WEIHENSTEPHAN · TRIESDORF
University of Applied Sciences

Test Report

(Translation from German to English)

on the investigation of the root resistance of membranes and coatings for green roofs according to the FLL Method (2002)

Product Name:

WOLFIN IB

Client:
BMI Group
Am Rosengarten 5
63607 Wächtersbach-Neudorf

This report consists of 32 pages and may only be used in its unabridged form.
The report is valid until 10 August 2028.
Report date: 10 October 2023

This is the second extension of report no. 16/08 dated 10.08.2008
(First extension: Report 14/18 dated 18.07.2018)

Information provided by WOLFIN Bautechnik GmbH on 22 November 2006 regarding the key data and material properties of the tested membrane.

WOLFIN IB

- **Product name:** WOLFIN IB
- **Application area:** Roof and building waterproofing
- **Material designation:** PVC-P-BV
- **Thickness of the membrane (without lamination):** 1.5 mm
- **Construction (top to bottom):** Homogeneous throughout
- **Delivery format:** Rolls 1100 mm and 1620 mm
- **Manufacturing method:** Extrusion
- **Material standards:** DIN 16730, DIN 16937
- **Test certificates:** e.g., DIN 16726, DIN 53387, DIN 53472, SIA 280
- **Year of manufacture:** 2006
- **Layer responsible for root penetration protection:** Entire membrane
- **Installation method at test site:**
  - Overlap: approx. 5 cm
  - Joining method: Welded with hot air, swell welding
  - Joining agent: THF (tetrahydrofuran)
  - Seam sealing: none
  - Corner reinforcement: with preformed corners made of the same material
  - Cover strips over seams: none

- **Biocidal additives (concentration details):** none

The test was originally commissioned by Wolfin Bautechnik GmbH, Wächtersbach.

1 Problem Definition

To prevent damage, root protection systems must have a permanently high resistance to penetration by plant roots and rhizomes (underground shoots).
In the study conducted, the WOLFIN IB membrane from BMI Group, Am Rosengarten 5, 63607 Wächtersbach-Neudorf, was tested for root and rhizome resistance.

2 Test Facility and Execution

The testing was carried out in accordance with the “Procedure for Investigating the Root Resistance of Membranes and Coatings for Green Roofs” with a 2-year duration (FLL, 2002). The test was conducted from August 2006 to August 2008. It involved 8 containers fitted with the membrane under investigation and 3 containers without membrane as controls for plant growth.

In accordance with specifications, 5 pieces of membrane from BMI Group were joined per container and installed. Each container included longitudinal seams, 4 wall corner seams, 2 bottom corner seams, and 2 T-joints.

Samples from the tested membrane were taken before and after testing and stored at the testing institute.

The containers were placed in a heated greenhouse.

Test plants used were:
Firethorn (*Pyracantha coccinea* 'Orange Charmer')
Couch grass (*Agropyron repens*)
These were chosen because they thrive under the set climate conditions even during winter. Couch grass, a native species, forms rhizomes (underground runners) that, like roots, are capable of damaging membrane systems.

A detailed description of the procedure is provided in Appendix 3.

3 Manufacturer’s Information on the Tested Membrane

The investigation of root penetration resistance is tied to the material specifications and properties of the tested membrane, as well as the applied joining and manufacturing methods. The relevant details from the manufacturer on WOLFIN IB can be found on Page 2 of this report.

4 Results

4.1 Plant Development

The planted shrubs and the sown couch grass showed good development throughout the testing period. The required minimum growth rate of the shrubs in the test containers (80% of the average growth performance in the control containers) was clearly exceeded, with values ranging from 97% to 106% on the four evaluation dates. From the first interim evaluation (February 2007) onwards, couch grass displayed a high plant density throughout the entire test. On average, 70–79% of the container surface area in the 8 test containers was covered with couch grass (target: ≥ 40%). Detailed plant growth data is provided in Appendix 2.

4.2 Root Penetration

After 2 years (August 2008), the tested WOLFIN IB membrane showed no root or rhizome penetration, either through the surface or seams (see photos in Appendix 1).

5 Conclusion

According to the "Procedure for Investigating the Root Resistance of Membranes and Coatings for Green Roofs" (FLL, 2002), the WOLFIN IB membrane from BMI Group, tested between August 2006 and August 2008, showed no root or rhizome penetration in any of the 8 test containers.

Therefore, WOLFIN IB is deemed:
Root-resistant according to the FLL method, and
Rhizome-resistant against couch grass under the same method.
The FLL method includes all relevant elements of European Standard EN 13948, even exceeding them in parts, and is therefore considered of higher quality. From a technical standpoint, the WOLFIN IB membrane tested according to the FLL method can also be labelled root-resistant under EN 13948.
The test is based on the material properties and manufacturing details listed on Page 2, and retained membrane samples are stored at the Institute of Horticulture.
The original test report from August 2008 was valid for 10 years, extended in 2018 by 5 years, and now, considering the current (2008) FLL procedure, extended again by another 5 years. The report is valid until 10 August 2028. This report consists of 32 pages and may only be used in its unabridged form.

