SMARTeST Deliverable 2.2: Tests of flood resilient products

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Prepared by

Name	V. Gabalda, B. Koppe, TUHH; D.Kelly, K.Hunter, BRE; C.Florence, CSTB; S. Golz, IOER; J. Diez, J.V. Monnot, P.Marquez, UPM;
Position	WP2 Partners
Signature	Vincent Gabalda

Approved on behalf of SMARTeST

Name	Jean-Luc Salagnac	Dr Stephen L Garvin
Position	Scientific Director	Coordinator
Date	23 December 2012	23 December 2012
Signature		

BRE Scotland
Kelvin Road
East Kilbride
Glasgow, G75 0RZ
T + 44 (0) 1355 576200
F + 44 (0) 1355 576210
E eastkilbride@bre.co.uk
www.bre.co.uk

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Executive Summary

Within the SMARTeST project Flood Resilient Technologies were defined as “technologies with the ability to resist flooding and to enable protection to/from flooding” (SMARTeST Glossary, 2011). Based on this definition the report D2.1 identified the flood resilient products and classified them as follow:

- Perimeter Technologies
- Aperture Technologies
- Building Technologies
- Infrastructure Technologies

One of the main aims of workpackage 2 is the development of an evaluation scheme of technology reliabilities. To complete this objective, various technologies had to be tested in special testing facilities to investigate their functionalities and their shortcomings. Task 2.2 of workpackage 2 covers this testing phase and the results are presented in this report D2.2.

Within this report:

- The flood resilient product market has been assessed. Surveys, carried out by members of the various NSG’s, show that the scope of the current market of FRe technology remains generally unknown although estimates made by some members suggest promising potential for FRe products.
- National, international standards, protocols and guidance document related to the assessment of the flood resilient Technologies were reviewed. Limitations of these standards in the reliability assessment of the FRe Technologies were identified. The testing phase of the FRe products were mainly based on these documents.
- Test results of 25 products including perimeter, building aperture, building and infrastructure technologies are presented. In cooperation with FRe producers[1], the tests were carried out at five test facilities:
  - TUHH for perimeter and aperture technologies
  - CSTB for aperture technologies
  - UPM for water resistant materials
  - BRE for building technologies and infrastructure technologies
  - IOER for building technologies

[1] Mobildeich GmbH, Karsten Daedler e.K., Optimal Planen-& Umwelttechnik GmbH, AQUA-STOP Hochwasserschutz GmbH, IBS Vertrieb GmbH, Aquafence, Tilt-Dam/Spring Dam limited, AquaBurg Hochwasserschutz, Collados/SARL, UK Flood Barriers, Dyson Energy sevice, Gairesa, Quimilock, Sika

- The test results enable to assess the functionalities of different Flood Resilient products and to improve their performance by detecting the product weaknesses, although these which are not noticeable in theory. Several products in the same resilient technology category were tested to assess if a comparison of performance is possible. Furthermore, these tests initiate the development of the objective 2.3[2] and gave hints that no fixed testing scheme can be defined for the performance assessment of the huge variety of perimeter technologies available, but a testing matrix must be developed for the set-up of appropriate testing procedures.
- The cost of Perimeter Flood barriers was assessed. Not only the performance and function of FRe technologies are important criteria for the selection of the appropriate product but also costs play an important role in the decision process.

[2] "to develop guidance as the basis of standards for testing and approval of FRE-products, harmonizing the different European standards on FRe-product and approval procedures."

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1 Introduction

Many major floods have affected Europe in the past decade causing damage to the built environment. In 2010 flood events affected Germany, Poland, France and the UK, which has resulted in damage to property across wide areas.

Drivers such as climate change and rapid urbanisation will increase the likelihood of further flood events affecting Europe in years to come. The Foresight Future Flooding project identified potential increases in flood risk by the 2080s of up to 20 times the current economic risk to the UK as a whole, unless current policies and investment levels are changed (Hall et al., 2005). According to EU policy (EC 2003, EC 2007/60), flood risk management is the appropriate strategy to cope with this increasing flood risk. This concept is a move away from traditional flood defence strategies which try to reduce the flood risk through blocking the pathway using dikes and walls at the flood source. Flood risk management deals with the flood problem in a more holistic way and considers all elements that contribute to, and affect, a flood event.

Evolving flood risk management will introduce resilience into the built environment ‘system’. The ‘system’ includes a number of elements (buildings, infrastructure, flood defence, etc) which will contribute to its inherent resilience. In this context the flood resilience strategy gains great importance as it seeks to reduce the exposure and vulnerability of the receptors which are the population, the built environment and the urban infrastructure.

The role of flood resilience technology (FRe technology) in alleviating problems for a range of stakeholders, from government departments to individual homeowners, has not yet been fully addressed. Consequently, flood resilient technology is not as yet seen as an integral part of flood management strategies across Europe

Despite the paradigm shift of the EU water policy, the market for flood resilient technologies is not well developed. Barriers to their integration can be identified at a product level where stakeholders demonstrate a reluctance to accept FRe technologies without robust performance and test data.

1.1 Background to SMARTeST

The SMARTeST FP7 project has the overall aim to improve the Road to Market of innovative FRe technologies. This will be achieved by reducing deficiencies and obstacles in the implementation of Flood Resilience Measures. This, in turn, will facilitate the design of more holistic flood defence systems, and support the implementation of the new EU flood risk management policy of “Living with Floods”.

The SMARTeST project has a series of objectives that relate to flood resilient technology, systems and tools. The key project objectives with regard to these technologies are as follows:

Development and enhancement of innovative technology for the protection of buildings and urban infrastructure from flood:

- to evaluate the reliability and efficiency of FRe-measures
- Development and testing of flood resilience solutions which progress technology and test methods beyond the current state of the art, including:

- o Innovative products that can respond and react to flood incidents with minimal human intervention.
- o Products designed to increase the resilience of urban infrastructure, focussing on transportation, bridges and dams.
- o Technology to adapt streets, parks and corridors for conveyance of storm water.

Systematically testing the performance of FRe-products with experimental facilities and deriving guidelines for the validation of FRe-technologies and systems.

The SMARTeST project is set out in six main work packages (WP), as follows:

- WP1 – Project management
- WP2 – FRe Technology
- WP3 – System design
- WP4 – FRe implementation tools
- WP5 – Integration and practice
- WP6 – Dissemination.

1.2 Work package 2: Flood resilient technologies

Work Package 2 is composed of three main objectives in order to help the integration of FRe technologies in flood management, as follows:

- O2.1 Develop innovative and smart technologies to enhance the flood resistance of the built environment and infrastructure, with a specific focus on new materials and smart deployment and control.
- O2.2 Test and assess the performance of FRe-technology (products and materials).
- O2.3 Develop guidance as the basis of standards for the testing and approval of FRe-products, harmonizing the different European standards on FRe-product and approval procedures.

This report is the second deliverable of Work Package 2 (D2.2) and is relevant to the second objective (O2.2). Linked with the deliverable D2.1, this report explores the Flood Resilient Technologies in terms of their performance. According to the state of the art defined in objective O2.1, the WP2 partners have investigated the functionalities expected from the FRe products to develop testing with experimental facilities in hydraulic laboratories.

This report describes the performances of existing and in development FRe products. The aims of the testing are identified as follows:

- To compare product performance of FRe technologies tested to identical standards
- To suggest performance improvement
- To contribute to the work being undertaken in WP4 with performance data from the FRe products tested (leakage rate at hydrostatic condition, mounting time).

In addition to the functionality evaluation of the FRe Technologies, the testing phase has been used to identify appropriate test methods for FRe technologies. This is the first step towards the development of a Code of Practice guidance document for the FRe technologies industry and new industry standards for the testing and approval of FRe-products (O2.3). The testing of different types of FRe products has allowed the SMARTeST team to assess the feasibility of an industry standard for evaluation and approval of FRe products.

This report also describes the result of a survey which was used to assess the size of the FRe market at a national and European level. Several companies were invited to respond to the survey in order to highlight the supply and demand of this market.

The development and growth of the FRe market will not only depend on accurate performance data, but also detailed cost information. This report will investigate the cost of FRe products and focus on the direct and indirect costs associated with their use.

1.3 Methodology

1.3.1 D2.1 output and extension

The definition and classifications of the Flood Resilient Technologies set in report D2.1, is extended in this report to include information on water-resistant material, anti-corrosive products and alarm systems.

This report also uses the previous definitions of 'innovative' FRe to assess the performance and operation of technologies. These innovative parameters will be evaluated through performance criteria in the testing phase.

A web based platform has been developed for use by communities, private stakeholders and companies in order to familiarise them with the diversity of flood resilient strategies technology and products. It gives an overview of the current market offer of FRe technologies.

The project partners investigated the potential growth and the current market size of flood resilient technologies. This investigation has been carried out using a survey of companies who provide FRe technologies. The results of this survey are provided in this report.

1.3.2 Basis for the testing procedures and review of standards

Preliminary work to meet the objective 2.3 has been started. In order to test the functionality of the FRe products, test procedures were defined. For this purpose, a review of existing standards was undertaken. The tests within the project were carried out mainly based on these standards.

1.3.3 Testing

Five WP2 partners contributed to the testing phase (TUHH, CSTB, BRE, UPM and IOER). A total 27 Products were tested:

- 9 Perimeter Flood barriers
- 6 Aperture Flood Barriers
- 4 Water-resistant membranes
- 1 anti-corrosive material
- 1 Infrastructure protection

- 6 Building elements

1.3.4 Test results

The testing of FRe technology was carried out in order to achieve the following outputs:

- To assess the performance of FRe technologies/materials
- To compare the performance of FRe technologies and materials using similar test conditions
- To improve the performances of tested products
- To develop knowledge of testing procedures that will contribute to the delivery of Report D2.3
- To provide information to WP4 with the performance of FRe products tested (leakage rate at hydrostatic condition, mounting time).

1.3.5 Cost analysis

The purchase cost of FRe products depend on several parameters. An initial study of these parameters has been undertaken based on the example of Perimeter flood barriers.

The purchase costs of FRe products may be insufficient in order to make an informed judgement on the benefits of any investment under consideration. The parameters influencing the long term costs and possible benefits of investing in flood perimeter barriers have also been investigated in this report.

1.3.6 Structure of Deliverable D2.2

The report is set out in a series of sections that report work undertaken to address the performance assessment of flood resilient products. A number of appendices are used to provide details on the testing carried out within the project.

WP2 partners contributions

Partners	Contribution to Task 2.2	Contribution to D2.2
BRE	Physical testing to evaluate the performance of an FRe building technology product Investigation of FRe technology market in the UK	Preparation of parts of Report D2.2 2.2 Market Analysis (UK survey, collation of other country results, conclusions) 4.1.3 Test Facilities at BRE 4.2.3 Contributions re insulation material 4.2.4 Infrastructure Technologies 5.4 Insulation material Product Performance (Test Results) 5.5 Non-Return Road Gully

		Product Performance (Test Results)
TUHH	Lead of the Work package 2 for the task 2.2 Physical tests to evaluate the performance of 12 FRe Products: - 4 Temporary perimeter flood barriers - 3 Demountable perimeter flood barrier - 2 Pre-installed flood barrier - 3 building aperture flood barriers Review of the standards related to flood barriers (perimeter technologies and aperture technologies) Investigation of flood perimeter barriers market of in Germany Cost analysis study of perimeter flood barriers Elaboration and edition of the Flood Resilience Technologies Website	Preparation of the Report D2.2 Edition of parts: 1.Introduction 2.2.3 Market Analysis of Flood Technology in Germany 4.1.1 Test facilities and procedures at TUHH 5.1 Perimeter flood barriers 6.1 Objectives of testing procedures 6.2 Perimeter flood barriers 7. Cost analysis Conclusions
CSTB	Physical tests to evaluate the performance of 3 FRe aperture flood barriers Review of the standards related to flood barriers (perimeter technologies and aperture technologies) Editing of part "Dry proofing" of the Flood Resilience Technologies Website	Edition of parts 3. Review of standards 4.1.2 Test facilities and procedures at CSTB 4.2.2 Scope of tested aperture flood barriers 5.3 Test results on Aperture flood barriers
UPM	contributions to the WP2 website	D2.1 Outputs and extension

	testing templates: - Liquid membranes - Polimeric panels - Anticorrosive solutions - Local sealings review of standards	writing Appendix 1 Water proofing membranes and anti-corrosive measures Appendix 4 Summary of testing of Building Technologies (Water resistant material and anti-corrosion material) Market Analysis of FRe Technology in Spain
IOER	Physical tests to evaluate the performance of building constructions - 4 external wall constructions - 2 floor constructions Contributions about flood proofing for the Flood Resilience Technologies Website	Edition of parts: 4.1.4 Test facilities and procedures at IOER 4.2.5 Building elements 5.6 Building construction
TUDelft	Analysis of Dutch flood barrier market Research on the state-of-art of standards in the Netherlands Elaboration and edition of the Flood Resilience Technologies Website	Participation in discussion on early draft of report structure 2.2.4. Market Analysis of FRe Technology in the Netherlands

2 Deliverable D2.1 Output and extension

The report D2.1 based the research focus on flood resilient measures (see Figure 1) and technologies (see Figure 2):

- Perimeter technologies for dry-floodproofing measures behave like a shield for the protected area.
- Aperture technologies for dry-floodproofing measures seal the opening of the house such as doors, windows, garage doors and pipes
- Building technologies regroup different categories of products which may be necessary when the dry-floodproofing measures (building sealing) is chosen. It includes:
    - Building element that are not significantly affected by flood
    - Water resistant material to seal the building walls
    - Anti-corrosion products
    - Local warning system
- Infrastructure technology which include perimeter technologies and product to reduce the risk of erosion.

A current overview of the market of FRe Technologies including more than 100 companies is available on the Flood Resilient Technology website: www.tech.floodresilience.eu/.

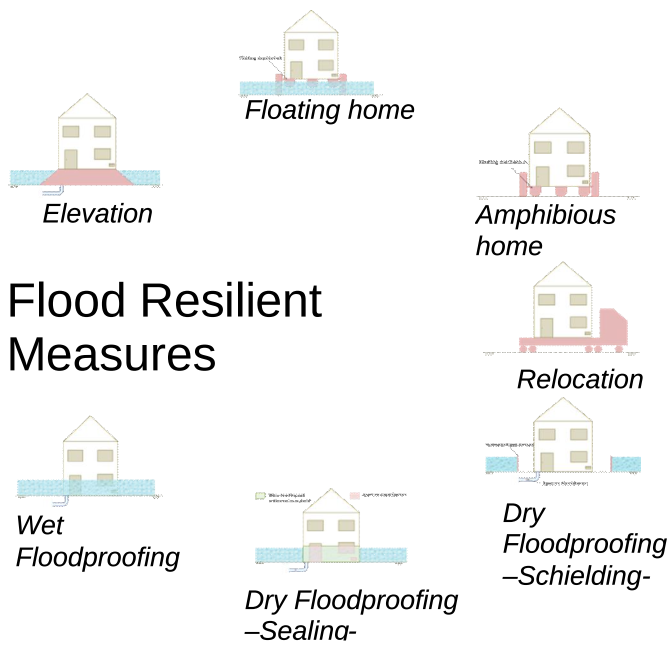


Figure 1: Flood Resilient measures

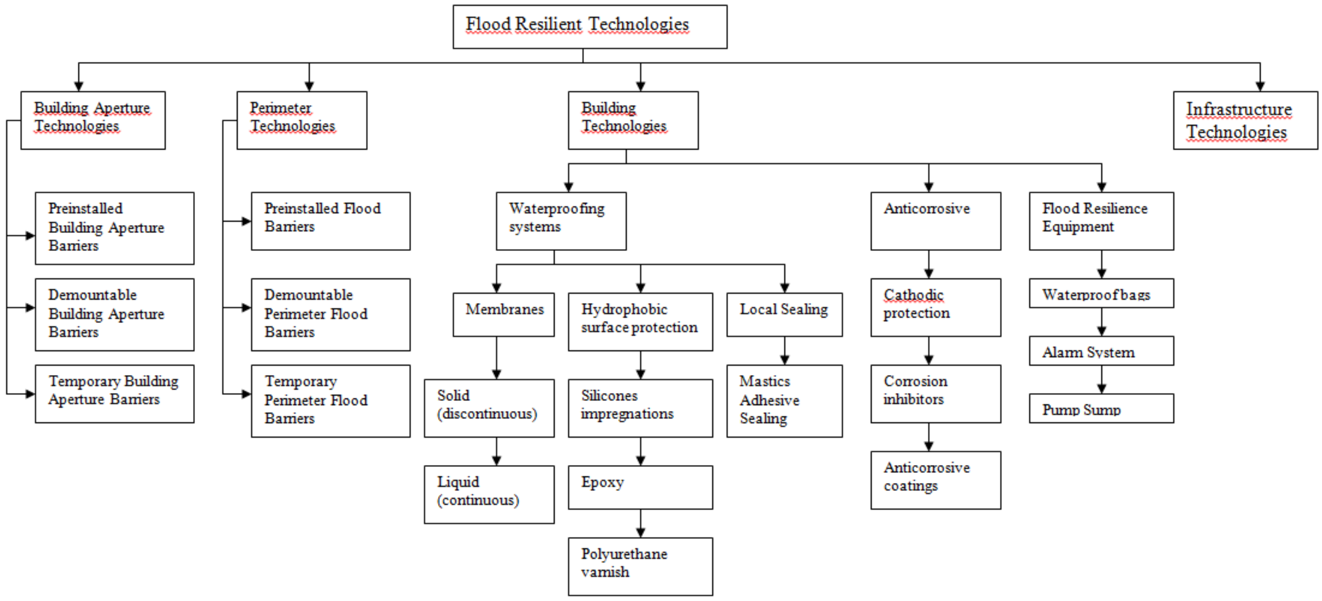


Figure 2: FRe Technologies categories

This first chapter will complete D2.1 with more detailed information on the water-resistant material, anti-corrosive products and alarm systems.

A study on the market analysis was carried out in all the countries participating to the project. The first results will be presented in this chapter.

2.1 D2.1 extension

2.1.1 Waterproofing and wetproofing products

FRe waterproofing products as a category encloses a so wide and heterogeneous range of solutions that addressing them all exhaustively gets beyond SMARTeST's scope. Waterproofing products include all products that, incorporated or applied to some building element produce the result to enhance its resistance to water. Those products are based either on thermoplastic and thermosetting polymers, or on reinforced polymeric composites like glass-fibre thermosetting polymers or rigid-thermoplastics. On the other side, wet-floodproofing is a strategy based on allowing water to come inside a property rather than preventing its ingress. Hence, the principle intention of wet-floodproofing is to change the design and/or the material of potentially affected building constructions in order to mitigate their flood vulnerability and to minimise the extent of necessary repair works. Basically wet-floodproofing comprises the application of improved materials for layers of flood-prone wall, ceiling and floor constructions, which are low susceptible to floods. According to the FLOODsite Glossary, susceptibility is "*the propensity of the people, property or other receptors to experience harm*". Beside the building construction wet-floodproofing also addresses the building facilities as highly vulnerable to floods in case of flooding. Basically wet-floodproofing measures comprise the relocation of susceptible services, like central heating, electrical installation, ventilation and air conditioning above the expected flood level to reduce the risk of future flooding.

2.1.1.1 Membranes

Membranes are usually obtained from polymeric materials. They are designed either for continuous applications, i.e. without joints (liquid membranes) or for discontinuous applications (solid membranes). All of them present a solid final aspect. Liquid membranes are in-situ superficial applications that few minutes after being applied to the support turn themselves into continuous (joint-less) membranes, joined to the substrate. Within the liquid membranes field, the innovative co-elastic technology supposes a step forward since this particular solution is based on the optimization of polymeric combination, seeking synergies between different polymers in order to improve conventional technologies. Asphaltic and bituminous emulsions are continuous membranes that can be obtained as impregnations or other treatments. Their main range of application addresses infrastructures and granular structures needed to enhance their cohesion. Emulsions can be modified by the addition of filler and polymers. Reactive pre-polymers and non reactive pre-polymers shall also be pointed out in this place. The reactive group involves products like epoxies, polyurethane, poliureas, hybrid polyurethane and others. Non reactive polymers include hybrid polymers, styrene-butadiene and acrylic.

2.1.1.2 Hydrophobic surface protection

There are two major alternatives to seal a building element. The first one, the waterproofing membranes technology, consists in applying a waterproofing coating over the element’s surface and has been described above. The second alternative aims to modify the external superficial structure of the building element through a shallow penetration of its matrix. This penetration can be obtained either by an impregnated or by a special coating in case of granular elements. This is the here so-called hydrophobic surface protection, and main commercial application are silicones, epoxies and polyurethane varnishes.

2.1.1.3 Local sealings

Local sealings address localized applications of waterproofing product that seal water penetration channels: joints, anchors, cracks… At this regard, silicones and composites are suitable

Additionally, some particular waterproofing solutions, particularly composites polymers, can also be used to shape authentic autonomous watertight structural panels for barriers. Indeed, building waterproofing products are thus highly versatile solutions performing as water barriers in all cases, sometimes as a waterproofing complement, and other times as an autonomous structure. In the latter case, they shall be tested as authentic barriers as described latter in this document.

2.1.1.4 Important note:

Building sealing causes important hydrostatic load the building structures. It shouldn't be applied without a preliminary stability analysis. According to the Defra publication (Department for environment Food and Rural Affairs) "Improving the flood performance of new buildings Flood resilient construction" in 2007 :

"This strategy is favoured when low flood water depths are involved (not more than 0.3m). […] Standard masonry buildings are at significant risk of structural damage if there is a water level difference between outside and inside of about 0.6m or more."

2.1.2 Anticorrosive products

Waterproofing FRe solutions are not always enough to prevent the triggering of corrosion processes. Anticorrosive protective measures are usually used to simply improve the durability of the structure, and three main classes of anticorrosive technologies can be divided: preventive cathodic protection, corrosion inhibitors and armour coating.

2.1.3 FRe equipments. Alarm systems

Flood warning is on the responsibility of both public authorities and general public. Heavy rainfall can be extremely damaging for settlements and infrastructure. Huge economical damages are often due to the lack of warning in due time [see D2.1 "3.2 Early warning systems"], and the latter results from the complex structure of precipitations over a wide range of space-time scales hindering the reliability of deterministic forecasts.

Flood Alarm systems can be structured according to three different parts even if they work together in one single consolidation systems. A flood alarm systems can be classified according to acquisition systems, hydrological data models and publication systems.

2.1.3.1 Acquisition systems: sensors

Sensors can be distinguished according to many criteria. From the flood type point of view, groundwater, river and meteorological sensors can be identified. Each one measures a different flood parameter, respectively, the water pressure, the water speed and water level or rainfalls. Radars are also considered to be sensors, and a few decades ago, the introduction of hydrometeorological radars had already huge impacts on rainfall forecast and water management. Various rainfall nowcasting methods based on statistical processing of radar images have been readily developed to fill up the short term forecast deficit. The rather recent technology of the X-band radars may unlock this scale bottleneck: due to their higher frequency, the X-band radars are not only offering a higher spatial resolution, but are more versatile (much smaller parabola and lighter mechanical systems) and affordable. Acquisition system also involves the previous storage of data before being processed by hydrological data models.

2.1.3.2 Hydrological data models

As a consequence of the huge spatial and time variability of rainfalls, stochastic multiscale forecasting techniques shall be considered as privileged hydrological models since contrary to the methods previously mentioned, they have a physical basis and their predictability is therefore much higher.

2.1.3.3 Output tools

Output tools involve both publication and alarm systems.

Publication systems are usually software aiming to the final display of the processed information. This information can be used for many regards. Alarm systems are publication systems aiming to trigger the warning to populations at risk or to the responsible authorities.

After sensors provided rainfall data, and after having been processed by tools, the resulting information can be used for several applications.For example, water levels forecasting (TETIS, LISFLOOD), water management (AQUATOOL) or early warning to populations at risk.

2.2 Market Analysis

As the aim of the SMARTeST European project is to improve the road to market of FRe technologies and products it is preferable to understand the current market for such products. Much of the understanding has been gained through discussions with National Support Group members in each country. This has typically revealed that the penetration of FRe technology is at present limited, and confined almost exclusively to the UK, France and Germany, with some use in the Netherlands. In Spain, Greece and Cyprus there was limited experience and a lack of an indigenous supplier market.

The creation of the FRe technology products database (http://tech.floodresilience.eu/) has given an indication of the types of products and their proliferation in the market place of different countries. The scale and nature of much of the flooding problem is set out for the UK, Germany and France in this section as an indication of the potential to grow this market.

A survey of FRe technology providers was used to supplement the meeting discussions, but it resulted in few responses.

2.2.1 Market Analysis – UK

The market is currently of limited size in the UK, an overall industry turnover of £10 million was estimated by the UK NSG. However, there are no accurate figures on the market and thus this estimate should be taken with some caution.

2.2.1.1 Risk of flooding in the UK

The Environment Agency suggests that over 5.2 million homes in England are at risk of flooding from rivers, sea or surface water. This equates to 1 in 6 homes. (Defra & EA 2011a) The number of homes at risk is shown in Table 1.

Flood risk source	
River or coastal	2m*
surface water	3.8m*
failing reservoir	1.1m

*Table 1: Number of homes at risk (in millions) in England (Defra & EA 2011a,b; Houston et al. 2011) *1 million homes are at risk of both river or coastal flooding and surface water flooding)*

Annual costs of flood damage are currently at least £1.1 billion and are expected to rise in coming years as the risk of flooding increases due to climate change. The EA (Environment Agency) estimates an annual flood defence increase of £20m will be required to combat rising flood risk, but in reality their budget is set to reduce in line with spending cuts. (Defra & EA 2011a) Pluvial flood risk accounts for one third of all flood risk in the UK (Houston *et al.* 2011) and controlling this risk alone could require investment of £150 million per year. (ABI 2010) Insurance claims from the 2007 surface water floods outnumbered claims for river and sea flooding by 6:1. (Defra & EA 2011a)

Properties (both domestic and non-domestic) at risk of river or coastal flooding have been categorised as at low (<0.5%), moderate (0.5%-1.3%) or significant (>1.3%) risk by the EA (see Table 2). The region with most properties at risk is the Thames region (which has since been combined with Southern to create the South East region). (Defra & EA 2011a)

England Properties (inc. non-domestic)	
Low risk	1,115,000
Med risk	778,000
High risk	486,000

Table 2: Number of properties (including non-domestic) at risk of flooding in England (by risk category) (Defra & EA 2011)

Currently 490,000 properties have a 1 in 75 or greater chance in any given year of flooding (from coastal waters or rivers) but by 2035 this will have increased by more than 350,000. (Defra & EA 2011b) Approximately 2 million people in urban areas (settlements with a population of more than 10,000) are exposed to an annual pluvial flood risk of 0.5%, or 1 in 200 years. Climate change may increase the UK population at risk from pluvial flooding by 16% by 2050. Pluvial floods are the type most likely to increase in severity as a result of climate change. (Houston *et al.* 2011)

In Scotland, there are currently estimated to be 2.5 million properties. Those at risk of flooding are outlined in Table 3. Glasgow is the Scottish local authority with the most properties at risk of flooding. (ABI 2010) Northern Irish properties at risk of flooding are shown in Table 4.

