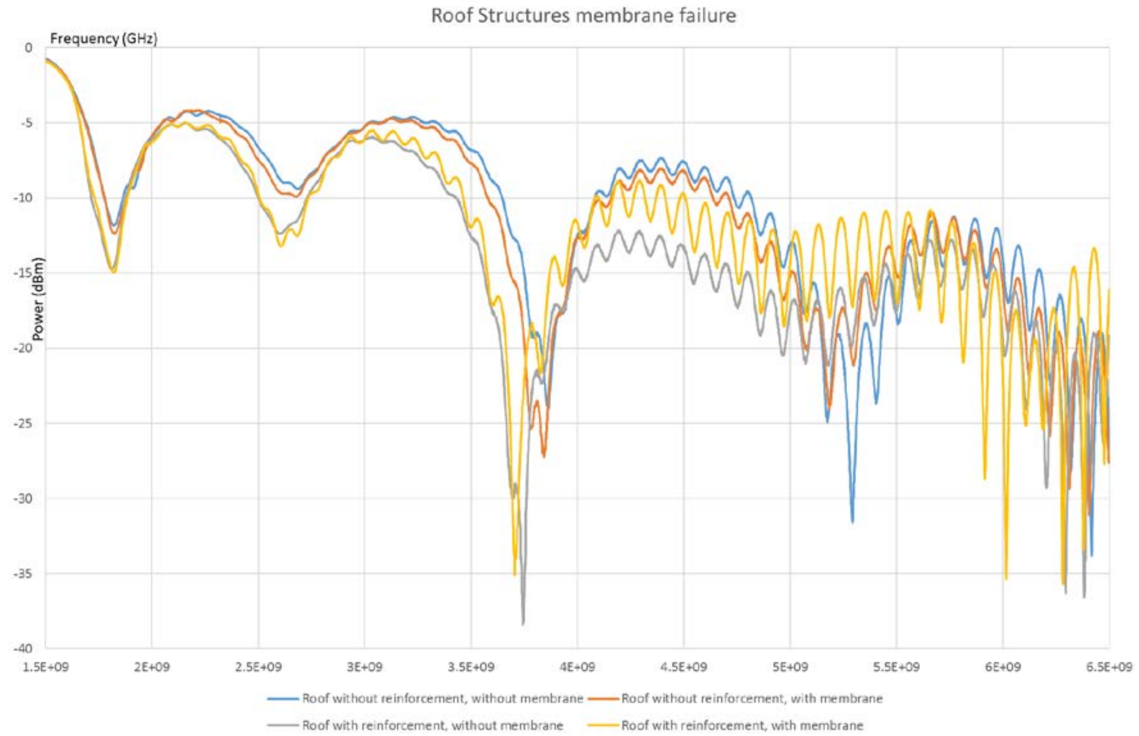

Figure 12: Membrane comparison.

Final experiment has been undertaken to monitor drying off process of the flat roof without reinforcement. Antenna has been placed on the top of the screed layer. Data has been recorded every 2 hours. Results are presented on the Figure 13. Microwave spectrum amplitude has been shifted, while flat roof layer has been drying off. Dielectric properties of water enables water to absorb microwave signal well, which cause amplitude shift when the water is evaporating from the roof structure.

