Diagnostics of Flat Roofs with Flexible Sheets for Waterproofing

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Abstract. This paper deals with diagnostics of flat roofs with flexible sheets for waterproofing (membrane). The diagnostics is focused on defects and water tightness of membrane. The roof is one of the building's most important building envelope. In case of defect, the other layers of the roof, including the structure frame, are degraded. The introduction gives an overview of individual methods and their division. The following part describes advantages and drawbacks of the individual methods. The next part is focused on the following type of test - High Voltage Membrane Testing. The test is described in detail, including the Conductive detection membrane, which was developed specifically for this method. This test, in combination with other methods, seems optimal, but it is most reliable to prevent possible defects by following technological procedures.

1. Introduction

This paper deals with diagnostics of flat roofs with flexible sheets for waterproofing (membrane) with a focus on tightness of waterproofing. The issue is dealt with for example [1], electrical methods [2] and thermographic methods [3]. In the case of damage to the membrane, other layers of the roof could be severely degraded. This mainly concerns a possible degradation of the thermal-technical properties of the thermal insulation layer. The degradation is due to increased humidity.

Moisture on the inner surface may not always be a sign of damage of the waterproofing layer. Moisture on the inner surface may be caused by condensation. However, the amount of water (moisture) is higher in the case of leakage than in the case of condensation.

The diagnostics of flat roofs with layer waterproofing can be divided into a basic and a detailed research. The basic research uses visual checking and commonly available tools. The detailed research uses more sophisticate measuring tools and instruments. This paper focuses on these devices and methods.

As a part of the basic survey, the compliance with the application technology and the tightness of the membrane are checked. These are mainly laying membrane considering alternation of individual flexibile sheets, keeping the width of transverse and longitudinal overlaps, making joints (welding, gluing, roll-over) [4], mutual connection of layers for bitumen sheets and making details [5]. Checking the tightness of the membrane is aimed at checking the area and joints. In the case of an area inspection except of the joints, a visual control is applied to ensure that the membrane has not been damaged. In the case of polymer membrane with a signal layer, this control is easier. Polymer membranes which are composed of two layers have a bottom layer dark and a top light colour (yellow, orange). Joint testing needle is used to control the joints for the polymer membrane film. Pulling this Joint testing needle on the joint surface mechanically verifies the quality of the joint. The Joint testing needle should be slightly pushed on. As for bitumen sheets, specific instrument, so called an insulation spatula is used to check the joints. The procedure is the same as for polymer membrane films. Only for bitumen sheets there is the limitation for use at temperatures between 5 (10) - 20 (25) °C.

2. Material and methods of testing for detailed research

As mentioned above, more sophisticated instruments are used for detailed research. These devices are also used when the membrane is covered with another layer, for example, a roof with a vegetation layer.

Devices for diagnosis of flat roof defects can be divided according to destructive or non-destructive methods. Another division is based on whether the diagnosis directly identifies the defect or not - these are direct and indirect methods.

Direct method - the instruments which are used, can directly identify a mechanical defect in the membrane. The identification of this damage is either local (mostly in joints) or in the area except for joints. The manifestations of defect can then be recorded objectively (mostly air pressure measured) and the test is repeatable or indicative (usually we observe visually and, in this case, it is not possible to repeat the test). An overview of the methods, see the table No. 1., has been prepared on the basis of [6, 7].

Table 1. The quantity of non-combustible residues [6, 7].

Type of method	Testing method	Membrane damage	Tested area	Qualitative aspect
Direct	Press box	non-destructive	local	objective
	Press of double joints	destructive	local	objective
	Low voltage horizontal scanning platform	non-destructive	local	indicative
	Mapping vector of electric field with low voltage (vector mapping)	non-destructive	local	indicative
	Low voltage scanning of membrane surface	non-destructive	local	indicative
	Low voltage scanning of membrane surface	non-destructive	local	indicative
	Smoke method	destructive	whole area	objective
	Tracer-gas-box method	destructive	whole area	objective
	Overflow method	destructive	whole area	objective
Indirect	Impedant defectoscopy	non-destructive	local	objective
	Thermographic Defectoscopy	non-destructive	local	objective

2.1 Direct methods

2.1.1 *Pressure box*

The test is based on the application of a transparent bell on the membrane surface, which is covered with a solution of water and soap or detergent. Vacuum of about 20 kPa is created under the bell. In case of a damage of insulation there is leak and bubbles appear on the surface. The disadvantage of the method is time and work consuming procedure. Also, there is the temperature limitation of use od this method. Due to the solution, the method cannot be carried out at temperatures around 0°C and bellow. The method is mainly used for polymer membranes.