Type of flood risk	Percentage of total homes	Total number	Number of dwellings	Number of commercial properties
Fluvial	2.90%	73,313	68,492	4,821
Coastal	1%	26,181	23,952	2,229

Pluvial	0.60%	15,000	-	-

Table 3: Homes at risk of flooding in Scotland, by source of risk and property type (Houston et al. 2011)

Type of flood risk	
Pluvial	2,300
Fluvial	3,000
Coastal	1,000

Table 4: Homes at risk of flooding in Northern Ireland, by source of risk (Houston et al. 2011)

Defra (the Department for Environment, Food and Rural Affairs) is the responsible government department (in England) for flood and coastal risk management. They spent £664 million in 2010-11, 95% of which went to the EA who are responsible for the operational responses to flooding. The EA improved protection (reduced risk) to 10% of households previously at risk between 2008/09 and 2010/11. This is broken down as shown in **Error! Reference source not found.**.

Year	No. of households
2008/2009	37,150
2009/2010	67,290
2010/2011	77,762

Table 5: No. of households at risk of flooding in England (Defra & EA 2011a)

Areas with larger numbers of at risk homes are being prioritised over more sparsely populated areas. (Defra & EA 2011a) Infrastructure is also at risk from flooding. Over 55% of water and sewage pumping stations, 14% of electricity and 28% of gas infrastructure; 20% of railways and 10% of major roads are in areas at risk of flooding. (Defra & EA 2011b) The EA also suggests that 185,000 businesses are directly at risk from flooding. (ABI 2010)

In the UK, there is a feeling amongst some individuals and organisations that flood protection should be the responsibility of the state, they believe that central or local government should be constructing suitable structural defences to protect them. FRe technologies must also be affordable to purchase as beyond 2013, the insurance industry's 'Statement of Principles', an agreement to provide flood insurance to everyone, will not be renewed, stressing that the onus for flood protection on the individual.

The UK Government has estimated that for England that about 20,000 homes have been protected by flood defences that have built in the past few years. No indication however was given of the number that are protected by FRe technology and whether or not the extensive floods during 2012 had 'tested' these measures under real flood conditions.

2.2.2 Market Analysis – Spain

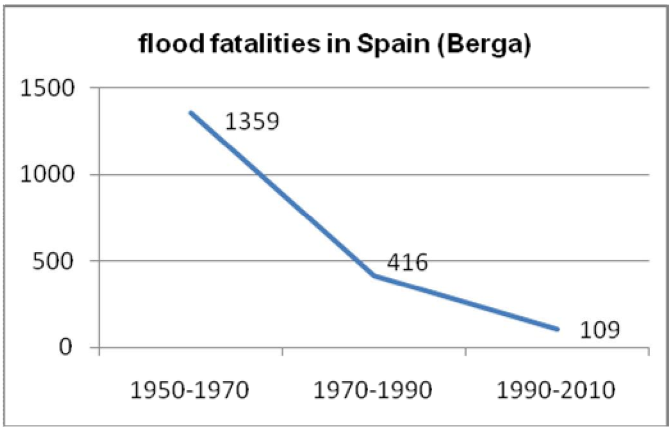
The market analysis in Spain has addressed the simultaneous implementation of structural and non-structural FRe measures. While structural measures aim to impact directly on the flood hazards, non-structural measures rather aim to mitigate flood damages. Traditionally, in Spain, structural measures have been successfully adopted; the country especially relied on dams. There is still a need however, to supplement these measures with the implementation of non-structural FRe measures.

2.2.2.1 Risk of flooding in Spain

Flooding is the most significant natural risk in Spain, and over the last 10 years, flood events have represented 29% of all incidents by natural catastrophe in Spain. Table 6 quantifies flood damages since 1950.

Time Period	Damages [fatalities]	Damages/year [fatalities/year]
1950-1970	1359	68
1970-1990	416	21
1990-2010	109	6

Table 6: Flooding damages in Spain



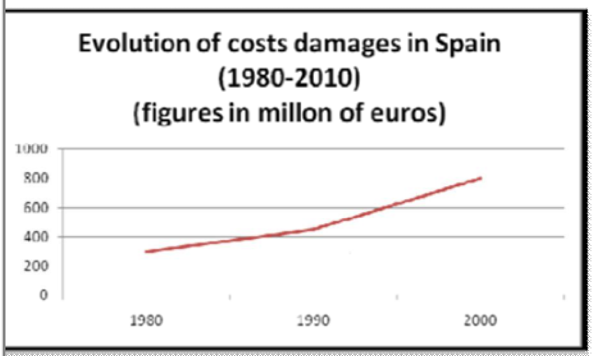


Figure 3: Evolution of fatalities and cost damages in Spain (1980-2010)

Annual costs of flood damage are currently in the range of 800M€[3]/ year (0.7% PIB) (Figure *3*). The main causes aregreat population growth in urban areas;migration of population and concentration of buildings in flood risk zones close to rivers;low quality of buildings and, in many cases, lack of safety measures in case of flood andchanges in land uses preventing natural drainage.

In Spain there are many individuals and organisations active in flood protection. However, the final responsibility lies with the State. The Ministries of Environment, Interior and Defence share responsibility at a National level for flood risk management, flood prevention and assistance post-flood. At a regional level,

[3] 800M€: 800 million Euros

local authorities also have some responsibilities relating to local flood management and providing assistance to victims of flooding.

2.2.3 Market Analysis – Germany

There are no specific figures available describing the current and expected market of FRe technology in Germany. The main parameters influencing the market are:

- Number and extent of flooding events in Germany today and future expectations
- Status and popularity of current flood protection measures, both structural (permanent and FRe technologies
- Costs of FRe technologies
- Distribution channels of flood protection technology

These parameters are discussed in the following sections.

2.2.3.1 Flooding events in Germany

Natural disasters in Germany are most often linked to storm events followed by flood events (Figure 4). In the period 1970 to 1998, storm events accounted for 65% of the overall number of natural disasters, 75% of the economic losses and 86% of the insured losses.

The Western and Southern parts of Germany are affected more often than the Northern and especially Eastern part of Germany. Nevertheless, storm surges with immense damage potentials play an important role in the Northern part of Germany.

The number of flood events with damages of more than €1 million in Germany, in the period 1982 to 2006, is shown in Figure 5. The red trend line indicates a rising number of severe flood events over the reviewed period. Looking at the overall damages of flood events Germany in the same period (Figure 6), the highest damage amount was reached in 2002 with the flooding at the rivers Elbe and Donau, and in general large damages occurred in the period 1993 to 2005. The available data gives grounds for assuming a rising trend of flood damages in the future.

Two flooding events at the river Rhein in 1993 and 1995, resulted in similar flooding discharges and flooding heights at gauges at the river Rhein, Mosel, Main, and Neckar However, the event in 1995 caused only half the damages of the flooding event in 1993 (Figure 6). The damage reduction can be explained by structural modifications (e.g. raising of electrical installations and heating systems), neighbourly assistance and reduction of damage potential (e.g. vacating cellars, underground car parks and low lying floors, which are likely to be flooded)[4]. This example demonstrates that comparatively simple and low-priced means can lead to a significant damage reduction in case of a flood event.

[4] Source: http://undine.bafg.de/servlet/is/13880/

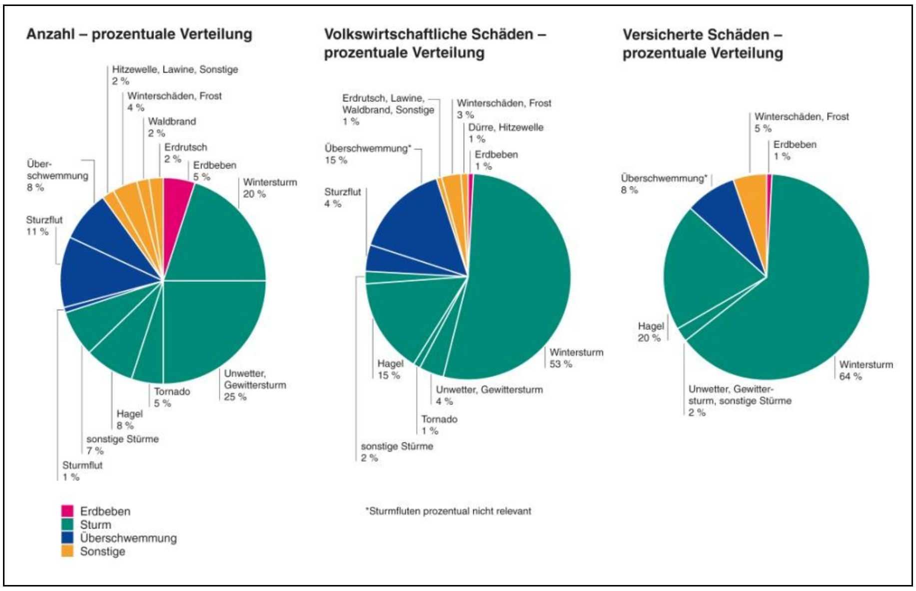


Figure 4: Natural disasters in Germany in the period 1970 to 1998 - Number of natural disasters due to earthquake, storm, flooding, and others (left), economic damages (middle) and insured damages (right) (MUNICH RE, 1999)

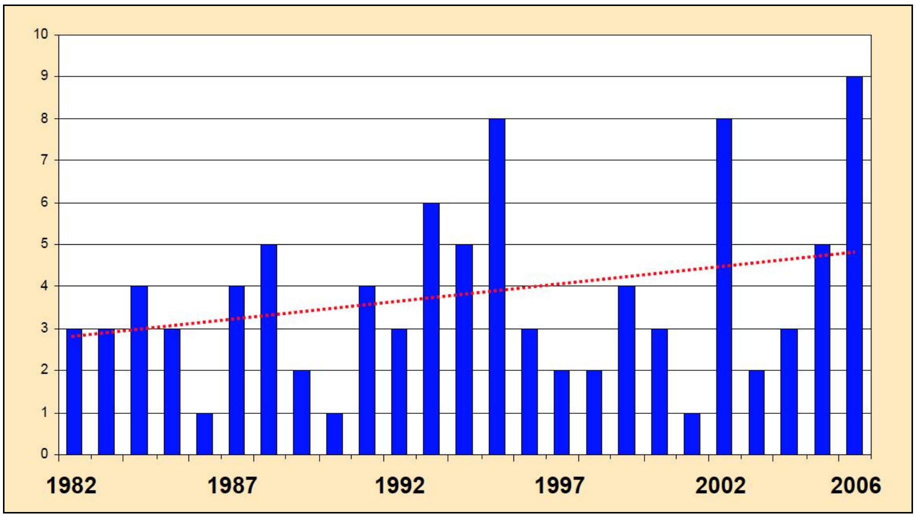


Figure 5: Number of flooding events in Germany with damages of more than 1 million Euro in the period 1982 to 2006 (MUNICH RE, 2007)

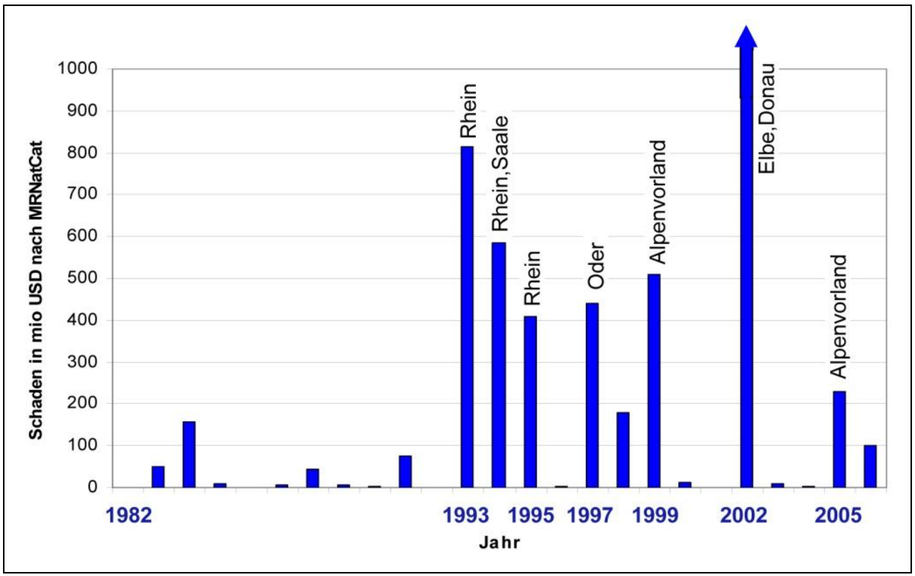


Figure 6: Damages from flooding events in Germany in the period 1982 to 2006 in millions US-Dollar (inflation corrected) (MUNICH RE, 2007)

2.2.3.2 FRe Technology in Gemany

In Germany flood protection mainly includes dykes and flood protection walls, plus permanent installations drainage system (backflow valves and sewage lifting units). Sandbags are used in emergencies. FRe technologies are rarely employed in public flood protection works. These technologies are more often used in private flood protection where no public flood protection measures are available. The use of FRe technology for flood protection is limited to demountable perimeter barriers in urban areas with limited space, or tourist areas where visual links onto the river, lake or sea must be maintained. Examples of these locations are as follows:

- Cologne, a city with 1 million inhabitants. Perimeter protection measures account for 15% (approx. 10 km) of the overall protection length at the river Rhein, started after the flood of 1995, completed in 2008[5]
- Frankfurt / Oder, a city of 60,000 inhabitants, is protected by a 300 m long perimeter flood protection system made of aluminium beams on a concrete apron with perimeter system height of 2.0 m, completed in 2004[6]

The reason that FRe products are not more frequently utilised lies in the higher costs for these perimeter barriers than for permanent structural flood protection measures (with comparable safety standard) and in the larger number of personnel needed for maintenance and deployment. Most of the existing perimeter flood protection systems in Germany, both public and private, have been completed during the last decade.

[5] http://www.hkc-koeln.de/de/ueber-das-hkc/entstehung-entwicklung/index.html
[6] http://www.ptw-dresden.de/fachbereiche/flussbau/daemme/ref_2004_01_mhws_ffo.shtml?navid=20

As most of the perimeter flood protection technique in Germany is manually deployed; a sufficient early warning time is required. Therefore, the use of perimeter technologies is very rare at coasts, as well as in upper catchment regions, where warning times of less than one hour up to one or (at the maximum) two days are available. Only in the middle and lower catchment areas of larger river systems is the available early warning time sufficiently long for the deployment of manually deployed perimeter technologies. The German city with the largest length of perimeter flood protection measures is Cologne with 9.5 km perimeter barriers (HKC, 2012). The overall flood protection length in Cologne is 65 km (StEB, 2009).

In Germany, public flood protection management belongs to the individual federal state. The federal governments are the decision-makers of programmes for technical flood protection and for measures of preparation and relief in the case of endangering by flooding. Nevertheless, no individual legal entitlement exists for the protection against flooding and there are rural and urban areas with low flood protection levels.

It is hard to get comprehensive information on flood protection measures at state level, as in most cases this information is only available for single river catchments or even parts of these.

The use of FRe technology systems in the private sector is mainly limited to the use of building aperture products and dry proofing. However, especially for larger housing projects in waterfront locations, it can be expected that flood perimeter systems will have an increasing deployment. Here, automatic systems are of special interest, reducing the personnel demands during the flood event.

For emergency use, most public responsibilities rely on personnel and time demanding sandbag constructions. In future, it can be expected that more sophisticated emergency systems will be in use. This will be increasingly necessary as the number of available disaster control personnel decreases as a result of the military reform in Germany (AG, 2011). Therefore, there is a strong need for an increased deployment of innovative emergency systems for flood control.

2.2.3.3 Costs of perimeter flood protection techniques

The costs of FRe technologies are generally higher than these for permanent flood protection measures (with comparable safety standards) due to:

- Higher purchase costs of the construction itself
- Additional requirements to train personnel and provide information to the public
- Additional allocation costs for storage area for equipment
- Additional maintenance costs including control and repair of the system
- Additional deployment costs including personnel, transports, loss of components and equipment

All these costs will be site specific, depending on these numerous factors. The only cost group that may be lower for FRe technologies compared to permanent structural protection systems are the costs for land acquisition.

2.2.3.4 Distribution channels

FRe technologies may be purchased by the public and private sectors. Supreme and Lower Authorities (public sector) have authority over flood protection on 1st, 2nd and 3rd order water bodies. Emergency flood protection is also the responsibility of the public sector, namely the Federal Ministries of Interior, state administration and district and city authorities. The military, fire brigades and the German Rescue organisation DLRG may also use FRe technologies.

In the private sector, companies, businesses and homeowners may turn to FRe technologies to protect their assets.

2.2.4 Market Analysis – the Netherlands

The market analysis in the Netherlands has identified the extent of previous flood damage in the country and has made an attempt to relate this to the potential market of FRe technology. In the Netherlands the central and regional governments traditionally play an important role in providing flood protection. This has resulted in high protection levels for most types of flooding, which has its influence on the market potential FRe technology and potential adopters of the technology. In Table 7 an overview of flood management responsibilities is presented.

Water related damages	Examples of causes	Responsible for flood management
Damage around or in building	• Breach of a water pipe inside a building • Rainfall leaking through a roof • Water flowing from garden into a building	Homeowner
Damage due to sewer flooding	• Sewer surcharge inside a building • Water on the street flowing into a building	Municipality (local government)
Damage due to flooding from regional watercourses	• Overflowing of watercourses causing water to enter a building	Water board (regional water authority)
Damage due to flooding from rivers or sea	• Failure of river or sea dikes and other protection structures	National government

Table 7: Responsibilities for flood protection in the Netherlands

2.2.4.1 Risk of flooding in the Netherlands

An overview of expected flood damage at a national level is not available. Several regional estimates have been made in separate studies, as well as an estimate of claimed damage from insurance companies.

Some figures are presented here to provide an impression of potential damage and the potential market size for FRe Technology. (Adviescommissie Water 2005)

The responsibility for protection from surface water flooding (from heavy rainfall and overloaded drainage systems) lies with private homeowners. In most cases homeowners and tenants seek insurance for damage to property and property contents. Damage related to this type of flooding can be derived from reports from insurance companies. A database covering about 30% of damage claims from insurance companies has been made available by the Dutch Association of Insurers, for research within the SMARTeST project. Some relevant results of this research are presented here; the main characteristics of the database are summarised in Table 8 (Spekkers et al. 2011). The average claim for building contents (not related to water pipe leakage) is €799. The average property claim is €1098, with half of the claims smaller than €582. The average damage per year is €7.5 million for content damage (excluding water pipe leakage) and €17.8 million for property damage (including water pipe leakage).

Record type	Period	Total number of policies in millions per year	Total number of claims	Total damage [million euro]	Damage per year [million euro/year]	Mean [euro]
Content	1992-2009	1.8	174324a 160406b	137a 128b	8.1a 7.5b	785a 799b
Property	1986-2009	0.8	372959	409	17.8	1098

Table 8: Key characteristics of water damage in database of Dutch Association of Insurers

a)Categorized as 'water pipe leakage' b)Categorized as 'rainfall, snow or meltwater', 'rest group' or 'cause unknown'

The risk from fluvial flooding from regional water courses amounts to an estimated €22 million annually(Kok and Lammers 2000). This amount includes damage to private homes and industries.

Polder areas in the Netherlands are protected by a total length of 14,000 km of levees. Regional water authorities are responsible for the management of these levees In Table 9, the risk estimates for several polder areas are shown (Kolen and van der Braak 2005).

Polder area	Damage (million €)	Probability of levee failure	Number of houses	Risk per house per year (€/year)
AGV19	0.02	1/50	25	16
AGV10	3.4	1/150	55	350
AGV15	8.8	1/500	200	70
AGV1	34	1/1500	2500	6

AGV14	90	1/5000	3000	4

Table 9: Risk estimates of flooding by levee failure for several polder areas in the Netherlands

Failure probabilities of primary protection structures (e.g. dikes) in the Netherlands are low compared to most other countries, because the potential damage after failure of a primary structure is large. The total flood risk at national level is being investigated under a national project called “Mapping of safety in the Netherlands” (Veiligheid Nederland in Kaart, VNK). Final results are expected by 2015. At present, figures are only available for some individual polder areas; three of which are presented here for illustration: Noord Oost polder, Zuid Holland and Betuwe en Culemborgerwaarden (Table 10).

Name of polder area	Damage (million €)	Probability of levee failure	Number of houses	Risk per house per year (€/year)
Noord Oost polder	2	1/4000	26,000	20
Zuid Holland	18	1/10,000	1,500,000	1
Betuwe en Culemborgerwaarden	11	1/1,250	130,000	70

Table 10: Risk estimates of flooding by dike failure for several polder areas in the Netherlands

Less than 1% of the population lives in areas unprotected by structural defences. The expected damage from this type of flooding is therefore limited.

2.2.5 Survey on Market Analysis

A market survey was undertaken with NSG members in the UK and Spain. NSG members are a mix of industry, public sector and consultants. The response to the survey was largely disappointing, with few responses.

The survey asked the NSG members to estimate, for their own country and for Europe as a whole:

- the value of the current FRe market
- the number of properties and infrastructure at risk of flooding. (For some countries (e.g. the UK) this data is publicly available.)
- the average cost of damage from flood events
- the potential market for FRe technologies

As few responses were received, and many returned questionnaires were incomplete; it is difficult to draw any conclusions from this survey.

2.2.6 Conclusions

Across Europe millions of homes and businesses are at risk of flooding; coastal, riverine or pluvial. The cost of damage runs to hundreds of million Euros each year. The risk of flooding in Europe is likely to increase further due to climate change and increased urbanisation. Funding for flood defences is unlikely to rise in line; in fact often budgets are being cut as overall government spending is reduced.

In the UK, the ‘Statement of Principles’ agreement from insurers to provide flood insurance to everyone will end in 2013, this means the onus will be on the individual to protect their homes and FRe technologies will be a large part of that. The public however still largely considers that flood risk should be alleviated by government and that properties should be protected by large scale defences. In Spain, the final responsibility for flooding lies with the State although, as in the UK, many departments are responsible for different areas of flood management.

Germany has a history of natural disasters caused by storms leading to flood events. Available data gives ground for rising trend of flood damages in the future. Permanent flood barriers are mainly used to manage flooding with demountable perimeter barriers used only in some urban areas where permanent barriers would be obstructive. It is suggested that in Germany the costs of maintaining demountable barrier means they are more expensive than permanent barriers. There are also concerns regarding the large number of personnel required to deploy non-automatic systems and the early warning required to ensure this happens in sufficient time to be effective. Flood protection management here lies within the jurisdiction of individual federal states. Building level technologies are rare in public buildings and are only used in private homes where no public flood management is available.

In the Netherlands, central and regional governments are responsible for flood risk management from sewer, river or coastal flooding. In the result of pluvial flooding from heavy rainfall, the responsibility for protection lies with the house owner. Tenants and homeowners usually take out insurance for damage to their property and contents.

In the Netherlands less than 1% of the population of the Netherlands live in areas unprotected by primary or secondary defences. An important conclusion from the market survey here was that NSG members found that there was little potential market for small scale FRe products in the Netherlands as primary flood defences are intended to protect much of the population.

The research has shown that there is a large potential market for FRE technology in Europe. However, its implementation will depend on a number of factors, some of which are local and others that apply generally. Research in Work Package 5 of the project has shown the need for appropriate testing, standards and guidance and these are essential components of improving the road to market. However, the national (legislation, finances, etc) and more relevantly the local context (flood type, risk, availability of FRe technology, etc) will dictate the extent to which the FRe market can grow in the future.

3 Review of reference documents

3.1 Introduction

A critical review of existing FRe technology testing protocols is a first step in the development of guidance for FRe technology testing. This section reports on a description and an analysis of these protocols.

According to report D2.1 and update in section **Error! Reference source not found.** of the present report, four main categories of FRe technologies are considered:

- Building aperture technology,
- Perimeter technology,
- Building technology,
- Infrastructure technology.

This review will be completed in the report D2.3 especially for the products of the category Building Technologies.

As far as testing is concerned, we will not directly address the “infrastructure technology” category because we consider that testing methods associated to the three first categories also cover the needs for this fourth category.

The testing methods/protocols we are looking for can be described in many different documents, i.e. in standards as well as in other documents. We then introduce this variety of document in this sub-chapter.

Then the reviewed standards and other relevant documents are classified, in following sub-parts, in relation with their aim: to define testing method, to describe a product or to give specifications about installation. For each of these three categories, we are looking for **information about testing protocol** which could be included in these documents.

As a large range of related information currently exists, the initial review will focus on defining documents that are under consideration.

"Standard" is defined as "*an **official** rule, unit of **measurement**, or way of **operating** that is used in a **particular area** of manufacturing or services*" in the Cambridge Business English dictionary. Pursuant to the Council Directive laying down a procedure for the provision of information in the field of technical standards and regulations, of 28 March 1983 (83/189/EEC), “standard” is a technical specification approved by a recognized standardizing body for repeated or continuous application, with which compliance is not compulsory in general.

In existing documents, specifications validated by a national or international standardization body are generally considered at the highest level of **recognition**. Therefore, in order to develop this report, the two following types of official documents were reviewed:

- National or international standards
- Protocols or guidance documents.

Moreover, as written above, standards and other relevant documents can deal either with method of testing or with products assessment, or installation/implementation. Among the documents linked with FRe technology we have listed, we choose to define three types:

- Material or compound **testing**
- Products testing and/or **assessing**
- Installation **guidance**.

As specified in definition above, standards have to be written "in a **particular area** of manufacturing or services". FRe technologies are almost exclusively applied in circumstances for which they were designed and manufactured. The same may not be true for products and materials that may have several applications out of the flood domain. Therefore, in relation to this report, we consider reference documents directly linked with flood protection.

It can be noted too that FRe Building technologies that are included in a permanent manner in the construction, are particular cases of FRe Technologies. In this sense, they can be considered as building products, and may fall within the scope of the “Construction Products Directive” (Directive 89/106/EEC),), which will be replaced by the “Construction Products Regulation” (305/2011/EU - CPR) from 1 July 2013.

In the following paragraphs, documents that have been reviewed will be presented following the three categories defined earlier: material or compound testing, products testing and/or assessing, installation guidance. For each of these categories, the information reviewed will include the type of existing documents, their contents, their scope and limits in relation with SMARTeST WP2 objectives. Links with Smartest FRe technologies categories will be made.

3.2 Material or compound testing

3.2.1 Type and context of documents

There is a wide range of materials used in FRe technologies and products and a review of all related standards would be a difficult task. The list presented in Table 11 is not exhaustive but gives examples of the various types of existing documents.

Table 11: Various types of material or compound testing reference documents

Existing document	Type	FRe Category	Organism
ASTM C1549 **ASTM D570** **ASTM D638** **ASTM D2846** **ASTM D3359** **ASTM F2298** **ASTM F2769** **ASTM G109**	National standard	Building technology	ASTM International
Approval 2510	Other protocol document	Building aperture technology Perimeter technology	FM Global
EN ISO 62:2008 **EN ISO 527** **EN ISO 15148:2003**	International standard	Building technology	ISO
EN 1931 **EN 1062-3**	International standard	Building technology	CEN
EOTA TR-003 **EOTA TR-004** **EOTA TR-012**	Other protocol document (Technical Reports)	Building technology	EOTA

In summary, there are a number of organisations who deal in product standardisation. Some of these organisations offer standards against a wide range of products and others operate in more niche markets, providing detailed information on a specific range and application of technology

FM Global is a company which offers insurance products but also certification and testing services for industrial and commercial loss prevention. Certification is based either on national or international standards, or on Approval Standards developed by FM Global. Approval Standard n°2510 relates to flood abatement equipment and the first part of the performance requirements concerns the characterization of materials.

