WEIHENSTEPHAN · TRIESDORF
University of Applied Sciences

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

Product description:

WOLFIN IB

Client:

BMI Group
Am Rosengarten
5
63607 Wächtersbach-Neudorf

The report comprises 32 pages and may only be used in unabridged form.
The report is valid until 10.08.2028 Date
of the report: 10.10.2023

This report is the 2nd extension of report no. 16/08 dated 10/08/2008 (1st extension: report 14/18 dated 18/07/2018).

Information from WOLFIN Bautechnik GmbH dated 22 November 2006 on the characteristics and material properties of the tested sheeting

WOLFIN IB

- **Product names:** WOLFIN IB
- **Area of application:** Roof and building waterproofing
- **Material designation:** PVC-P-BV
- **Thickness of the sheet (without lamination):** 1.5 mm
- **Equipment/structure (from top to bottom):** homogeneous throughout
- **Delivery form:** Rolls 1100 mm and 1620 mm
- **Manufacturing technology**: Extrusion
- **Material standards:** DIN 16730, DIN 16937
- **Test certificates:** e.g. DIN 16726, DIN 53387, DIN 53472, SIA 280
- **Year of production:** 2006
- **Layer that assumes the function of root penetration protection:** entire path
- **Installation technology at the test site:**
  - Overlap: approx. 5 cm
  - Joining technology: Welding with hot air, swell welding
  - Joining agent: THF (tetrahydrofuran)
  - Seam sealing: none
  - Corner reinforcement: with prefabricated corners made of the same material
  - Cover strips over seams: none
- **Biocidal additives with information on concentration:** 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 and penetration by plant roots and rhizomes (underground shoots).

In the study carried out, the WOLFIN IB membrane from the BMI Group, Am Rosengarten 5, 63607 Wächtersbach-Neudorf, Germany, was tested for root and rhizome strength.

2 Test facility and realisation

The test was carried out according to the "Procedure for testing the root resistance of membranes and coatings for green roofs" with a 2-year duration (FLL, 2002).

The test was carried out from August 2006 to August 2008. It comprised 8 vessels, which were equipped with the test track and 3 vessels without track as a control for plant growth.

In accordance with the specifications, the BMI Group joined 5 sections of the membrane per test vessel at the test site and installed them in the vessels. In addition to longitudinal seams, 4 wall corner seams, 2 bottom corner seams and 2 T-seams were made per vessel

Retained samples were taken from the tested web before and after the test and stored at the testing institute.

The containers were placed in a heated greenhouse.

Firethorn (*Pyracantha coccinea* 'Orange Charmer') and couch grass (*Agropyron repens*) were used as test plants, which also grow well in the winter months under the set climatic conditions. Couch grass, a native grass, forms rhizomes (underground shoots) which, like roots, are capable of damaging pathways.

The complete description of the procedure is given in Appendix 3 of this report.

3 Manufacturer's information on the tested railway

The investigation of root penetration resistance is linked to the characteristics and material properties of the tested sheeting and the joining and manufacturing technology used. The manufacturer's specifications for the tested WOLFIN IB sheeting are listed on page 2 of the report.

4 Results

4.1 Plant development

The planted shrubs and the sown couch grass showed good development throughout the study period.

The required relative minimum growth performance of the woody plants in the test containers (80 % of the average growth performance of the woody plants in the control containers) was clearly exceeded at 97-106 % on the four evaluation dates.

From the first interim evaluation (February 2007) onwards, couch grass exhibited a high population density throughout the duration of the trial. On average, 70-79 % of the area in the 8 test containers was covered with couch grass on the individual evaluation dates (target value ≥ 40 %).

Detailed information on the growth performance of the test plants is summarised in Appendix 2.

4.2 Rooting in or through

After 2 years (August 2008), the tested WOLFIN IB sheet showed no roots or rhizomes growing in or through both the surface and the seams (see photos in Appendix 1).

5 Conclusion

The BMI Group's WOLFIN IB membrane tested from August 2006 to August 2008 in accordance with the "Procedure for testing the root resistance of membranes and coatings for green roofs" (FLL, 2002) showed no penetrating or penetrating roots or couch grass rhizomes in any of the 8 test containers.

The WOLFIN IB membrane is therefore considered root-resistant according to the FLL method and rhizome-resistant against couch grass according to the FLL method.

The FLL method includes all the relevant elements of the European standard EN 13948, even going beyond its requirements, and is therefore considered by experts to be of higher quality. From a technical point of view, the WOLFIN IB membrane tested in accordance with the FLL method can therefore also be labelled as root-resistant in accordance with EN 13948.

The root resistance test is linked to the characteristic data and material properties of the tested sheeting listed on page 2 of the report and the joining and manufacturing technique used. Retained samples of the tested sheeting are kept at the Institute of Horticulture.

The test report prepared in August 2008 with a validity period of 10 years was extended in 2018 for the first time by 5 years and now for the second time by 5 years, taking into account the requirements of the current FLL test procedure (2008). The report is therefore valid until 10 August 2028. The report comprises 32 pages and may only be used in unabridged form.

signed. Heinz-Josef Schmitz
Dipl.-Ing. (FH) Heinz-Josef Schmitz
10.10.2023

signed. Dieter Lohr
Dr Dieter Lohr
10.10.2023

Weihenstephan-Triesdorf University of Applied Sciences,
Institute of Horticulture , Am Staudengarten 14, D-85354 Freising
Tel.: +49 (0) 8161 / 71-5659, Fax: +49 (0) 8161 / 71-3348
E-mail: heinz-josef.schmitz@hswt.de

Appendix 1

Photos of the tested railway WOLFIN IB (August 2008)

Fig. 1: Top of the railway (detail)