Signed:	Signed:
Dipl.-Ing. (FH) Heinz-Josef Schmitz	Dr. Dieter Lohr
10.10.2023	10.10.2023

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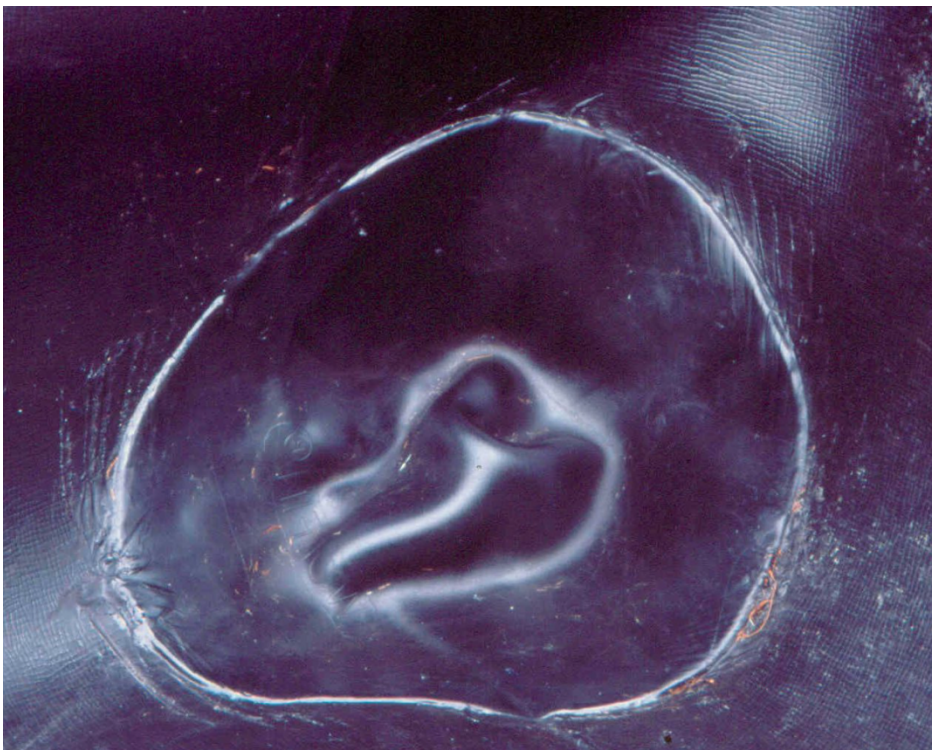
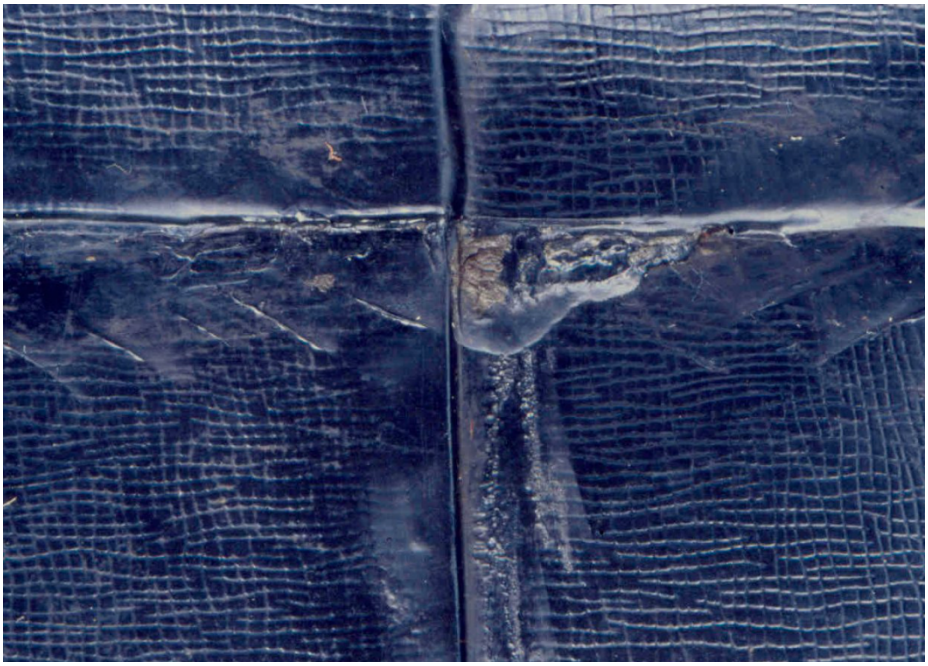
Appendix 1: Photos of the Tested Membrane WOLFIN IB (August 2008)

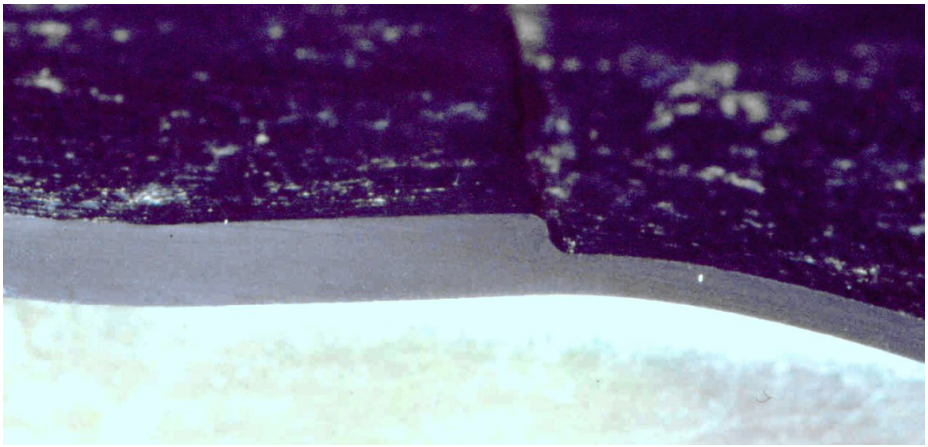
Top side of the membrane (detail)



Top side of the membrane with reinforced corner



Top side of the membrane with T-joint



Cross-section through a seam of the membrane

Appendix 2: Data on Plant Development

Table 1: Height and stem diameter of Firethorn (Pyracantha coccinea) in the 3 control containers