ASTM International, formerly known as the American Society for Testing and Materials (ASTM), has a dominant role among standards developers in the USA and deals with diverse industries ranging from metals to construction, and petroleum to consumer products. Using a consensus process, its standards are collectively developed by technical committees, with members from all around the world.

The international organization for standardization, widely known as **ISO** is composed of a network of the national standards institutes of 163 countries.

CEN is the acronym for Comité Européen de Normalisation or European Committee for Standardization. This organisation, with its thirty national members, develops European Standards (ENs) in various sectors. CEN is officially recognized as a European standards body by the European Union. To avoid duplication between standardization at international and European levels, CEN and ISO signed an agreement which means they are approved by both organisations.

European Organisation for Technical Approvals (EOTA) is an international non-profit association. It was established under the provisions of the European Community Council Directive of December 21, 1988 relating to construction products (Construction Products Directive 89/106/EC or CPD). EOTA is composed of organizations nominated by the European Union (EU), European Free Trade Association (EFTA), and the European Economic Area (EEA). EOTA works in close co-operation with these organisations and with CEN, European trade associations and industrial organizations. The role of EOTA is primarily to monitor and progress the drafting of ETA Guidelines (ETAGs) and to co-ordinate all activities relating to the issuing of ETA's (European Technical Agreement). EOTA Technical Reports (EOTA TR) are guidance documents which go in details in some specific aspects. They are used as reference documents to ETAG.

3.2.2 Content of the documents

In general terms, any flood protection technology would be expected to provide information on performance relating to the following aspects:

- Installation (rapid deployment and installation)
- Water-tightness
- Stability (to remain stable mechanically, even in specific environment)
- Durability (to ensure performances during a long period, or/and after several uses and idle periods) .

Some characteristics, which are intrinsic to materials or compounds, match each of these four aspects of performance. For example, water-tightness is linked with water vapour diffusion resistance, or stability with tensile strength. Using the list of standards presented in Table 12, the characteristic(s) of FRe technology, as described in standardisation documents, are proposed in the following

Table 12.

Table 12: Content of material or compound testing reference documents

Existing document	Type	FRe category	Characteristic(s) for which test specifications are given	Associated function
FM global Approval 2510	Other protocol document	Building aperture technology Perimeter technology	• Examination • Extreme temperatures • Cap/valve locking ability • Hydrostatic and leakage test • Tensile/compression tests • Impact and Wear resistance • Abrasion resistance • Vibration resistance • Tear and puncture resistance tests • Cycling • Salt spray corrosion • Environmental corrosion • Hail resistance • UV light test • Air oven aging tests • Accelerated aging tests	• Installation • Watertightness • Stability • Durability
ASTM C1549	National standard	Building technology (waterproofing membrane)	Solar reflection	Durability
ASTM D570	National standard	Building technology (waterproofing membrane + local sealing)	• Mechanical properties • Immersion of specimens until saturation in water at two different temperatures	• Stability • Durability
ASTM D638	National standard	Building technology (local sealing)	Mechanical properties	Stability
ASTM D2846	National standard	Building technology (waterproofing membrane)	Hot water resistant	Durability
ASTM D3359	National standard	Building technology (waterproofing membrane)	Adhesion	Installation Stability
ASTM F2298	National standard	Building technology (waterproofing membrane)	Water vapour diffusion resistant	Watertightness
ASTM F2769	National standard	Building technology (waterproofing membrane)	Hot water resistant	Durability

ASTM G109	National standard	Building technology (Anticorrosive coatings)	Corrosion	Durability
EN ISO 62	International standard	Building technology (local sealing)	Immersion of specimens until saturation in water at two different temperatures	Durability
EN ISO 527	International standard	Building technology (waterproofing membrane + local sealing)	Mechanical properties	Stability Durability
EN ISO 15148	International standard	Building technology (local sealing)	Immersion of specimens until saturation in water at two different temperatures	Durability
EN 1931	International standard	Building technology (waterproofing membrane)	Water vapour diffusion resistant	Watertightness
EN 10623	International standard	Building technology (waterproofing membranes)	Capillary water absorption	Watertightness
EOTA TR-003	Other protocol document	Building technology (waterproofing membrane)	Watertightness testing	Watertightness
EOTA TR-004	Other protocol document	Building technology (waterproofing membrane)	Adhesion	Installation Stability
EOTA TR-012	Other protocol document	Building technology (waterproofing membrane)	Hot water resistant	Durability

3.2.3 Limits of the documents

Concerning Building aperture and Perimeter technology, FM global protocol has put together numerous characterizations of products and how they perform under various test parameters. There is a costly knock-on effect of having multiple tests for a single product. SMARTeST reference testing could be based on FM Global protocol and others, but should propose second option if characterization is possible by expert analysis or by comparison with other characteristic already known.

Concerning building technology, standards listed in the following tables are not specific to flood conditions. Therefore, this list is not exhaustive and contains references to other related documents. In main cases, International or European standard are preferred, except in cases for which other standards are more complete. In conclusion, the standards for consideration and in relation to building technology are presented in Table 13.

Table 13: Considered material testing reference documents for building technology

Existing document	Type	Building technology category	Characteristic(s) for which test specifications are given	Associated function
ASTM C1549	National standard	Waterproofing membrane	Solar reflection	Durability
EN ISO 527	International standard	Waterproofing membrane	Mechanical properties	Stability Durability
EN 10623	International standard	Waterproofing membrane	Capillary water absorption	Watertightness
ASTM D570	National standard	Local sealing	• Mechanical properties • Immersion of specimens until saturation in water at two different temperatures	• Stability • Durability
ASTM D638	National standard	Local sealing	Mechanical properties	Stability
ASTM G109	National standard	Anticorrosive coating	Corrosion	Durability
EN 1931	International standard	Waterproofing membrane	Water vapour diffusion resistant	Watertightness
EOTA TR-003	Other protocol document	Waterproofing membrane	Watertightness testing	Watertightness
EOTA TR-004	Other protocol document	Waterproofing membrane	Adhesion	Installation Stability
EOTA TR-012	Other protocol document	Waterproofing membrane	Hot water resistant	Durability

3.3 Testing and assessing products

3.3.1 Type and context of documents

Reference documents relating to flood protection products, concern building aperture and perimeter technologies. Table 14 presents the documents reviewed and which provide the greatest level of information to characterize FRe products and their performances.

Table 14: Types of products testing reference documents

Existing document	Type	FRe category	Organism
Approval 2510	Other protocol document	Building aperture technology Perimeter technology	FM Global
PAS 1188-1 **PAS 1188-2** **PAS 1188-3** **PAS 1188-4**	National standard	Building aperture technology Perimeter technology	BSI
CSTB protocol	Other protocol document	Building aperture technology	CSTB
DIN 19569-4	*National standard*	*Building aperture technology*	*DIN*

The FM Global's protocol presents the compounds and material testing, test protocol for temporary Perimeter Flood Barriers and Opening Barriers.

British Standards Institution (BSI) is the National Standards Body of the UK and produces standards on a wide range of products, services and processes. BSI is responsible for producing and publishing British Standards and for representing UK interests in international and European standards organizations such as ISO or CEN for example.

BSI PAS (publically Available Specification) 1188 (2009) ‘Flood protect products’ has four defined sections which categorise flood protection products and their associated test procedures. The four sections of this document are as follows:

- PAS 1188-1: Building aperture products, in relation with SMARTeST category "Building aperture technology",
- PAS 1188-2: Temporary products, in relation with SMARTeST category "Perimeter technology",
- PAS 1188-3: Building skirts systems, in relation with SMARTeST category "Perimeter technology",
- PAS 1188-4: Demountable products, in relation with SMARTeST category "Perimeter technology".

Centre Scientifique et Technique du Bâtiment (Scientific and Technical Centre for Building, CSTB) is the French national organization providing research and innovation, consultancy, testing, training and certification services in the construction industry. CSTB is a member of EOTA, it is an approval body nominated to issue ETA (European Technical Agreement). The protocol developed in 2004 to assess aperture barriers, was required by the French Department of Infrastructure to give to users a better understanding of the performances of the products they could use.

DIN 19569 is the German Standard for wastewater treatment plants and describes the principles for the design of structures and technical equipment. It is published by Deutsches Institut für Normung (German Institute for Standardization – DIN). Its original aim was not to categorise products used in flood protection. However, some German companies (i.e. company HWS-System GmbH[7], IBS GmbH[8]) assessed the watertightness functionality of their products according to the Part 4 of this standard: "Specific principles for shutoff devices as penstocks, sluice gates, stoplogs etc". This standard also defines structural design- and technical equipment-specifications.

3.3.2 Content of the documents

In relation to building aperture technologies, FM Global protocol, PAS 1188-1 and CSTB protocol have a lot of common points. Similarities also exist for FM Global protocol, PAS 1188-2 and PAS 1188-4 for perimeter technologies.

The main observations in relation to these reference documents are listed below:

- Flood perimeter barrier layout testing is described in terms of means (geometrical description of the test rig) in FM Global whereas it is written in terms of objectives ("capable of accommodating the test specimen", "test specimen shall include intermediate joints and internal and external corners" for example) in PAS 1188-2 or PAS 1188-4.
- Hydrostatic tests:
  - Sequential fill: the rate, or stages, of water level depth described in the tests may affect products differently. Permanent products may perform differently in relation to temporary barriers.
  - Test duration is specified between 22 to 48 hours, this parameter could be significant in case of creep.
  - Type of surface of the support for aperture technologies: masonry for PAS 1188-1, concrete for FM Global Protocol, concrete/steel for CSTB protocol.
  - Leakage rate acceptable is :
    - For perimeter barriers: 40l/h/m for PAS 1188 and 45 l/h/m for FM Global Protocol
    - For aperture barriers: 1l/h/m for both
- Hydrodynamic load tests :
  - Incidental wave is not tested in PAS 1188.
  - Characteristics of wave-induced tests and currents tests differ slightly in PAS 1188 and in FM Global protocol.

[7] http://www.hochwasserschutz.de/de/produktbereiche/hochwasserschutz-fensterklappen-platten.php
[8] http://hwssystem.de/produkte/

- o Overflow test is only required by FM Global protocol
- o Concerning aperture technologies, wave and current tests are considered in PAS 1188-1 but not in FM Global and CSTB protocols.

- Security is assessed by bending tests in CSTB protocol whereas it is indirectly determined by deformability for FM Global protocol and PAS 1188.
- Impact tests are not specified in PAS 1188.

In DIN 19569-4 watertightness classes are defined with respect to leakage rates (Table 15). The measuring conditions are described as follows:

- The leakage rate measurement refers to the watertightness line, which is defined as the contact area of the sealant between frame and plate.
- The water pressure condition has to be agreed on by the manufacturer and the testing institute
- The tests have to be carried out with distilled water
- The measurement time is 10 minutes.

Table 15: Watertightness classes according to DIN 19569-4

Class	Maximal acceptable leakage rate per meter of the watertightness line (l/s/m)
1	Between 0,3 and 1,0
2	Between 0,1 and 0,3
3	Between 0,05 and 0,1
4	Between 0,02 and 0,05
5	Less than 0,02

The duration of exposure tests for wastewater treatment products differ from similar products used primarily for flood protection. Leakage rates for wastewater products are also less onerous than those described in FM Global or PAS 1188.

3.3.3 Other documents in development

The "European Flood Protection Association", founded in May 2011 as an alliance of 18 companies from five European countries working in the area of flood protection, plans to found a research institute for certification marks[9]. This association published a test standard for quality label in December 2011. This

[9] http://www.europaverband-hochwasserschutz.eu/Pressemitteilung-FINAL-Englisch.pdf

standard concerns three categories of products: temporary flood barriers, aperture flood barriers and pre-installed/demountable perimeter flood barriers. The evaluation criteria are:

- Transport and storage volume
- Time of mounting
- Water tightness
- Control of static proof
- Manufacturer's expertise.
- Depending on the performance, a classification is attributed to the product.

The testing centre for construction elements[10] (Prüfzentrum für Bauelement, PfB) developed a guide for testing and classification of the watertightness functionality of flood aperture barriers defining the terms 'water proofed' and 'flood resistant' as follows:

- Water proofed: leakage rate through the structure less or equal 20 ml/h after a water load of 24 h
- Flood resistant: leakage rate through the structure less or equal 10 l/h after a water load of 24 h
- The PfB guideline was applied e.g. to the product "Flood Protection Door Teckentrup"[11].

3.3.4 Limits of the documents

In relation to flood barriers, the wide technical range of products available means that it is difficult to work out any fixed standard evaluation procedure. A comprehensive testing matrix for perimeter flood barriers will be developed. This will serve as a basis for the definition of a specific testing procedure for a specific perimeter flood barrier technique. Therefore, the user will have to pay attention not only to the certification mark but to the underlying testing conditions to select the appropriate technology for any specific application.

Moreover, the added-value of the SMARTeST guidelines should be to provide clear and precise information about the reasons for undertaking each test and the conditions of use. This will also provide information on which procedures are obligatory and which are not.

3.4 Installation guidelines

3.4.1 Types of documents

The installation guidelines are not directly concerned with the testing procedure of products. Indeed, even if there are some assessments by in situ tests of barriers, for example, no reference documents with in situ test protocol have been reviewed.

In Germany different technical inspection organisations like TÜV (Technischer Überwachungsverein) or DEKRA (Deutscher Kraftfahrzeug-Überwachungs-Verein) validate the safety of products of all kinds to

[10] http://www.pfb-rosenheim.de
[11] http://www.teckentrup.biz/produkte/tueren/hochwasserschutztueren.html

protect people and the environment against hazards. Many companies (i.e. HOP Logistik[12], Aquastop[13]) producing flood barriers asked these associations to evaluate the product stability in flood event.

Standards relating to installation of products have also been reviewed. A selected number of these standards have been listed below: (cf. Table 16).

Table 16: Types of installation reference documents

Existing document	Type	FRe category	Organism
DTU 14-1	National standard	Building technology	AFNOR
BS 8533	National standard	All categories	BSI
EPTB Saône et Doubs Guidance	Other guidelines document	All categories	EPTB
BWK Guidance	Other guidelines document	Perimeter technology	BWK
DWA Guideline	Other guidelines document	All categories	DWA

3.4.2 Content of the documents

In France, AFNOR, the French national organization for standardization, published the standard named "DTU 14-1:Travaux de cuvelage – Partie 1: Cahier des clauses techniques, NF P 11-221-1", for tanking works in buildings. Three types of "waterproofing" applications are described in this document:

- Tanking with waterproofing coating, which is applied to the internal surface(s) of a structure.
- Tanking for relatively watertight structure, without any coating, for which acceptable leakage rate is defined as:
    - o For the whole structure :
    - o annual average : 0,5 l/m2/day ;
    - o weekly average : 1,0 l/m²/day

[12] http://hop-logistik.de/
[13] http://www.aquastop.de/service/glassysteme/

- For part (10 m² with side ratio is between 0,4 to 2.5) of the resisting structure
  - weekly average : 2,0 l/m²/day

Tanking with watertight coating, which is plastic, elasto-plastic, or elastic, and applied on external surface of the structure. These materials are able to resist to water forces even if the adhesive properties are not continuous.

For each of these levels, DTU 14.1 gives specifications about design, materials choice, installation and treatment of joints and interfaces.

Watertight coatings are mainly described by referencing the "Avis Technique" or other technical assessments. These products are not widely applied and their use or application cannot be standardized at this stage, At the present time there are approximately ten products which can provide watertight tanking and reference an "Avis Technique".

In UK, **BS 8533** is the national standard relating to flood risk and assists users in selecting appropriate flood risk management solutions. It's not strictly a guideline for installation of products but more a code of practice of flood risks management.

In France, **EPTB Saône et Doubs** is a public organization which works in collaboration with local authorities to manage and develop river basins. It has published a guidance document to give technical specifications to adapt housing in case of flood. Building aperture technologies are proposed but without any quantitative information about leakage rate. Height of protection is limited to 90 cm and the document indicates that installation of barriers should not be the only solution, and should be combined with others measures (closure of all the building apertures, for example) to be efficient. A more recent guide based on a coherent approach was published in July 2012[14]

In Germany, the **BWK (Association of Engineers for Water Management, Waste Management and Land Improvement)** published guidance in December 2009 for demountable, temporary and pre-installed flood barriers. The document identifies different types of flood barriers and relevant design parameters. Flood actions and geotechnical limitations are qualitatively described and formulas for the quantification of loads as well as the geotechnical safety concepts are presented. Furthermore, logistic and risk aspects are discussed and field examples are given with respect to urban planning as well as alarm and application planning. Due to the constant development of new products on the market, an update of this document is planned. Moreover, an additional guideline on testing and certification of flood barriers will be provided by the BWK. This guideline will be developed in cooperation with the German SMARTeST project partners. The publication date is not expected before 2013.

The **Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall (DWA)** is currently working on guidance for dry-proofing and wet-proofing techniques. No information on the planned date of publication is available.

3.4.3 Limits of the documents

In Germany, no comprehensive testing and certification guideline for Flood Resilient Technologies currently exists. Product tests and certifications have been completed, but without the establishment of an accepted testing scheme. It is expected that the projected guidelines on testing and certification of flood barriers by the BWK and on dry-proofing and wet-proofing techniques by the DWA will close this gap.

[14] http://www.developpement-durable.gouv.fr/Referentiel-de-travaux-de.html

Finally, there are various types of documents about installation of products but just a few refer to FRe specific characteristics. The FRe users are various and it may be difficult to propose documents that are suitable for all potential users. SMARTeST guidance documents should define the end user of any guidance that is produced, and ensure that the content is relevant to their background and discipline.

4 Testing of FRe technology

Within the SMARTeST project various FRe Technologies have been tested at different testing facilities. The types of FRe technologies that have been assessed include:

- Perimeter flood barriers
- Building aperture flood barriers
- Building technologies
- Infrastructure technologies

In the following sections of this report, the different test facilities and procedures will be described, as well as the range of products tested and the associated results. More detailed information are available in appendix 1 to 7.

All tests were performed using clean tap water. Latent damages due to polluted water were not addressed

4.1 .Test facilities

4.1.1 Test facilities and procedures at TUHH

The test laboratory at the TUHH consists of a basin made of watertight concrete with the dimensions 20m long, 15m wide and 2m high (Figure 7). The base of the testing facility is finished in smooth and even concrete. The basin is enclosed by even rectangular concrete walls with an opening of 3m on one elevation to enable easy transportation of the testing material into the basin. The opening can be closed by demountable aperture flood barriers made of aluminium. Furthermore, two water storage tanks are located in the testing facility, which are also enclosed at two sides by demountable flood barriers. For dynamic impact load tests, the right hand segment wall can be dismantled to provide an acceleration area for debris load testing.

For static load tests, fresh water is pumped out of the storage tanks into the testing tank. The total leakage rate, i.e. leakage rate underneath the structure, between single elements of the structure, between structure and basin walls as well through the structure itself, can be measured by a dimensioned pump sump with a size of 50x50x50 cm³ (Figure 8).

The tests carried out at the TUHH, assessed the performance of perimeter flood barriers i.e. perimeter flood barriers with and without permanently installed elements as well as building aperture flood barriers. The latter can be included in a wall segment that can be erected in the test basin.

When using perimeter flood barriers, specific safety related aspects have to be accounted for. These include:

- mode of operation
- construction and the usable materials
- available early warning time

- static and dynamic loads from water level
- waves
- ice pressure
- flotsam impact
- physical stresses due to weathering effects and required protection height.

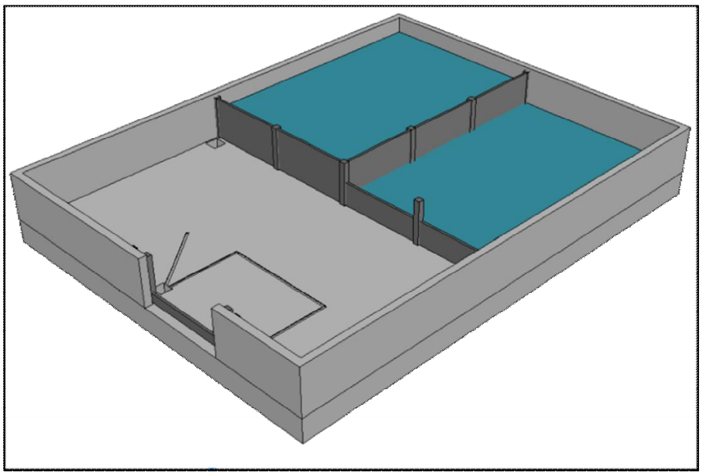


Figure 7: Testing facility of the TUHH in Hamburg Wilhelmsburg

Figure 8: Pump sump for leakage measurement

Beside the general stability, the risk of failure of the perimeter flood barrier is mainly dependent on the safe assembly of the system. Important parameters are:

- available early warning time
- number of skilled helpers mobilized in a short time
- manageability of protective components even under bad weather conditions

A strict assembly schedule should be implemented, based on locally defined threshold values of forecasted water levels.

A low risk of failure for perimeter flood barriers can only be guaranteed, if technical components as well as administrative conditions are suitable designed. The procedure in the testing facility of the TUHH aims to assess the technical functionalities of perimeter flood barriers. Main aspects of the test procedures are the following:

- Readiness Assessment
- Mounting and dismounting of the system, with or without time measurement
- Assessment of watertightness

- Hydrostatic load tests including leakage rate measurements for different system and/or product configurations as well as different water levels
- Stability Assessment
- Hydrostatic load tests including displacement measurements for different system and/or product configurations as well as different water levels
- Hydrostatic load tests up to system failure (high degree of displacement) for different system and/or product configurations
- Dynamic impact load / current load executed by a heavy water outfall at one side of the structure
- Dynamic load impact / debris load tests with different debris weights, impact angles and a fixed water level
- Overflow test / observation of the product stability for situation of overflow
- Assessment of the effect of wear
- Durability test: 100 cycles of mounting/dismounting of the product with check of the movable parts every cycles.

4.1.2 Test facilities and procedures at CSTB

The tests carried out at the CSTB focussed on building aperture barriers. The purposes of these tests are as follows:

- to determine the behaviour of the barrier under hydraulic load of a defined water height of hw meter of water and the evolution of the performance of this technology after a mechanical impact
- to determine the behaviour of the barrier under the action of a distributed load. This test conducted on the largest item in the range of the technology is used to define the failure load of the barrier and, therefore, the safety factor of the product.

4.1.2.1 Test facility

a) <u>Watertightness and impact tests</u>

Test facility is built with a horizontal element (the slab) and two vertical elements (walls) to simulate a building aperture (door, French windows, garage door …) and will be capable to accommodate two barriers, one in front of the other.

The wall coating can be:

- concrete,
- masonry,
- steel.

The slab can be in manufactured in concrete or in steel. No perpendicular deviation of walls or slope deviation of opening threshold is taken into account in this test. The length of the tested specimen is the maximum length claimed by manufacturer, and up to 3m.

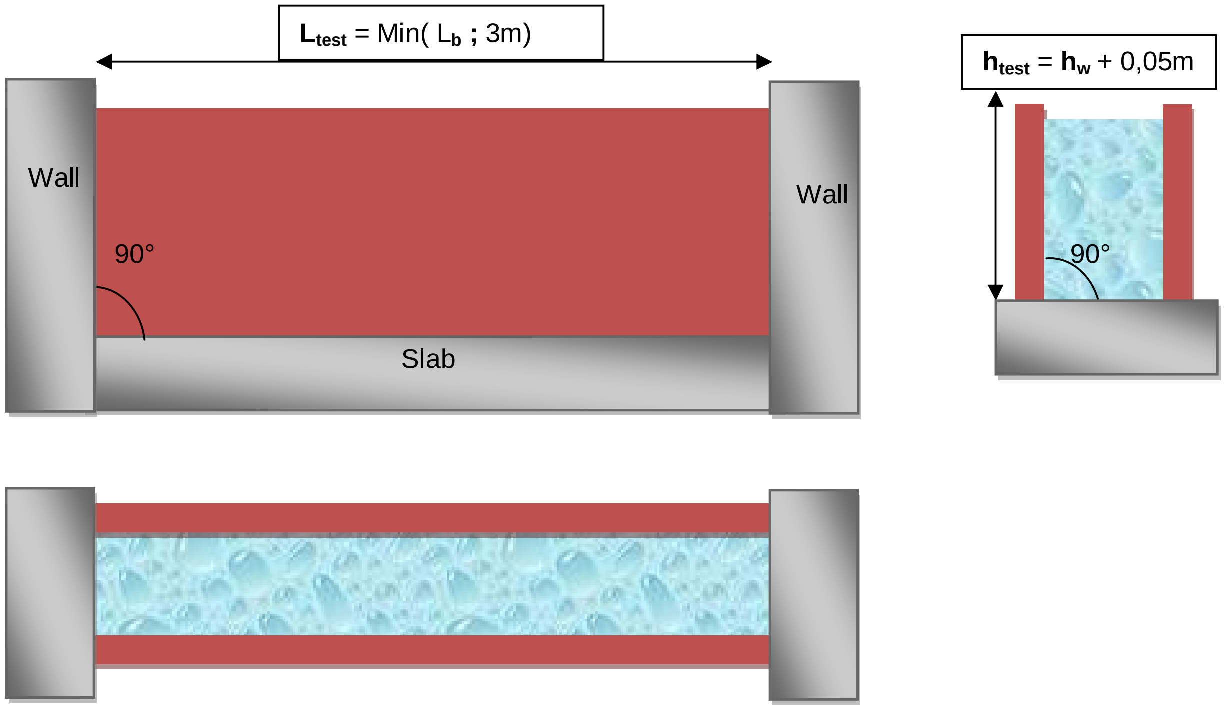


Figure 9: CSTB hydrostatic test facility

The height h_w is equal to the height h_b claimed by the manufacturer, up to 1 m: h_w = min (h_b; 1m). Water load is statically applied with h_{test} height. h_{test} is equal to h_w plus 5cm to take into account dynamic pressure created by a 1m/s current, perpendicular to the barrier surface.

$h_{test} = h_w + 0{,}05$m.

b) <u>Bending tests</u>

Test facility consists of:

- the frame (threshold and walls), used for hydrostatic test, on which one barrier remains mounted
- a carriage supporting a horizontal hydraulic jack to transmit the load to the test body.

Figure 10 shows the principle of this test, with ‘a’ and ‘L', the dimensions to adapt in accordance with the geometry of the barrier and its constitution (one or more elements, vertical or horizontal elements).

4.1.2.2 Test procedures

a) <u>Watertightness and impact tests</u>

The barriers are installed according to supplier instructions. Water is filled up to h_{test} height.

Verification of the leakage rate is made over a 24 hour period, together with displacement measurements at the top and bottom of the barrier (location of measurement points is chosen according to geometry of the tested barrier). Water level remains constant throughout the duration of the test. In case of creep of the panel, tests can be extended to 24 hours more.