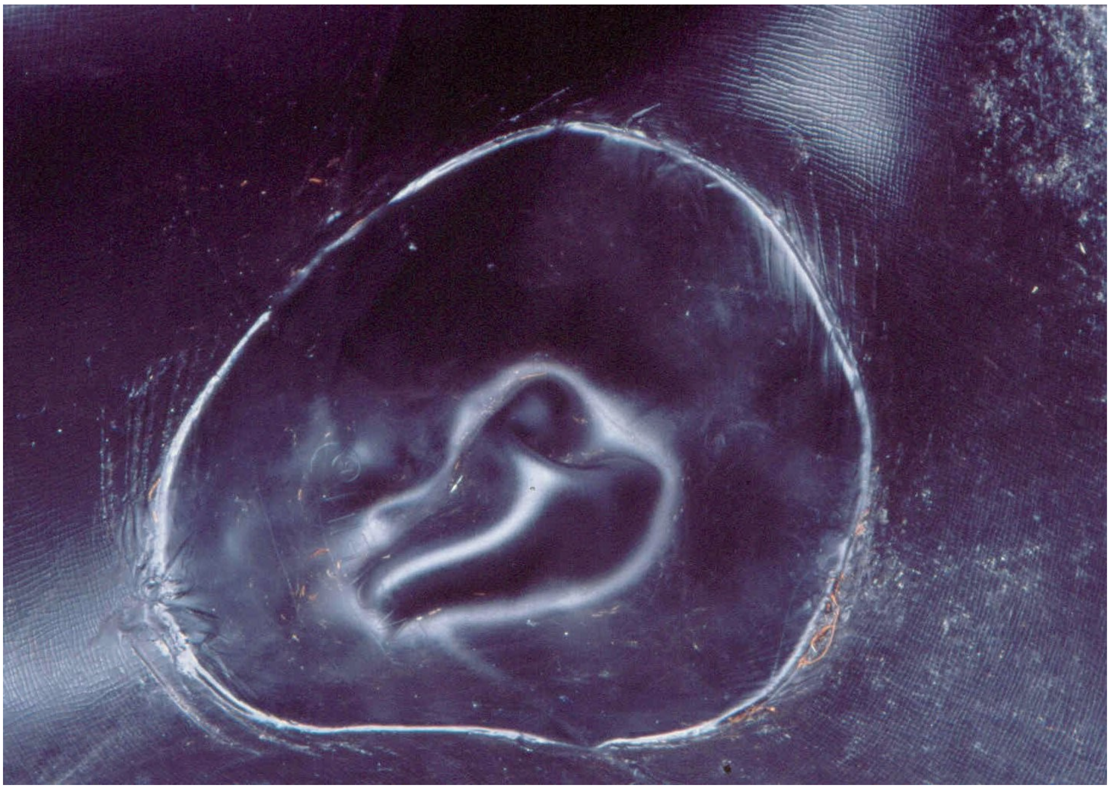

Fig. 2: Track top with reinforced corner

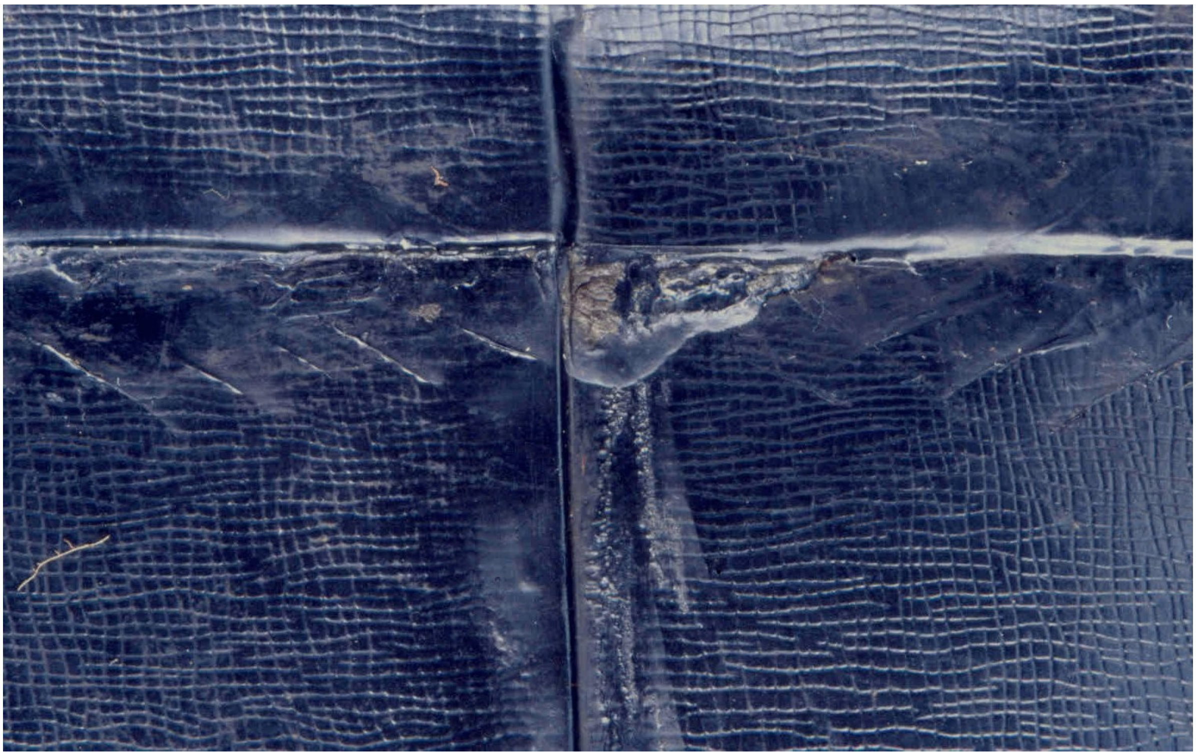

Fig. 3: Track top with T-joint

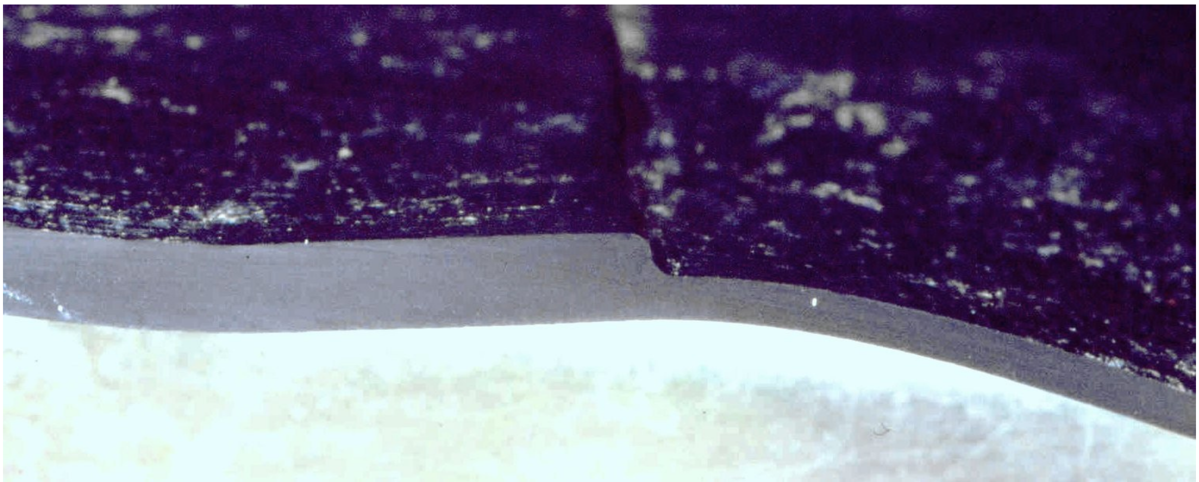

Fig. 4: Section through a seam of the web

Appendix 2

Data on plant development

Table 1: Height and stem diameter of firethorn in the 3 control containers

Vessel no.	Wood no.	february 2007		August 2007		february 2008		August 2008	
		Ø (cm) 1)	Height cm	Ø (cm) 1)	Height cm	Ø (cm) 1)	Height cm	Ø (cm) 1)	Height cm
K 1	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
K 2	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
K 3	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

Vessel no.	Wood no.	february 2007		August 2007		february 2008		August 2008	
		Ø (cm) 1)	Height cm	Ø (cm) 1)	Height cm	Ø (cm) 1)	Height cm	Ø (cm) 1)	Height cm
K 1- K 3	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

Vessel no.	Wood no.	februar y 2007		August 2007		februar y 2008		August 2008	
		Ø (cm) 1)	Heig ht cm	Ø (cm) 1)	Heig ht cm	Ø (cm) 1)	Heig ht cm	Ø (cm) 1)	Heigh t cm
P 1	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
P 2	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
P 3	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
P 4	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
P 5	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
P 6	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
P 7	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
P 8	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

1) Stem diameter, measured 20 cm above the substrate surface

Table 4: Average height and stem diameter of firethorn in the 8 test containers

Vessel no.	Wood no.	februar y 2007		August 2007		februar y 2008		August 2008	
		Ø (cm) 1)	Heig ht cm	Ø (cm) 1)	Heig ht cm	Ø (cm) 1)	Heig ht cm	Ø (cm) 1)	Heigh t cm
P 1- P 8	1-4	1,36	213	1,59	241	1,83	261	2,13	310

1) Stem diameter, measured 20 cm above the substrate surface

Table 5: Average values of firethorn in the 8 test containers in relation to the values of the plants in the 3 control containers (target value: 80 %)

Vessel no.	Wood no.	februar y 2007		August 2007		februar y 2007		August 2008	
		Ø %	Height %	Ø %	Height %	Ø %	Height %	Ø %	Height %
P 1- P 8	1-4	103	104	104	106	101	97	100	100

1) Stem diameter, measured 20 cm above the substrate surface

Table 6: Assessment of couch grass population density in the 3 control pots

Vessel no.	februar y 2007	August 2007	februar y 2007	August 2008
	Stock density (in %)	Stock density (in %)	Stock density (in %)	Stock density (in %)
K 1	65	75	75	80
K 2	65	60	60	65
K 3	65	75	80	80

Table 7: Average values of couch grass population density in the 3 control plots

Vessel no.	februar y 2007	August 2007	februar y 2008	August 2008
	Stock density (in %)	Stock density (in %)	Stock density (in %)	Stock density (in %)
K 1- K 3	63,3	71,2	71,2	75,0