2.1.2 *Double joints press*
This test can be performed for double and folded joints. These joints are mainly made with polymeric films. The test is based on creating overpressure inside the joint. The pressure must not drop by 10% during the first 10 minutes. See No. [1].

2.1.3 Low Voltage Horizontal Membrane Scanning Platform.
When using low-voltage electrical potential scanning, the membrane must be moistened (water-covered). Moisture gets under the membrane at the point of breach. For methods using low voltage electrical potential, a controlled covering of water on the surface forms the conductive path horizontally across the membrane to any membrane breach. At a breach location, an electrical path to the deck is formed through the water leaking to the deck below. A sensitive receiver detects the leakage current and alerts the operator. For further details, see No. [2]. Membrane Scanning Platform is based on creating voltage potential between platform (membrane) and roof deck and detecting any leakage current passing through the membrane. After the tested membrane is wetted, a voltage with respect to area is generated, followed by locating the areas where electrical current flows from the platform through membrane breaches to the deck. The platform has two sets of metal sweeps making continuous electrical contact with the membrane surface. The outer sweep forms a continuous perimeter around the platform with the inner sweep contained within the perimeter of the outer sweep.

2.1.4 Low Voltage Membrane Electric Field Vector Mapping
The principle is as described in [2]: "The electric field vector mapping technique uses an electric potential gradient across the membrane surface, along with a sensitive voltmeter and probes to locate membrane leaks. Conductor cable loop is installed around the perimeter of the tested area. A signal generator is connected to the loop cable and the building ground. The area within the loop is sprayed with water to make a continuous conductive surface in the tested area. Most roofing/waterproofing membranes are nonconductive. Thus, the electrical signal from the perimeter cable loop, searching for an electrical path over the wet area of the roof to breach area, completes the circuit to the substrate. The resulting current from the point of breach to the perimeter cable sets up a voltage gradient in the water within the perimeter."

2.1.5 Low Voltage Vertical Membrane Surface Scanning
The principle is as described in [2]: "The moistened sensor, which is connected with a cable to the voltage source in the receiver, is pressed onto the tested surface. This pushes the water onto the membrane surface. A leakage current then flows over the moistened sensor. Consequently, the receiver registers a deflection on the signal level meter accompanied by an audible alert. The vertical surface leak locator is used for testing the membrane integrity of corners, parapet walls, and seams."

2.1.6 High Voltage Membrane Testing (spark test)
The principle is as described in [2]: "High voltage testing is performed on a dry horizontal or vertical surface using a limited current at voltage within 10 - 40 kV, depending on the membrane thickness. One conductor from the portable current generator is grounded to the roof deck with a sufficient conductive substrate. Another conductor is attached to a special electrode brush made of conductive metal bristles. The brush electrode is then swept over the surface of the roof membrane. An electric arc jumps from the electrode when any damage in the membrane, completing a circuit between the brush and the roof deck. Where there are no damages, the membrane acts as an insulator and prevents the flow of current to the deck. This method may be used to test waterproofing up to the thickness 26 mm. For the effective test, there must be conductive layer under membrane."

2.1.7 Smoke method
Leakiness of the membrane is tested by driving of thick or coloured smoke under the membrane. This test is suitable for one - layer systems. Construction frame must be airtight, or must consist of vapour-

barrier layer. Observed smoke reveals the point of breach. The pipes are part of the roof system; thus, it is necessary to damage membrane and consequently to locally repair it. The method is quick, however, there is the limitation of use as for the size of defect. Based on our experience, the revealed area must exceed the size of 10 mm. For more details, see [1].