Container No.	Plant No.	Feb 2007		Aug 2007		Feb 2008		Aug 2008	
		Ø (cm)	Height (cm)	Ø (cm)	Height (cm)	Ø (cm)	Height (cm)	Ø (cm)	Height (cm)
K1	1	1.4	225	1.4	255	1.7	295	2.2	335
	2	1.4	205	1.6	280	1.8	305	2.0	330
	3	1.4	190	1.6	200	1.8	255	2.1	365
	4	1.2	230	1.6	170	1.9	280	2.3	265
K2	1	1.4	185	1.7	295	1.7	250	2.0	300
	2	1.4	180	1.6	180	2.0	300	2.3	280
	3	1.2	180	1.4	200	1.7	230	2.1	280
	4	1.4	230	1.5	230	1.9	230	2.1	285
K3	1	1.2	205	1.5	205	1.6	200	1.9	270
	2	1.3	230	1.5	225	1.8	285	2.2	350
	3	1.2	200	1.4	215	1.8	320	2.2	275
	4	1.4	200	1.6	285	2.1	280	2.3	370

[1] *Stem diameter measured 20 cm above the substrate surface.*

Table 2: Average height and stem diameter of Firethorn in the 3 control containers

Container No.	Plant Nos.	Feb 2007		Aug 2007		Feb 2008		Aug 2008	
		Ø (cm)	Height (cm)	Ø (cm)	Height (cm)	Ø (cm)	Height (cm)	Ø (cm)	Height (cm)
K1–K3	1–4	1.32	205	1.53	228	1.82	269	2.14	309

[1] *Stem diameter measured 20 cm above the substrate surface.*

Table 3: Height and Stem Diameter of Firethorn in the 8 Test Containers

Container No.	Plant No.	Feb 2007		Aug 2007		Feb 2008		Aug 2008	
		Ø (cm)	Height (cm)	Ø (cm)	Height (cm)	Ø (cm)	Height (cm)	Ø (cm)	Height (cm)
P1	1	1.4	175	1.6	220	1.8	210	2.0	330
	2	1.3	200	1.6	245	1.7	255	1.9	290
	3	1.4	220	1.6	210	1.9	235	2.3	365
	4	1.3	195	1.7	240	1.8	265	2.2	335
P2	1	1.3	210	1.5	225	1.7	240	2.1	305
	2	1.4	225	1.6	230	2.0	265	2.3	315
	3	1.3	195	1.6	255	1.8	180	2.0	305
	4	1.3	220	1.5	230	1.9	210	2.1	285
P3	1	1.5	235	1.7	250	2.0	300	2.3	300
	2	1.3	205	1.6	195	1.8	215	2.1	275
	3	1.4	230	1.7	290	2.0	315	2.2	305
	4	1.4	210	1.6	225	1.8	185	2.2	350
P4	1	1.4	180	1.5	235	1.8	215	2.1	295
	2	1.4	225	1.6	285	2.2	300	2.3	380
	3	1.3	200	1.5	270	1.7	250	2.0	320
	4	1.4	210	1.6	180	1.9	210	2.3	235
P5	1	1.4	175	1.7	180	2.0	215	2.3	265
	2	1.2	245	1.4	240	1.6	250	1.8	285
	3	1.3	210	1.7	210	1.8	240	2.0	275
	4	1.3	220	1.6	300	1.7	275	2.1	335
P6	1	1.4	250	1.6	270	1.8	265	2.1	275
	2	1.4	230	1.6	255	1.8	300	2.3	315
	3	1.4	195	1.5	210	1.8	290	2.3	265
	4	1.5	240	1.7	300	2.0	285	2.2	365
P7	1	1.3	170	1.6	200	1.8	215	2.1	280
	2	1.4	240	1.6	215	1.8	240	2.0	350
	3	1.4	220	1.7	290	2.1	310	2.4	325
	4	1.3	195	1.5	240	1.7	265	2.1	310
P8	1	1.4	170	1.6	220	1.7	255	1.8	330
	2	1.4	175	1.6	220	1.8	210	2.0	330
	3	1.3	200	1.6	245	1.7	255	1.9	290
	4	1.4	220	1.6	210	1.9	235	2.3	365

Note: [1] Stem diameter measured 20 cm above the substrate surface.

Table 4: Average Height and Stem Diameter of Firethorn in the 8 Test Containers

Container No.	Plant Nos.	Feb 2007		Aug 2007		Feb 2008		Aug 2008	
		Ø (cm)	Height (cm)	Ø (cm)	Height (cm)	Ø (cm)	Height (cm)	Ø (cm)	Height (cm)
P1–P8	1–4	1.36	213	1.59	241	1.83	261	2.13	310

Note: [1] Stem diameter measured 20 cm above the substrate surface.

Table 5: Average Values Compared to the Control Containers (Target ≥ 80%)

Container No.	Plant No.	February 2007		August 2007		February 2008		August 2008	
		Ø %	Height %	Ø %	Height %	Ø %	Height %	Ø %	Height %
P 1–P 8	1–4	103	104	104	106	101	97	100	100

Table 6: Couch Grass Density in Control Containers (%)

Container No.	February 2007	August 2007	February 2008	August 2008
	Population density (%)	Population density (%)	Population density (%)	Population density (%)
K 1	65	75	75	80
K 2	65	60	60	65
K 3	65	75	80	80

Table 7: Average Couch Grass Density in Control Containers

Container No.	February 2007	August 2007	February 2008	August 2008
	Population density (%)	Population density (%)	Population density (%)	Population density (%)
K 1–K 3	63.3	71.2	71.2	75.0

Table 8: Couch Grass Density in the 8 Test Containers (%)

Container No.	February 2007	August 2007	February 2008	August 2008
	Population Density (%)	Population Density (%)	Population Density (%)	Population Density (%)
P 1	70	75	75	75
P 2	75	80	80	70
P 3	70	80	85	85
P 4	65	70	85	70
P 5	65	65	60	65
P 6	75	75	85	75
P 7	70	70	80	85
P 8	70	80	70	70

Table 9: Average Couch Grass Density in Test Containers (Target ≥ 40%)

Container No.	February 2007	August 2007	February 2008	August 2008
	Population Density (%)	Population Density (%)	Population Density (%)	Population Density (%)
P 1–P 8	70.0	75.0	78.8	72.5

Appendix 3

Procedure for Testing the Root Resistance of Membranes and Coatings for Green Roofs

FLL
Research Society for Landscape Development and Landscaping e.V.
Colmantstr. 32
53115 Bonn

Introduction

To prevent vegetation-related building damage from green roofs, in 1984 a working group of the Research Society for Landscape Development and Landscaping (FLL) developed a “Procedure for Testing Root Resistance of Root Protection Membranes.” This procedure is designed to test membrane resistance to penetration by plant roots. The procedure is based primarily on years of experimental findings using various sealing membranes and plant species, conducted by the Institute for Soil Science and Plant Nutrition at FH Weihenstephan between 1975 and 1980. The FLL method was revised in 1992 and most recently in 1995.