Table 8: Assessment of couch grass population density in the 8 test containers

Vessel no.	february 2007	August 2007	february 2008	August 2008
	Stock density (in %)	Stock density (in %)	Stock density (in %)	Stock density (in %)
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 values of couch grass density in the 8 test pots (target value: 40 %)

Vessel no.	february 2007	August 2007	february 2008	August 2008
	Stock density (in %)	Stock density (in %)	Stock density (in %)	Stock density (in %)
P 1-P 8	70,0	75,0	78,8	72,5

Appendix 3

Method for analysing root strength of membranes and coatings for green roofs

FLL

Research Association for Landscape Development Landscaping e.V.

Colmantstr. 32
53115 Bonn

Introduction

In 1984, a working group of the Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V. (FLL) developed a "Procedure for investigating the root penetration resistance of root protection membranes" to rule out vegetation-related structural damage caused by green roofs. The method is essentially based on experience and findings from several years of tests with different geomembranes and different plant species, which were carried out at the Institute of Soil Science and Plant Nutrition, Weihenstephan University of Applied Sciences, from 1975 to 1980. The FLL method was revised in 1992 and for the last time in 1995.

It is highly valued by manufacturers, planners and contractors, as evidenced by the large number of completed and ongoing studies.

In 1993, the FLL decided to re-examine the previous procedure with a test duration of 4 years, with the aim of reducing the test duration to 2 years without weakening the intended strict standards of the previous test.

After numerous trials at the Institute of Soil Science and Plant Nutrition, Weihenstephan University of Applied Sciences, it was finally possible to agree on these specifications: The 2-year test takes place in a climate-controlled greenhouse, whereby the plant species used grow throughout the year under the appropriate temperature and light conditions. This results in an effective growth period of 24 months, which is of a similar duration to the 4-year test, taking into account the annual dormancy phase of the vegetation under outdoor conditions lasting several months. Both tests are considered equivalent and are described together in this new version of the method.

In the course of changes to the content, a formal reorganisation was also carried out to make the procedure easier to understand and to make it easier for the audit institutions to assess the results found.

1 Scope of application

The method applies to the determination of the resistance to penetration and penetration of roots and rhizomes of the test plants used for

- Root protection sheets,
- Roofing and sealing membranes and
- Coatings in liquid application

for all forms of green roofs (intensive green roofs, simple intensive green roofs, extensive green roofs).

