

PERFORMANCE OF STRAINED BITUMINOUS WATERPROOFING MEMBRANES UNDER HYDROSTATIC PRESSURE

Performance of bituminous membranes

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Abstract

Basement walls and floors of new constructed buildings are sometimes exposed to water that exerts pressure from the outside due to the existence of high level of ground water. Therefore, oxidized and modified bituminous membranes are applied as external or internal tanking for waterproofing. In such applications; the membranes are strained excessively due to the effects of the mechanical agents that are generated from the construction, and meanwhile they are exposed to water pressure that is originated from the groundwater. The watertightness integrity of these membranes are determined according to the existing test methods which can only measure the resistance of unstrained membranes to water pressure. The aim of this paper is to propose a modified test method which evaluates the performance of the strained bituminous membranes under hydrostatic pressure. In this test method; the effects of the mechanical agents on the membranes which are the deformation of the membranes under compressive pressure and the excessive strain of the membranes over the cracks are simulated in laboratory conditions. Then, the conditioned test samples are exposed to hydrostatic pressure with a modified testing equipment and the watertightness integrity of strained test samples under hydrostatic pressure are evaluated with a moisture/water sensor.

Keywords: Bituminous membranes, hydrostatic pressure, modified bitumen, performance standards, testing, waterproofing

1 Introduction

Bituminous membranes have been used to provide a waterproof barrier in below-grade and roof waterproofing systems for dwellings, industrial and commercial buildings. However, most of the laboratory and field research has only been directed towards gaining knowledge about the agents, and their effects to determine the performance of bituminous membranes used in roofs. Thus, performance requirements in conjunction with test methods have been established for bituminous membranes that are used for roofing. The performance evaluation of the membranes have been determined according to these test methods. However, the same type of membranes are also used in below-grade waterproofing. Obviously, these membranes are exposed to different kinds of agents than the factors defined for roofing, therefore it should be understood that most of the performance test methods can not be used to measure the behaviour of bituminous membranes in-service conditions in below-grade waterproofing.

The bituminous membranes used for below-grade waterproofing systems are oxidized and modified bitumen membranes with polyester reinforcement. Modified bitumen membranes have a widespread usage in below-grade waterproofing systems than oxidized bitumen membranes. However, modified bitumen membranes have been developed to meet the short-coming of the oxidized bitumen to roof climatic factors such as heat, UV radiation, and air; the mechanical performance of reinforcements to meet the requirements for roofing and the final assembly of the roofing system. Although the performance of modified bitumen is better than the oxidized bitumen used for roofing, the performance of both membranes when exposed to below-grade agents are still unknown.

The efficient and effective use of bituminous membranes in below-grade waterproofing systems needs identifying the agents and their effects that should be considered in determining and predicting the performance of the membranes during their service life.

2 The agents and their effects to below-grade waterproofing systems

Basements walls and floors of new constructed buildings are sometimes exposed to water that exerts hydrostatic pressure from the outside due to the existence of high level of groundwater. Water that exerts hydrostatic pressure may damage the structural components such as reinforcing steel corrosion, and make interior spaces inhabitable causing poor indoor air quality. Groundwater may also contain harmful chemicals that may deteriorate below-grade building elements. Thus, groundwater is considered to be the essential agent that naturally occurs externally. Therefore, the fundamental function of a waterproofing system is to prevent the leakage of water into, through or out of the basement floors and walls under hydrostatic pressure without disruption and decay through the whole life of building. Waterproofing is also required to protect the building elements from deterioration when exposed to harmful chemicals that may be found in the groundwater. To perform its function, waterproofing must surround the entire structure with a continuous membrane. To resist the effects of hydrostatic pressure, the membrane, weak in itself, must be loaded by a mass of material at one side and must be protected from damage at the other side. Therefore,

the bituminous membranes are sandwiched between two layers in either an 'external tanking' arrangement where the tanking is protected by a protective layer on the excavation side with the structural wall and floor slab internally or alternatively by an 'internal tanking' arrangement where the structural wall and floor slab retains the excavation and sandwiches the membrane with the protective layer internally. In both cases, care must be taken to avoid thinning, puncturing of the membranes and in formation of joints, laps and corners. Besides, the membrane must have good suitability to substrate such as they must not slide on vertical planes and failure must not occur at corners.

In either external or internal tanking, the membrane remains under compressive pressure between the structural floor slab especially under the columns where the loads are relatively high and the concrete blinding. Thus, the 'plastic' bituminous membranes follows the structural deformation.