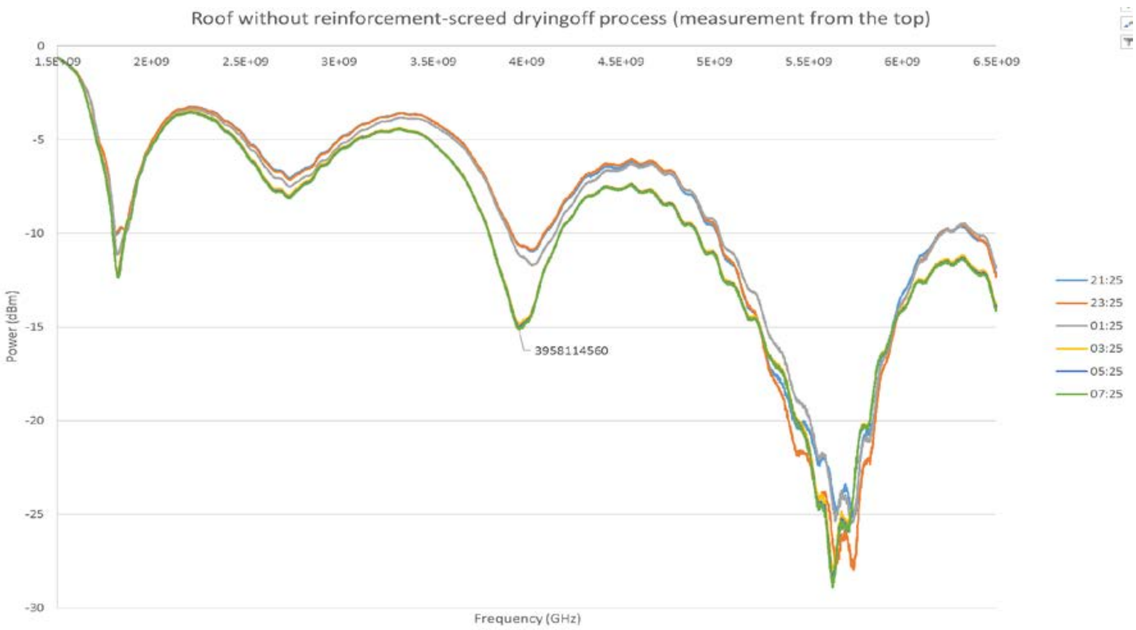

Figure 13: Roof without reinforcement-screed drying off process.

It was essential to select one of the peaks to analyse water evaporation process. Figure 14 presents one peak at every data collection (2hours period). Flat roof has been drying off in continuous manner which confirms that microwave technology can be used to identifying moisture content of roof structure by analysing properties of the concrete roof and water.

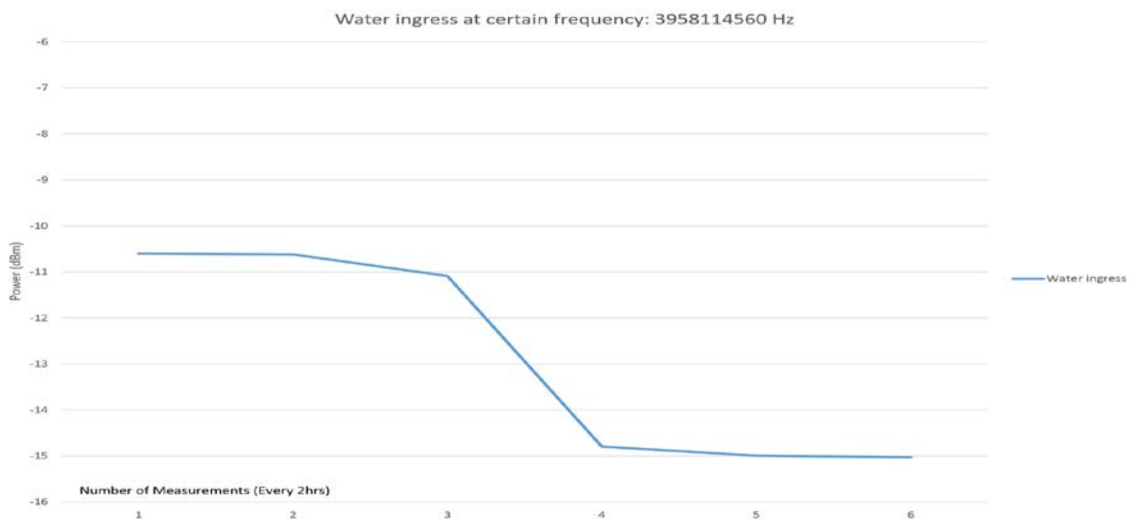

Figure 14: Water ingress at 3958114560 Hz frequency.

Conclusion

The purpose of this paper was to investigate the potential of microwave technology as a tool to monitor and investigate leakage of concrete flatroof due to failure of membrane layer. Experiments were performed by analyzing properties of concrete flat roof structures built with reinforcements and membrane and flat roof structures with reinforcement and without membrane respectively. The experiments performed indicated that the microwave signal was able to identify properties of the concrete flat roof by recording different microwave spectrum due to the dielectric properties of membrane, steel rebar and water in the concrete roof structure. This has study determined that microwave technology can be used to an effective non-destructive method of determining leakage problems in concrete flat roof in real time before the defects become critical.