The procedure includes the testing of products including the associated joining techniques. It is therefore only permissible for testing individual membranes or coatings. It is not possible to test a roof waterproofing system, i.e. a roof waterproofing structure consisting of several layers.
For testing reasons, it may be necessary to install a separate layer under the coating in the case of liquid-applied coatings. This is permitted if the manufacturer clearly states that the root resistance is achieved solely by the coating applied on top.
Lamination, i.e. a separate layer on the web or coating to be tested, is excluded in all cases.

The result of the tested sheet or coating is not transferable to the penetration and penetration resistance against plants with strong rhizome growth (e.g. bamboo and Chinese reed species). If such plant species are used, structural precautions over and above the penetration and penetration protection found must be taken and special maintenance measures provided.

The procedure does not include any assessments of the environmental compatibility of the products tested.

2 Definitions

The following definitions apply to the application of this procedure:

2.1 Test vessels

Vessels with minimum dimensions specially equipped for the test, which are filled with the web or coating to be tested (test vessels) or with a fleece (control vessels).

2.2 Moisture layer

The moisture layer consists of coarse-grained mineral material that is placed underneath the membrane or coating to be tested. It is kept constantly moist and thus enables roots and rhizomes that have penetrated the membrane or coating to grow through to the transparent base of the vessel, thus enabling early detection of penetrations.

2.3 Protective layer

Fleece compatible with the web or coating, which is placed directly under the material to be tested on the moisture layer in order to achieve even pressure distribution.

2.4 Vegetation support layer

Standardised growing medium (mixture of substances) that is available or can be produced in the same way at all times and at all test locations. It is structurally stabilised, has a favourable water/air balance and low basic fertilisation, thus promoting optimum root development of the test plants. The vegetation support layer is in direct contact with the track under investigation.

2.5 Test plant species

2.5.1 For the 2-year examination

- *Pyracantha coccinea* 'Orange Charmer', an ornamental shrub that exhibits root growth suitable for the test under the specified greenhouse conditions all year round, and
- *Agropyron repens*, couch grass, a native grass with low-growing rhizomes, whose colonisation on green roofs can hardly be avoided and which also grows sufficiently throughout the year under the test conditions.

2.5.2 For the 4-year examination

- *Alnus incana*, grey alder, a wild shrub that exhibits root growth suitable for the test under the specified outdoor conditions during the growing season, and
- *Agropyron repens*, couch grass.

2.6 Sufficient growth performance of the test plants

The woody plants (firethorn or alder) in the test containers must have an average of at least 80 % of the average growth performance (height, stem diameter) of the plants in the control containers during the entire test period. This allows any impairment of the test plants by plant-damaging substances released by the sheeting or coating to be recorded. The spread of couch grass on the substrate surface is assessed visually (bonitised, see 2.7). From the first interim evaluation (see 7.1), the plants in the test containers must have an average stand density of at least medium throughout the duration of the trial (see 2.7).

2.7 Assessment of the couch grass population

In the visual assessment, numbers are assigned to the stand density of the couch grass growth. The following categorisation is used:

1 = hardly any couch grass present (around 0-20 % of the area covered)
2 = sparse stand (about 20-40 % of the area covered)
3 = medium stand (around 40-60 % of the area covered)
4 = dense stand (around 60-80 % of the area covered)
5 = very dense stand of couch grass (covering around 80-100 % of the area)

2.8 Equivalent joining techniques

It is permissible to combine different joining techniques in the test, as long as the aim is to achieve seam joints that are homogeneous in terms of material (e.g. swell welding - with a solvent that volatilises - and hot gas welding). Such seam joints are regarded as equivalent. In contrast, combinations of adhesive-free joints and joints with adhesive mass or joints with 2 different adhesive masses are not considered to be of equal value.

2.9 Root penetration

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

Not to be categorised as root penetration, but to be listed in the test report:

- Roots (i.e. no damage) that have grown into existing pores of a web or coating (surface or seam or interruption joint). In order to ensure a clear assessment, it is necessary to examine the relevant sheet or coating sections under a microscope.
- Roots that have grown into the surface or seam or work interruption joint ≤ 5 mm with membranes and coatings that contain radical active substances (root inhibitors), as the root-inhibiting effect can only be developed after the roots have penetrated. To enable such an assessment, such membranes or coatings must be clearly defined by the manufacturer at the start of the test as "containing radicides".
- Roots growing into the surface in the case of products consisting of several layers (e.g. bitumen sheeting with copper tape inlay or PVC sheeting with polyester fleece inlay), if the layer that provides the penetration and penetration protection is not damaged in the process. To enable such an assessment, this layer must be clearly defined by the manufacturer at the start of the test.
- Roots penetrating into seam seals (without damaging the seam).

2.10 Root penetration

Roots growing in the surface or in the seams of a tested sheet or coating, which have already utilised existing pores in the sheet or coating or have actively created cavities.

2.11 Root-proof" certificate

A sheet or coating is considered root-resistant if no root penetration in accordance with Section 2.9 and no root penetration in accordance with Section 2.10 can be detected in any of the test containers after the test period has elapsed. It is also a prerequisite that the woody plants used in the test have achieved sufficient growth performance in the test containers throughout the entire test period in accordance with Section 2.6.

2.12 couch grass rhizomes

Since the analysis differentiates between roots and rhizomes, a reliable determination of these underground plant organs is essential.

The following information can be used as a guide:

The couch grass rhizomes (underground shoots) spreading in the vegetation support layer have a uniform thickness of approx. 2 mm and little branching. They are divided into individual sections, delimited by nodes to which inconspicuous leaflets enveloping the stem and thin roots are attached. Between the nodes, the couch grass rhizomes are hollow (see Figure 1).

In contrast, the roots of firethorn vary greatly in thickness and are highly branched. They also never bear leaves and are not hollow.

If the testing institute cannot clearly differentiate between rhizomes and roots, specialist advice should be sought.