During construction; after the pumping out of the groundwater is stopped, the rising water will fill the air pockets and push the air to the membrane. The air under pressure will force the membranes which may not be airtight and as a result, air will penetrate through the membranes providing easy access for the water afterwards.

In external tanking, the concrete blinding; and in internal tanking, the structural floor slab, in contact with the membrane, may be attacked by harmful chemicals that are found in the groundwater such as sulphates. The effect is dramatic, as the pressure will force the aggressive chemicals into the concrete through the whole life of building. Sulphates will react with the hardened cement paste of the concrete to form either ettringite or gypsum which eventually will cause the cracking and spalling of the concrete unless preventive measurements are taken.

In external tanking, the surface of the reinforced concrete structural slab in contact with the membrane may also crack due to the excessive tensile stress met by the steel reinforcement. Shrinkage may occur in concrete building elements when concrete loses its construction moisture. The resultant movement is another cause of cracking on the surface of the structural floor slab and reinforced concrete walls. Due to the cracking, a narrow part of the membrane may strain excessively.

Concisely, the mechanical agents that are generated by the construction strain the bituminous membranes excessively. The mechanical properties of the bituminous membranes may withstand the stresses satisfactorily but on the other hand it is not known whether the strained bituminous membranes will still maintain its watertightness function efficiently or lose its watertightness integrity under hydrostatic pressure.

Therefore, a test program which predicts the performance of bituminous membranes under hydrostatic pressure on the basis of the mechanical agents induced in below-grade systems is determined. These are defined as:

1. In either external or internal tanking; cracks may not occur on the surfaces of the structural walls where the bituminous membranes are applied, therefore, they do not undergo to any strain and only water pressure is exerted on the membranes,
2. In either external or internal tanking; cracks may occur on the surfaces of the structural walls in contact with the bituminous membranes, therefore, the membranes may strain excessively and meanwhile they are exposed to water pressure,
3. Basement floors in contact with bituminous membranes are under compressive pressure especially under the column bases; therefore, they are strained according to the strain of the structural members and meanwhile they are exposed to water pressure,

4. Basement floors in contact with bituminous membranes are strained due to the compressive pressure and cracks, and meanwhile they are exposed to water pressure.

Therefore, the resistances of both strained and unstrained bituminous membranes to the penetration of water under pressure must be determined by a convenient test method.

3 Current test methods for resistance to water pressure

Some of the current standards and general performance documents comprising the test methods for determining the resistance of bituminous membranes to water pressure are given in Table 1.

Table 1: Current standards and documents

Origin	Designation	Date	Title
1. Canada	CSGB 37-GP-56M	1980	Standard for: Membrane, Modified, Bituminous, Prefabricated and Reinforced for Roofing
2. Denmark	UEAtc General Guideline	1983	General Directive for the Assessment of Roof Waterproofing Systems
3. Europe	UEAtc		
	MOAT 27		
4. France	UEAtc General Guideline	1985	Testing of Bitumen and Polymer Bitumen Sheetting and Felts
5. Germany	DIN 52123		
6. Italy	UNI 8202/21	1981	Test Methods for Roof Membranes
7. South Africa	ACTMAP No:1	1991	General Performance Criteria and Requirements for the Assessment of Roof Waterproofing Systems
8. Sweden	UEAtc General Guideline	1995	Polymer Bitumen Sheetting for Fusion Welding for Use in Waterproofing Applications
9. Turkey	TS 11758		
10. USA	ASTM D 5385	1993	Standard Test Method for Hydrostatic Pressure Resistance of Waterproofing Membranes

TS and DIN proposes the same method where unstrained bituminous membranes are exposed to 200 kPa of water pressure for 24 hours. The leakage is observed by naked eye. The UEAT Guidelines follows the same application but differ in water pressure level which is 60 kPa. UNI proposes a similar method where the unstrained bituminous membranes are exposed to 500, 250, 60 and 10 kPa of water pressure for 24, 24, 1 and 1 hours, respectively. The observation method is same as TS and DIN. These test methods are sufficient to measure the resistance of unstrained membranes to water pressure but can not be developed to measure the hydrostatic resistance of strained bituminous membranes. Therefore; these test methods can only provide a guidance for the watertightness quality of bituminous membranes and can be used to compare the hydrostatic resistance of the membranes, but fall short to determine the performance of strained bituminous membranes under hydrostatic pressure.