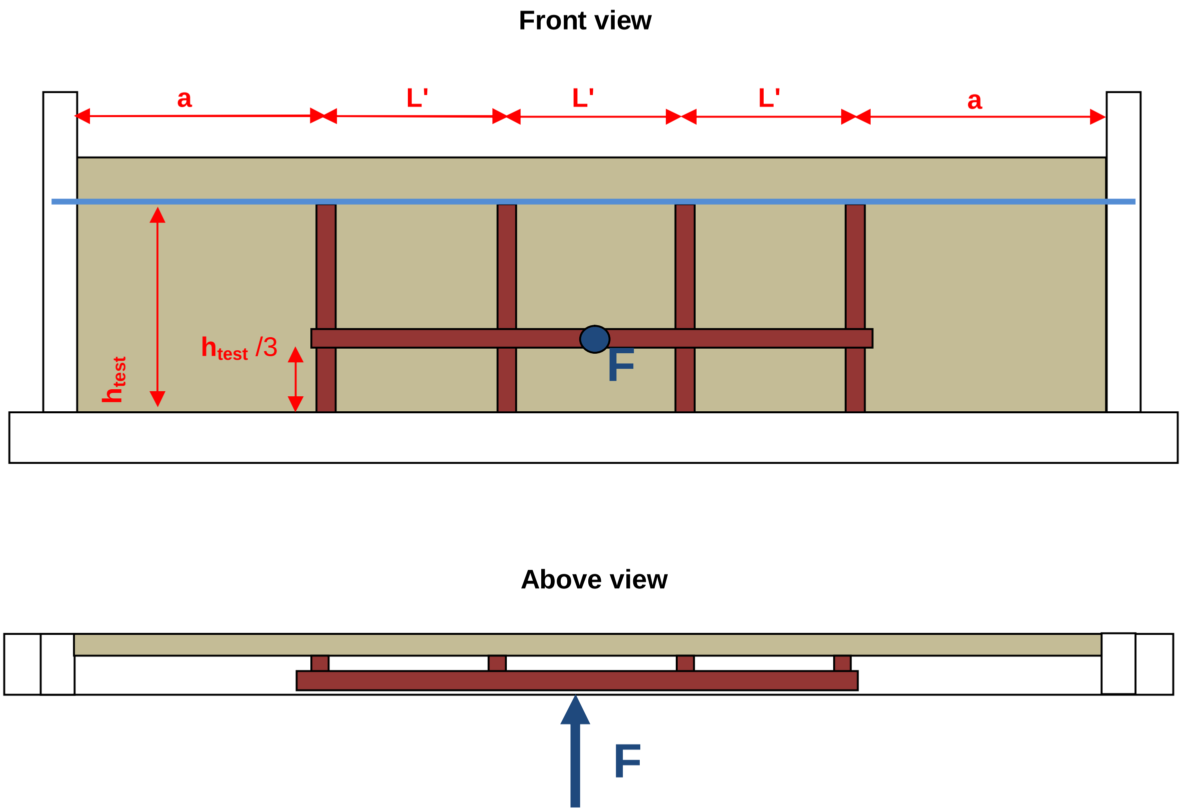


Figure 10: CSTB bending test facility

The impact test aims to simulate the shock resulting from the docking of a rescue boat along the barrier. This impact is called "safety" impact because of the danger for people inside the building in case of failure.

After the hydrostatic test, the tank is emptied and a 600J impact test is conducted. Possible damage to the barrier is observed and recorded. After this shock test, the water tightness of the barrier is tested again over a 24 hour period, according to the described hydrostatic test protocol. Leakage rate during second hydrostatic test is measured.

b) <u>Bending tests</u>

The test barrier is instrumented with a maximum of 10 displacement transducers, located in accordance with the geometry of the tested barrier. The measurements are made at the base of the specimen and at the top (same locations than hydrostatic measure points).

Bending load is increased at a constant rate and until failure occurs.

4.1.3 Test facilities at BRE

4.1.3.1 Test rig

A test facility at BRE was constructed to test insulation material injected within masonry cavity walls. The test facility was designed to create four test bays as shown in Figure 11.

The bays were divided by double leaf solid block-work walls and the base was made from concrete paving slabs. The blockwork surfaces were treated with a tanking material. The existing wall at the back and sides was covered in polythene to prevent water leaking through, and a damp proof membrane (DPM) was installed below the base of the test walls, and below the paving slabs to prevent water seeping out into the ground.

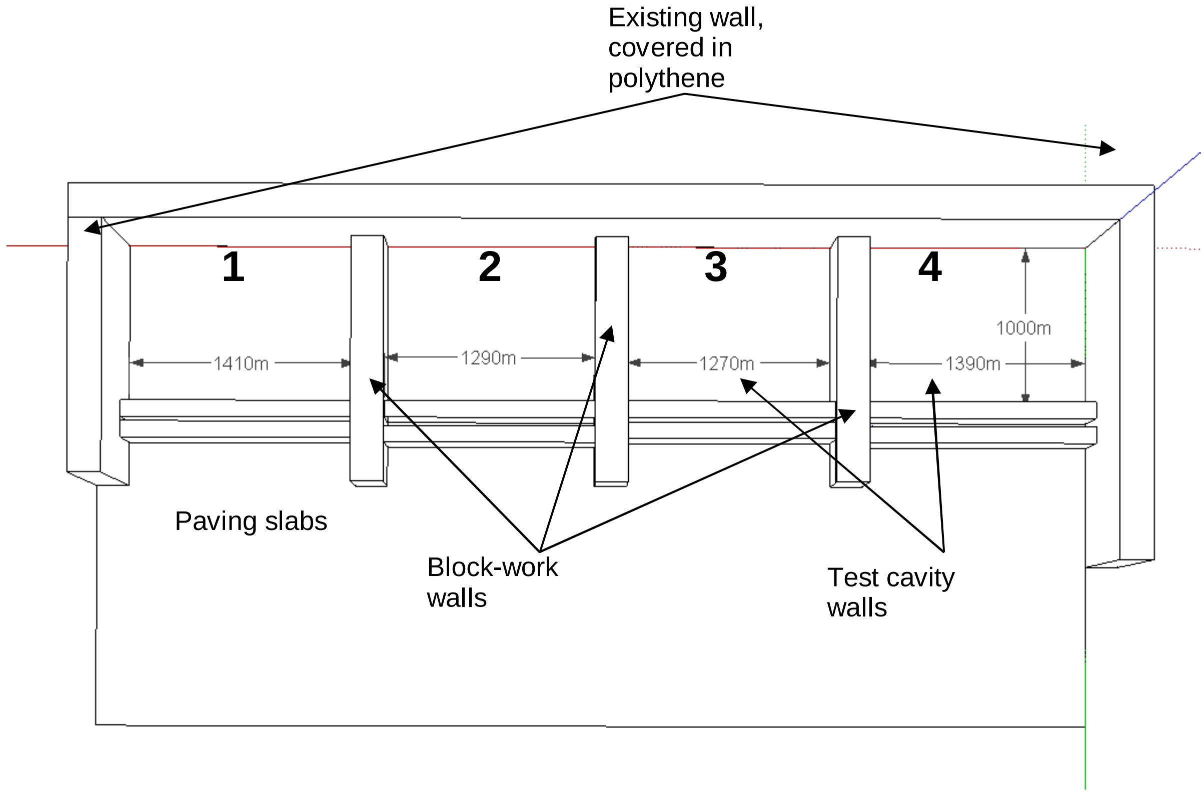


Figure 11: Plan view of the test tanks

4.1.3.2 Test procedure

Table 17 shows the formation of each test wall with details of the brick type and the cavity width in each tank. The test walls were formed from two leafs of the same type of brick.

The insulation material is injected into the cavity as a liquid which then expands and sets. The insulation material is commercially available and has full third party certification. The insulation is a technology that can be applied to any building with masonry cavity walls.

Table 17:Test wall details

Test tank	Brick type	Cavity Width (mm)
1	Medium absorption standard brick	25
2	Medium absorption standard brick	50
3	Low absorption engineering brick	25
4	Low absorption engineering brick	50

The test procedure was as follows:

1. The masonry cavity walls were constructed using two types of brick, an engineering brick of low absorption and a standard clay facing brick of medium absorption value. Two cavity walls were built of each type, with 25 mm and 50 mm cavities, the quality of construction was deliberately not to a high standard. A section of plastic pipe was placed through both leafs of the cavity wall just about the first course. The height of each wall was 900 mm and the width as shown in figure 24. The mortar was allowed to set for more than 28 days before further work was undertaken.

2. A hydrostatic test was carried out by filling the tanks using a hose pipe connected to the mains water supply. Leakage from the test rigs was assessed by visual observation and measuring water lost from the tank over time against the rate of filling carried out. The test was continued for 5.5 hours.

3. The tank was drained fully and the wall allowed to dry under covers for a period of seven days.

4. The insulation material was then injected into the cavity walls in the test rigs by a manufacturer approved contractor.

5. A second hydrostatic test was then carried out by filling the tanks using a hose pipe connected to the mains water supply. Leakage from the test rigs was assessed by visual observation and measuring water lost from the tank over time against the rate of filling carried out.

To supplement the hydrostatic tests moisture absorption tests were undertaken, see *Table 18*. Samples were either partially or fully immersed in water. Each sample contained varying amounts of cut or moulded surfaces. The sample was formed in a perspex mould and cut into the 12 sections. In practice, the material installed in a cavity has its surfaces moulded by the brickwork. The sample moulded surfaces would be considerably smoother than the moulded surfaces that would be found in practice in a brick cavity wall, which would impact on the absorption characteristics.

After the hydrostatic tests, two tanks demonstrating different brick type and cavity width, were filled again to approximately 500mm and then left to drain overnight. Samples of the insulation material were then removed from the cavity walls from above and below the level of the water. These samples were weighed and then dried in an oven at 50°C for 7 days. A difference in weight after drying would show the weight (and volume) of water that was originally present in the insulation.

Test sample	Number of cut surfaces	Number of moulded surfaces	Immersed /Submerged	Immersed surface area (mm^2)
1	3	3	Immersed	13701
2	4	2		13305
3	3	3		13115
4	4	2		12924
5	3	3		13212
6	4	2		13309
7	3	3	Fully submerged	42576
8	4	2		46364
9	3	3		43740
10	4	2		48606
11	3	3		40324
12	4	2		45202

Table 18: Absorption samples

4.1.4 Test facilities at IOER

The water-tight tank used for the tests is made of transparent acrylic glass. This allows processes such as seepage flow to be closely observed during the test runs. The specific geometry of the water tank enables the simultaneous examination of two constructions per test run. Its design can be seen in the schematic diagram in Figure 12. The inside of the water tank has a length of approximately 200 cm, a height of 50 cm, and a width of 50 cm. Two frames increase the rigidity of the tank construction. The front and back panel of the water tank can be removed for the in-situ construction and deconstruction of the test arrangements.

The lateral connections between the edges of the tested wall arrangements and the water tank have to be carefully sealed to avoid lateral water penetration into the construction and, in consequence, the falsification of the test results. In order to ensure a sufficient lateral bonding, steel plates (thickness 3 mm) are adhered to the sidewalls of the water tank with silicon sealant (cf. Figure 13). Then, the construction joints between the built test specimen and the steel plates are sealed with mortar. This task needs to be carried out with care to eliminate any leakage through the joints. After completing a test run, the test specimens and the steel plates are removed from the water tank. Then, the silicone sealant is peeled off from the acrylic glass tank and the steel plates are thoroughly cleaned before use in the next test run.

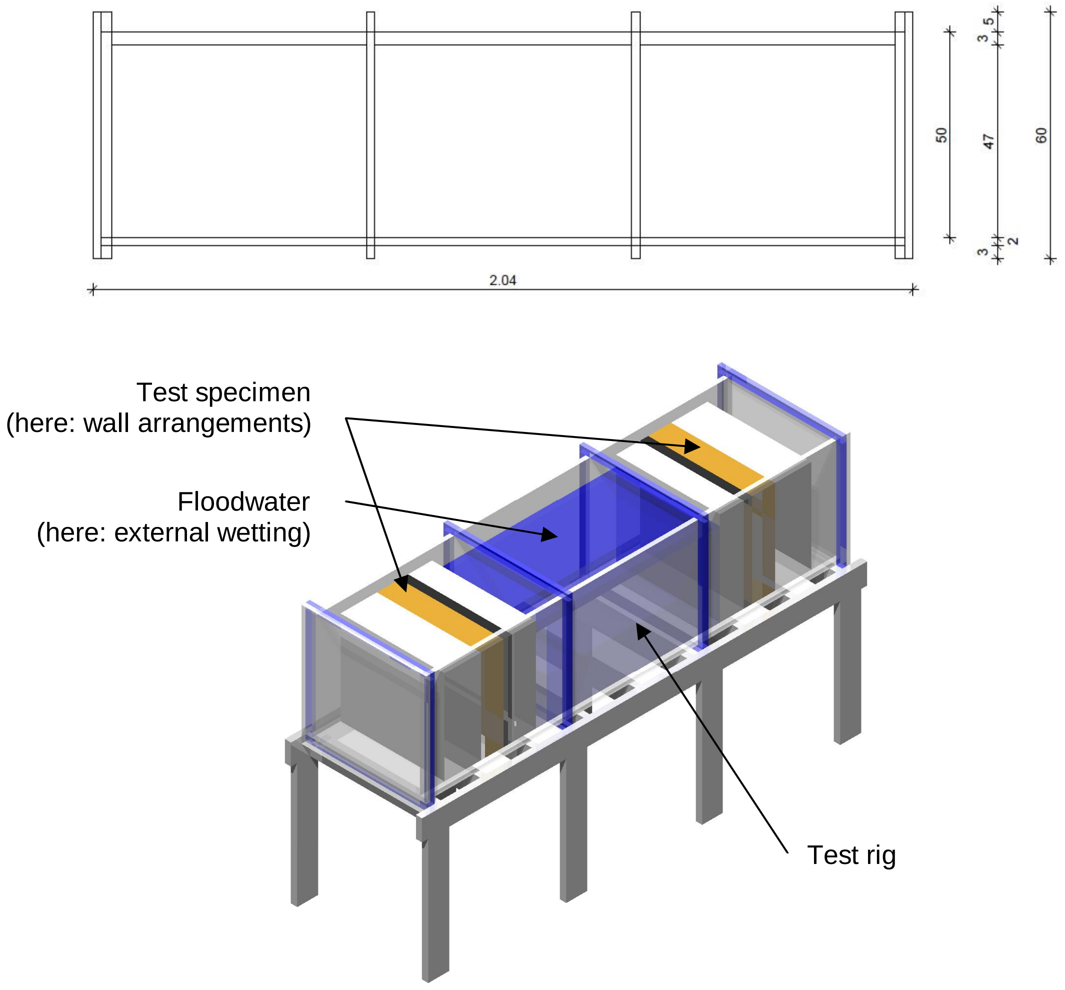


Figure 12: Top: Schematic plan of the water tank used for testing. Bottom: Oblique view of the water tank with two test specimen.

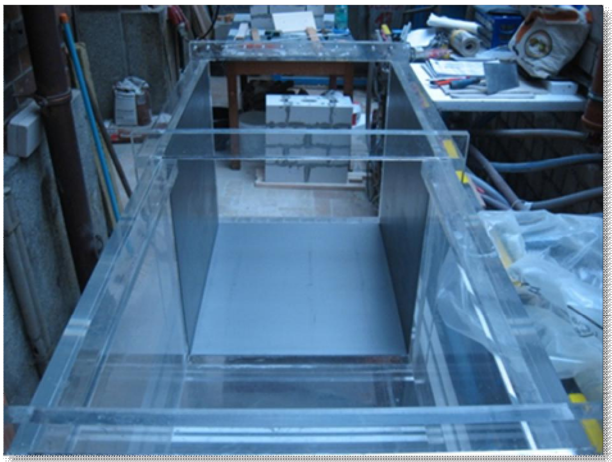


Figure 13: Steel plates for lateral connections.

4.1.4.1 Measuring equipment

The objective of the test runs is to determine the water seepage through the wall and floor constituents. To quantify this effect, the laboratory tests clarify to what extent liquid water penetrates the materials of each building construction. The material samples used for this purpose are obtained by using diamond-head core drills with a diameter of 68 mm. The samples are weighted on a precision balance with an accuracy of 1 mg. For the determination of their dry-mass, the samples are dried in a laboratory oven to constant mass at a specified temperature[15]. The air temperature and relative humidity in the laboratory was measured and recorded in regular intervals using a digital data-logger. The test runs were daily captured using a digital camera. The pictures document water levels in the tank as well as the system behaviour over the entire test period of seven days.

[15] The oven temperature is 105° C (WTA 2002).

Figure 14: Digital data-logger to record air temperature and relative humidity in the laboratory at regular intervals. Picture: www.conrad.de

Figure 15: Precision balance with readout down to 1 mg. Picture: www.kern-sohn.com

4.1.4.2 Test procedures

Building envelopes, as well as floor constructions, need to be adequately designed and constructed to cope with floodwater. To analyse their system behaviour, four common wall and two typical floor arrangements were tested in a water engineering laboratory at the Dresden University of Technology. The testing program was designed to simultaneously analyse two wall arrangements in each test run. Therefore, the front and the back panel of the water tank were removed to allow access for in-situ construction of the test specimens.

The experimental work requires a number of model assumptions as follows:

(1), The cracking behaviour observed during the tests is not the same as for real structures – this is caused by the small dimension of the tested wall panels and the lateral restraint at the edges of the water tank

(2) Because of a tight schedule of the testing program, the wall arrangements were left to cure only for 14 days. It is clear, that mortar (the same applies also for the plaster) reaches his strength value very close to its ultimate value at the end of 28 days, but after 14 days curing period the mortar achieved sufficient strength and bonding characteristics.

(3) The testing protocol was not designed to observe long term drying shrinkage, which can also lead to cracking. The test specimens were flooded on their external face with clean tap water to exclude the broad variety of damage processes that can be caused by contaminated water. Every day the water levels on both the internal and the external face of the wall constructions were measured and documented. To indicate the water seepage particularly through the structural layers of the exterior walls, a moisture sensitive probe was inserted through boreholes from the top. After the simulated flood duration of seven

days, material samples were taken to obtain information about moisture content[16]. To quantify the moisture content and to determine the degree of saturation, the gravimetrical DARR-method[17] is used. Moisture profiles illustrate the moisture distribution over the wall thickness. Testing results are the rate of leakage through the whole wall construction and the seepage through wall materials (represents by the degree of saturation).

Figure 16: Water tank with two wall test arrangements that are under construction in-situ. In front: the double shell masonry of sand-lime bricks with heat insulation and air gap. In the background: the single shell masonry of hollow bricks with external heat insulation and ventilated curtain façade.

Test specimens were selected to cover two commonly used floor constructions simulating the floor arrangement of the basement. These tests were also performed in the test rig described in Figure 12 and Figure 13. During the testing program both the timber floor construction as well as the concrete floor construction was precast in the laboratory, before they were horizontally installed in the water tank. The test specimens were fixed at the bottom plate of the water tank to prevent floating due to buoyancy forces. The wetting phase lasts four days for each construction, before material samples are taken and analysed.

The wall samples were subjected to 40 cm depth of water. Due to the selected water level, structural failures of the test specimen were avoided. In addition, it was intended to simulate a flood situation in which object-related barriers[18] could be reliably implemented at the building envelope. It is assumed, that the depth of flood water should not be more than 1 m[19] to prevent structural damage to the wall constructions induced by considerable horizontal hydrostatic forces, because of unequal floodwater levels on different sides of the exterior wall. Also, vertical buoyancy forces can cause severe structural damage to the entire building. Prior to the implementation of flood barriers, which prevent the ingress of water into the

[16] The moisture content can be defined as either the mass of moisture per unit volume of the dry material, or the mass of moisture per unit mass of the dry material, or the volume of condensed moisture per unit volume of the dry material (Trechsel 2001). That means, the moisture content can be defined as the ratio, expressed as a percentage, of the mass of the pore water to the mass of the dry material.

[17] The DARR-method is a highly accurate procedure to quantify the moisture content of building materials by gravimetric analysis.

[18] Object-related barriers are for example building aperture technologies, which prevent water ingress through windows and doors. These include amongst other door boards, flood guards, and flood shields.

[19] There is evidence (e.g. Garvin et al. 2005, Escarameia et al. 2009) that structural failure can occur even below the limit of 1 m, depending on a number of factors, such as the length of the wall panel between vertical supports or joints and the materials used.

building, the stability of the building envelope must be verified by static calculations. The two tested floor samples were completely inundated to simulate their wet-proofing performance when flood water enters the building.

The testing program simulates a flood event which lasts seven days for each test run. In the first phase, the wall constructions were exposed to floodwater on the external face for 96 hours. Following that 4 day duration, the internal face was flooded for three days to analyse the impacts to building construction when floodwater is entering the building. However, the floor arrangements were tested for four days.

Many construction materials have a porous structure. Water can undergo several physical and chemical processes when it interacts with materials (Trechsel 2001). Most of the constituents of the analysed wall and floor samples absorb water by capillary forces[20]. In laboratory studies the DARR-method (cf. WTA 2002) is used, which is a highly accurate procedure to quantify the moisture content of building materials. The moisture content in a homogeneous sample is measured gravimetrically by determining the weight loss due to evaporation of water after it has been placed in an appropriate oven[21] and dried to constant mass[22] at 105° C[23]. A building material is dry when it contains no vaporable or only chemically bounded water. Based on the weight of the wet sample [m_{wet}] and the dry sample [m_{dry}], the mass related content of moisture [u_m] can be calculated using the following equation:

$$u_m = \frac{m_{wet} - m_{dry}}{m_{dry}} * 100\%$$

The degree of saturation specifies how much of the pore volume of a certain building material was filled with water when taking the samples. That means, the degree of saturation [S_w] indicates the ratio between the material moisture content [u_m] and the maximum moisture content [u_{max}] that can be attained by the material and is determined using the following equation:

$$S_w = \frac{u_m}{u_{max}} * 100\%$$

A detailed analysis of the degree of saturation is the basis for (1) assessing the susceptibility of applied building materials to moisture seepage and for (2) providing an effective redevelopment concept for enhancing the resilience properties.

[20] Building material absorbing water by capillary forces are called capillary active.
[21] The oven should be capable to maintain a temperature of 103° ± 2° C.
[22] Constant mass has been achieved when less than 0.1 % of the test sample wet mass is lost during an additional exposure to the drying process.
[23] The drying temperature for gypsum and calcium sulphate containing building materials is only 40° C to remain chemically bounded water.

The used method for moisture determination requires taking core samples from building components. These material samples are obtained by using diamond-head core drills with a diameter of 68 mm. Regarding the requirements from WTA (2002), the weight of each collected sample must be greater than the minimum weight of 50 g. Both the selected core diameter as well as the minimum weight of the samples minimises the impact of heat, generated by drilling without cooling water, on the moisture content of the core samples. The samples are then vacuum-packed and labelled before their wet weight is determined in a materials testing laboratory. To visualise the quantity of water seepage in the cross section, moisture profiles were created.

Figure 17: Building material test samples

Figure 18: Building material test samples in the drying oven to determine their oven-dry mass.

4.1.5 Test facilities of UK NSG member

The test facilities of a UK NSG member were used to test a product for the SMARTeST project. The results of these tests were passed to BRE. This test facility is the only BSI Approved testing facility dedicated to the research and development of flood products and the flood defence sector.

The 85,000 litre tank allows products to be tested for water-tightness under static and dynamic loads. The test facility, which measures 54m^2, can produce flood depths of up to 1 metre, current speeds of up to 1.5 metres/second as well as wave simulations.

The ‘flood zone’ allows the testing and demonstration of a range of FRe products which combined would provide full house protection. A wall separates the wet and dry areas. Openings built in this wall allow the testing of door and window defence barriers which can be removed to simulate a flood situation. Airbrick protection can also be tested here.

See-through pipe-work runs through the wall and to two adjacent ‘bathrooms’ which are set out to demonstrate the ability of a non-return valve to defend against sewage flooding as one is flooded, and the other remains protected.

To simulate a flood event, two, 20,000 litre storage tanks are opened. Monitoring equipment and sensors measure the actual flow of water and current speed within the rig during testing.

Figure 19: The UK NSG member's test facility (UK Flood Barriers)

4.1.6 Test facilities and test procedure at the UPM

4.1.6.1 Water vapour diffusion

Humidity effects on constructions
Humidity as a flood action causes itself main damages to constructions, and the effects of humidity on constructions shall be considered in FRe strategies. As the "breathing" of constructions constitutes an efficient protection against humidity, there is an interest in testing its water vapor permeability.

Type of testing

Water vapour diffusion is tested according to a weight assessment (analytical balance) of the moisture flow rate through the test specimen. The test specimen is sealed to the open flange of a test cup containing a desiccant. The assembly is then placed in an atmosphere with a controlled temperature and humidity (hermetic chamber). When mass take-up is linear over a period of time, the assembly is weighed periodically to determine the density of moisture flow rate through the test specimen into the desiccant.

Testing facilities

In order to carry out the previous procedures, the main testing facilities required are presented below.

Cups (Figure 20) are of pure, cold drawn aluminium of 1 mm thickness. Their aim is to seal the product at the required edges.

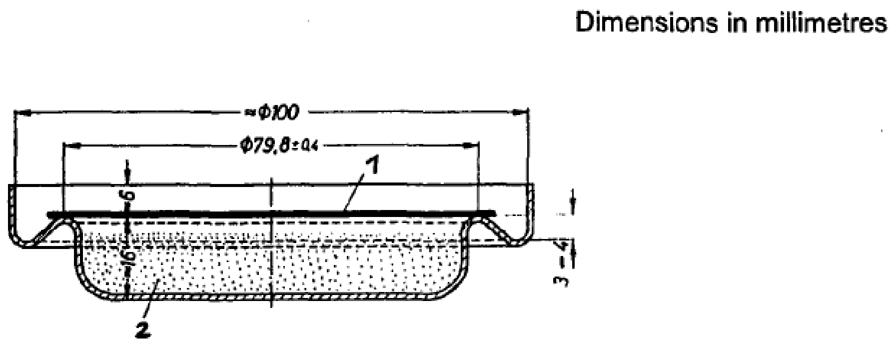


Figure 20: Cups. BS EN 1931

Mechanical gauge (Figure 21) is used to determine the thickness d of specimen to the nearest 0,05 mm ±0.I mg.

Figure 21: Mechanical gauge

The analytical balance shall be capable of weighing specimens with an accuracy of ± 0.1 mg.