It is widely accepted by manufacturers, planners, and contractors—evidenced by the large number of completed and ongoing tests. In 1993, FLL decided to revise the prior 4-year testing method, aiming to shorten the testing period to 2 years—without relaxing the rigor of the original test. After many trials at the Institute for Soil Science and Plant Nutrition at FH Weihenstephan, this adjustment was successfully achieved. The 2-year test is conducted in a climate-controlled greenhouse, where selected plant species experience consistent temperature and lighting conditions year-round, ensuring continuous growth.

Thus, a 24-month growing period equivalent in effect to the previous 4-year outdoor test (which included long dormant phases during winter) is achieved.Both test formats are considered equivalent and are described jointly in this revised procedure. The revision also includes formal restructuring to improve clarity and make it easier for testing institutions to evaluate results.

1 Scope of Application

This procedure applies to determining resistance to root and rhizome penetration from the test plants in:

- Root protection membranes
- Roof and waterproofing membranes
- Coatings applied in liquid form

for all types of green roof construction (intensive green roofs, simple intensive green roofs, extensive green roofs).

The method includes testing of complete products along with their joining techniques. It is not suitable for testing individual layers or coatings alone.
Testing entire waterproofing systems (i.e., multi-layered assemblies) is not permitted.
In the case of liquid-applied coatings, it may be necessary to include a separate layer below for technical reasons. This is only acceptable if the manufacturer provides a written declaration that the root resistance is solely due to the top (tested) coating layer.
Laminations (additional layers placed underneath the tested layer) are explicitly excluded.
The results cannot be applied to protection against aggressive root systems (e.g., bamboo or Chinese reed). When using such species, additional structural or maintenance measures beyond what is tested are necessary.

This procedure does not include any evaluation of environmental compatibility of the tested products.

2. Definitions

The following definitions apply for the purposes of this procedure:

2.1 Test Vessels

Specially equipped containers with minimum dimensions, filled with either the membrane or coating to be tested (test vessels) or with a fleece layer (control vessels).

2.2 Moisture Layer

This layer consists of coarse mineral material placed beneath the membrane or coating to be tested. It remains constantly moist and allows roots and rhizomes that penetrate the membrane/coating to continue growing toward the transparent vessel bottom, thus allowing early detection of root penetration.

2.3 Protective Layer

A chemically compatible fleece laid directly underneath the membrane or coating being tested, placed over the moisture layer to ensure even pressure distribution.

2.4 Vegetation Support Layer

A standardized, structurally stable growth substrate (material mix) that is always available at all test locations. It has a favorable water-air balance and light base fertilization, promoting optimal root development in test plants. It is in direct contact with the membrane being tested.

2.5 Test Plant Types

2.5.1 For the 2-Year Test

- **Pyracantha coccinea** *'Orange Charmer'* – A firethorn shrub used for its year-round root growth under greenhouse conditions.
- **Agropyron repens** – Couch grass, a native grass with slow-growing rhizomes that commonly appears on green roofs and grows sufficiently throughout the year under test conditions.

2.5.2 For the 4-Year Test

- **Alnus incana** – Grey alder, a wild shrub that shows suitable root growth under natural outdoor conditions during the vegetation period.
- **Agropyron repens** – Couch grass.

2.6 Adequate Growth Performance of Test Plants

The shrubs (Firethorn or Alder) in the test vessels must show at least 80% of the average growth performance (height and stem diameter) of the control vessel plants throughout the test period. This ensures that any damage or plant growth inhibition caused by the tested material is identified. The spread of couch grass on the substrate surface is visually assessed (see 2.7). From the first interim inspection onward, the couch grass in test vessels must show on average at least moderate density over the test duration.

2.7 Visual Assessment of Couch Grass Coverage

The visual density of couch grass is scored using the following scale:

- Barely present (approx. 0–20% surface coverage)
- Sparse coverage (approx. 20–40%)
- Moderate coverage (approx. 40–60%)
- Dense coverage (approx. 60–80%)
- Very dense coverage (approx. 80–100%)

2.8 Equivalent Joining Techniques

It is permissible in the test to combine different joining techniques, provided that they exclusively aim to produce materially homogeneous seam connections (e.g., solvent welding – using a volatile solvent – and hot air welding). Such seam connections are regarded as equivalent. In contrast, combinations of adhesive-free joints and joints with adhesive material or joints using two different types of adhesives are not considered equivalent.

2.9 Root Ingress

Roots that have grown into the surface or seams of a tested membrane or coating, whereby the underground plant parts have actively created cavities and thus damaged the membrane or coating.

Not to be considered as root penetration, but to be recorded in the test report, are:

- Roots grown into already existing pores of a membrane or coating (surface or seam or work interruption joint) (i.e., no damage). To ensure a clear assessment in such cases, microscopic examination of the respective membrane or layer sections is required.
- Roots grown into the surface or seam or work interruption joint ≤ 5 mm in membranes and coatings that contain radicidal agents (root inhibitors), as the root-inhibiting effect only develops after the roots have penetrated. In order to permit such an assessment, these membranes or coatings must be clearly defined by the manufacturer as containing radicidal agents at the start of the test.
- Roots grown into the surface of products composed of multiple layers (e.g., bitumen membrane with copper tape insert or PVC membrane with polyester fleece insert), if the layer that provides the penetration resistance is not damaged. To enable such an assessment, this layer must be clearly specified by the manufacturer at the beginning of the test.
- Roots that have penetrated into seam seals (without damaging the seam).