2.1.8 Tracer-gas-box method
The test is similar to Smoke method. Leak tightness of the membrane is proved by detecting gas on the nitrogen and hydrogen basis. Hydrogen is recommended to check the leakiness. It has the highest molecular speed and its viscosity is lower than of other gases. However, it is necessary to use its nitrogen form.

2.1.9 Overflow method
In this test the membrane surface is covered by continuous water layer and drop of water level is observed. The test is very risky. It is necessary to consider using the test while designing new construction. It is not suitable for the finished roofs, as there is the risk of damaging the frame construction in case of leaking under the membrane and damaging the waste water pipes. The test is time - consuming. Minimum length of the test is 48 h. For more details, see No. [1].

2.2 Indirect methods - Humidity-detection method

2.2.2 Impedant defectoscopy
For this method special electronic resistance sensor is used. The principle of electric impedance enables the signal to penetrate the depth up to 100 mm. The signal detects the moisture even in the base layers under the membrane. There are some weather conditions limitations for this method. The temperature must not decrease bellow +4°C, and there must be no rain or increased air humidity approx. 12hours before starting the test. It is not possible to use this method for testing hydro insulation that include conductive element. (e.g. bitumen sheet with Aluminium foil), and covered with another layer (a concrete paver, gravel, substrate for green roofs).

2.2.3 Thermografical defectoscopy
The method is based on temperature gradient of dry and wet area. The dry area is cooled down and heated slower than wet area. At the sunset or shortly after that the dry areas are cooled faster. The wet area, thus have higher temperature. For the determined experiment conditions see No. [3]. They are the minimum inside–outside temperature difference, minimum daytime–night-time temperature swings, maximum wind speed, roof conditions, and precipitation limitations within 24 hours leading up to the scan. Evaluation of the results of infra-red data requires a large experience.

3. Results
The analysis of the methods results in the conclusion that there is no universal test for different roof constructions.

If checking the roof already leaking, it is possible to assume moisture in the roof construction. In this case, the combination of impedant defectoscopy along with some of the electric methods seems optimal.

The method is necessary to be considered already when designing the roof construction. There are two solutions: non-conductive construction, b - conductive construction.

The new non-conductive construction is possible to check only after exposure to water stress. Consequently, the roof acts like the leaked roof. As a result, it is possible to use the two methods mentioned above (the combination of impedant defectoscopy along with some of the electric methods). In short, only the wet breach is found.

The new conductive construction is tested without exposing to water stress, as the water may cause large damage when leaking the construction. Conductive construction may be tested by some of the electric methods. There is the advantage of higher accuracy and possibility of detecting a potential leaking point already before leaking. In short, the dry hole is detected, which may have appeared just before testing. Conductive constructions, however, cannot be tested by impedant defectoscopy.

Another problem may have reconstructed roofs with polymer membrane without thermal insulation. New polymer membrane is necessary to separate from the current membranes. The occurred condensation between the new and old membrane during the year influences the results of impedance defectoscopy in negative way. The conductive layer under membrane thus must perform separating function. As a result, conductive layer has been developed performing the terms mentioned above. Se the picture No. 1.