The constant-temperature, constant-humidity chamber is used in order to maintain a relative humidity of 75 ±2% and a temperature of 23 ±1ºC. The relative humidity at the upper test specimen surface must be kept constant during test. An air movement of 0,02 m/s to 0,3 m/s in the vaporizing atmosphere shall be produced by a propeller

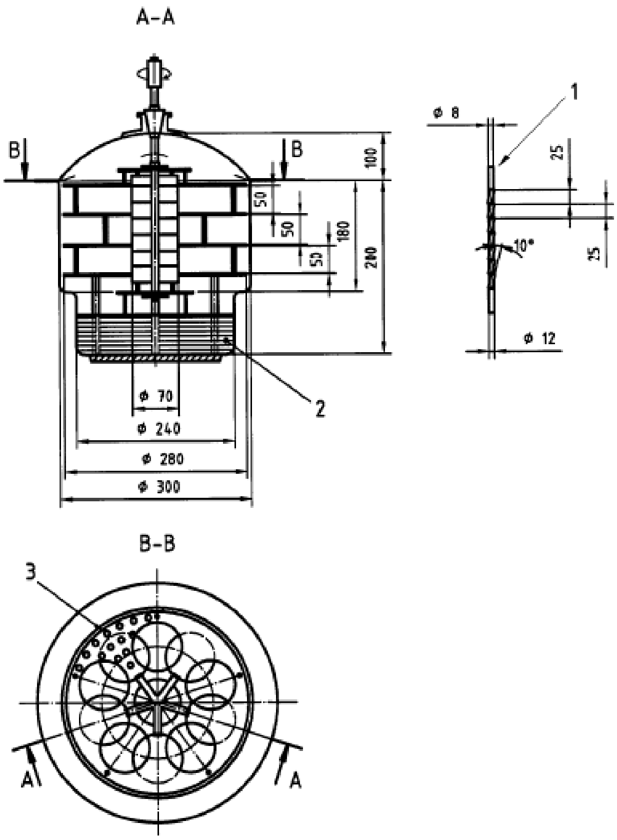
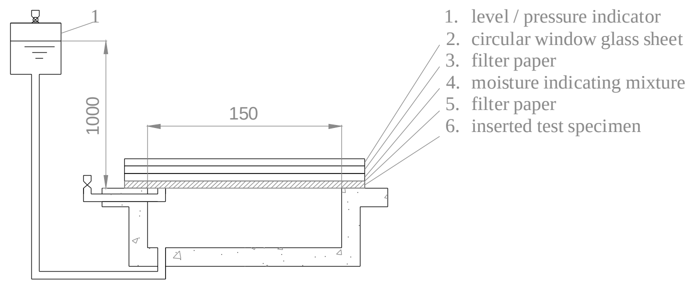


Figure 22: Evaporation atmosphere (BS EN 1931) 1 side view of the propeller with blades. 2 saturated salt solution with remaining solid at the bottom. 3 125 holes Φ 8 per plate

4.1.6.2 Watertightness

Type of testing

for solid membranes/ polymer and cured composites materials



TEST SPECIMEN AND APARATUS .
All measurements in milimeters [EOTA TR003]

In a flanged box (see

Figure 23) at (23 ± 2) °C place the test assembly consisting of sealing gasket, test specimen (exposed side to water), filter paper, moisture indicating mixture, filter paper, circular window glass sheet and sealing gasket. Watertightness is assessed by the visual recognition of the moisture indicator.

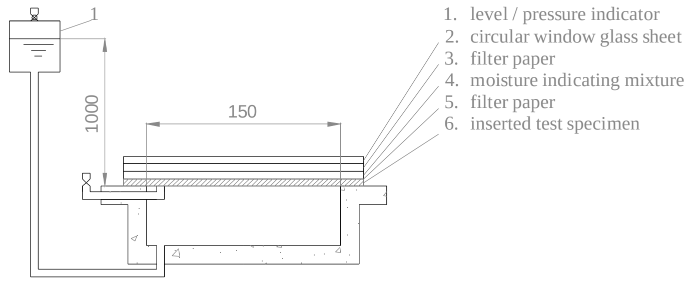
for liquid membranes

Watertightness is determined by applying a specified water pressure to the exposed side of the installed product by means of a hydrostatic head of water for a fixed period of time and detecting any water leakage.

Testing facilities

Flanged box (Figure 23)

The flanged box is needed in order to provide the requested hydrostatic pressure. It shall be connected to an open ended pipe or vessel which rises to a specified height or a pressure vessel. The flanged box includes a manometer and inlet and exhaust valves.



TEST SPECIMEN AND APARATUS .
All measurements in milimeters [EOTA TR003]

Figure 23: Schematic diagram of flanged box. EOTA TR 003–

Moisture indicator
It is composed by a mixture of fine white (icing) sugar (99,5%) and methylene blue dye (0,5%) sieved over a 0,074 mm mesh and dried over calcium chloride in a desiccator.

4.1.6.3 Resistance to UV radiation in presence of moisture

Type of testing & testing conditions (Figure 24)

Samples are exposed in a fluorescent UV artificial weathering apparatus at a specified irradiance, black and white standard temperature, relative humidity and spray cycles. Changes in other performances are determined after 2000 hours.

Figure 24: Resistance to UV radiation in presence of moisture. Ref: Sika

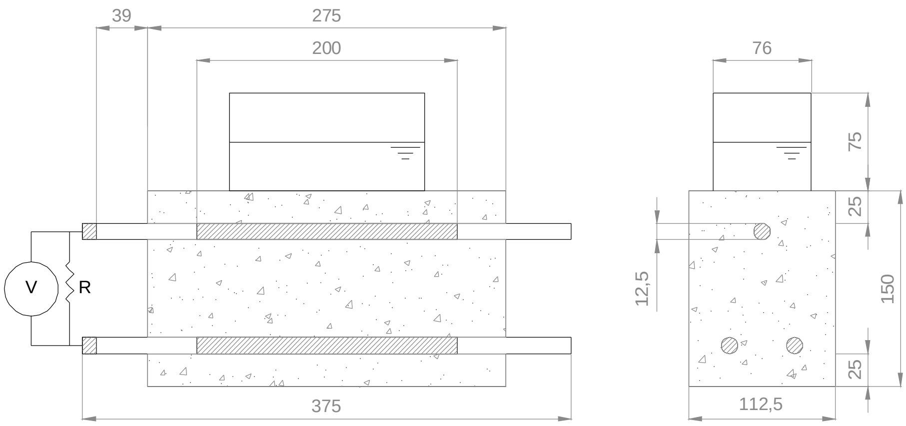
4.1.6.4 Anticorrosive resistance

Type of testing

The test consists in the measurement of the voltage across the resistor using the voltmeter. At the same time, the corrosion potential of the bars against a reference electrode that is placed in the dam containing the salt solution shall be measured (Practice G3 and Test Method ASTM C876).

Testing facilities

- The apparatus required for the evaluation of corrosion inhibitors includes a high impedance voltmeter (at least one MOhm) capable of measuring to 0.01 mV, a 100 Ω (65 %) resistor.
- Steel Reinforcement Bars, deformed, with a diameter between 10 mm and 16 mm, and a length of 360 mm (14 in.), drilled and tapped at one end to be fitted with coarse-thread stainless steel and nuts



TEST SPECIMEN AND APARATUS . All measurements in milimeters (ASTM G109-92)

Figure 25: Concrete Beam (ASTM G109)

4.2 Scope of FRe technology tested

The range of FRe Technologies in the SMARTeST project includes the following four types of tested products:

- Perimeter flood barriers
- Building aperture flood barriers
- Flood-resistant building materials
- Infrastructure technologies

In addition to this, laboratory analysis of selected building construction provided baseline information on their flood resilience properties.

4.2.1 Perimeter flood barriers

Perimeter flood barriers differ in material, construction, elements, and available protection height. The flood barriers can be divided in temporary, demountable and pre-installed systems. Within the SMARTeST project, different perimeter flood barriers have been tested to cover the range of systems available. All tests have been executed in the test facility of the TUHH.

Temporary flood barriers include:

- Sandbag System - Temporary flood barriers (Figure 26)
- Mobildeich System - Temporary flood perimeter barrier consisting of water-filled tubes (Figure 27)
- DAEDLER System - Trapezoidal water-filled tube system (Figure 28)
- OPTIMAL System – Water-filled double tube system (Figure 29)

Demountable flood barriers include:

- AQUASTOP DAMM – Demountable perimeter flood barrier (Figure 30)
- IBS Mobile Wall System - Demountable flood barriers / dam beams (Figure 31)
- Aquafence - Demountable perimeter flood barrier (Figure 32)

Pre-installed perimeter flood barriers include:

- Spring Dam System - Pre-installed flood barrier- Manually folding stand-by (Figure 33)
- AquaWand- Pre-installed flood barrier- Manually folding stand-by (Figure 34)

Figure 26: Sandbag system – temporary flood barrier

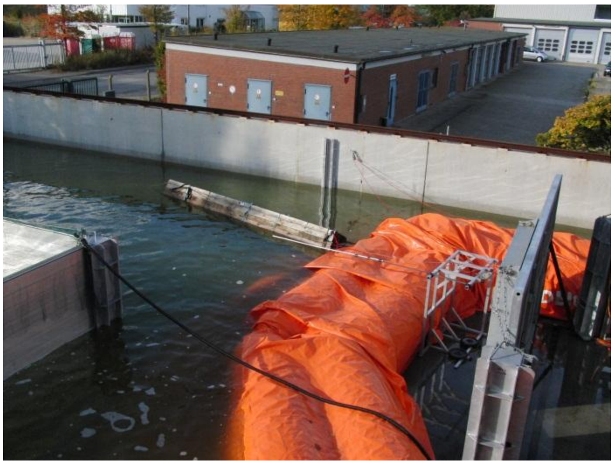


Figure 27: Mobildeich system – temporary perimeter flood barrier consisting of water-filled tubes

Figure 28: DAEDLER system – trapezoidal water-filled tube system

Figure 29: OPTIMAL system – water-filled double tube system

Figure 30: AQUASTOP Damm – demountable perimeter flood barrier

Figure 31: IBS mobile wall system – Demountable flood barriers/dam beams

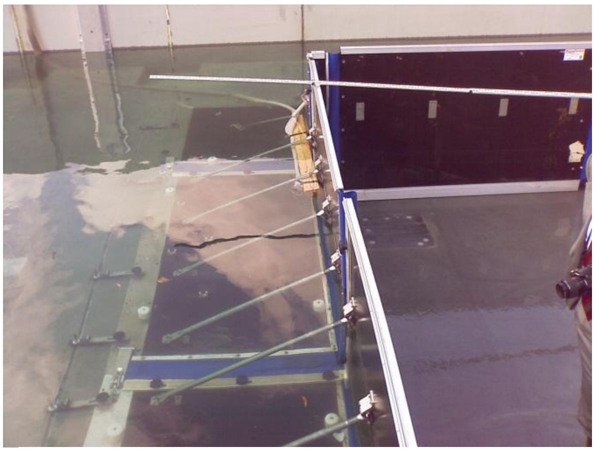


Figure 32: Aquafence – demountable perimeter flood barrier

Figure 33: Spring dam system – pre-installed flood barrier

Figure 34: AquaWand system - pre-installed flood barrier

4.2.2 Building aperture flood barriers

Building aperture flood barriers serve as a closure of openings in buildings. They can be divided in pre-installed, demountable as well as temporary systems. The temporary systems are always handled manually, whereas the permanently installed and demountable systems can be handled manually or automatically. The latter requires an automatic water level detection system for a timely closure of the barrier.

The following building aperture flood barriers have been tested in the SMARTeST project by TUHH and CSTB:

- Aqua-Stop: Pre-installed - Automatically operated flood barriers (TUHH) (Figure 35)
- Collad'eau: Demountable flood barriers (CSTB) (Figure 36)

The Collad'eau's water-tightness is ensured by an inflatable tube located between the rim of the barrier and the wall. The tube is protected by a butyl rubber envelope. The dimensions of the panels are as follows: width between 0,73 m to 1,03 m; height 0,98m and thickness 21 mm. Adjacent elements are placed to fill the building opening. Elements with customised dimensions can be made. The water tightness depends on the air pressure in the inflatable tube (typically 2.5 - 3 bars).

Figure 35: Aquastop system – Door, window and basement window barriers

Figure 36: Collad'eau

- Barrier n°3 : Demountable flood barriers (CSTB) (Figure 37)

Barrier n°3 is a PVC barrier which is installed between steel reinforced PVC columns mechanically anchored to the threshold. Water-tightness is ensured by EPDM band around the barrier, which has to be compressed to be active.

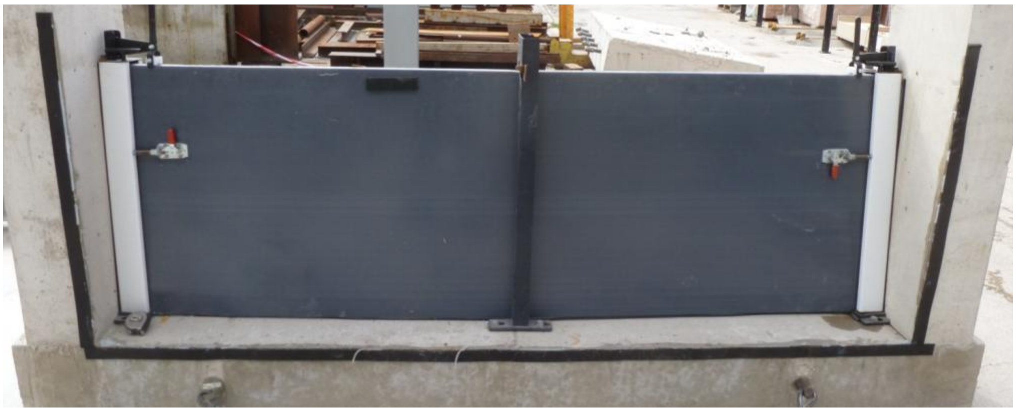


Figure 37: Barrier n°3

- Barrier n°4: Demountable flood barriers (CSTB) (Figure 38)

Barrier n°4 is a typical aluminium barrier, with EPDM band to ensure water-tightness and which is installed between aluminium columns.

Figure 38: Barrier n°4

4.2.3 Water proof or flood resistant building material

Flood resilience does not only address intrinsic structural properties of materials, but principally the additional external flood resilience contribution they provide to structures or infrastructures when applied as constitutive or additive elements.

4.2.3.1 Products tested by UPM NSG partners

Under the broad heading of Flood Resilient Building Technological Products, all products that can be incorporated or applied to some building element have been included as long as they:

- enhance its waterproofing characteristic (for example, waterproofing membranes)
- enhance its water resistance (for example, anticorrosive solutions).

Those products are based either on thermoplastic[24] and thermosetting[25] polymers, or on reinforced polymeric composites like glass-fibre-thermosetting polymers or rigid–thermoplastics. All of them are suitable for successive layer applications, one of these layers being an initial one providing mass and stability to the whole. Additionally, some of them can also be used to confirm authentic autonomous watertight structural barriers. Building Waterproofing Products are thus highly versatile solutions performing as water barriers in all cases, sometimes as a waterproofing complement, and other times as an

[24] Thermoplastic polymer: A polymer that softens when heated and that returns to its original condition when cooled to ordinary temperatures

[25] Thermosetting: A polymers in a soft solid or viscous state that changes irreversibly into an infusible, insoluble polymers network by curing

autonomous structure. Corresponding tests were carried out by UPM National Support Group manufacturers.

Details of these materials are given in Appendix 1.

4.2.3.2 Products tested by BRE

Also in this category is a polyurethane insulation material, which when injected into a wall cavity, prevents the ingress of flood water through the wall. Technitherm® is already used as cavity wall insulation to increase thermal performance, with third party certification demonstrating its credentials to improve the structural integrity of a building. The foam material is injected into the cavity as a liquid which then expands and sets to create a permanent barrier to floodwater.

Technitherm® is a building technology which can be applied to any building with cavity walls. It can be retrofitted by injection. Corresponding tests were carried out by BRE.

4.2.4 Infrastructure technologies

Infrastructure technologies provide flood protection to infrastructure components such as road, rail routes, pathways and permanent flood defences which can be seriously impacted in a flood event. Innovative infrastructure products could include surfacing materials, automatic barriers and membrane technologies.

An innovative infrastructure technology, a non-return valve (Figure 39) can helps to alleviate flash flooding in urban areas by dealing with road flooding. The power of floodwater activates the non-return valve, preventing water from backing up onto the road. The non-return road gully is a permanently installed resilient technology requiring no human intervention or warning system. Tests on this non-return valve were carried out by a UK NSG member and results were passed to BRE.

Figure 39: Non-return valve, in open and closed positions.

4.2.5 Building element

4.2.5.1 Potential damage process due to flooding

The identification and classification of relevant flood-induced damage processes is a fundamental requirement for a better understanding of material behaviour and for enhancing the resilience properties of building constructions. Hence, the exploration of failure mechanisms in traditional building materials is required. When building materials are exposed to flood water, they often take on moisture, because of their capillary porous structure. Moisture can migrate by various modes of moisture transport, such as vapour transport, liquid transport, and phase changes. In principal, any moisture transport process depends on a mass/temperature gradient as a driving force. Depending on the building material, the resulting moisture content can cause damage and can have a considerable negative influence on several material parameters which influence durability and performance, This can also lead to stress cracking and increased susceptibility to water penetration.

There are few building materials and composite constructions, which are not vulnerable to some form of moisture attack. The two columns in the middle of the scheme in Figure 40: Potential flood damage process. describe potential failure mechanisms. In contrast the right column refers to the failure effects. The complete chain from failure mechanisms to failure effects is called damage process. Through review on relevant literature the wide range of damage processes is confirmed (e.g. ATSM 1982). This systematic analysis of physical phenomena is a necessary basis for the development of engineering approaches to enhance the resilience particularly of composite building constructions such as wall and floor arrangements.

4.2.5.2 Description of test specimens

The detailed specifications of wall and floor assemblies, to be tested were proposed by the Leibniz-IOER. The following arrangements are all common constructive solutions which are detailed in current building standards. Information on the specifications of the test specimen was obtained from relevant professional literature and from DIN-standard[26]. All arrangements consist of individual materials combined in composite wall and floor constructions.

The tested wall arrangements were as follows:

W1: Double shell masonry of sand-lime bricks with thermal insulation and air space (Figure 41)

W2: Single shell masonry of hollow bricks with external thermal insulation and ventilated curtain façade (Figure 42)

W3: Single shell masonry of traditional solid bricks (Figure 43)

W4: Single shell wall of light (aerated) concrete blocks with thermal insulation composite system (Figure 44)

[26] DIN is the abbreviation for “Deutsches Institut für Normung” (German Institute for Standardisation)

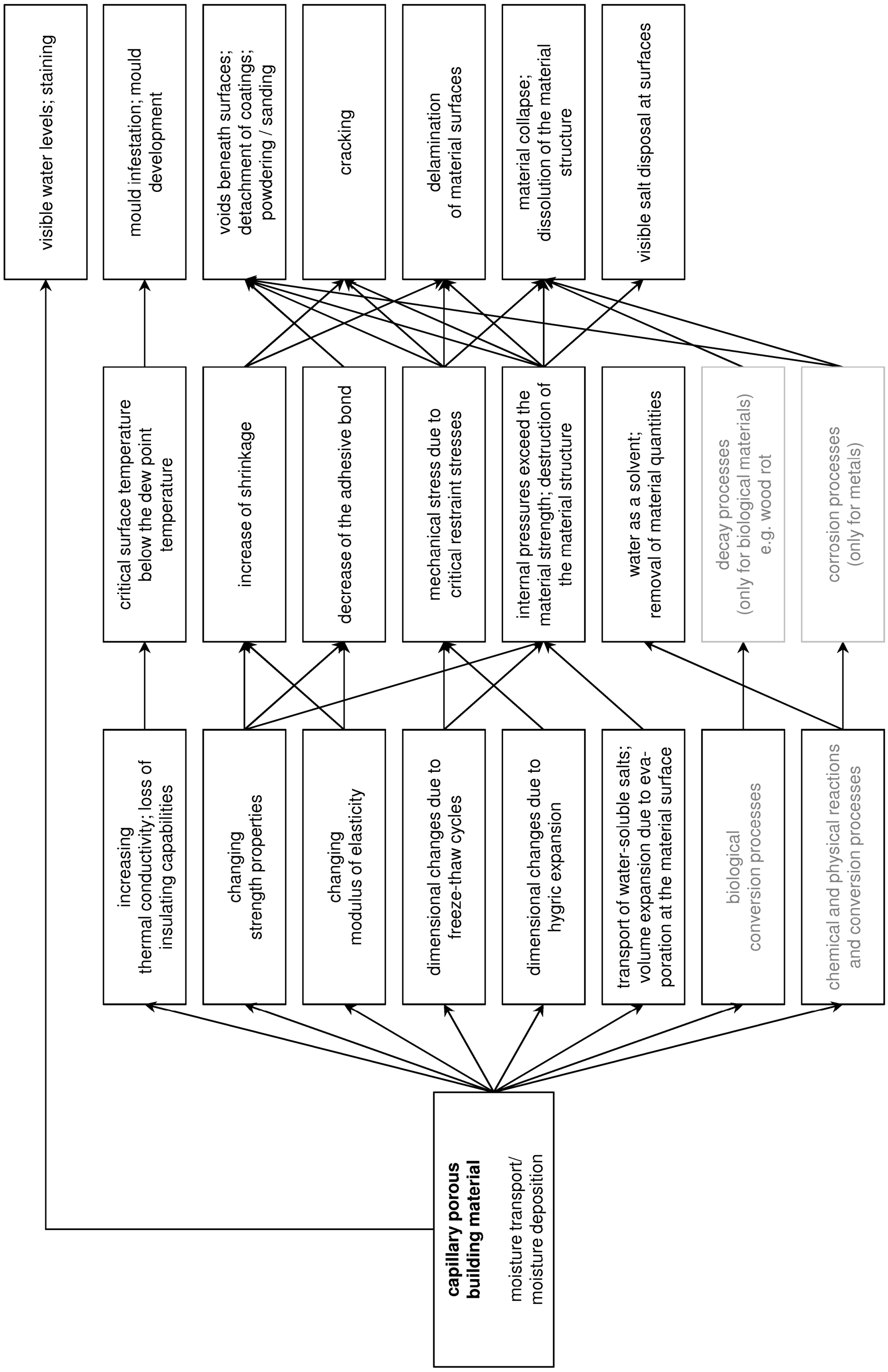


Figure 40: Potential flood damage process.

The geometry of all four test specimen is 50x50 cm and the thickness of the composite construction depends only on structural and physical needs. In the following sections of this report, the tested construction elements and their constituent materials are described in detail.

Figure 41: Wall arrangement W1

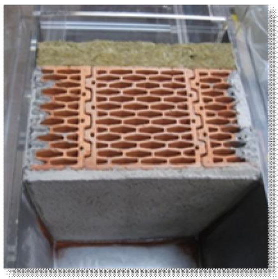


Figure 42: Wall arrangement W2

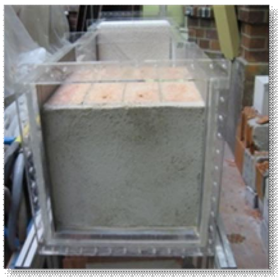


Figure 43: Wall arrangement W3

Figure 44: Wall arrangement W4

In addition two common floor types are tested:

- **F1**: Timber floor (Figure 45)
- **F2**: Concrete floor (Figure 46)

Figure 45: Floor arrangement F1

Figure 46: Floor arrangement F2

5 Test results

5.1 Objectives of testing procedures

The main objectives of the testing phase were:

- To assess the functionalities of different Flood Resilient products as defined in D2.1.
- To suggest improvements in these products if limitations in performance are observed.
- To benchmark the performance of FRe Technologies
- To inform the delivery of objective 2.3: “to develop guidance as the basis of standards for testing and approval of FRE-products, harmonizing the different European standards on FRe-product and approval procedures.”

5.1.1 Product functionalities assessment

Prior to the tests being initiated, the expected product function and performance were investigated and defined. In order to quantify the product performance for a given functionality, parameters to be measured and/or assessed were defined as follows:

- leakage rate
- deformation
- displacement.

As proven by these tests carried out, the results in term of performance do not depend only on the products, but also on the surrounding conditions. The test results presented in this report are linked with the testing conditions and cannot be extrapolated to every possible location, installation, environment or flood conditions. For this reason, test results should not be presented without the associated test conditions. The conditions which have a significant influence on the product performances are listed in this report.

5.1.2 Product improvements

The tests carried out, aim to provide a better understanding of the in-use performance of the product. This will assist in the detection of failures and limitations of the products, which are not noticeable in the designing and manufacturing phase. Consequently, some improvement suggestions have been made following the completion of these tests.

5.1.3 Benchmark of performances

Initially, the SMARTeST description of work expected that a benchmark of the performance of the FRe Technologies would be obtained from the completion of these tests. Benchmarking implies a comparison of the product performances. In order to fairly compare the products to each other, they have to be tested in the same conditions. In reality, the testing conditions differ as the various testing facilities offer different conditions with respect to the built environment as well as the measurement technique employed. Furthermore, the system functionality differs from product to product and different testing conditions are often required. For example, some of the systems are only built for the protection against low water levels or for straight and not curved protection lines. Therefore, not all tests results can be directly compared.

5.1.4 Test guidance

When developing a guidance document for FRe testing, the following questions should be considered:

1. What is expected from the guidance?
2. What product performance parameters should be investigated?
3. What test procedure and test conditions are relevant for the end users?
4. Is a standard test protocol responding to the demand of the end users?
5. Can approval procedures be standardized for FRe Technologies?

The objectives of the tests have been described, and the products that were assessed in the SMARTeST project can be categorized as follows:

- Perimeter flood barriers
- Aperture flood barriers
- Dry flood proofing measures
- Waterproofing material for, building material for wet flood proofing measures
- Anti-corrosive measures
- Infrastructure technology

Comprehensive descriptions of executed tests and the results are listed in the appendix 2 to 6.

5.2 Perimeter flood barriers

A total of nine perimeter flood barriers were tested. These products were representative of the following categories of perimeter flood barriers:

- temporary
- demountable
- pre-installed.

All of these products were tested at the test facility of the River and Coastal Engineering Institute of the University of Technology (TUHH).

5.2.1 Product performance

Some of the tested products (i.e. Daedler, Aquastop aperture flood barrier, Optimal) are in development phase and no conclusive statements on the product performance can be reported. The test results are summarized in Table 20. According to the diversity of the products tested, the testing procedures can differ from product to product. The single testing procedures are listed in the test sheets in Appendix 2.

The product test data alone should not be used to fully characterize the product's predicted performance. When analyzing the product performance, the testing conditions always have to be taken into account as the product performance can differ depending on the conditions of test. For illustration two examples are given:

The water tightness functionality of the product is assessed according to the leakage rate. The leakage rate is dependent on how the product is sealed as well as on external conditions (e.g. Geotechnical characteristics of the ground, topography, type of ground surface, and flood actions). The products were tested in basin made of smooth and flat concrete. These conditions can be qualified as ideal with respect to the watertightness of the underground and the absence of gaps. However, the smooth concrete results in a very low friction coefficient between the underground and the protection structure leading to a sliding of not-fixed constructions like non-stationary tube systems.

The time to mount the product is assessed in m/h/pers. During testing the transportation timescales have been short and the weather conditions have been fair. This may be different in real situations leading to time- and personnel-consuming mounting conditions.

In order to highlight the dependence of performance on testing or deployment conditions, the parameters influencing the product functionalities are shown in Figure 47.