2.10 Root Penetration

Root penetration means that roots have grown through the tested membrane/coating or its seams by exploiting or actively creating cavities.

2.11 Certification as “Root-Resistant”

A membrane or coating is considered root-resistant if, in all test containers, no root intrusions as defined in Section 2.9 and no root penetrations as defined in Section 2.10 are detected at the end of the test period.

A further prerequisite is that the shrubs used in the test must have demonstrated sufficient growth performance throughout the test period in the test containers, in accordance with Section 2.6.

2.12 Couch Grass Rhizomes (Quecken-Rhizome)

Since a distinction must be made between roots and rhizomes during the evaluation, reliable identification of these underground plant structures is essential.
The following criteria may help with identification:
Rhizomes of couch grass (Agropyron repens) spreading in the vegetation support layer (underground runners) have a uniform diameter of approximately 2 mm and show low branching. They are segmented by nodes, which carry small, inconspicuous leaf-like sheaths surrounding the stem and thin roots. Between the nodes, the rhizomes are hollow (see Fig. 1). By contrast, firethorn roots vary significantly in diameter, are highly branched, lack leaves, and are not hollow. If the testing institution cannot clearly distinguish between rhizomes and roots, expert consultation is recommended.

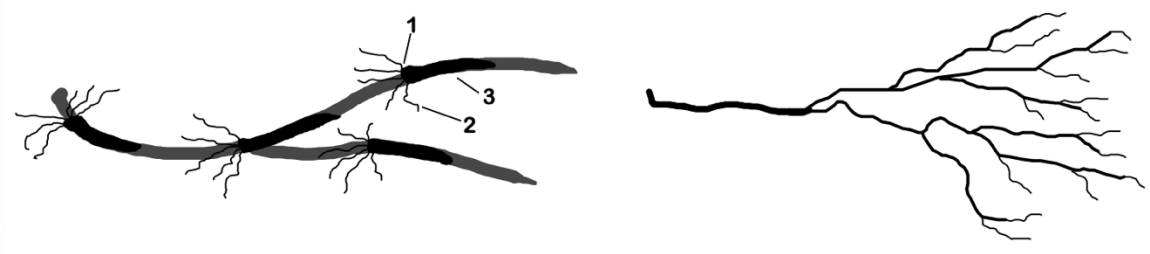


*Figure 1: Schematic diagram of a couch grass rhizome (left) with: (1)*Nodes, (2) Roots, (3) Leaf sheaths compared to a **firethorn root** (right)

2.13 Evaluation of Couch Grass Rhizomes

Rhizomes that have grown into or through the membrane or coating (surface or seam) must be documented in the test report, but are not considered in the root resistance evaluation.
If no damage to the product by rhizomes is detectable, this must still be explicitly noted in the test report (see 2.14).

2.14 Certification as “Rhizome-Resistant Against Couch Grass”

A membrane or coating is considered resistant to couch grass rhizomes if, after the test duration, no rhizome penetration or rhizome breakthrough (as defined in sections 2.9 and 2.10) is observed in any test vessel. Additionally, couch grass must have shown sufficient growth performance throughout the test period (see section 2.6).

2.15 Conditions for Premature Termination of the Test

If penetration by roots or rhizomes is detected in the membrane or coating during evaluations in the course of testing (see 7.1), the client must be informed. The test must be terminated if the penetration was caused by roots. If the penetration was caused by rhizomes, testing may continue in consultation with the client. If more than 25% of the woody plants die during the test period, the test must be restarted, including replanting and replacing the vegetation support layer with a new substrate mixture. The test start date must be reset accordingly.
The same procedure applies if the test plants do not exhibit sufficient growth performance during the test (see 2.6).

3 Brief Description of the Procedure

In a container test under standardized conditions, the penetration resistance of root protection as well as roofing and waterproofing membranes or coatings is examined against roots and rhizomes of the test plant species acting upon them. In the 4-year test, this is done under outdoor conditions using alder and couch grass as test plants. The 2-year test is conducted in a climate-controlled greenhouse using firethorn and couch grass. The membrane or coating to be tested—which must contain multiple seams and/or a work interruption joint—is installed in 8 test containers. An additional 3 containers are used without a membrane or coating, serving as controls for plant growth. A thin vegetation support layer is filled into the prepared containers. By using dense planting, moderate fertilization, and limited watering, the goal is to generate a high root pressure. At the end of the test, the vegetation support layer is removed and the membrane or coating is inspected for roots or rhizomes that have intruded or penetrated. Retention samples of the tested membrane or coating are stored at the testing institute.

4 Test Facilities and Materials

4.1 Test Site

4.1.1 For the 4-Year Test

A hall with a transparent roof and open sides is recommended to replicate outdoor conditions while preventing waterlogging due to rainfall. Alternatively, an unheated greenhouse with adequate ventilation and frost protection may be used.

4.1.2 For the 2-Year Test

A greenhouse with controllable heating and ventilation is required. Set daytime temperatures to 18±3°C and nighttime to 16±3°C. Ventilation must begin at 22±3°C; sustained internal temperatures over 35°C must be avoided. Natural light in Central Europe is sufficient year-round, so shading in summer or artificial lighting in winter is not required. Each container (800 x 800 mm) requires 1.5–2 m^2 of space, depending on spacing (see 6.1).

4.2 Test Containers

Containers must have internal dimensions of at least 800 x 800 x 250 mm. Larger containers may be necessary depending on installation requirements. They must have a transparent base (e.g., acrylic glass) to allow observation of root growth without disturbing the vegetation. The base should be darkened (e.g., with light-impermeable foil) to prevent algae growth in the moisture layer. The transparent container bottom is preferably constructed as an insert with a 20 mm high upstand, to ensure that the moisture layer can be sufficiently supplied with water. Water is supplied via an inlet pipe (approx. Ø 35 mm), installed at an upward angle, connected to the outer side of the containers. The pipe ends at the level of the upstand of the insert bottom (see Figure 2 below).