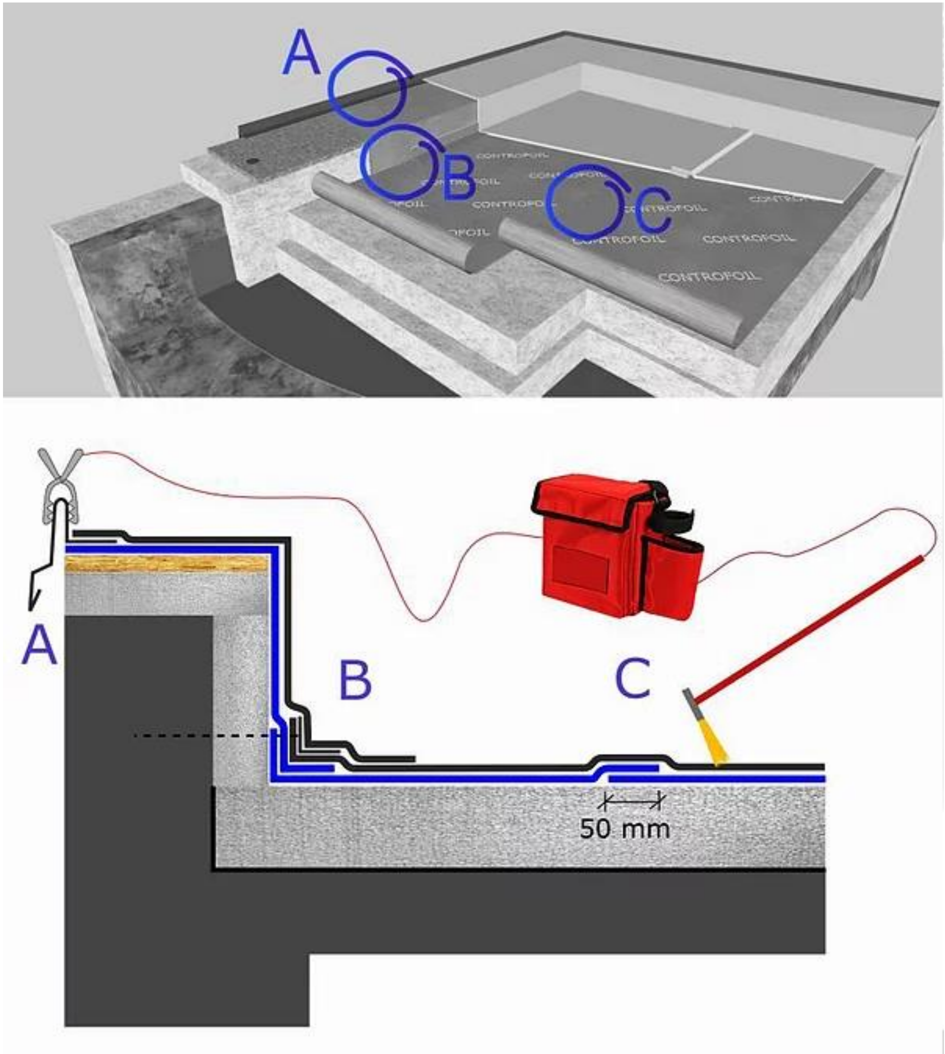

Figure 1. Position of conductive membrane under waterproofing [8].

4. Discussion

On the basis of the research the conductive detection membrane with separating function has been developed. Conductive layer is multilayer reinforced with perforated aluminium foil.

The upper layer consists of the blue coating and perforated aluminium foil. Due to perforation, S_d = 0,65 m. The temperature conditions for the use of conductive foil are determined within -30/+ 80°C.

The application of the conductive detection membrane is as follows. Conductive detection membrane is placed on the thermal insulation material directly under waterproof membrane (SBS bitumen, PVC-P membrane). By overlapping at least 50 mm creates a full-surface conductive layer.

- In case of roofs with the overburden it is not necessary to use geotextile between materials such as: EPS polystyrene and PVC-P membrane, because of incompatibility, as the conductive and separating layer has suitable properties,
- the conductive layer - conductive detection membrane is finished on a horizontal surface of the parapet wall under a PVC coated metal sheet (drip mould) and creates a circumferential anchor point for performing a high voltage testing.

A B

Figure 2. Application of conductive detection foil under waterproofing. A - waterproofing from PVC-P, B - waterproofing from bitumen sheets [9].

5. Conclusion

Electric methods are commonly used for Diagnostic of the waterproofing membranes. Particular attention should be paid to testing single-layer membrane systems [10]. High voltage membrane system testing and other electric methods require the completed electrical circuit before detecting the membrane breach, both above and under the membrane. To accomplish the closed electrical circuit for the roofs with classic layer order, there must be placed the conductive layer or conductive material directly under the tested membrane.

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