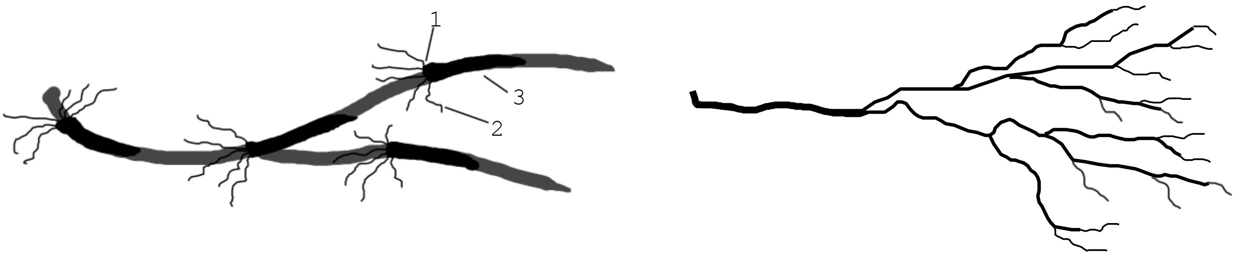

Fig. 1: Schematic representation of a couch grass rhizome (left) with nodes (1), roots (2) and leaves (3) compared to a firethorn root (right)

2.13 Evaluation of couch grass rhizomes

Creeping rhizomes growing into and through the sheet or coating (surface or seam) are detected and listed in the test report, but are not evaluated with regard to root resistance. However, if no damage to the product by rhizomes can be recognised, this is explicitly noted in the test report (see 2.14).

2.14 Test certificate "rhizome-resistant against couch grass"

A sheet or coating is considered to be resistant to couch grass rhizomes if no rhizome penetration or rhizome penetration can be detected in any of the test containers after the test period has elapsed - analogous to root penetration (see 2.9) and root penetration (see 2.10).

A further prerequisite is that the couch grass in the test containers has produced sufficient growth performance throughout the course of the trial (see 2.6).

2.15 Circumstances for premature cancellation of the examination

The client of the test must be informed if roots or rhizomes penetrate the web or coating to be tested in the course of evaluations during the test (see 7.1). The test is cancelled if the penetrations were caused by roots. If rhizomes have penetrated, the test can be continued in consultation with the client.

If more than 25 % of the woody plants fail in the course of the trial, the trial must be replanted, i.e. a new planting must be carried out, whereby the vegetation support layer must also be replaced by a new mixture. The start of the trial must be re-dated accordingly.

The same procedure should be followed if the test plants do not achieve sufficient growth performance in the course of the trial (see 2.6).

3 Brief description of the procedure

In a vessel test with standardised conditions, the penetration resistance of root protection and roofing and sealing membranes or coatings to the roots and rhizomes of the test plant species acting on them is investigated.

In the 4-year test, this is carried out under field conditions using alder and couch grass as test plants. The 2-year test is carried out in a climate-controlled greenhouse using firethorn and couch grass.

The web or coating to be tested, which must have several seams or an interruption joint, is installed in 8 test vessels. A further 3 containers are used in the test without the sheet or coating. They serve as a control for plant growth.

A thin layer of vegetation support is filled into the containers treated in this way. The desired high root pressure should be generated with dense planting, moderate fertilisation and restrained watering.

At the end of the test, the vegetation base layer is removed and the sheet or coating is checked for penetrating and penetrating roots or rhizomes. Retained samples of the analysed sheeting or coating are stored at the testing institute.

4 Experimental equipment and material

4.1 Location for the realisation

4.1.1 For the 4-year examination

A hall is to be provided that is equipped with a transparent roof covering and is otherwise open on all sides. This creates almost open-air conditions, but precipitation that could lead to waterlogging in the drainage-free containers is kept out.

An unheated greenhouse is also permitted as a location, provided it has sufficient ventilation options and allows frost exposure.

4.1.2 For the 2-year examination

A greenhouse equipped with adjustable heating and ventilation must be provided. The heating must be set so that the internal temperature is (18±3)°C during the day and (16±3)°C at night. From an internal temperature of (22±3)°C, the greenhouse must be ventilated. A sustained indoor temperature > 35 °C must be avoided.

The natural light conditions in Central Europe ensure favourable growth of the test plants throughout the year at the specified temperatures. Shading of the plants in summer or artificial lighting in winter are not necessary.

The space required per container (800 x 800 mm) while maintaining the required minimum distance in accordance with section 6.1 is around 1.5 to 2 m², depending on the arrangement of the containers.

4.2 Test vessels

The test vessels must have internal dimensions of at least 800 x 800 x 250 mm. It may be necessary to use larger test vessels if installation requirements are taken into account.

The test containers should be fitted with a transparent base (e.g. acrylic glass) so that roots that have grown through can be recognised during the experiment without disturbing the vegetation support layer. The soil must be darkened (e.g. with light-impermeable foil) to prevent algae growth in the moisture layer.

The transparent container base should ideally be designed as an insert with a 20 mm high upstand in order to provide the moisture layer with sufficient water. The water is fed into the moisture layer via a filling pipe (Ø approx. 35 mm), which is attached to the outside of the containers and is positioned diagonally upwards and flush with the upstand of the insert base (see Figure 2).

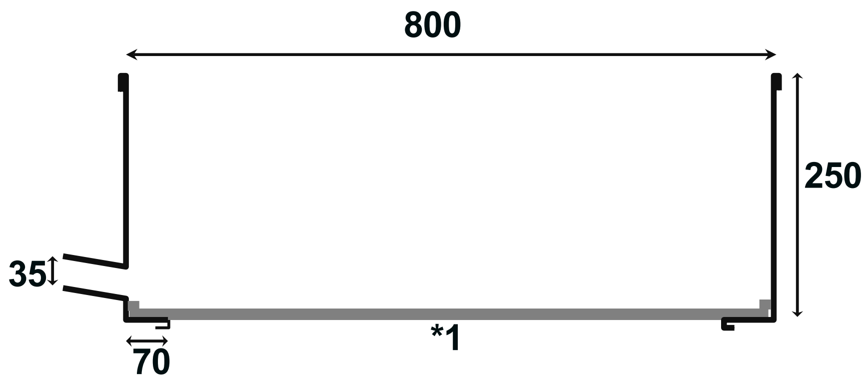

Fig. 2: Structure of the test vessels (minimum dimensions, in mm, *1= transparent base with upstand)

8 test vessels are required for each web or coating to be tested. In addition, 3 control vessels (without web or coating) must be prepared for each test run, regardless of the number of webs or coatings to be tested.