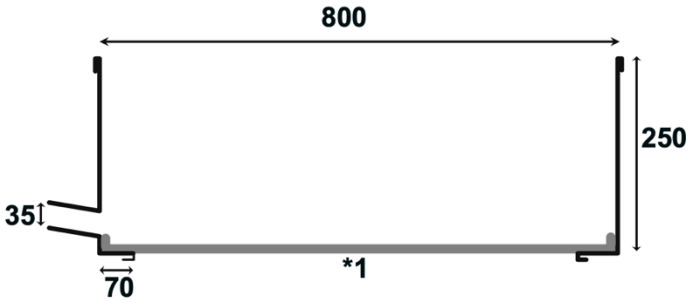


Figure 2: *Construction of the test container (minimum dimensions in mm).
1 = transparent bottom with upstand

For each membrane or coating to be tested, 8 test containers are required. Additionally, for each test run—regardless of the number of membranes or coatings being tested—3 control containers (without membrane or coating) must be provided.

4.3 Moisture Layer

This layer consists of expanded shale or expanded clay (grain size 8–16 mm), meeting the quality standards listed in Table 1. To avoid the need for own laboratory analysis, it is recommended to use products that are subject to regular quality control. The manufacturer must guarantee that the material meets the required properties. With the required layer thickness of (50 ± 5) mm (see 6.1), the material requirement is approx. 32 liters per test container (800 x 800 mm).

4.4 Protective Fleece

A fleece made of synthetic fibers with a weight of approx. 200 g/m^2 must be used.
The material compatibility of the fleece with the membrane or coating being tested must be ensured. The required amount of material is 0.64 m^2 per test container (800 x 800 mm).

4.5 Membrane or Coating to Be Tested

The membrane or coating must be installed or applied according to Section 6.1. For each container with minimum dimensions (800 × 800 × 250 mm), this results in a surface area to be covered of approximately 1.3 m^2 (excluding overlap), considering the 50 mm thick moisture layer.

4.6 Vegetation Substrate

The substrate consists of:

- 70% by volume of slightly decomposed high-moor peat, and
- 30% by volume of expanded clay or expanded shale (grain size 8–16 mm), which must meet the quality requirements specified in Table 1.

As described in Section 4.3, it is advisable to use only products that are subject to ongoing quality control by the manufacturer to ensure compliance with the specified properties.
By adding calcium carbonate ($CaCO_3$), the pH value of the substrate must be adjusted to between 5.5 and 6.5 (see Section 4.7).
The base fertilization defined in Section 4.8 must be homogeneously mixed into the vegetation layer before filling. The substrate requirement for the 4-year test with a layer thickness of (150±10) mm is about 96 L per container (800 × 800 mm). For the 2-year test, considering the substrate volume from the root balls of the plants, about 88 L per container (800 × 800 mm) is required.

Table 1: Required Quality of Expanded Clay/Expanded Shale Determined in water extract (1:10 ratio of milled material to demineralized water):

Parameter	Limit
Soluble salts (as KCl)	< 0.25 g/100 g
CaO	< 120 mg/100 g
Na_2O	< 15 mg/100 g
Mg	< 15 mg/100 g
Cl (Chloride)	< 10 mg/100 g
F (Fluoride)	< 1.2 mg/100 g

4.7 pH Adjustment

To achieve a pH of 5.5–6.5, different amounts of calcium carbonate may be required for the vegetation layer. The required amount can be determined using the following procedure:

- Take 5 samples (1 L each) from the well-mixed vegetation substrate.
- Moisten the samples with tap water.
- Mix in different amounts of calcium carbonate (4, 5, 6, 7, or 8 g).
- Place samples in plastic bags, seal and label them.
- Store for 3 days at room temperature.
- Send samples to a testing lab using VDLUFA methods and request a pH analysis using $CaCl_2$.
- The amount of lime that yields the target pH in the 1 L sample is scaled up for the total volume of the vegetation substrate.

4.8 Fertilizer

The base fertilization should consist of a compound fertilizer with approx.: 15% N, 10% P_2O_5, 15% K_2O, 2% MgO, ≤ 0.5% Cl, plus trace nutrients such as: Fe (iron), Cu (copper), Mo (molybdenum), Mn (manganese), B (boron), Zn (zinc). Apply 30 g of fertilizer per container (800 × 800 mm). The trace nutrients must be used in the amounts recommended by the fertilizer manufacturer. For top-dressing, use a slow-release, coated compound fertilizer (15% N, 10% P_2O_5, 15% K_2O) with a duration of 6–8 months. Apply 30 g per container (800 × 800 mm).

4.9 Tensiometer

To monitor irrigation, a tensiometer with a measuring range of 0 to -600 hPa must be installed in each container.

4.10 Test Plants

For the 4-year test, the following plants must be used:

- Alnus incana – Grey alder, 2-year-old transplant, height 60–100 cm.
- Agropyron repens – Couch grass, seed.

For the 2-year test, the following plants must be used:

- Pyracantha coccinea 'Orange Charmer' – Firethorn, in 2-liter containers, height 60–80 cm.
- Agropyron repens – Couch grass, seed.

Each 800 × 800 mm container should have: 4 shrubs (alder or firethorn), and 2 g of couch grass seed. This equates to 6.25 shrubs/m^2 and 3.13 g of seed/m^2. If larger containers are used, the plant and seed quantities must be adjusted to maintain this density. When purchasing shrubs, uniform plant quality must be ensured.

4.11 Irrigation Water

The irrigation water must meet the minimum quality standards listed in Table 2.
Water quality must be confirmed by the local water supplier. If any value in Table 2 is exceeded, the irrigation water must be diluted with desalinated water or rainwater.