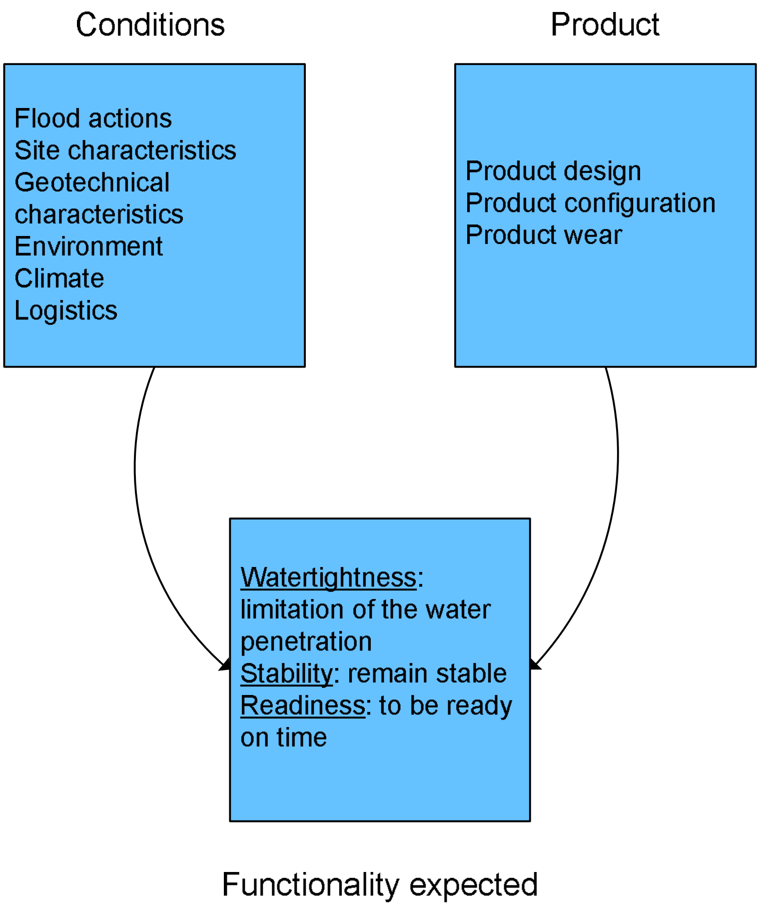


Figure 47: Conditions and product characteristics influencing the product functionalities expected

From these observations, information on the field of use for perimeter flood barriers can be offered. This is particularly relevant for products like temporary flood perimeter barriers for which no preparation of the ground is required. The guidance for demountable, temporary and pre-installed flood barriers of the BWK, 2005 (Association of Engineers for Water Management, Waste Management and Land Improvement) provides the following recommendations:

- The application of temporary flood barriers is not recommended for large flood depths and high dynamic loads resulting from wave impact, flow velocity and/or flotsam impact shifts, as well as for short warning times.
- Temporary flood barriers used on an unknown site should not be used in case of flood water levels reach higher than 0,6m above ground level. This recommendation is related to the risk ok of ground failure. In fact, the product might be able to withstand the load of more than 0,6m hydrostatic pressure, but there is a risk of ground instability like hydraulic base failure or inner erosion.
- In case of the installation of temporary flood perimeter barriers on a known site, the limit height is recommended as 1.2 meters above ground level in case geotechnical characteristics at the site cannot withstand the resulting load.
- Regarding the demountable and pre-installed perimeter barrier no limits are set, assuming that these barriers are designed according to the design loads and the ground is prepared accordingly.

5.2.2 Suggestions for improved performance

The testing phase allowed observations on the product limitations to be gathered. It was observed that many products were designed to perform specific functionalities like readiness or water tightness. Problems can arise when functionalities have not been properly considered. It is expected that the flood barriers are not only mounted in time, to be stable and sealed, but to perform all these three functionalities at the levels expected. In collaboration with the product manufacturers, the performance of the products were analyzed and suggestions on improvements were made.

Suggestions for the technical improvement of the products tested are included in the testing sheets in the appendix 2. Following the tests, some general observations were made as follows:

The product documentation of the products tested was assessed. It was observed that these documents were not adapted to emergency situations as they contained too much text and little in the way of descriptive pictures or drawings had been included. Additionally, it would be advantageous if the manual itself would be water-proofed to withstand weather conditions at site. Considering the presentation of information of these products will have an influence on the quality of installation and the performance of the product.

The durability test was carried out for some products allowing the identification of weaknesses within the product. Thanks to the durability test results product improvement suggestions could be given to increase the robustness of the product against wear and tear.

5.2.3 Comparison of product performance

The specification and evaluation of perimeter flood barriers must always be based on application conditions like local circumstances and requirements. Therefore, it is not possible to make a general evaluation of perimeter flood barriers. The evaluation process is a complex problem, which can be described as follows (Warnecke et. al, 1996):

- Different solutions must be compared
- Multitude of evaluation parameters have to be considered, both quantitative and qualitative criteria
- Subjective assessment of relative parameter importance by the decision maker is necessary.

The evaluation should be based not only on quantifiable criteria (e.g. costs, measured characteristics) but also on qualitative criteria (e.g. handling). The aim of the evaluation is to provide an integrated assessment approach based on all relevant criteria. The workflow of the value benefit analysis is as follows:

- Definition of aims and performance criteria
- Assessment of weighting factors
- Assessment of performance grades
- Calculation of benefit values.

The following aspects have to be considered in value benefit analysis:

- Number of main criteria should be limited to avoid small differences in weighting factors. The optimum number of main criteria is 5 to 10 (Warnecke et al., 1996)
- Weighting factors of main criteria indicate relative importance of every single criterion. The sum of the weighting factors of all main criteria is 100 %
- Weighting factors of sub criteria indicate relative importance of every single criterion. The sum of the weighting factors of all sub criteria of every main criterion is 100 %
- Performance grade can be described by numbers of points in the range of 0 to 10. A score of 10 indicates best performance
- The part benefit value is the product of weighting factor and grade of performance of the respective criterion
- The overall benefit value of a system is the sum of part benefit values of the particular system.

In comparison with existing testing standards the described approach offers a comparison of different flood barrier types taking local circumstances into account and serves as an evaluation scheme in specific flood protection projects.

5.2.3.1 Main and sub criteria for evaluation of perimeter flood barriers

The following evaluation scheme for perimeter flood barriers is based on the respective scheme presented in Koppe, Ode (2006). The evaluation scheme consists of 6 main and 31 sub criteria listed in Table 19. The main criteria are:

- System safety
- System characteristics
- Required specific equipment
- Logistics

- Costs
- Safety.

No.	Main criterion	No.	Sub criterion	Best meet of requirements
1	System safety	1	Load capacity	Required load analyses are available or can be done easily
		2	Leak tightness to the ground	Watertight on all types of ground
		3	Leak tightness to the neighbouring system elements and final systems	Watertight to the neighbouring system elements and to all possible final systems
		4	Sliding safety	No sliding on inclined ground
		5	Tilting safety	No tilting on inclined ground
		6	Functional safety	Deployment at any circumstances
		7	Overflow	Stable even in case of overtopping
2	System characteristics	1	Ground adaptation	Compensation of unevenness
		2	Assembling time	Short assembling time (incl. filling), immediate effectiveness of protection
		3	Protection height	Usable for large protection heights
		4	Adaptable in height	Variable protection heights, subsequent heightening possible
		5	Curve radius	Fit to all curves
		6	Assembling under water	Assembling under water possible
3	Specific equipment	1	Transportation	No transportation equipment necessary
		2	(Dis)assembly	No equipment for (dis)assembly necessary
		3	Filling equipment	No filling equipment necessary
4	Logistics	1	Handling	Easy handling of elements

No.	Main criterion	No.	Sub criterion	Best meet of requirements
		2	Prearrangements	No prearrangements necessary
		3	Required manpower	Small required manpower for (dis)assembly
		4	Disassembly, disposal	Easy disassembly, clearance, no or non-problematic disposal
		5	Filling material	No use and transport of filling material
		6	Storage conditions	No (climatic) requirements for storage
		7	Storage volume	Space saving storage
5	Costs	1	Purchase	Low purchase costs
		2	Recycling, lifetime	Whole system is reusable, long lifetime
		3	Filling material	No costs for filling material
		4	Personnel	Low personnel costs
		5	Equipment	No equipment needed for transportation, assembling and disassembling
		6	Storage	No storage space needed
6	General safety	1	Thief-proof	Elements cannot be stolen easily
		2	Vandalism	Simple vandalism, e.g. knife cut, cannot affect functionality

Table 19: Main and sub criteria for evaluation perimeter flood barriers (temporary, demountable and pre-installed)

A value benefit analysis can only be done if input parameters, i.e. level of performance and weighting factors, can be assessed properly. Therefore, specific flood protection systems have to be regarded as well as specific sites for use of constructions.

Two examples explain how to use this approach in appendix 7.

Guidance for testing procedures should be developed which describes the most suitable form of testing to accurately determine the product performance. In simplistic terms, the user should be able to select the appropriate product based on test results presented. The difficulty in this process is to define the actual test conditions and procedures in order to deliver relevant information to the end users. The performance of perimeter flood perimeter barriers is dependent on external conditions (see Figure 47). The conditions related to real flooding events are very diverse with respect to the type of site, type of environment and type of flood actions. Therefore, guidance for testing should take into account all these influencing factors and deliver relevant information to the end user to enable the decision-making process.

The same remark can be raised regarding the product configuration. Some products are not designed to perform properly in the configuration of the FM Approvals, 2006 but can serve as an effective product in many real flooding situations. Therefore, to get precise results, products should be tested according to their design and relevant deployment situations and not according to a standardized test protocol.

The term “approval procedures” is related to a decision based pass/fail criteria, which permits the approval of a product. This approval should be based on the comparison of the product performance with a pass/fail threshold. This kind of approval procedure is not appropriate for perimeter flood barriers for two reasons:

1. As the product performance is dependent on external conditions, it means that all products should be tested in the same condition. Consequently, the test has to be standardized. As previously demonstrated, the test results will then not be relevant for the end users unless the testing conditions are similar to those interesting the end user
2. The threshold pass/fail is a subjective criteria, which is depending on the needs of the end users.

An alternative solution could be the development of a kind of classification of performance with different levels. However, in order to use this classification to compare the products against each other, the testing should be consistent. Consequently, the test results will not be relevant for the end users unless the conditions are similar to those relevant to the end user.

According to the experiences gained through the testing phase, the guidance for testing of perimeter flood barriers should permit the evaluation of the product characteristics. For this purpose, the characteristics expected like stability, watertightness and readiness should be investigated and assessed. The testing conditions like length and geometry of tested devices, testing ground characteristics, contact walls etc. have to be described in the testing certificate. Therefore, a matrix of influencing factors should be developed to define the appropriate testing conditions for the product as well as for the needs of the end user.

Further remarks for the objective 2.3:

- Physical tests are required to assess the functionality of a product in case no theoretical proof can be provided. However, the overall functionality of a newly designed construction should always be physically tested prior to the deployment in a real flooding situation.
- No approval decision should be provided by the testing institute. They should provide the results of the test and no threshold should be set to formally approve a product.
- A classification can be provided, however the corresponding test conditions should always be referred to. This will ensure that the class A in a specific test condition would not be representative of the class A in another test condition.
- The tests are dealing only with product flood-related performance and no site specific characteristics like e.g. base failure can be analyzed.
- The tests showed that the mounting of temporary perimeter flood barriers will influence the product performance significantly. In order to obtain more accurate results, the product should be mounted and subsequently tested several times and mean values of product performances should be calculated.

- Documentation, like installation manuals, are part of the product and should also be evaluated.

Table 20: Test and test results of the perimeter flood barriers

Category of FRe	Type of product	Product/material tested	Test facility	Product configuration	Test carried out (see Appendix 2 for test procedures)	Performance (see Appendix 2 for more detailed information)
Perimeter flood barriers	Temporary perimeter flood barriers	Sand bags	TUHH	According to FM Approval* 0.9m high, circa 18m long	Hydrostatic load test	Stability at 0.9m water depth: no displacement Leakage rate: 790 l(m/h) at 0.9m water depth
					Hydrodynamic load test	Withstand a parallel current of 2m/s without leakage rate increase
					Impact test	Withstand the debris impact
					Overflow test	No damage observed
					Mounting test	185 minutes with 19 persons
		MOBILDEICH	TUHH	According to FM Approval* 0.22m long and 0.93m high	Hydrostatic load test	Stability: no displacement Leakage rate: 430 l(m/h) for maximum water depth of 0.8m
					Hydrodynamic load test	No displacement
					Impact test	No damage and no displacement
					Mounting test	4 persons installing 10m in 30 minutes
		DAEDLER	TUHH	According to FM Approval*	Hydrodynamic load test	Product in development
					Impact test	
					Mounting test	
		OPTIMAL	TUHH	According to FM Approval* and 15m long	Hydrostatic load test	Product in development
					Impact test	
		AQUAFENCE	TUHH	According to FM Approval* 1.2m high	Hydrostatic load test	Stability: No permanent deformation Leakage rate: <65 l(m/h) for maximum water depth of 0.9m
					Hydrodynamic load test	Stability: No permanent

						deformation Leakage rate: < 65 l(m/h)
					Impact test	No damage
					Durability test	60 deployments for all aluminium components, anvas and gaskets 100 cycles for the plywood wall
					Mounting test	With workforce of 4 people, 200 minutes per 10m of wall element
	Demountable perimeter flood barriers	IBS	TUHH	According to FM Approval* 0.95m high	Hydrostatic load test	Stability: Monopan fences damage causing system failure. No permanent damages for displacement observed for the aluminium fences Leakage rate:
					Hydrodynamic load test	No damage
					Impact test	No damage
					Wear test	No reduction in performance but some distortion of the seals occurred from the 10th test cycle
					Mounting test	Approximately 6hours for 100m with two persons
		AQUASTOP DAMM	TUHH	According to FM Approval* 1.0m high for aluminium fences and 1.17m high for Monopan fences	Hydrostatic load test	Stability: Monopan fences damaged causing system failure. No permanent damages for displacement observed for the aluminium fences Leakage rate: high variability in the results. At 1m the leakage rate varied between approximately 80 l(m/h) and 310 l(m/h) for different mountings
					Hydrodynamic load test	No leakage increase and no damage or instability
					Impact test	Permanent deformation of

						the fence with no effect on the system stability. Tear of the cover increased the leakage rate
					Overflow test	No instability observed
					Mounting test	Approximately 6 hours for 100m with two persons
	Pre-installed perimeter flood barriers	SPRING DAM	TUHH	Straight line composed of two elements, each 3m long and 1.4m high	Hydrostatic load test	Stability: maximum of 3 mm deflection in the dam alignment Leakage rate: small leakage only at the junction of the horizontal and vertical seals with a maximum of 12 liters/hour at 1.6m water depth (the equivalent of 2 l/(m/h)
					Hydrodynamic load test	No leakage increase and no damage or instability caused
					Impact test	No leakage increase and no damage or instability caused
					Durability test	No reduction in performance but some distortion of the vertical seals occurred (due to overtightening of the supporting bolts) and led to increased installation time
					Mounting test	Easy to mount

*The temporary barrier shall be constructed to form a skewed u-shaped structure. Each structure shall have an approximate length of 20m as measured along the line where the seal is formed with the ground.

5.3 Aperture flood barriers

5.3.1 Product performance

The main objectives of this series of tests on aperture flood barriers is to address the difficulties to adapt existing protocols to various types of barriers and to well understand the influence of some of the tests parameters. Moreover it is an opportunity to suggest improvements in tested products if limitations are observed.

The analysis of the test barrier performance is based on the following functions and the corresponding methods of assessment:

- **Water tightness**: characterized by leakage rate (Litres/hour/meter of barrier width : L/h/m) before and after impact test
- **Stability**: qualitative analysis (visual observations) coupled with quantitative analysis based on elements displacement measurements
- **Readiness**: measurement of mounting time.

These performances depend on many variables. A parametric study of all of these variables is not the aim of this series of tests. To define which ones could be interesting to assess, we propose first to list the conditions which could have an effect on the performances:

- **Water tightness**:
  - Flood action (i.e. water pressure, waves, current, sedimentation)
  - Others actions (permanent action, variable action (wind), accidental action (floating objects, impact, person loads, overflow)
  - Impact resistance
  - Nature of the aperture wall and threshold (masonry, concrete)
  - Aperture dimensions
  - Internal and peripheral fastening (linear / punctual…)
  - Ground properties
  - Mounting quality
- **Stability:**
  - Flood action (i.e. water pressure, waves, current, sedimentation)
  - Others actions (permanent action, variable action (wind), accidental action (Car impact, Person loads, overflow))
  - Impacts resistance
  - Aperture dimensions

- o Internal and peripheral fastening (linear / punctual…)
- o Ground properties
- o Mounting quality

- **Readiness:**
  - o Required manpower
  - o Product documentation
  - o Motivation and training of people in charge of installation of the barriers
  - o Logistic conditions
  - o Weather conditions
  - o Site particularities

In this series of tests, we choose to concentrate on the influence of:

- <u>peripheral fastening</u>,
- <u>nature of the support,</u>
- <u>impact resistance</u>.

Others variables are considered as:

- either constant for all tests (ground properties, mounting quality)
- or constant for all the tests on one technology (water height load, aperture dimensions, required manpower, product documentation)
- or not reproduced in tests conditions (wind actions, overflow, motivation and training of people in charge of installation, logistic conditions, weather conditions, site particularities)

The results of these tests are summarized in Table 21.

Due to the limitations mentioned above (constant variables, not reproducible conditions), test results are strongly connected to tests conditions. But, like in any fields, some methodology exists to extrapolate results, by combining tests and calculation and/or tests and experts analysis, provided that enough information on products and site are available.

In the following paragraphs, we propose to give an example of methodology we could use. It is based on the Eurocodes which are a set of harmonized technical rules developed by the European Committee for Standardisation for the structural design in European Union of construction works (buildings and public works). They are divided in ten parts: the first one concerns the basis of structural design, the second part is about the actions on structures, one is about geotechnical design, six among them are intended for design of each type of six types of structure (concrete, steel, composite steel and concrete, timber, masonry, aluminium) and design of structures (all types) for earthquake resistance is separately dealt with in another part.

In Eurocode 0 (basis of structural design) one of the methodologies proposed is called "design by testing". The derivation from tests of the design values for a property is carried generally by assessing a characteristic value, which is then divided by a partial factor and possibly multiplied if necessary by an explicit conversion factor. In the context of Eurocode, the characteristic value is obtained by statistical analysis. In case of a limited number of test results, statistical uncertainty will be taken into account. Partial factors have to be chosen to be comparable to those used in Eurocodes and to allow the level of reliability required for the relevant design situation.

This methodology is well adapted to structural design. Even if FRe barriers are not structural elements, its main principles could also be re-used in the context of assessment of FRe aperture barriers in a field of use larger than tests conditions. We propose here a simplified example. Let us consider one FRe technology for which tests lead to leakage rate r_1 = 1,5 l/h/m for water load h_1. If leakage rate limit is 1 l/h/m, it could be interesting to assess the height h until which leakage rate is less than 1 l/h/m, all things being equal. Difference is then concentrated on applied water pressure. As resultant force varies like water height squared, we could estimate the leakage ratio $r(h)$ for water height h as r_1 multiplied by the ratio of height squared $(h/h_1)^2$ and by a safety factor g_r to take into account uncertainty on the model. Choosing g_r equal to 2, the leakage ratio $r(h)$ could be written as $r(h) = \gamma_r \left({}^{h}/_{h_1} \right)^2 r_1$. In this conditions for h ≤ 0,58 m, we could assess that the leakage rate $r(h) \leq 1$.

5.3.2 Suggestions for improved performance

Tested products are more or less in development and those tests are a good opportunity for manufacturers to evaluate the limits of their technology. Some improvements were suggested and included in the testing sheets in appendix 3. Two examples of suggestions are given in following paragraphs.

For one of the products, various configurations of perimeter barrier connections were tested to assess the influence of this parameter. The results obtained show that connection is an important parameter. In tested case, the connection by locking on top of the panel provides the best performance because it avoids vertical sliding. Clamping connection does not seem to be optimized to ensure this function.

In the same type of idea, experimental observations on the behaviour of Barrier n°3 installed on the largest aperture defined by manufacturer shows that this FRe technology is too flexible to retain water or that the type of seal bands are not compatible with the deformation of the barriers.

This analysis allows us to suggest improvement to manufacturers but also gives us information to do expert analysis on new product or on the definition of the field of use.

5.3.3 Comparison of product performance

Comparison of product performances could be done if the field of use of technologies were exactly the same. Indeed, to assess FRe technology performance, it is important not to dissociate the product and its field of use. Concerning FRe technologies tested here, there is no exact correspondence between two pairs (FRe Technology – Field of use) but results obtained allow us to make some observations on similarities and differences between products.

First observations were made on the fact that products are well adapted or not to the targeted market. The use of many accessories which could be easily lost is a disadvantage for any customers and maybe more for home owners. In the same idea, the use of specific tools to prepare the support, which are not common in an individual's garage, is not a good point to easy the road to market for this type of product, except if preparation of support is systematically proposed by the company.

Another point concerns the presence of permanent elements. This characteristic is more particularly important in case of individual houses market, because of aesthetic aspect and psychological consequence to view every day something linked to flood risk of one's own house. In this sense, barriers which use permanent element already present on aperture (like stopping window for example) are advantaged. But unfortunately, this choice seems to have negative effect of the water tightness function of the barrier, at least in the particular case of the tested barrier.

5.3.4 Development of guidance for testing and approval procedures

Firstly, a major defect during tests (e.g. explosion of an inner tube ensuring the barrier water-tightness function), confirms the importance of multiple tests when it is possible. Moreover multiple tests are necessary to define characteristic values and extrapolate properly the field of use.

Secondly, various types of connection between panels and support were tested. The importance of these choices of connections was demonstrated. The added value of the SMARTeST test guidance could be to inform the end user of the importance of each of the parameters. For example, it could be highlighted in the test guidance the need to consider the whole system e.g. panels and connections.

In addition, one of the differences identified between existing test protocols for aperture barriers concerns the surface of the walls : British protocol considers fair-faced masonry, French protocol uses concrete walls and FM Global approval does not precise the nature of the surface. Comparative tests on concrete and masonry support were carried out at CSTB to experiment the feasibility and advantages of various surfaces. Steel walls are also tested as reference, to test water tightness in case of smooth surface.

Only few tests give us information to compare steel and concrete support, but they seem to show that differences are not significant.

Concerning tests on masonry, because in France the term "masonry" is generally linked to concrete blocks, this type of product was used to build the test rig. But without coating, water tightness of the walls is not ensured and tests lead to very high leakage through masonry support. In these conditions, leakage due to test rig cannot be distinguished from leakage in relation with the tested technology and test results cannot be used for barriers performance assessment.

However these tests lead us to understand the importance of a harmonised description of the test rig. Harmonisation should not be about precise description of test rig elements because of the risk of confusion on the used characteristics or definitions in relation with building rules of the art of each country. But it could be about the fact that test rig walls have to be water-tight in all cases of course and they have to reproduce type of walls surfaces generally found in targeted countries.

Compared with prior aperture barrier tests carried out at CSTB, two main points of the test protocol were modified:

- Test on two barriers at the same time (see § 4.1.2 and Figure 21): the main difference between the two test rigs is that in case of the first one there was a concrete wall instead of a second barrier.
- Wood log used as impact object instead of bag full of glass balls.

"Double" configuration (Figure 21) was initially developed to test two identical products in the same time and in the same conditions. This configuration has also the advantages to limit the number of rig connections which have to be perfectly water-tight and to limit the volume of water needed for the test (compared to the volume of water needed to a basin).

But after operational use it appears that this solution is not well adapted for technologies requiring space for installation (size of the footing). The installation of two such barriers may require a test rig with an important thickness (two times the size of footing at the minimum). Moreover this design creates difficulties (double installation, double measure equipment).

Considering that for some technologies, numerous drillings in the support, with diameter which could be large are needed, this support cannot be used several times or if it is the case with condition of meticulous filling and resurfacing works to ensure constant surface conditions.

All this practical observations on the manufacturing of the test rig could be included in the guidance testing.

Concerning the choice of the impact object, impact with wood log is considered as a hard one and impact with a bag full of glass balls as a soft one. FM Global Approval considers wood log and the initial CSTB protocol considered the impact of a bag full of glass balls (now replaced by a wood log). British PAS 1199-1 does not cover impact testing. As energy applied is the same in both cases, impact with wood log is the most severe. This deduction is confirmed by experimental results; impact resistance becomes in these conditions a discriminating criteria. As wood log is closer to real impact in case of flood, this type of impact object or another hard impact object should be specified in the guidance testing.

In addition, one of the objectives 2.3 is to propose a Code of Practice for installation fo FRe Technologies, with the aim to set out good practices in this field.

Test series allows us to provide arguments for code of practice too. Indeed, some panels to be tested were installed on the test rig but because of various logistical reasons, they were stored outdoors during some months, without being tested. When tested, it appears that the seal bands were damaged by climatic conditions and by long compression state. That is why it would be interesting in code of practice to highlight the importance of storage conditions of the elements, training of the staff and maintenance of products but also the need for uninstalling FRe technologies after flooding within a reasonable time to avoid possible damage.

Moreover, in particular cases, critical points of leakage at support/barrier connections, were treated with silicone. This type of treatment could be made in real conditions if flood alert time and silicone setting time are compatible. For basic silicone, and temperature around 20°C, water loading shall be applied after at least 24 hours and preferably after 48 hours. However silicone with quick setting time exists too but the manufacturer should inform precisely the user of the required silicone characteristics. This point could be pointed in code of practice too.

Table 21: Test and test results of the aperture flood barriers

Category of FRe	Product/material tested	Test facility	Product configuration	Test carried out	Performance (see Appendix ? for detailed results)
Building aperture barriers	Collad'eau	CSTB		Mounting test	Installation: - 5 hours per 6m for 1st installation with 3 persons - 16.5kg per panel - Installation guidelines included on panel
			Configuration No1 with steel support	Hydrostatic load test	At 0.8m ± 0.05m water depth: - Stability after 24 hours, maximum displacement 0.024m - Water tightness leakage rate 0.5 l/m/h
				Impact test with bag full of glass balls	No visual damage
				Hydrostatic load test after impact test	At 0.8m ± 0.05m water depth: - Stability after 24 hours, maximum displacement 0.026m - Water tightness leakage rate 1.0 l/m/h
				Bending test	Stability: Max load before failure = 40 kN with displacements at least twice higher than measured displacement during hydrostatic test
			Configuration No2 with concrete support	Hydrostatic load test	At 0.8m ± 0.05m water depth: - Stability after 20 hours, damage of the opposite barrier - Water tightness leakage rate 0.7 l/m/h after 17 hours
			Configuration No3 with concrete	Hydrostatic load test	At 0.8m ± 0.05m water depth:

			support		- Stability after 20 hours, explosion of the inner tube and vertical displacement of the panels - Water tightness leakage rate 0.7 l/m/h after 17 hours

			Configuration No4 with concrete support	Hydrostatic load test	At 0.9m + 0.05m water depth: - Stability after 48 hours, maximum displacement 0.027m - Water tightness leakage rate <0,1 l/m/h
				Impact test with wood log	Deformation and failure of the panel, partial displacement of the inflatable tube out of the rim
				Hydrostatic load test after impact test	At 0.9m + 0.05m water depth: - Leakage rate = 13,2l/h/m - Leakage's locations correspond to areas damaged by impact tests.
Building aperture barriers	Barrier n°3	CSTB		Mounting test	Installation: - 1,5 hours per 3m for 1st installation with 2 persons - 16 kg per panel - Installation guidelines included on panel
			Configuration with concrete support	Hydrostatic load test	At 0.75m + 0.05m water depth: - Leakage rate = 10l/h/m - Leakage's locations correspond to drilling points and at the base of PVC columns - Large deformation of panel

					- Tests on barriers installed 6 months ago and stocked outdoors in winter conditions.
				Impact test with wood log	Displacement of the panel with sliding of the PVC column and deformation of intermediate steel frame until failure of the welding
			Configuration with masonry support	Hydrostatic load test	At 0.8m + 0.05m water depth: - No stability because of too high leakage rate - Large deformation of the panel and the intermediate column - Sliding and unsticking of the seal band
Building aperture barriers	Barrier n°4	CSTB		Mounting test	Installation: - 1,5 hours per 3m for 1st installation with 2 persons - 18,7 kg per panel - Installation guidelines included on panel
			Configuration with concrete support	Hydrostatic load test	At 1.0m + 0.05m water depth: - Many leakage points (more than 1l/minute) - Leakages are located on the height of the column and at its base, at horizontal connection between panels - Tests on barriers installed 6 months ago and stocked outdoors in winter conditions. - Test with new seal bands gives

					similar results
			Configuration with masonry support	Hydrostatic load test	At 1.0m + 0.05m water depth: - No stability because of too high leakage rate - Leakages are located on masonry support and at the base of aluminium column - Difficulties to distinguish leakage linked to test rig from leakage linked to tested technology
				Impact test with wood log	Weak deformation of the panel at the positions of impact s

5.4 Waterproofing materials for dry-proofing and anti-corrosive measures

As previously stated, "FRe building technological solutions" involves a huge variety of products (see appendix 1). But in relation to test protocols, the problem is even more complex. For each existing product, many testing procedures and protocols can be found. For these two reasons, the classification effort made in Figure 2 shall be considered as a necessary step in order to obtain a common testing procedure for FRe technologies.