CSGB, UNI and UEAT Guidelines propose test methods to determine the resistance of water pressure of strained bituminous membranes. The watertightness integrity of the membranes which have been subjected to either puncture or flexibility test are determined using a 50 mm. of water column. CSGB and UNI conducts the test for 16 and 24 hours respectively but UEAT Guidelines does not propose any time

limit. Leakage of water is observed by either naked eye in UNI and UEAT Guidelines or a filter paper which the colored water stains, as proposed in CSGB. These test methods can not be used to determine the hydrostatic resistance of strained membranes as 50 mm. of water column is not adequate to simulate the hydrostatic pressure. Furthermore, the test method can not be developed for higher values of water pressure.

ASTM has also established a test method which measures the hydrostatic resistance of unstrained membranes under controlled laboratory conditions. Unstrained membranes are subjected to water pressure starting from 103 kPa up to 690 kPa by increasing the pressure in 103 kPa steps each hour. Leakage is observed by naked eye. No correlation has been established between the performance of this test method and that in field. But, among the existing test methods, only ASTM test method is considered appropriate to be modified measuring the hydrostatic resistance of strained bituminous membranes.

4 Modified test method for performance testing of bituminous membranes under hydrostatic pressure

ASTM test method has been modified appropriate for simulating both the effects of the mechanical agents on the membranes which are the deformation of the membranes under compressive pressure and the excessive strain of the membranes over the cracks and the exposure of the strained membrane samples to hydrostatic pressure. Besides, a new observation method which determines whether water molecules has penetrated through the membrane during exposure to hydrostatic pressure, has been developed. The advantage of this sensor is that the penetration of water in either moisture or liquid form can be measured.

4.1 Apparatus

4.1.1 Hydrostatic testing equipment includes a chamber, a clamping bracket, a rubber gasket and fasteners to form the completed assembly, Figure 1.

Fig. 1: Hydrostatic testing equipment, the chamber and the clamping bracket

4.1.2 Source of compressed air

4.1.3 Compressive strength testing machine

An universal testing machine is used to load and thus, strain the membrane samples to a predetermined point of compressive pressure and form.

4.1.4 Precast concrete blocks

The precast concrete blocks are used as substrates for the membranes. Two different types of blocks are prepared for the tests. 'Type 1 precast concrete block' is composed of two parts and the width, length and height of one part is 96, 400, and 50 mm., respectively. The dimensions of the concrete block assembly formed by these two parts are 200 by 400 by 50 mm., leaving a gap of 8 mm. between the widths of the two parts. The gap is used to monitor the leakage of water through the membrane during testing. 'Type 2 precast concrete block' has a kerf 4 mm. deep lengthwise down the center of the block and the width, length and height of the block are 200, 400 and 50 mm., respectively. This type of block is used to simulate the cracks that may occur on the surfaces of the substrates. The compressive strength of both types of concrete blocks are determined to be minimum 14.7 N/mm^2 .

4.1.5 Metal elements

Metal elements used as tools in testing are steel spacers, steel plates and steel frames. Three types of spacers which differ in thickness are used as tools to simulate the occurrence of cracks on the surfaces of the building elements in contact with the membranes. The width and the length of all the steel spacers are 50 by 50 mm., and the thickness are 6, 8 and 10 mm.

The two steel plates which sandwiches the membrane sample are used as supports to the strained membrane sample after the samples are loaded to a predetermined point of compressive pressure in the universal testing machine. Then, two steel frames are used to fix the membrane sample in strained position. The width, length and height of the steel plates and the steel frames are 200, 400 and 30 mm., and 260, 460 and 2 mm., respectively.

4.1.6 The moisture/water sensor

The sensor utilizes a water absorbent polymer which is a swellable substance that can absorb water molecules and retains it by forming a gel. The thin layer of polymer is deposited between two vertically placed electrode plates which one of them is made of porous metal. The length and the height of the electrodes are 300 and 6 mm., respectively. The two vertical electrode plates with the polymer between is situated in a polycarbonate case which the length, width and height are 300, 6, and 6 mm, respectively. The case is closed on all sides except the front side. The vertically placed porous electrode plate takes place in the front side of the case so that the thin layer of polymer behind the porous plate can directly receive the water molecules which penetrates through the membrane.

The sensor is connected to a $1 \text{ M } \Omega$ resistor in series. A step-down transformer with an input of 220 V AC and an output of 36 V AC is used and between the terminals of 36 V AC, the serially connected sensor and resistor is placed. The two probes of a high accuracy multimeter are attached to the terminals of the resistor. Because of high impedances and low signal voltages, the measurements are very sensitive to stray

noise. To obtain high precision, a Faraday cage is used to isolate and eliminate these noise signals. The transformer, the resistor and the multimeter are placed in the Faraday cage. The cabling of the sensor is shielded. Before making any measurements, the cage is completely closed and latched.