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References

Burkinshaw, R. and Parrett, M. (2002).Diagnosing Damp in Buildings, RICS, London, September.

Buyukozturk, O., Yu, T. Y. and Ortega, J. A. (2006). A methodology for determining complex permittivity of construction materials based on transmission-only coherent, wide bandwidth free-space measurements.*Cem. Concr.Compos.,28*(4), 349-359

Davies, M., and Ye, Z. (2009). A "pad" sensor for measuring the moisture content of building materials*, Building Serv. Eng. Res. Technol., 30*(3), 263-270

Fear, E. C., Li, X., Hagness, S. C. and Stuchly, M. A. (2002). Confocal microwave imaging for breast cancer detection: Localization of tumors in three dimensions. *IEEE Trans. Biomed. Eng., 49*(8), 812-822

Grinzato, E., Bison, P. G. and Marinetti, S. (2002). Monitoring of ancient buildings by the thermal method.*J. Culi. Herit., 3*(1), 21-29

Jadin, M. S., &Taib, S. (2012). Recent progress in diagnosing the reliability of electrical equipment by using infrared thermography.*Infrared Physics &Technology, 55*(4), 236-245

Korostynska, O., Mason, A. and Al-Shamma'a, A. (2014). Microwave sensors for the non-invasive monitoring of industrial and medical applications. *Sens. Rev., 34*(2), 182-191

Li, Z., Yao, W., Lee, S., Lee, C., & Yang, Z. (2000).Application of Infrared Thermography Technique in Building Finish Evaluation.*Journal of Nondestructive Evaluation, 19*(1), 11-19

Maksimovic, M., Stojanovic, G. M., Radovanovic, M., Malesev, M., Radonjanin, V., Radosavljevic, G. and Smetana, W. (2012). Application of LTCC sensor for measuring moisture content of building materials.*Constr. Build. Mater., 26*(1), 327-333

McCullough, E. A., Kwon, M. and Shim, H. (2003). A comparison of standard methods for measuring water vapour permeability of fabrics. *Meas. Sci. Technol.,14*(8), 1402-1408

Mukhopadhyay, S. C. and Yunus, M. A. (2011). Novel Planar Electromagnetic Sensors for Detection of Nitrates and Contamination. *IEEE Sensors Journal, 11*(6), 1440-1447

Talib, R. (2008). The Problem of Flat Roofing System in Tropical Climate: Case Study- A Highrise Building in Kuala Lumpur, Malaysia, CIB W070 Conference in Facilities Management, Heriot Watt University, Edinburgh

Tsang, A.H.C. (1995). Condition-Based Maintenance: Tools and Decision Making.*Journal of Quality in Maintenance Engineering, 1*(3), 3-17.

Svatos, J., Vedral, J. and Fexa, P. (2011), Metal detector excited by frequency swept signals.*Metrol. Meas. Syst., 18*(1), 57-68.

Phillipson, M., Baker, P, Davies, M., Ye, Z., Galbraith, G. and McLean, R. (2008). Suitability of time domain reflectometry for monitoring moisture in building materials. *Build. Serv. Eng. Res. Technol., 29*(3), 261-272

Vijayakumar, R., Rajasekaran, L. and Ramamurhy, N. (2002). Determinig the Moisture content in Limestoce Concrete by Gamma Scattering Method: A Feasibility Study. Presented at NDE2002, to predict.assure. improve. National Seminar of ISNT, the Indian Society for Non Destructive Testing Hotel Taj Connemara and Raja Muthiah Hall, Chennai, 05 – 07 December, 2002 no. 1, pp. 1-10, 2002.

Vijayakumar, K., Wylie, S. R., Cullen, J. D., Wright, C. C. and Al'Shamma'a, A. I. (2009). Non-invasive rail track detection system using microwave sensor. *J. Phys. Conf. Ser.,178*(1) 012033

Wittmann, F., Zhang, P., Zhao, T., Lehmann, E. and Vontobel, P. (2008). Neutron Radiography, A Powerful Method for Investigating Water Penetration into Concrete. *Adv. Civ. Eng. Mater.,*The 50-year Teaching and Research Anniversary of Prof. Sun Wei, 15 October 2008, Nanjing, China, 61-70