This classification aimed to group products according to both their intrinsic (chemical) nature and their range of application. As a result, each category is expected to provide specific FRe functionalities according to a comparable product's behaviour.

Due to the unexpected complexity of this approach, it has not been possible within SMARTeST to carry out all the necessary tests that fully characterize the behaviour of the products assessed. The measurement of these characteristics requires the determination of the mechanical properties against water absorption, and this is a lengthy process, not achievable within the SMARTeST lifetime. Nevertheless, tests performed by UPM are described in the appendix 4. The results of testing undertaken on a building technology product by BRE are in the following sections.

5.4.1 Product performances

5.4.1.1 Hydrostatic tests

Hydrostatic tests were carried out in the test tanks built at BRE using the procedure described in section 4.1.3.2. The initial test without the polyurethane foam insulation resulted in substantial water leakage through the test walls. Water was also found in the tests to leak laterally between the tanks, with around 6% of water leakage being made up from that source for tanks 1 to 3, but for tank 4 it was around 24%.

In test tanks 1 and 4 a substantial volume of water leakage was though the opening created by the plastic drainage pipe. In tank 1 it was 28% and tank 4 around 13% of the total water leakage.

The visual observation of leakage in the initial hydrostatic tests without insulation showed that water would not fill the test tanks without leakage, especially through the test walls. Leakage occurred around the pipe, but also leakage also occurred under the test walls. Meaningful quantitative data on leakage through the test wall was therefore not possible to determine. However, observations showed that leakage could occur through the cavity wall brickwork, under the walls, through the gaps around the pipe, as well as laterally between tanks.

After the insulation was injected into the cavity walls, tests were run again to identify if the walls showed any improvement in their ability to prevent water ingress. The amount of water lost during the tests was reduced. However, as meaningful leakage rates through the wall was not possible, the visual observations of leakage were relied upon. In the second hydrostatic test there was no observed leakage through the wall or around the pipes through the walls. Leakage under the wall and laterally was noted. However, the material did not allow water to pass directly across the cavity wall from one leaf to another and out of the tank.

5.4.1.2 Absorption testing

Absorption testing was carried out on 12 samples of the insulation material, as described in Section 1.1.1.2. The proportion of cut to moulded surfaces of the samples was seen to have an effect on the amount of water absorbed in both partially and fully immersed samples. Samples which had fewer cut surfaces were found to absorb less water (see results in Table 22 and Table 23).

Sample No.	Amount absorbed (g) – 24 hours	Amount absorbed (g) – 192 hours	% by weight – 24 hours	% by weight – 192 hours	% by volume – 24 hours	% by volume – 192 hours
1	0.33	0.49	1.34%	1.98%	0.00056%	0.00083%
2	0.34	0.46	1.25%	1.68%	0.00053%	0.00071%
3	0.32	0.73	1.19%	2.68%	0.0005%	0.00113%
4	0.46	0.47	1.71%	1.75%	0.00072%	0.00074%
5	0.37	0.49	1.7%	2.24%	0.00071%	0.00094%
6	0.99	1.24	4.13%	5.12%	0.00173%	0.0022%

Table 22: Moisture contents of partially immersed samples

Sample No.	Amount absorbed (g) – 24 hours	Amount absorbed (g) – 192 hours	% by weight – 24 hours	% by weight – 192 hours	% by volume – 24 hours	% by volume – 192 hours
7	5.88	9.13	21.7%	30.1%	0.91%	1.264%
8	8.35	11.04	23.4%	28.8%	0.98%	1.20%
9	6	9.35	19.4%	27.3%	0.82%	1.15%
10	9.23	13.23	25.4%	32.8%	1.07%	1.38%
11	5.83	9.04	22.1%	30.6%	0.93%	1.20%
12	7.08	11.83	22.9%	33.2%	0.97%	1.39%

Table 23: Moisture contents of fully immersed samples

The weight of water that was absorbed during the partially immersed test was very low in terms of the actual weight, and when viewed as a percentage by weight and volume. The weight per immersed surface area and the calculated moisture content were also low; 1-5% by weight for the partially immersed samples. These levels of moisture content are unlikely to have any significant effect on the thermal performance of the material.

The results for moisture within the samples removed from two test tanks are given in Table 24. Samples from the two different cavity thicknesses (25mm and 50mm) and two different brick types were tested. The moisture content of the samples that had been below the waterline was greater than for the samples from above the waterline and also greater than the absorption samples described above. However, the moisture content by volume remains relatively low and the impact on thermal performance is therefore insignificant.

The samples in a cavity wall would also dry out over time after a flood thus reducing the moisture content and therefore the thermal performance would not be permanently affected.

Sample(s) location	Moisture content by weight (%)	Moisture content by volume (%)
Tank 2 – above 500mm	38.28	1.61%
Tank 2 – below 500mm	54.72	2.3%
Tank 3 – above 500mm	47.67	2.00%
Tank 3 – below 500mm	53.87	2.26%

Table 24: Moisture content of insulation samples taken from test walls

The insulation was seen to bond better to the red clay bricks than to the blue engineering bricks. This was to be expected as the surface of the engineering bricks is smoother, allowing for less adhesion. However, this does not seem to have caused much difference in the test results from the different tanks.

This polyurethane, closed cell insulation material greatly reduced the water ingress through the brick cavity walls, although this observation is essentially qualitative rather than quantitative. The insulation was not degraded as a result of contact with the water in the tests. It remained in place and acted to prevent the passage of water over the cavity. The moisture content although increased would be insignificant as far as any impact on thermal performance. The closed-cell polyurethane material has retained its form and shape and its insulating properties.

At a reference temperature of 25 °C, the thermal conductivity of water is λ = 0.58 W/(m·K). As the thermal conductivity of most common insulation materials ranges between 0.020 W/(m·K) and 0.050 W/(m·K), water absorption due to immersion in water leads to an increase in thermal conductivity. However, water absorption has only a small impact on the thermal conductivity of rigid polyurethane foam (PUR/PIR). Studies undertaken by the Forschungsinstitut für Wärmeschutz e. V. Munich have shown that the increase in thermal conductivity of rigid polyurethane 10 foam (PUR/PIR) expanded with pentane after 28-day immersion in water is negligible, amounting to around 0.0018 W/(m·K).

The normal (dry) thermal conductivity is 0.03 at most, therefore wet it is 0.0318, so it is minor at worst. In addition, 28 days water immersion is far in excess of what we have tested. Therefore, whilst this has not been measured in the tests, the scientific literature and knowledge backs up our report. We can add a reference if required.

5.4.2 Suggestions for Improved Performance

Functionality, including leakage rate, deformation and displacement, have been considered during the testing of the insulation material. During testing, the leakage of the test tanks was found to be greatly decreased when the insulation material had been injected into the cavity walls. Samples of the material inspected after the water-tightness testing did not have any degradation. If installed to the manufacturer's recommendations, there is no improvement necessary for the insulation material to achieve the expected performance.

After installation, the product is 'ready' and no further action is required in a flood event. However, the material can only prevent the passage of water through the wall cavity in a flood situation. Further measures will be required to address openings and service penetrations.

5.4.3 Comparison

As the testing procedure is different from all other products tested, a comparison of test results is difficult. To fairly compare two or more products, they must be tested in the same conditions.

5.4.4 Output for the Elaboration of Guidance for Testing and Approval Procedures

In developing guidance for the testing of this type of product, it must be considered that the product, once installed, will be in place for many years, and requires no further action in the event of a flood. Testing guidance would therefore be required, most likely, only for installers, who can test their installation procedure.

The product functionalities of water-tightness, stability and readiness should be tested for all FRe technologies. Building technology products will be installed or applied well in advance of a flood event, and so water-tightness and impact on stability of the structure should be considered. For some of the products, material performance testing is more appropriate, to judge the behaviour of the products under flood conditions. For products, such as the insulation material however, a standardised approach to water-tightness testing could be developed.

5.5 Infrastructure Technology

The non-return road gully is an innovative infrastructure technology that was tested at a BSI approved test centre. The test centre is able to test products in a flood simulated conditions at depths of up to 1 metre, with wave simulation and water speeds in excess of 1.5 metres/second.

The test operator was satisfied that the test conditions were more rigorous than the potential operation environment and as such the non-return valve would be suitably capable in a real flood event.

5.5.1 Product performance

A static water test and a wave and current simulation test were carried out on the product. During the static wave test, slow rising flood waters are simulated to 300mm, 600mm, 900mm and 1000mm depth. At each level the water is allowed to stand for 72 hours. Leakage and visual inspections are carried out during this time and recorded at 18 hours, 48 hours and at the end of testing. During the static water test, no water passed through the non-return valve when it was sealed. No damage was seen to be done to any parts of the non-return valve as a result of the testing.

During the wave and current simulation tests, at each of the water levels (300mm, 600mm, 900mm, 1000mm), a current was introduced to a maximum of 1.2m/s. This was measured using VS100 flow meter over a six hour period. At each of the above levels, waves (height 100mm ±10mm) were also introduced for a period of six hours. At the end of each cycle records were taken and no leakage was observed.

5.5.2 Suggestions for Improved Performance

As no leakage was observed and the test operator was satisfied that the test conditions were more rigorous than the potential operational environment, no improvements are necessary for the non-return road gully to operate successfully in a flood situation. As the product is ‘fit and forget’, there is no potential for failure due to insufficient warning or installation time.

5.5.3 Product Performance Comparison

No other infrastructure technologies have been tested and as such comparisons with other similar products and testing procedures cannot be drawn. However, parts of the method used to test the non-return road gully may be comparable with testing carried out on perimeter and aperture barriers.

5.5.4 Output for the Elaboration of Guidance for Testing and Approval Procedures

Testing guidance for the non-return road gully should consider that it will be fitted and then left in place at all times, both prior, during and after flood events. End users will likely want to know that the product has been suitably tested to prove water-tightness and stability.

The testing method used and detailed above could be standardised for all products of this type. However, infrastructure technologies encompass membranes, surfacing materials as well as automatic barriers such as the non-return road gully. It is for this reason that a single testing guidance for infrastructure technologies may not be suitable, but rather a range of guidance to cover the different product types.

5.6 Building construction

5.6.1 General conclusions for tested wall constructions

As described in section 4.2.5.2 the test program comprised four standardized wall and two ordinary floor arrangements, whose flood resilience properties were so far largely ambiguous. For the derivation of wet-proofed constructions[27] it is important to analyse initially the system behaviour (vulnerability) of usual assemblies, particularly for the case of water ingress into a building. Basically, the behaviour of composite wall or floor systems cannot be predicted solely from the behaviour of its individual components. The whole construction need to be analysed to consider significant interactions between the wall constituents. The following conclusions can be drawn from the test results on walls.

W1: Double shell masonry of sand-lime bricks with heat insulation and air space. The accumulation of water in the cavity of double shell masonry constructions is important to assess. As described in Appendix 6, the butt joints of facing wall's first brick course are regularly not filled with mortar to provide ventilation to the air gap. Floodwater can built up in the cavity, saturate the insulation, and soak into the inner masonry shell. After flooding, the water in the cavity can be drained through these openings, but it is often difficult to dry out the insulation material. Thus, the requirements for refurbishment are extensive. The mineral fibre insulation used in this wall construction absorbed a huge amount of water and became saturated and fragile to handle. It lost its strength and dimensionally stability as well as insulation properties.

W2: Single shell masonry of hollow bricks with external heat insulation and ventilated curtain façade. The test proved that masonry walls using hollow brick blocks are very susceptible to flooding. The brick blocks are joined together using tongue and groove formation. Water seeps easily through the construction passing the brick blocks at the butt joints. This results in a significant rate of leakage. If the wall assembly is not-rendered at its external face, as in this arrangement, it offers less resistance against water penetration. In this example, the water uptake by capillary action, caused by the porous material structure, is very high. The degree of saturation reached approximately 80 M.-%. The capillary porous structure of the blocks allows rapid water absorption. Capillary ascending moisture was observed within the blocks, several centimetres above the flood level. Depending on the mortar mixture[28] the bed joints between brick blocks can temporarily act as a horizontal barrier layer. Panels of a curtain façade element can be removed after flooding, so that the insulating material underneath can be replaced. Wall assemblies with a curtain façade have potential to dry out evenly from the external face. The used mineral fibre insulation absorbed a

[27] Wet-proofing can be an appropriate approach to improve the flood resilience of new and existing buildings, particularly in areas at high flood risk. The principle intention of wet-proofing is to change the design and/or the materials of potentially affected building constructions in order to mitigate their flood vulnerability and to minimise the extent of necessary repair works. Therefore damage to buildings from future flooding is going to be reduced, but damage cannot be completely prevented. Basically, wet-proofing comprises the application of improved materials for layers of flood-prone wall and floor constructions, which are low susceptible to flooding.

[28] The properties of the mortar depend on its ingredients (binding material [cement or lime], aggregate [grain size max. 4 mm], water, chemical admixtures) and the mortar mix formula (e.g. w/c-ratio).

huge amount of water and became totally soaked and fragile to handle. It has lost its strength and dimensionally stability as well as insulation properties.

W3: Single shell masonry of traditional solid bricks. Water seeps through micro cracks in the bricks in the bottom part of the wall. These cracks are generated by plastic shrinkage of the used mortar mix in an early stage and provide paths for the ingress of water. The shrinkage rate is, in turn, affected mainly by mortar composition. Cracking generated by plastic shrinkage of the mortar is caused by an increasing capillary tension whilst drying. The result is a decrease in volume as an irreversible shrinkage deformation. It becomes evident therefore, that the mortar mixture has significantly influence on water seepage.

W4: Single shell wall of light (aerated) concrete blocks with thermal insulation composite system. Light (aerated) concrete blocks are highly insulating and consist of a closed-pore structure (up to 80% air). Hence, the determined water uptake of the material is minimal. Similar to the hollow brick blocks the butt joints are not filled with mortar, so that water can pass the light concrete blocks and seep through the internal plaster. After three days a slow leakage rate was observed on the inside. As the external thermal insulation composite system (ETICS) was not fully adhered to the wall, water was easily running behind the ETICS and penetrated into the masonry.

5.6.2 General conclusions for tested floor constructions

Test results for floor constructions can be summarized as follows:

F1: Timber floor Gypsum plasterboard ceiling: Gypsum plasterboard remained sound in appearance during the wet phase but disintegrated into small pieces when removed, as it was only being held by the backing paper sheets. The granulated thermal (and sound) insulation, which was placed between the floor joists, was completely saturated. After draining the water basin, a significant amount of water remained in the construction. Thus, the weight of the floor system increased considerably, which can in turn endanger their structural stability. It becomes evident, that the insulation material must be removed after flooding. To ensure the drying of the timber floor joists and to replace the insulation material, the floorboards have to be removed. It is clear that wood is not dimensionally stable after is has been exposed to flooding. It shrinks or swells due to loss or gain of bound water from the cell walls. Hence, before remounting floorboards its movement and stability should be assessed. In summary, the timber floor is susceptible to considerable damage after a flood event.

F2: Concrete floor; The floating floor cement screed has an effect on the system behaviour, because water can reach between the construction layers via the wall/floor junction. This implies that water can easily penetrate the mineral fibre insulation as well as the expanded polystyrene (EPS) rigid foam boards. The mineral fibre insulation absorbed significant amounts of water. It became saturated and fragile to handle. . The measured vertical compression of the insulation was irreversible. Moreover, if the vertical compression is unequal it may generate cracking of the overlying cement screed. To replace the mineral fibre insulation both the cement screed as well as the expanded polystyrene (EPS) rigid foam boards should be removed. The 14 cm thick concrete floor slab absorbs a considerable amount of water under the test conditions. Its degree of saturation was approximately 80%.

Results: The test program confirmed the weaknesses of typical wall and floor arrangements regarding their behaviour in case of flooding and confirmed the requisite to think about more resilient constructions. There is evidence that the analysed assemblies are highly susceptible to flooding. However, based on the test results general findings for the design of wet-proofed constructions can be drawn. Basically, applied wall materials should have a closed-pore structure to minimise water uptake and, in consequence, to enable their rapid drying. All joints (bed as well as butt joints) of masonry should be filled with mortar to prevent water seeping easily through the construction. Insulation materials should not suffer irreversible deformation and should not store water within their structure. Wall linings should be easily removable to enable the rapid drying of underlying layers. The arrangement of regular joints in highly vulnerable structures (e.g. EIFS – Exterior Insulation Finishing System) facilitates their easily exchange in case of flooding. Based on the test results, detailed recommendations (like constructional drawings) for wet-proofed wall and floor arrangements can be given.

6 Cost analysis

The evaluation of the FRe Technology performance and function are important criteria for the selection of the appropriate product. However, decision makers base their choices not only on functionality but also on the cost parameters. In order to make a fair comparison between different products, both cost groups should be analysed:

- Direct costs
- Indirect costs

The following cost analysis method focus on the flood barriers. The parameters influencing direct and indirect costs are listed in Table 25.

- Determination of direct costs
- Direct costs are purchasing and construction costs.
- Purchasing costs

The product design and its cost will depend on the following parameters:

- The flood actions expected (US Army Corps of Engineers, 1995) :
    - o Depending on physical flood actions (hydrostatic, hydrodynamic, flotsam and current impact as well as wave load) the type of material, product design and foundation design are chosen.
    - o Depending on non-physical flood actions (chemical and biological actions) the type of material is chosen.
- The system to protect:
    - o Depending on the geometry, topography, boundary conditions, ground characteristics related to the system to protect, the barrier configuration (length, wall connection, angles) and foundation design can be chosen.
- Taking the local environment into account:
    - o Depending on the climate, material can be chosen
    - o Depending on geographical location, material can be chosen
    - o Depending on the use of the system between flood events (i.e. vehicle loads, built environment aesthetics) the design of the barrier can be chosen.
- The level of performance expected:
    - o Depending on the water tightness level expected the water tightness design can be set

- o Level of automation.

Depending on all these parameters, the purchasing costs differ significantly. The more detailed these parameters are, the more precision can be applied to the assessment of purchasing price. In the case of known expected lifespan of the structure, the purchasing cost can be expressed in purchasing cost per year, enabling a cost comparison of different products.

Once the design is defined the purchasing cost of the product can be calculated. Some products (e.g. pre-installed and demountable flood barriers) need to be completely or partly pre-installed on site. This construction costs will include personnel, equipment and material costs.

6.1 Determination of the indirect costs

Indirect costs are all the costs over the lifetime of the product which should to be taken into account to fully assess the product. Three cost categories can be identified:

- Storage costs
- Operating costs/Training costs
- Maintenance costs.
- Storage costs

Storage costs are related to temporary and the demountable flood barriers. They depend on required storage conditions as well as required storage area and volume. The latter can be expressed by the term Storage-Volume and Storage-Surface per installed product length and height.

Regarding the storage conditions, some product can be stored outside while some need to be stored in an enclosed area with specific ventilation requirements.

6.1.1 Operation and training costs

The operating costs are related to the required product specific activities like transport, mounting, dismounting and cleaning. The training costs are related to mounting and dismounting of the product.

These costs are depending on the frequency of trainings and flood events, which can be determined according to training plan and flood probability, respectively.

Some of the products need auxiliary material (e.g. sand), which is not included in the purchase cost. The cost of this material, if viable, should as well be included in the operating/exercise cost.

In order to transport, mount, dismount and clean the product labour forces are needed. Thus, costs for personnel have also to be included in the cost analysis. The required number of personnel, as well as mounting and dismounting time, is dependent on the chosen product.

Costs related to the required equipment and transport means (depending on the Storage-Volume and Storage-Surface per product length and height) should be considered. The distance between storage and deployment site is not depending on the product type (not taking into account the pre-installed barriers) but has an influence on the costs.

On the basis of this information, the operating cost per linear meter of barrier for a given height as well as training costs per meter for a given height can be defined.

6.1.2 Maintenance

Maintenance costs have also to be taken into account in the indirect costs. These costs depend on the required maintenance/replacement schedule of the chosen product.

The prior execution of durability tests consisting of several cycles of mounting and dismounting of the product allows the identification of existing weak points. This would inform the replacement of specific components after a certain number of cycles. Therefore, results of durability tests can serve as a base for the assessment of expenses related to component replacement.

→→→Chain of cost determination→→→					
Direct Cost	Purchasing Costs	Flood action	Physical	Hydrostatic load	Product design
				Water depth	
				Hydrodynamic load	Foundation design
				Impact load	
				Wave load	Material choice
			Non Physical	Chemical action	
				Biological action	Type of water tightness choice
		System to protect		Geometry	
				Topography	
				Boundary conditions	
				Ground characteristics	
		System environment		Climate	
				Geographic location	
				Usage of the system between flood events	
		Level of performance expected		Allowed leakage rate	
				Level of automation	
	Construction Costs			Need of preliminary works (e.g. foundation)	Personal, Equipment, Material
Indirect Costs	Storage costs			Product characteristics and required storage conditions	Storage condition needed
					Storage surface needed
					Storage volume needed
	Operating Costs/Training Cost			Product requirements	Transport
					Mounting
					Dismounting
					Cleaning
				Frequency of training	
				Frequency of flood events	
	Maintenance				Maintenance work

Table 25: Parameters influencing direct and indirect costs

7 Conclusions

SMARTeST project's deliverable D2.2 of work package 2 on flood resilient (FRe) technologies is focusing on testing and performance assessment of FRe products and materials.

As a basis for the definition of test procedures a review of existing European and US American standards on FRe technologies as well as related standards in development was undertaken. The following types of standards and guidelines can be distinguished:

- Standards for material or compound testing
- Standards for testing and assessing building aperture as well as perimeter technology
- Guidelines for installation of building aperture as well as perimeter technology

Standards for material and compound testing are focussing on characteristics like mechanical properties, corrosion, water-tightness which are relevant for FRe materials but are not specific to flood conditions. The standards are developed for the building industry and are mostly not focussing on flooded structures but on characteristics like water vapour diffusion and capillary water absorption.

Standards on building aperture and perimeter technology focus on hydrostatic and hydrodynamic load tests. Available standards define standard testing schemes enabling the comparison of different types of technology. On the other hand, standardized testing schemes fit only to specific products whereas other products are excluded from testing and performance assessment although they might be powerful technologies in real flooding events. Therefore, variable testing schemes enabling the performance assessment of various FRe technologies are more effective and will be developed in SMARTeST project.

Different installation guidelines for building and perimeter technologies exist in Europe. They are not directly linked to testing procedures but some information on leakage rates and relevant hydrostatic and hydrodynamic loads are given.

Based on the review of existing standards testing procedures have been developed for material and compound testing, building aperture and perimeter technology. The scale and extent of testing is always dependent on the available testing facility as well as on the available time for testing. The following testing facilities have been available in SMARTeST project:

- Water basin at the TUHH for hydrostatic, hydrodynamic and impact load tests in 1:1 scale of building aperture and perimeter technologies
- Building aperture facility at the CSTB for hydrostatic and static load tests (bending tests) in 1:1 scale of building aperture technology
- Testing rig at BRE for testing wall materials under hydrostatic load
- Water-tight tank at IOER for hydrostatic load tests of building envelopes
- Test laboratory for water resistant material at UPM

Within the testing of perimeter technologies system handling and functionalities like leakage rate, deformation and displacement have been assessed. Some of the tested technologies have not been on the market yet and the testing has been used not only for performance assessment but also for product improvements. The execution of tests shows clearly that the system architecture and the expected system functionality differ significantly from product to product. Therefore, for the range of products no strict testing procedure can be defined but specific product features have to be taken into account in testing. For example, a simple emergency flood protection system might be effective only as a linear or slightly curved combination of the single sections but no corner elements are available. In this case, the testing procedure should be able to take this restriction into account and to test the system as a linear perimeter system.

The testing experiences gained in SMARTeST project shows that the guidance for testing perimeter flood barriers should permit the valuation of the product characteristics for the specific tested product. In the testing certificate the testing conditions like lengths and geometry of tested devices, testing ground characteristics, contact walls, load characteristics etc. have to be clearly stated and have to be taken into account in the performance and functionality assessment.

As the performance assessment of perimeter technology cannot be based on fixed testing routines but on testing schemes differing with respect to tested products and functionalities expected at potential flood sites, no direct comparison of testing results of different technologies is possible. Therefore, an evaluation scheme for the comparison of different technical solutions considering a multitude of evaluation parameters is described exemplified for different flood barriers and specific site characteristics. This evaluation scheme has to be adapted on the characteristics of the planned deployment site and the functionalities and performances expected of the protection technology.

The executed performance tests on aperture flood barriers show that the connection between the technology and the building is the weakest system point and improvements have been suggested for tested products. The guidance for testing and approval procedures has to focus on the whole system, i.e. on the panels as well as on the connection points. Moreover, always multiple tests have to be executed for assessment of product performance and advices on test rig characteristics can be deduced from this series of tests and provide in guidance testing.

Due to the huge variety of waterproofing materials for dry-floodproofing and anti-corrosive measures only a limited range of available materials could be tested within SMARTeST project.

As building constructions composite wall systems and floor constructions have been tested. The behaviour of composite wall systems cannot be predicted solely from the behaviour of its individual components but the whole construction should be analysed to include interactions between the wall constituents.

Not only the performance and function of FRe technologies are important criteria for the selection of the appropriate product but also costs play an important role in the decision process. Not only direct costs like purchasing and construction costs but also indirect costs like operating, training, maintenance and storage costs have to be considered.

In summary, the tests executed in SMARTeST project show that

- no fixed testing scheme can be defined for the performance assessment of the huge variety of perimeter technologies available, but a testing matrix must be developed for the set-up of appropriate testing procedures

- for assessment of product performance and functionality of perimeter technology the testing characteristics have to be clearly stated in the testing certificate
- for comparison of different perimeter technologies an evaluation scheme considering a multitude of evaluation parameters can be used, which has to be adapted on the site characteristics as well as on the expected performances and functionalities

Composite building materials have to be tested as a whole as the performance of the single components might differ significantly from the performance of the composite system

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Appendix 1 – Water proofing membranes and anti-corrosive measures

Membranes are usually obtained from polymeric materials. They are designed either for continuous applications, with no joints (liquid membranes), or for discontinuous applications. All of them present a solid layer. Solid membranes need joints (usually, expansion joints), and this is why they are also known as discontinuous membranes. They are applied in pure thermoplastic solutions, or in watery emulsions. On the contrary, liquid membranes enable continuous (joint-less) applications, and they ensure the maximum waterproofing efficacy. Indeed, this joint-less element fits optimally the structure; in case of failure it does not allow the water to seep under the membrane, and thus it is very easy to detect the failure location. They can be obtained from manufactured prepolymers, or after the *in-situ* polymerization. They are applied as pure solutions or in mixtures with inert and uniform additional compounds.