Table 2: Minimum Quality of Irrigation Water

Parameter	**Limit**
Conductivity	< 1000 µS/cm
Total hardness (alkaline earths)	< 5.4 mmol/l
Acid capacity (to pH 4.3)	< 7.2 mmol/l
Chloride	< 150 mg Cl/l
Sodium	< 150 mg Na/l
Nitrate	≤ 50 mg NO_3/l

5 Sample Collection and Manufacturer Information

Before and after testing, the testing institute must take a retain sample of the membrane or coating. The sample must include at least one seam (e.g. weld or joint) and cover an area of at least 0.5 m^2. The retain sample must be stored at the testing institute: In a dry and dark place, At temperatures between 5 °C and 25 °C. The storage period must match the validity period of the test report (see Section 8). Any incompatibilities of materials must be taken into account during storage.

In order to clearly identify the tested product, the following details must be requested from the manufacturer at the beginning of the examination: Product name, area of application, material designation, material standards, thickness (without lamination), configuration/setup, delivery form, manufacturing technique, test certificates, year of manufacture, installation technique at the examination site (overlap, applied joining techniques, adhesives, type of seam sealing, cover strips over seams, special corner and angle connections), addition of biocides (e.g. root inhibitors) including information on concentration. In addition, a product data sheet of the membrane or coating to be tested must be provided to the test institute.

For products composed of multiple layers (e.g. bitumen membrane with copper tape insert or PVC membrane with polyester fleece insert), the manufacturer must clearly specify at the beginning of the test which layer is responsible for penetration and root resistance.

6 Test Conditions

6.1 Preparation and Installation of the 8 Test Vessels

The following layer structure is provided in the vessels (from bottom to top):
moisture layer, protective layer, membrane or coating to be tested, vegetation support layer, planting.
Directly above the transparent base of the vessel, the lowest layer—the moisture layer—is applied with a thickness of (50±5) mm.
The protective layer is cut to match the base dimensions of the vessel and placed directly on the moisture layer.
The membrane or coating to be tested is then installed on the protective layer as described in Sections 6.1.1 and 6.1.2.
After the installation of the membrane or coating to be tested, the vegetation substrate is firmly filled to a layer thickness of (150±10) mm. This corresponds to a substrate volume of 96 l for test vessels of 800 x 800 mm (4-year test) and 88 l (2-year test) (see 4.6).

For each test container measuring 800 x 800 mm, 4 Alnus incana (grey alder) are to be planted for the 4-year test, and 4 Pyracantha coccinea (firethorn) for the 2-year test, evenly distributed over the available area (see Figure 3). In addition, 2 g of Agropyron repens (couch grass) seed per container are to be evenly sown on the vegetation support layer for both tests. If larger test containers are required, the number of plants must be increased to ensure at least the same planting density is achieved (see Section 4.10). The ceramic cell of the tensiometer must be placed in the vegetation support layer directly above the membrane or coating, so that the measurement occurs in the lowest region of the root zone. The tensiometer must be arranged at a uniform distance from the plants (see Fig. 3). The containers should preferably be placed on racks, to allow periodic inspections for root penetration. A minimum distance of 0.4 m on all sides between containers must be maintained. The containers are to be arranged randomly.

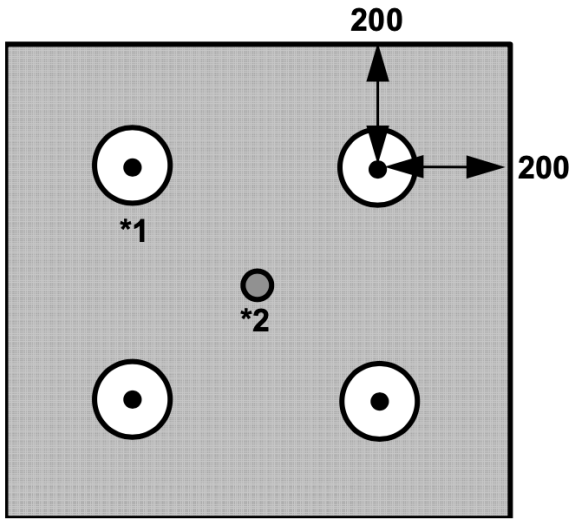


Fig. 3: Arrangement of the shrubs (*1) and the tensiometer (*2) in the vegetation-bearing layer in a vessel of 800 x 800 mm (dimensions in mm)

6.1.1 Installation of Root Protection, Roof, and Sealing Membranes to Be Tested

Sections of the membrane to be tested are cut out and professionally installed and joined in the vessels at the test site under the responsibility of the client. The installation must include 4 wall corner seams, 2 floor corner seams, and 1 centrally running T-joint (see Fig. 4). It is permissible to use different joining techniques as long as they are equivalent (see 2.8). The membrane must be extended up the vessel walls to the edge.

6.1.2 Installation of Coatings to Be Tested in Liquid Application

The coatings in liquid application are also to be professionally installed in the containers at the test site under the responsibility of the client. The coating must be applied in 2 work steps, with a continuous work interruption joint to be arranged in the middle of the container. The time interval between the two work steps must be at least 24 hours. The coating must be extended up to the edge of the container wall.

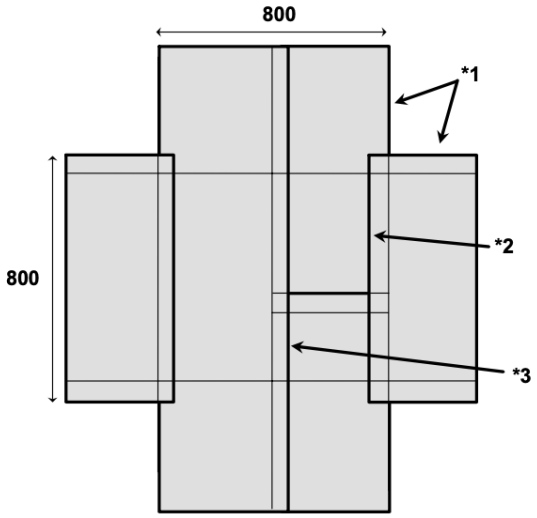


Fig. 4: Arrangement of the seams (*1 = wall corner seam, *2 = floor corner seam, *3 = T-joint) in the membrane to be tested (dimensions in mm)

6.2 Preparation and Installation of the 3 Control Vessels

The preparation and installation of the control vessels is carried out as described in section 6.1, but no membrane or coating to be tested is installed, i.e., directly above the protective layer, the vegetation layer follows.