When the water absorbent polymer is dry, its ohmic resistance is very high. Nearly no AC current flows in the circuit; thus, no AC voltage can be measured between the terminals of the resistor. As the water molecules penetrate through the porous electrode plate; the water content of the polymer increases, resulting in a decrease in the ohmic resistance of the polymer. The sensor responds to the change in its environment by increasing its current output, then by running the current through the resistor, an increasing voltage is produced. The multimeter can then monitor the increasing voltage between the terminals of the resistor. The measured data is recorded and stored in a computer program to be evaluated periodically.

The meter readings in terms of AC voltage are related to weight of water molecules in grams by a calibration curve.

4.2 Membrane test samples

Commercially available oxidized and modified bitumen membrane samples that will be used in testing are described in Table 2.

Table 2: Description of membrane test samples

Bitumen membranes	Reinforcement (gr/m ²)	Thickness (mm)	Number of plies
1 APP modified bitumen	Unwoven glass fibre, 60	3	1
2 APP modified bitumen	Polyester, 180	3	1
3 APP modified bitumen	Polyester, 180	4	1
4 APP modified bitumen	Polyester, 180	3+3	2
5 SBS modified bitumen	Glass, 60	3	1
6 SBS modified bitumen	Polyester, 180	3	1
7 SBS modified bitumen	Polyester, 180	4	1
8 SBS modified bitumen	Polyester, 180	3+3	2
9 Oxidized bitumen	Unwoven glass fibre, 60	2,4	1
10 Oxidized bitumen	Woven glass fibre, 200	2,9	1

4.3 Tests for measuring the hydrostatic resistance of unstrained and strained bituminous membranes

Four types of tests related to the test program defined in Section 2, have been established.

4.3.1 Test no 1

This test simulates the condition of the membranes applied on the surfaces of the structural walls where cracks may not occur and measures the hydrostatic resistance of the unstrained membranes. There is no pre-formed strain on the membranes prior to hydrostatic pressure testing. This test will be conducted to all types of membrane samples defined in Section 4.2.

- The procedure

The surface of the Type 1 precast concrete block which will receive the membrane is primed as recommended by the manufacturer. The primer is permitted to dry for the minimum time recommended by the manufacturer. Liquid rubber is then applied to the remaining surfaces of the block. The membrane sample that will be tested is cut from the roll and installed over the primed surface of the prepared block and allowed to cure for the minimum time recommended by the manufacturer. The width and the length of the membrane sample is 200 and 400 mm., respectively. Two pieces of rubber which the width, length and height are 50, 50 and 8 mm., respectively, are placed at the ends of the gap.

Both sides of the rubber gasket are coated with vacuum grease and one side of the rubber gasket is fitted to the test chamber. The width and the length of the rubber gasket is 200 and 400 mm., respectively. The membrane side of the block is set against the gasket and then the steel bracket is set against the back of the block. The fasteners are tightened, clamping the block to the chamber gradually to form the completed assembly. Then the sensor is placed in the gap between the blocks. The vertically placed porous electrode plate faces the surface of the membrane sample. Then the gap is sealed with a strip of rubber in order to prevent the access of humidity to the gap.

With the air vent open, the chamber is filled with water. Then, both the air vent and water valve is closed. The assembly is monitored for leaks for 30 minutes. The air line is attached if no leakage is observed in the assembly. The air pressure is increased up to 50 kPa for one hour, and to 100 kPa for the next hour. The last upward pressure is 250 kPa for 24 hours. Meanwhile the meter readings are recorded in terms of AC voltage and converted to weight of water molecules that passed through the membrane under hydrostatic pressure.

4.3.2 Test no 2

This test simulates the excessive strain of the membranes caused by the cracks that may occur on the surfaces of the structural walls in contact with the membrane and measures the hydrostatic resistance of the strained membranes. The crack widths which will be simulated are 2, 4 or 6 mm. The strain of the membrane caused by the crack width of 2 mm. will be simulated in a membrane sample and the resistance of this membrane to water pressure will be measured. Afterwards, the deformation of the membrane due to the crack width of 4 mm. will be simulated in a new membrane sample of the same type and the resistance of this membrane to water pressure will again be measured. A new membrane sample of the same type will be strained due to the simulation of the crack width of 6 mm. Then, the watertightness level of each strained membrane samples under hydrostatic pressure will be evaluated. This test will be conducted to all types of membrane samples defined in Section 4.2.