4.3 Moisture layer

This layer consists of expanded shale or expanded clay (grain size 8-16 mm), which must be of the quality specified in Table 1. In order to avoid having to carry out your own analyses, it makes sense to only use products that are subject to constant quality control with regard to the specified guide values, whereby the manufacturer can guarantee the required properties.

With the required layer thickness of (50±5) mm (see 6.1), the material requirement is around 32 litres per test vessel (800 x 800 mm).

4.4 Protective fleece

A fleece made of synthetic fibres with a weight of approx. 200 g/m^{2}must be used. The material compatibility of the fleece with the web or layer to be tested must be ensured. The material requirement is 0.64 m² per test vessel (800 x 800 mm).

4.5 Web or coating to be tested

The membrane or coating must be installed or applied in accordance with section 6.1. For each container with the minimum dimensions (800 x 800 x 250 mm), the calculated area to be covered (minus the 50 mm thick moisture layer) is around 1.3 m² (without overlap).

4.6 Vegetation substrate

The substrate consists of:

- 70 % by volume of slightly decomposed raised bog peat and
- 30 % by volume expanded clay or expanded shale (grain size 8-16 mm), which must be of the quality specified in Table 1. As described in section 4.3, it makes sense to use only quality-tested products.

The substrate should be adjusted to a pH value ($CaCl_2$) between 5.5 and 6.5 by adding carbonated lime (see 4.7).

The basic fertiliser defined in section 4.8 is mixed homogeneously into the vegetation base layer before filling.

The substrate requirement for the 4-year test with the required layer thickness of (150±10) mm is around 96 litres per test container (800 x 800 mm), and around 88 litres per test container (800 x 800 mm) for the 2-year test (taking into account the substrate supply by means of the plants' pot bales).

Table 1: Required quality of expanded clay/expanded shale. Determination in the water extract of the ground material with demineralised water in a ratio of 1:10 (w/v)

Soluble salts (calculated as KCl)	< 0.25 g/100 g
CaO	< 120 mg/100 g
Na2O	< 15 mg/100 g
Mg	< 15 mg/100 g
Cl	< 10 mg/100 g
F	< 1.2 mg/100 g

4.7 pH adjustment

Different amounts of carbonated lime may be required for the vegetation base layer in order to achieve the desired pH value of 5.5-6.5.

The required quantity can be determined using the following procedure:

- Take 5 samples of the well-mixed vegetation base layer, 1 litre each,
- moisten the samples with tap water,
- Add different amounts (4, 5, 6, 7 or 8 g) of carbonated lime to the individual samples,
- Place samples in plastic bags, seal and label,
- Store samples in the bag for approx. 3 days at room temperature,
- Send samples to a test laboratory that works according to the VDLUFA association methods and request a pH analysis in $CaCl_2$,
- Extrapolate the amount of lime that led to the desired pH value in the sample of 1 litre to the entire volume of the vegetation base layer.

4.8 Fertiliser

A complex fertiliser with approx. 15% N, 10% P_2O_5, 15% K_2O, 2% MgO and less than 0.5% Cl as well as a trace nutrient fertiliser with iron (Fe), copper (Cu), molybdenum (Mo), manganese (Mn), boron (B) and zinc (Zn) should be used as a basic fertiliser. Apply 30 g of complex fertiliser per container (800 x 800 mm). The trace nutrient fertiliser is used in the quantity recommended by the manufacturer for substrates.

For top dressing, a slow-acting, coated compound fertiliser with approx. 15 % N, 10 % P_2O_5, 15 % K_2O and an effective period of 6-8 months should be applied. The fertiliser requirement per application is 30 g/container (800 x 800 mm).

4.9 Tensiometer

A tensiometer with a measuring range of 0 to -600 hPa should be used per container to check the irrigation of the vegetation base layer.

4.10 Experimental plants

In the 4-year test, the following 2 species are to be used as test plants in the specified qualities:

- *Alnus incana* - grey alder, 2-year-old transplanted seedling, height 60-100 cm and
- *Agropyron repens* - couch grass, seed.

In the 2-year test, the following 2 species are to be used as test plants in the specified qualities:

- *Pyracantha coccinea* 'Orange Charmer' - Firethorn, in a 2-litre container, height 60-80 cm and
- *Agropyron repens* - couch grass, seed.

Each test container measuring 800 x 800 mm should contain 4 woody plants (alder, firethorn) and 2 g of couch grass seed. This results in a planting density of 6.25 woody plants/m² and 3.13 g seed/m². If larger trial containers are used, at least the above-mentioned planting density must be achieved by increasing the number of plants or seed quantity.

When purchasing woody plants, care should be taken to ensure a uniform plant quality.

4.11 Pouring water

The irrigation water must be of the minimum quality specified in Table 2. The water quality can be obtained from the responsible waterworks.

If one of the values specified in Table 2 is exceeded, the irrigation water must be mixed with fully demineralised water or rainwater accordingly.

Table 2: Minimum quality of the irrigation water

Conductivity	< 1000 µS/cm
Total alkaline earths	< 5.4 mmol/l
Acid capacity (up to pH 4.3)	< 7.2 mmol/l
Chloride	< 150 mg Cl/l
Sodium	< 150 mg Na/l
Nitrate	□ 50 mg NO3/l

5 Sampling and information from the manufacturer

The testing institute must take a reference sample of the web or coating before and after the test. The section taken must contain at least one joint per joining technique or an interruption joint and have an area of at least 0.5 m². The retained sample must be stored at temperatures above 5 °C and below 25 °C in a dry and dark place at the testing institute.

The duration of storage must be at least as long as the validity period of the test report (see 8).

Material incompatibilities must be observed during storage.

In order to clearly identify the tested product, the following information must be requested from the manufacturer at the beginning of the test: Product name, area of application, material designation, material standards, thickness (without lamination), equipment/structure, delivery form, manufacturing technique, test certificates, year of manufacture, installation technique at the test location (overlap, joining techniques used, joining agent, type of seam sealing, cover strips over seams, separate corner and angle joints), addition of biocides (e.g. root inhibitors) with information on concentration. In addition, a product data sheet for the sheet or coating to be tested must be submitted to the testing institute.

In addition, in the case of products consisting of several layers (e.g. a membrane with copper tape inlay or PVC membrane with polyester fleece inlay), the manufacturer must clearly specify at the start of the test which layer provides the penetration and permeation protection.