6.3 Plant Maintenance During the Growth Period

The substrate moisture must be adjusted to the needs of the plants by watering from above onto the vegetation layer. The moisture (suction tension) is to be monitored using the tensiometer. To ensure proper seed germination and establishment of shrubs, irrigation is carried out during the first 8 weeks after greening whenever the suction tension falls below -100 hPa. During the remainder of the test period is only watered when the suction tension drops to a value between -300 and -400 hPa. The amount of water given must be measured so that a suction tension close to 0 hPa is achieved in the substrate. Care must be taken to ensure that

the entire vegetation support layer (including edge areas) is evenly moistened. Prolonged waterlogging in the lower part of the vegetation support layer must be avoided. To prevent damage to the tensiometer, it must be removed during the 4-year test at the beginning of the first frost period. Watering during the vegetation dormancy should be adjusted to the very low water requirements of the plants. After the last frost in spring, the tensiometer is to be reinstalled in the same place. Watering then continues as previously described.
The moisture layer must be kept constantly moist by pouring water into the fill pipe on the container.

Fertilization is carried out every six months during the 2-year test with a fertilizer and at an application rate as described in section 4.8. The first application is made 3 months after planting. During the 4-year test, fertilization is carried out once a year in March or April.
Any emerging weeds and dead plant parts on the surface of the vegetation support layer must be removed. Dead shrubs (firethorn or alder) must be replaced. To avoid significantly disturbing the developing root systems of the remaining plants, this is only permitted during the first 3 months of the 2-year test or during the first 6 months of the 4-year test. If more than 25% of the shrubs fail during the test, the test must be restarted (see 2.15).

Pruning of the shrubs (firethorn or alder) in height is not permitted. In the area of the paths between the containers, side shoots obstructing access may be pruned. An incomplete grass cover (less than 40% of the area covered) must be supplemented by up to two reseedings within the first 3 months (2-year test) or 6 months (4-year test). To avoid lodging of the grass, the stalks must be cut back to approx. 5 cm in length when a growth height of approx. 20 cm has been reached. In the case of severe pest infestation of the plants or the occurrence of harmful plant diseases, suitable plant protection measures must be taken.

7 Evaluations

7.1 Evaluations during the test

In the 2-year test as well as in the 4-year test, the transparent bottom of all 8 test containers must be checked from below at intervals of six months for visible roots and rhizomes (i.e., successful penetration). If penetrations are detected in the test containers, the client of the investigation must be informed. The test may be terminated (see 2.15). In addition, no interim results may be passed on in written form during the test. Every six months (2-year test) or annually (4-year test), the growth performance of the shrubs (firethorn or alder) in all test and control containers must be recorded by measuring the height and stem diameter at 20 cm above ground. The spread of grass on the surface of the substrate is also recorded (see 2.7). The average growth performance of the plants in the test containers must be determined and compared with the result of the control containers. If, according to section 2.6, insufficient growth performance is achieved, the test must be repeated (see 2.15). Any plant damage such as leaf deformation or leaf discoloration must be recorded separately.

7.2 Evaluations at the end of the test

The date of the upcoming final evaluation must be communicated to the client of the investigation to allow participation. The growth performance of the plants must be recorded finally, as described in section 7.1.

At the end of the test, the vegetation support layer is removed from all test containers and the membrane or coating is examined for penetrated roots and/or rhizomes. According to sections 2.9, 2.10, and 2.12, the number of penetrated roots and/or rhizomes for the tested membrane or coating is recorded in absolute figures. This is done separately for the following areas:

- for root protection, roof, and sealing membranes:
    - the surface area and…
- the seams;
- for liquid-applied coatings:
    - the surface area and, if applicable,
    - the work joint, if this is recognizable.

If more than 50 roots or rhizomes are found to have penetrated the surface of a membrane or coating per container, the evaluation of these penetrations is carried out—deviating from the aforementioned—only on a partial section of the tested material. The evaluation must extend over at least 0.2 m^2 (about 20% of the substrate-covered membrane or coating) and be conducted in the area shown in Figure 5. In the case of root or rhizome penetration in the overlap area of seams, the maximum penetration depth must be recorded. Roots or rhizomes that have penetrated must be documented photographically by way of example.

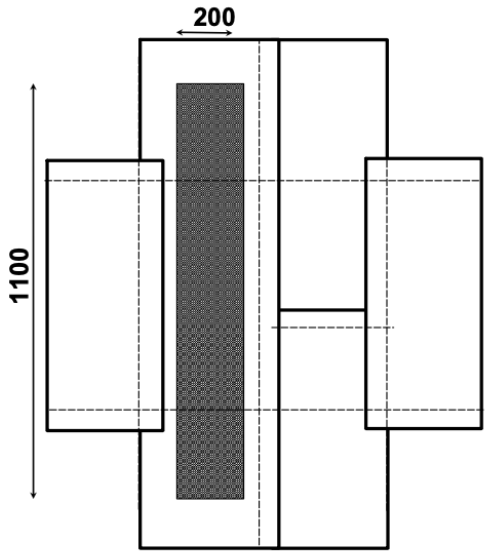


Fig. 5:
Area of evaluation of penetrations into the surface of a tested membrane or coating in the case of > 50 penetrations per container (dimensions in mm)

Samples must be taken from the tested membrane or coating that approximately reflect the result of the investigation. The samples are to be stored in accordance with Section 5.

8 Test Report

No interim results may be disclosed in writing during the test.