- The procedure

The flat surface of the Type 2 precast concrete block which will receive the membrane is primed and after the primer is dried, liquid rubber is applied to the remaining surfaces of the block. The membrane sample that will be tested is cut and installed over the primed surface of the prepared block. The width and the length of the membrane sample is 200 and 400 mm., respectively. With the waterproofed surface down, the block is supported at both ends directly under the kerf. Two steel spacers

which are 2 mm. thicker than the width of the kerf are inserted at each end of the kerf. Then the steel spacers are tapped with a hammer to break the balance of the block at the kerf. Thus, the occurrence of 2 mm. wide cracks on the surface of the structural walls which strains the membrane is simulated. In order to obtain the cracks which the widths are 4 and 6 mm., 8 and 10 mm. thick steel spacers are used in new membrane samples of the same type, respectively. The block is installed between the chamber and the steel bracket, and the fasteners are tightened to form the completed assembly. The sensor is then placed in the kerf and the kerf is sealed with the strip rubber. The strained membrane is exposed to the same water pressure levels as described in the procedure of Test no 1, and the meter readings are converted to the weight of water molecules which penetrated through the membrane during the exposure time.

4.3.3 Test no 3

In order to simulate the strain of the membranes when subjected to the compressive pressure under the column bases, a membrane sample will be strained at 10 t of compressive pressure and then, the hydrostatic pressure resistance of this strained membrane will be measured. New membrane samples of the same type will be used for each compressive pressure levels of 20 and 30 t., separately. The strained membranes will be evaluated on the basis of their performances under hydrostatic pressure. This test will be conducted to all types of membrane samples defined in Section 4.2.

- The procedure

The surfaces of Type 1 precast concrete block is prepared as described in the procedure of Test no 1. The membrane sample that will be tested is cut from the roll and placed between the two steel plates. The width and the length of the membrane sample is 260 and 460 mm., respectively. The two steel plates with the membrane sample between is then placed between the two jaws of the universal compressive strength testing machine. The test sample is loaded to a predetermined point of compressive pressure and then fixed between two steel frames while in strained position. The strained test sample with the steel frames is installed to the primed surface of prepared block and the block is installed in the hydrostatic testing equipment. The sensor is then placed in the gap and the gap is sealed. The same water pressure levels are applied to the membrane as described in the procedure of Test no 1. The meter readings are converted to the weight of water molecules by the calibration curve.

4.3.4 Test no 4

This test simulates the strain of the membranes when exposed both the compressive pressure and the cracks and measures the resistance of the strained membranes to water pressure. Initially, a membrane sample will be strained to 10 t. of compressive pressure level. Then, the strained membrane sample will further be strained by simulation of the 2 mm. wide crack and the performance of the strained membrane sample under hydrostatic pressure will be evaluated. A new membrane of the same type will be strained in 10 t. compressive pressure level and this time the crack width of 4 mm. will be simulated on the same sample. Afterwards, the crack width of 6 mm. will be simulated in a new membrane sample of the same type which has already been exposed to 10 t. of compressive pressure. The hydrostatic pressure resistance of the strained membrane samples will be evaluated. The same type of membrane will be strained to

20 t. of compressive pressure level, and the crack width of 2 mm. will be simulated on the same sample. New membrane samples of the same type will be used for each compressive pressure levels of 20 and 30 t., separately. In each compressive pressure levels, a new sample of the same membrane type will be used for the simulation of 2, 4 and 6 mm. wide cracks, separately. All types of membrane samples defined in Section 4.2 will undergo the same procedure.

- The procedure

The Type 2 precast concrete block is prepared as described in the procedure of Test no 2. Then the membrane sample which will be tested is strained in the universal compressive strength testing machine as described in the procedure of Test no 3. The strained test sample with the steel frames is installed to the primed surface of the prepared Type 2 precast concrete block. Steel spacers are inserted into the kerf and tapped with hammer. Thus, the strained membrane is furthermore strained due to the occurrence of crack. The block is placed to the hydrostatic testing equipment. The sensor is then placed to the kerf and sealed with the rubber strip. The predetermined levels of water pressure is applied as described in the procedure of Test no 1 and the weight of water molecules are determined from the calibration curve.

5 Concluding Remarks

Oxidised and modified bitumen membranes are not only used in roofing but below-grade waterproofing as well. The watertightness integrity of these membranes used in below-grade waterproofing are determined according to the existing watertightness test methods which do not take into account the mechanical agents that these membranes are exposed to. Therefore, a modified test method which measures the hydrostatic resistance of the membranes when subjected to mechanical agents that occurs in below-grade waterproofing is proposed. This modified test method is considered to be a new approach which will provide a better understanding of the performances of the bituminous membranes used in below-grade waterproofing.

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