6 Test conditions

6.1 Preparation and installation of the 8 test vessels

The following layer structure is provided in the containers (from bottom to top): Moisture layer, protective layer, membrane or coating to be tested, vegetation support layer, planting.

The moisture layer with a thickness of (50±5) mm is applied directly above the transparent container base as the bottom layer.

The protective layer is cut to the dimensions corresponding to the base area of the vessel and laid directly on the moisture layer.

The membrane or coating to be tested is installed on the protective layer as described in sections 6.1.1 and 6.1.2.

After the membrane or coating to be tested has been installed, the vegetation substrate is filled in firmly in a layer thickness of (150±10) mm. For containers measuring 800 x 800 mm, this corresponds to a substrate volume of 96 litres (4-year test) or 88 litres (2-year test) (see 4.6)

For each 800 x 800 mm test container, 4 *Alnus incana* (grey alder) must be planted evenly over the available area in the 4-year test and 4 *Pyracantha coccinea* (firethorn) in the 2-year test (see Figure 3). In addition, 2 g of *Agropyron repens* (couch grass) seeds are planted evenly per container in both tests.

sown on the vegetation base layer.

If larger test containers are required, the number of plants must be increased so that at least the same plant density is achieved (see 4.10).

The ceramic cell of the tensiometer must be placed in the vegetation support layer directly above the sheet or coating so that the measurement can be taken in the lowest area of the root zone. The tensiometer must be positioned at an even distance from the plants (see Fig. 3).

It is advisable to place the containers on racks to allow for periodic root penetration checks. A minimum distance of 0.4 m must be ensured between the containers on all sides. The containers should be arranged randomly.

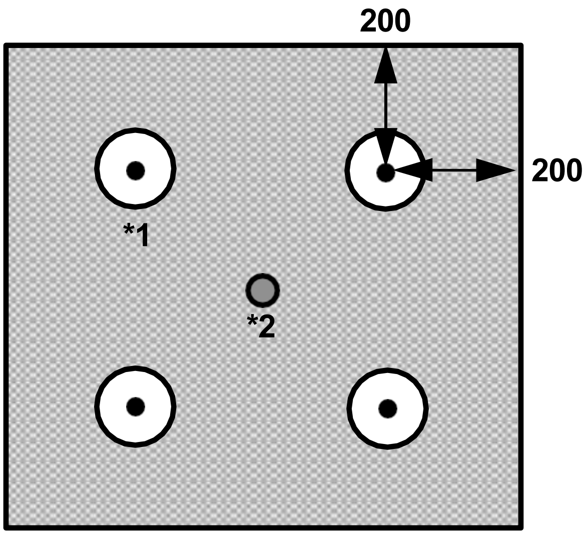

Fig. 3: Arrangement of the woody plants (*1) and the tensiometer (*2) in the vegetation base layer in a container measuring 800 x 800 mm (dimensions in mm)

6.1.1 Installation of root protection, roofing and sealing membranes to be tested

Parts are cut out of the web to be examined and installed and joined in the vessels at the place of examination under the responsibility of the person commissioning the examination. Four wall corner seams, two floor corner seams and one centred T-seam must be made (see Figure 4). It is permissible to use different joining techniques as long as they are equivalent (see 2.8). On the walls, the sheet must be pulled up to the edge of the vessel.

6.1.2 Installation of coatings to be tested in liquid application

The coatings in liquid application are also professionally installed in the vessels at the test site under the responsibility of the client of the test. The coating must be applied in 2 work steps, with a continuous work interruption joint in the centre of the vessel. The time interval between the two work steps must be at least 24 hours.

On the walls, the coating must be pulled up to the edge of the vessel.

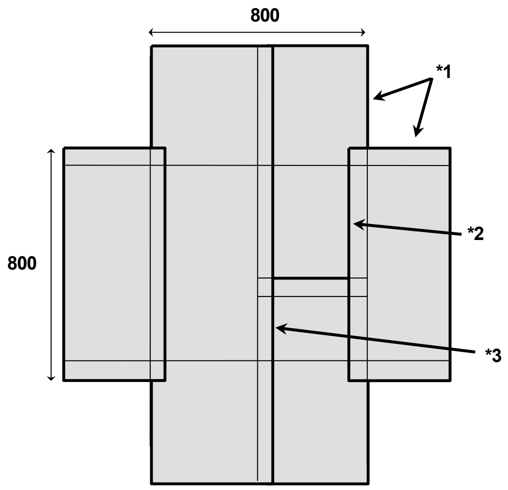

Fig. 4: Arrangement of the seams (*1= wall-corner seam, *2= floor-corner seam, *3 = T-seam) in the web to be analysed (dimensions in mm)

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. the vegetation base layer immediately follows the protective layer.

6.3 Care of the plants during the growing season

The substrate moisture should be adjusted according to the plants' requirements by watering from above onto the vegetation support layer. The moisture (suction tension) must be checked using the tensiometer.

In order to ensure good germination of the seed and growth of the woody plants, irrigation is carried out in the first 8 weeks after planting as soon as the suction tension falls below a value of -100 hPa. In the further course of the trial

is only watered when the suction pressure drops to a value between -300 and -400 hPa. The amount of water should be calculated in such a way that a suction tension in the substrate of almost 0 hPa is achieved. Care must be taken to ensure that the entire vegetation support layer (including edge areas) is evenly moistened. A persistent excess of water (waterlogging) in the lower area of the vegetation support layer must be avoided. To avoid damaging the tensiometers, they must be removed at the start of the first frost period during the 4-year test. Irrigation during the dormant period should be adapted to the plants' very low water requirements. After the last frosts in spring, the tensiometers should be replaced in the same place. From then on, water as described above.

The moisture layer must be kept constantly moist by watering via the filler pipe on the container.

In the 2-year test, top dressing is carried out every six months with a fertiliser and an application rate as described in section 4.8. The first dose is applied 3 months after planting. In the 4-year test, fertiliser is applied once a year in March or April.

Any foreign growth and dead plant parts on the surface of the vegetation base layer must be removed.

Dead woody plants (firethorn or alder) must be replaced. However, in order not to significantly disturb the developing root system of the remaining plants, this is only permitted during the first 3 months in the 2-year test and during the first 6 months in the 4-year test. If more than 25 % of the woody plants fail in the course of the trial, the trial must be replanted (see 2.15).

Pruning the shrubs (firethorn or alder) in height is not permitted. Obstructive side shoots may be pruned in the area of the paths between the containers.

A patchy couch grass stand (< 40 % of the area covered) should be improved by reseeding up to twice in the first 3 months (2-year test) or 6 months (4-year test).

To prevent the couch grass from lodging, the stalks should be cut back to a length of approx. 5 cm when they have reached a growth height of approx. 20 cm.

Suitable plant protection measures must be implemented in the event of severe pest infestation of the plants or the occurrence of plant diseases that endanger the crop.

7 Analyses

7.1 Analyses during the test

In the 2-year test as well as in the 4-year test, the transparent vessel bottom of all 8 test vessels must be checked from below for visible roots and rhizomes (i.e. if penetration has occurred) at six-month intervals.

If there are recognisable penetrations in the test vessels, the client of the test must be informed. The test can be cancelled (see 2.15).

Furthermore, no interim results may be passed on in written form during the experiment.

Every six months (2-year test) or every year (4-year test), the vigour of the woody plants (firethorn or alder) must be recorded in all test and control containers by measuring the height and stem diameter at a height of 20 cm. The spread of the couch grass on the substrate surface is also assessed (see 2.7). The average growth performance of the plants in the test containers is to be determined and compared with the result of the control containers. If no sufficient growth performance is achieved in accordance with section 2.6, the trial must be repeated (see 2.15).

Any plant damage that occurs, such as leaf deformation or leaf discolouration, must be recorded separately.

7.2 Analyses at the end of the trial

The time of the upcoming final evaluation must be communicated to the client of the study in order to enable him to participate.

Finally, the growth performance of the plants must be recorded as described in section 7.1.

At the end of the test, the vegetation support layer is removed from all test containers and the sheet or coating is checked for penetrating roots or rhizomes. In accordance with Sections 2.9, 2.10 and 2.12, the number of roots or rhizomes p e n e t r a t i n g or penetrating through the tested sheet or coating is recorded in absolute numbers.

This is done separately for the following areas

- for root protection, roofing and sealing membranes:
  - the area and

- the seams;
- for coatings in liquid application:
  - the area and, if applicable
  - the work interruption joint, if this is recognisable.

If more than 50 roots or rhizomes penetrating the surface of a sheet or coating are detected per container, these penetrations are only analysed on a section of the tested material - in deviation from the above. The evaluation must cover at least 0.2 m$^{(2)}$ (around 20 % of the substrate-covered sheet or coating) and be carried out in the area shown in Figure 5.

If roots or rhizomes penetrate into the overlapping area of seams, the maximum penetration depth must be recorded.

Roots or rhizomes that have penetrated and permeated the soil should be photographed as examples.

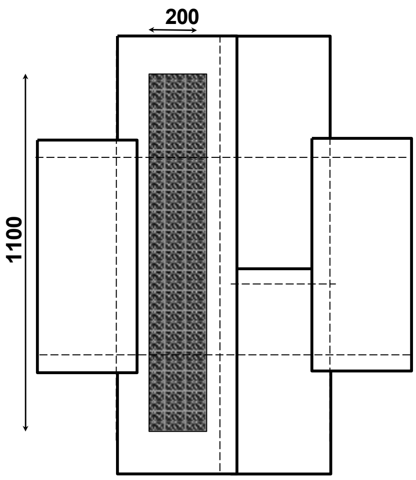

Fig. 5: Range of evaluation of penetrations into the surface of a tested sheet or coating with > 50 penetrations/vessel (dimensions in mm)

Retained samples must be taken from the analysed web or coating, which approximately reflect the result of the analysis. The samples must be stored in accordance with section 5.

8 Test report

No interim results may be announced in writing during the examination.

become.

After completion of the test, a complete test report in duplicate (1 copy each for the testing institute and the client) must be prepared by the respective testing institution, but only if the sheeting or coating has proven to be root-resistant in accordance with Section 2.11. Companies and products that have unsuccessfully participated in the test will not receive a test report, but only a written notification with the justified statement that the membrane or coating has not proven to be root-resistant according to FLL.

The report may only be used in unabridged form. It must contain the following data:

- Manufacturer's information on the analysed web in accordance with section 5,
- detailed information on the preparation of the test containers in accordance with Section 6 (or a note that the test was carried out in accordance with the FLL Guideline, whereby the guideline on which the test was based must be attached in the Annex),
- all results of the analyses are in accordance with section 7 and
- a summarised assessment of the examined railway in accordance with sections 2.11 and 2.13.

The report must also contain the following wording:

- "The test report comprises ..... pages and may only be used in unabridged form".
- "The test results are linked to the characteristic data and material properties of the tested sheet or coating listed in the test report in accordance with the requirements and the equivalent joining techniques used during the test."
- "Retained samples of the analysed web or coating are stored at the testing institute."
- "The test report was created at ..... and is generally valid for 10 years. The validity period can be extended in periods of 5 years by confirmation from the testing institute, but only if
  - the test principles have not been changed in essential points and
  - the tested product still corresponds to the applicant's current delivery programme." A sample test report can be requested from the FLL.

9 Responsibility

The client is responsible for

- Procurement and installation of the protective layer (see 2.3 and 6.1) and the membrane or coating to be tested (see 6.1),
- Submission of a material sample (see 5) and
- Details of the tested sheet or coating (see 5). The

testing institute must provide the following services:

- Provide a suitable area for carrying out the experiment (see 4.1),
- Removal and storage of a material sample (see 5),
- Procurement, composition and installation of the moisture layer and the vegetation base layer (see 4.3, 4.6, 6.1 and 6.2),
- Procurement and installation of tensiometers (see 4.9, 6.1 and 6.2),
- Procurement of the test plants or seeds and planting of the containers (see 4.10, 6.1 and 6.2),
- Care of the plants during the growing season (see 6.3),
- Carry out the evaluation (see 7) and
- Preparation of the test report (see 8).

The procurement of the test vessels (see 4.2) can be undertaken by both the client and the testing institute. The responsibilities must be laid down in a contract between the client and the testing institute. This must also regulate the assumption of the costs incurred during the test by the client.

A sample contract can be requested from the FLL.