Solid membranes are usually presented as elastoplastic coatings, applied in their natural state or with previous heating in views to their further setting. They are available not only for horizontal applications but also for vertical ones, and they require anchors and/or expansion joints. They can also be obtained from traditional (natural) thermoplastic materials (asphalts, bitumen, resins, rubber, etcor from artificial polymeric ones.

Bituminous solid membranes are laminar systems made from prefabricated waterproofing materials joined *in situ* by heating. They can be classified according to two parameters:

- the mastic, providing the waterproofing properties, as well as the membrane's thermal properties and durability. It may be obtained from elastomers like modified bitumen, SBS, plastomers modified bitumen, oxiasfalt, etc.
- the armor, responsible for the membrane's mechanical properties: polyester, glass fibers, polyethylene, etc.

For polymeric solid membranes, the main agent dispersed amidst the emulsifier is a polymer. For further regards, general considerations made for bituminous solid membranes shall be considered of application.

Example: TEIMLAM is a FRe Building Technological Product made from several macromolecules of different nature and obtained from different manufacturing processes. It has been designed to constitute solid horizontal membranes, for roofs or ceilings, and has even been successfully applied to dam reinforcement and waterproofing[1]. It is formed in its base by a composite fiber-glass membrane (to bear traction stresses) embedded in a thermostable polymer. Presented for liquid applications, it then acquire a rigid structure. Finally, it is covered by an additional polymeric layer, providing to the whole inertia and compression bearing capacity. If needed, a last sealing polymeric layer can be added, in order to provide particular superficial texture traffic friendly or slipping mitigating. Note that this material can also be applied to vertical barriers, if properly pre-manufactured, requiring in that case special anchors and joints depending on its particular application.

Due to the huge variety of existing products in the category of Membranes/Solid membranes, for the purposes of this SMARTeST project testing protocols research, TEIMLAM will be considered as representative of the whole category.

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[1] see "*The use of epoxy systems in civil engineering: dam repairs*". Proceedings of the International Conference held at the University of Dundee, Scotland, UK, 11-13 September 1990. Senén Paz and others.

Liquid membranes are *in-situ* liquid superficial applications that turn themselves into continuous (joint-less) membranes a few minutes after being applied to the support.

Within the liquid membranes field, the innovative co-elastic technology is a step forward in continuous waterproofing systems. These are solution based products which seek synergies between different polymers in order to improve conventional technologies. The main product's features are their high aging resistance to UV and thermal radiation (the principal responsible of membranes deterioration), and the enhanced elasticity and crack-bridging capacity. These products are also often made from a unique compound, which is user and environmentally friendly. Synergy between different technologies makes it possible to reach a quick, efficient and low-cost product specially designed and suitable for each application requirements. Co-elastic technology is not bound to waterproofing membranes, but is also an innovative field for other polymeric applications.

For asphaltic emulsions, the main range of application addresses infrastructure and the cohesion enhancement of granular structures. Previously mentioned bituminous solid membranes, in combination with proper additives, can produce continuous membranes. This means it is possible to apply asphaltic emulsions without the need to create dilatation joints. The liquid product disperses the bitumen by means of emulsifying and stabilizing agents. These types of emulsion break the bituminous matrix into particles dispersed over the emulsifier (water). In order to stabilize the system, the addition of emulsifiers is necessary. Depending on the emulsifiers used, cationic (the dispersed bitumen particles are positively charged) or anionic (the dispersed bitumen particles are negatively charged) emulsions are obtained. Anionic emulsions present good compatibility with calcium aggregates, while the cationic ones are compatible with siliceous and a wide range of calcium aggregates. They are generally used to stabilize grounds and platforms, without reducing the ground water permeability. Emulsions can be modified by the addition of filler and polymers (SBS), in order to be applied to waterproofing solutions. They are very useful to improve the water performance of different infrastructures. They may be substituted by polymeric products, like the Elastocoast or many other polymeric products, but there may be additional cost implications.

Examples of reactive pre-polymers include epoxies, polyurethane, poliureas, hybrid polyurethane or poliureas, styrene-butadiene, acrylic and hybrid polymers.

Epoxy is a polymer formed from two different chemicals: a resin and a hardener. The resin is obtained from a prepolymer or a short polymeric chain with an epoxide group, and the hardener from a polyamine monomer. Epoxy has been used for a wide range of applications.

Polyurethane products are usually available as varnishes, polyurethanes are also suitable solutions for surface treatment applications under membrane application.

Synthetic polymers obtained by polymerization reaction of a diisocyanate with a diamine. As the polyurethane can be classified into aromatic (lower cost, UV discoloration) or aliphatic (UV resistant). The other two categories are a mixture obtained from both technologies, with a different chemical and mechanical behavior.

This is a new technology based on the optimized combination of different polymers (acrylic, polyurethane, fluoro-polymers, siloxane, etc). The interaction between polymers provides unique properties and advantages against conventional technologies. It is possible to distinguish physical blends from chemical or polymerization blends.

With a styrene addition, it is possible to increase the hardness of thermoplastic and elastomeric polymers in natural state. Both monomers are hydrophobic with high water resistance. The main problem of these kinds of polymers is their low UV radiation resistance and consequent yellowing tendency.

Acrylic polymers belong to a versatile family of thermoplastic products. Selecting the proper monomers, the desired properties can be reached (e.g.flexibility, hardness). To this group belongs the styrene acrylic, widely used for concrete protections. They are coplymers based on styrene-acrylic ester wherein the secondary monomer is butyl acrylate which provides a high degree of flexibility.

There are two major alternatives to waterproof a building element. The first one, membranes, consists of applying a waterproofing coating over the element's surface. The second alternative aims to modify the external superficial structure of the building element, through a shallow penetration of its matrix. This penetration can be obtained either by an impregnated or by a special coating in case of granular elements. This is the here so-called "*hydrophobic surface protection*". Most commonly used are silicones, but other kind of solutions based on epoxy resin or polyurethane varnishes can also be used.

Silicones

Applying a breathable, water-resistant coating to a porous surface usually involves silicon-based materials. The most common varieties include siloxane, silane, and silicone rubber, which are interesting due to their effectiveness in penetrating substrates without compromising the porosity of the material. In addition to being silicon-based, these materials share a number of other characteristics, including a high level of breathability and the capacity to be applied to most products without noticeably altering their appearance. But despite their similarities, siloxane, silane, and silicone rubber products each have their own distinct attributes that affect how they are manufactured and used.

Epoxy

It is a polymer formed from two different chemicals: a resin and a hardener. The resin consists of prepolymer or short polymeric chains with an epoxide group. The most common are produced by reaction between epichorohydrin and bisphenol A. The hardener consists of polyamine monomers. Epoxy has been used for a wide range of applications.

Polyurethane varnishes

This is a polymer obtained from a chain of organic units joined by urethane (carbamate) links. Polyurethane polymers are formed through step-growth polymerization by reacting a monomer containing at least two isocyanate functional groups with another monomer containing at least two hydroxyl (alcohol) groups. Polyurethanes with very different properties can be found, due to the wide range of available polyols and isocyanates for their formulation, aromatic or aliphatic according their chemical structure. Aromatic polyurethanes have low cost, more rigid structure but show discoloration against UV radiation. Aliphatic polyurethanes has high cost and high resistance to UV radiation. Also can be found like one component, in pre-polymers form dispersed in solvent or water.

Local sealing

Local sealings address localized applications of waterproofing product that seal water penetration channels: joints, anchors, cracks, etc.

Example: GAIRECOM MA/LM 1792 (see appendix) is a last generation two component methylmethacrylate (MMA) structural adhesive. As a consequence of its nanostructured structure the fatigue endurance, toughness and resilience dramatically increase compared to unmodified structural MMA adhesives. Its relative long gel-time along with an easy mixing ratio, allows a suitable working time for many applications. GAIRECOM MA/LM 1792 is as a non-sagging gel, supplied in containers of different sizes. Due to the huge variety of existing products in the category of Local Sealings, for the purposes of this SMARTeST project testing protocols research, GAIRECOM MA/LM 1792 will be considered as representative of the whole category even if, obviously, this is a simplification

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Anti-corrosive measures

Waterproofing FRe solutions previously reviewed can be effective, but arenot always enough to prevent the triggering of corrosive processes. Consequently, dampness leads to dissolution of some materials, red-ox corrosion of others and finally to the building decomposition. In the case of reinforced concrete, porosity makes it difficult to control red-ox processes during its lifetime, especially under aggressive environments, like chloride solutions (Cl^-) or marine climates.. For this reason, preventive protective measures are to be taken into account as a feature of importance in FRe building.

Preventive cathodic protection

This system is based on applying a small electrical current to the armor leading them to a more negative potential. The anodes should be placed during the construction phase, with specific design.

Corrosion inhibitors

Corrosion inhibitors are substances able to reduce significantly the corrosion rate of the reinforcement under an aggressive media without changing the concrete physical properties, such as compressive strength, resistance to freezing / thawing, initial setting time, settlement of the concrete, air entrainment, etc. These products can be either added during mixing or applied to the later surface.

Example: MCI-2000 (see appendix) is a corrosion inhibitor suitable either for new structures (may be used for application in mass and on surface, depending on the geometry, and its use), and for deteriorated ones (applied to the total surface in order to stop and passivate corrosion processes existing in them, and that except removing all the coating structure, can hardly be stopped in areas where no direct access exists). Due to the huge variety of existing products in the category of Anticorrosive, for the purposes of this SMARTeST project testing protocols research, MCI-2000 will be considered as representative of the whole category even if, obviously, this is a simplification

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Armor coating

Historically, the first preventive anticorrosion solutions were based on coatings or on special alloys not prone to corrosion. Currently, anticorrosive systems based on electric potentials, firstly anodic and later cathodic, are of growing practical importance and efficiency. The more innovative method are based on corrosion prevention, as the product here proposed (MCI). The coating of the armor using epoxy can form a barrier between the attackers and the armor.

Stainless steel armors aremore resistant to attack by despasivantes and promote the durability of the structure. This armor there is deformed in cold and hot, is characterized by the high percentage of chromium (12%) that is enhanced by the addition of Nickel, Molybdenum and Nitrogen.

Appendix 2 – Summary of testing of Flood perimeter barriers

Appendix 2.1:

Summary of the FRe Technologies Testing – System OPTIMAL

General product description

Product description (type of product, stability characteristic, sealing characteristics, drawings, pictures, …)

Double Tube Flood Protection System OPTIMAL - Category: Temporary flood barriers / Tube systems

The double tube flood protection system OPTIMAL (Fig. 1) is a non-stationary water-filled tube system made of reinforced plastic liner and filled with water. Initially, a filling with air is required for alignment. For filling, special equipment is needed like compressors and pumps.

The system is designed for emergency use and a water level of 60 cm shall be controlled safely by the structure in conjunction with a minor leakage rate. Stability control is achieved by parallel coupling of two cylindrical tubes.

Fig. 1: Double tube flood protection system OPTIMAL in the testing facility of the TUHH in April 2011[1]

The single element's standard length is 10 m. It is possible to manufacture shorter as well as longer single elements. The latter will lead to larger element masses, which may result in handling problems. By coupling the single elements any system length can be achieved.

The sealing at the element joints is ensured by lateral enlargement of the single elements after water filling.

No additional anchorage like pegs and end constructions are necessary. The fixation of the construction is done only by its mass effect, which consequently does not require any permanent construction. Nevertheless, it is important to avoid any gaps between flood protection tube and structure. Indeed these will result in water leakage and, depending on the erosion stability of the ground, in a washout out of soil leading to system instability.

The emergency use of protection measures always requires some scope for improvisation. Hence, hand materials like rubber mats and filled sandbags to construct waterproofed wall connections should be available.

Because of its flexibility, the tube system is able to follow uneven grounds. However, problems occur if smaller gaps and joints exist as e.g. in case of paved surfaces. These potential water passages cannot be sealed by the structure itself, but tests with foam rubber mats (only charged by structural dead load) underneath the structure will be undertaken to assess the benefits. Additional tests on pavements are necessary for evaluation.

Large radius curves are easy to realize with the OPTIMAL system. For smaller curve radiuses special angle or corner elements are required, which are not developed properly yet. As a makeshift, corner parts may be constructed by sandbags.

Functionalities expected by this product

[1] Photo: Bärbel Koppe made within the research project HWS-Mobile executed in 2009 to 2011 at the Leuphana University Lüneburg with financial assistance of the German Ministry for Economy and Technology on the basis of a resolution of the German Parliament

Watertightness: It is expected that the product limits the water penetration

Stability: It is expected that the product remain stable

Readiness: It is expected that the product will be ready in time

What are the main sale arguments of this product?

The system OPTIMAL substitutes conventional sandbag constructions, which are highly demanding with respect to building material, employment and deployment time, number of staff and transport efforts.

The main sale arguments of the system OPTIMAL are associated to the readiness functionality:

- Low consumption of resources
- Short installation time
- Small number of personnel required
- Deployable at different undergrounds without any destructive installations

Field of use and limitation

- The water-filled tube system OPTIMAL shall serve as an emergency system for linear flood protection.
- For geotechnical reason, the temporary product shouldn't be used for expected water level higher than 0,6m (according to the BWK booklet[2]) in case no ground analyses are previously done.

Further substructures are normally not required, but the ground must

- be stable to bear structural and hydraulic loads,
- offer a sufficient static friction between the system ground / tube or the system ground / foam rubber mat / tube to enable a stable position of the flood protection device and
- not show any sharp edges (in case a foam rubber mat is used underneath eventually existing sharp edges will not damage the tube material)

General Testing Description

Functionalities tested

Watertightness

Stability

[2] BWK, 2005: "Mobile Hochwasserschutzsysteme - Grundlagen für Planung und Einsatz". Merkblatt 6, Bund der Ingenieure für Wasserwirtschaft, Abfallwirtschaft und Kulturbau (BWK) e.V., Sindelfingen

Readiness
Performance criteria
The functionalities were qualitatively and quantitatively assessed. The analyses were based on the following performance criteria: Criterion watertightness: Leakage rate (l/h/m) Criterion stability: Only a qualitative analysis was performed (observation of product failure) Criterion readiness: Qualitative analysis coupled with quantitative analysis based on the mounting time
List of conditions effecting the performance
Watertightness: – Flood action (water pressure, waves, current, sedimentation) – Type of superficial underground (e.g. plain concrete, pavement, grassland) – Wear between product and superficial underground – Geotechnical characteristics – Type of vertical connections (wall/tubes) Stability – Flood action (water pressure, waves, current, sedimentation) – Type of superficial underground (e.g. plain concrete, pavement, grassland) – Wear between product and superficial underground – Geotechnical characteristics Readiness – Type of equipment used – Number of personnel – Location of storage place – Logistics
Testing conditions
Laboratory tests were conducted in the testing facility of the Technical University Hamburg-Harburg (TUHH) (Fig. 2). The test facility is a basin made of watertight concrete with the dimensions 20 m length, 15 m width and 2 m hight. The ground of the testing facility is characterised by an even and smooth concrete ground. The testing facility is enclosed by even rectangular concrete walls with an opening of 3 m at the front side to enable easy transportation of testing material into the basin. The opening can be closed by demountable flood barriers made of aluminium beams. Furthermore, two water storage tanks are

located in the testing facility, which are also enclosed at two sides by demountable flood barriers. For dynamic impact load tests, the right hand segment wall can be dismounted to offer a sufficiently long acceleration distance for flotsam load testing.

For load tests fresh water is pumped out of the storage tanks into the testing tank. The total leakage rate, i.e. leakage rate underneath the structure, between single elements of the structure, between structure and basin walls as well through the structure itself, can be measured by a dimensioned pump sump with a size of 50x50x50 cm³ (Fig. 3).

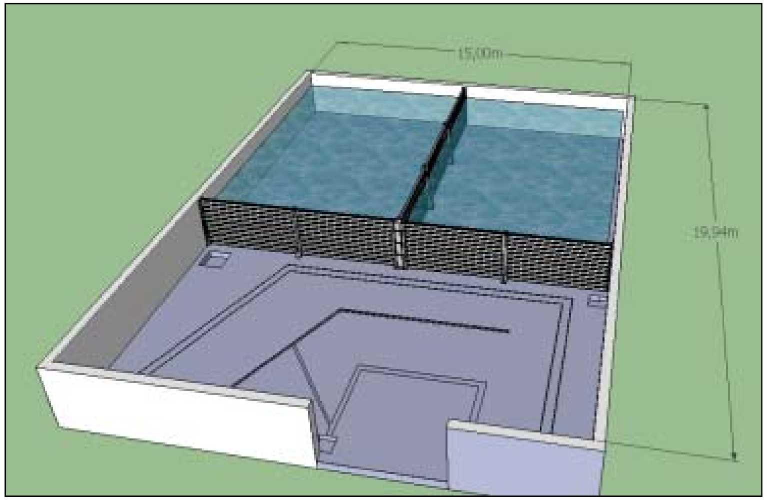

Fig. 2: Testing facility of the TUHH in Hamburg-Wilhelmsburg[3]

Fig. 3: Pump sump for leakage measurement[3 oben3]

Product configuration

Different product configurations have been tested.

First, a configuration according to the FM Approval[4] of the United States has been chosen recommending a minimum length of 18 m for the installed flood abatement system. Additionally, the FM Approval demands two corners, one with an angle of 90° and the other one with 60° (Fig. 4). Both ends of the flood abatement system need to be connected to a permanent straight structure, e.g. a concrete wall. In this arrangement, the flood abatement system behaves as a free-standing system. The length of the system and the curves and corners are a good basis for assessing the stability, the water tightness (impermeability) and the flexibility of the system. For this kind of testing special corner elements have been manufactured by the company OPTIMAL, which do not follow the double tube technology but consist only of a single tube (Fig. 5).

[3] Gabalda, V.; Daemrich, K.F., 2011: Performance of the Daedler and Optimal Flood Abatement System. TU Hamburg-Harburg, Mai 2011

[4] FM-Approval: Approval Standard for Flood Abatement Equipment, Class Number 2510, December 2006, FM Global

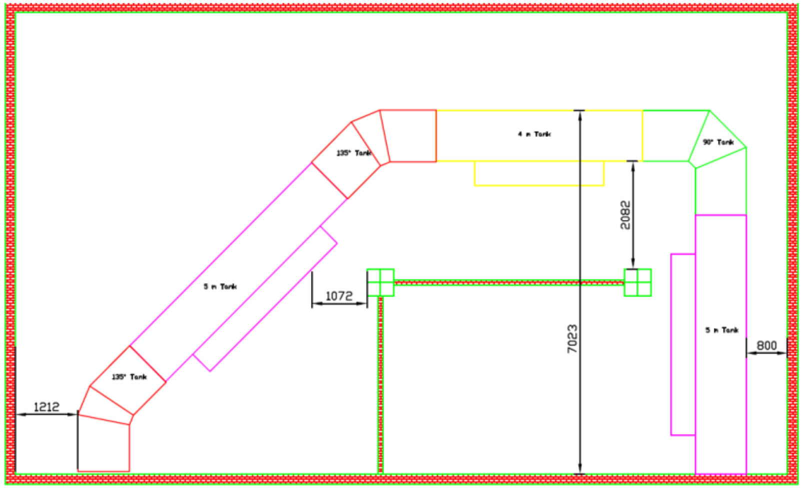

Fig. 4: Product configuration according to the FM Approval in the testing facility of the TUHH in Hamburg-Wilhelmsburg[5]

[5] Gabalda, V.; Daemrich, K.F., 2011: Performance of the Daedler and Optimal Flood Abatement System. TU Hamburg-Harburg, Mai 2011

Fig. 5: Product configuration of the system OPTIMAL according to FM Approval in the testing facility of the TUHH in Hamburg-Wilhelmsburg[6]

In a second test series a straight product line of 15 m consisting of two single elements with a length of 7.5 m have been tested (Fig. 1). Both elements are double tube elements.

Type of testing

Assessment of watertightness

– Hydrostatic load tests including leakage rate measurements for different system and/or product configurations as well as different water levels

Hydrostatic load tests have been carried out with different water levels. The highest water level for testing was defined by system failure, i.e. high degree of displacement of the system.

Stability Assessment

– Hydrostatic load tests including displacement measurements for different system and/or product configurations as well as different water levels
– Hydrostatic load tests up to system failure (high degree of displacement) for different system and/or product configurations
– Dynamic impact load / current load executed by a heavy water outfall at one side of the structure
– Dynamic load impact / debris load tests with different debris weights, impact angles and a fixed water level

Dynamic load tests have been carried out with a water level of approx. 58% of the system height and with two different flotsam weights of 225 kg and 400 kg, impact angles in the range of 70° to 90°, and impact velocities of 1.0 to 2.6 m/s.

Readiness Assessment

– Mounting and demounting of the system, partly including time measurement

Result assessment

Results of testing in term of performance

The intention of the executed tests was the improvement of the product characteristics including enlargement of product dimensions, changes in the coupling technology as well as of wand connections.
The research group developing the double tube system OPTIMAL has been able to improve the performance of the system significantly.
Conclusive tests for certification providing quantitative results concerning leakage rates and failure water levels are planned in spring 2012.

[6] Photos: Bärbel Koppe made within the research project HWS-Mobile executed in 2009 to 2011 at the Leuphana University Lüneburg with financial assistance of the German Ministry for Economy and Technology on the basis of a resolution of the German Parliament

The executed dynamic load tests showed a good behaviour of the structure. No damages occur at the system and the leakage rates increased only shortly in conjunction with the impact itself. Furthermore, the tests demonstrated that the assembly of the system must be competent and accurate to realize low leakage rates. Especially wall connections as well as connections between the single elements have to be installed with care.
Suggestion for improvement
– Selection of appropriate sealing material to decrease the leakage rate in case the system is used on pavements – Change of the location of zip fastener to open the elements for cleaning and maintenance - they should not be located at the elements sites as this creates seepage ways between the elements and the areas are not accessible for dismounting – Change of the fastening system to connect the elements – the ropes fastening the tube connection cover created seepage ways underneath the structure – Reducing the number of single elements like ropes, covers as there is a high risk of lost during a flood event
Input for WP4
As the system OPTIMAL is still in development <u>no</u> failure height and water level dependent leakage rates can be delivered for the use in HOWAD and FLORETO. Seepage into the underground cannot be taken into account. It must kept in mind that the executed tests are only valid for a real situation of the same characteristics, e.g. the use of the system on the same superficial underground like in the test basin. The model hypothesis should take this into account.
Input for Objective 2.3
The executed tests demonstrate that: – The standardization of the testing is not possible because of the diversity of the products. The application of the FM Approval Standards testing on the OPTIMAL system proved it. – The performance is depending on many conditions, which implies that a performance is not associated to a "product" but to a "product tested at defined conditions" – It would be advantageous if different underground characteristics could be tested in the test basin like e.g. plain concrete ground, pavement, grassland Without standard testing and relevant product performance, a certification will be hardly possible. In spring 2012 the company OPTIMAL will execute certification tests in the test basin of the TUHH monitored by an expert of the German Technical Control Board TÜV. The company will define the testing procedure on the basis of the test results executed in 2011. The TÜV will monitor the tests and will write an official report on the test procedure as well as on the qualitative and quantitative test results. Development and results of the certification testing can be used by SMARTeST as an example of a monitored and officially reported testing

procedure of flood resilient technology.

Appendix 2.2:

Summary of the FRe Technologies Testing – System DAEDLER

General product description

Product description (type of product, stability characteristic, sealing characteristics, drawings, pictures, …)

Tube Flood Protection System DAEDLER - Category: Temporary flood barriers / Tube systems

The tube flood protection system DAEDLER (Fig. 1) is a non-stationary water-filled tube system made of reinforced plastic liner and filled with water. Initially, a filling with air is required for alignment. For filling, special equipment is needed like compressors and pumps.

The system is designed for emergency use and a water level of 60 cm shall be controlled safely by the structure in conjunction with a minor leakage rate. Stability control is achieved by the trapezoidal shape of the structure.

Fig. 1: Trapezoidal tube flood protection system DAEDLER in the testing facility of the TUHH in April 2011[7]

The single element's standard length is 10 m. It is possible to manufacture shorter as well as longer single elements. The latter will lead to larger element masses, which may result in handling problems. By coupling the single elements any system length can be achieved.

The sealing at the element joints is ensured by lateral enlargement of the single elements after water filling and by foamed plastic wedges.

No additional anchorage like pegs and end constructions are necessary. The fixation of the construction is done only by its mass effect, which consequently does not require any permanent construction. Nevertheless, it is important to avoid any gaps between flood protection tube and structure. These would result in water leakage and, depending on the erosion stability of the ground, in a washout out of soil leading to system instability.

The emergency use of protection measures always requires some scope for improvisation. Hence, hand materials like rubber mats and filled sandbags to construct waterproofed wall connections should be available.

Because of its flexibility, the tube system is able to follow uneven grounds. However, problems occur if smaller gaps and joints exist as e.g. in case of paved surfaces. These potential water passages cannot be sealed by the structure itself, but tests with foam rubber mats (only charged by structural dead load) underneath the structure will be undertaken to assess the benefits. Additional tests on pavements are necessary for evaluation.

Large radius curves are easy to realize with the DAEDLER system. For smaller curve radiuses special angle or corner elements are in use like a 45° corner element. As a makeshift, corner parts may be also constructed by sandbags.

Functionalities expected by this product

[7] Photo: Manfred W. Jürgens made within the research project HWS-Mobile executed in 2009 to 2011 at the Leuphana University Lüneburg with financial assistance of the German Ministry for Economy and Technology on the basis of a resolution of the German Parliament

Watertightness: It is expected that the product limits the water penetration Stability: It is expected that the product remain stable Readiness: It is expected that the product will be ready in time
What are the main sale arguments of this product?
The system DAEDLER substitutes conventional sandbag constructions, which are highly demanding with respect to building material, employment and deployment time, number of staff and transport efforts. The main sale arguments of the system DAEDLER are associated to the readiness functionality: – Low consumption of resources – Short installation time – Small number of personnel required – Deployable at different undergrounds without any destructive installations
Field of use and limitation
– The water-filled tube system DAEDLER shall serve as an emergency system for linear flood protection. – For geotechnical reason, the temporary product should not be used for expected water levels higher than 0,6m (according to the BWK booklet[8]) in case no ground analyses are previously done. Further substructures are normally not required, but the ground must – be stable to bear structural and hydraulic loads, – offer a sufficient static friction between the system ground / tube or the system ground / foam rubber mat / tube to enable a stable position of the flood protection device and – not show any sharp edges (in case a foam rubber mat is used underneath eventually existing sharp edges will not damage the tube material)

General Testing Description
Functionalities tested
Watertightness Stability

[8] BWK, 2005: "Mobile Hochwasserschutzsysteme - Grundlagen für Planung und Einsatz". Merkblatt 6, Bund der Ingenieure für Wasserwirtschaft, Abfallwirtschaft und Kulturbau (BWK) e.V., Sindelfingen

Readiness
Performance criteria
The functionalities were qualitatively and quantitatively assessed. The analyses were based on the following performance criteria: Criterion watertightness: Leakage rate (l/h/m) Criterion stability: Only a qualitative analysis was performed (observation of product failure) Criterion readiness: Qualitative analysis coupled with quantitative analysis based on the mounting time
List of conditions effecting the performance
Watertightness: – Flood action (water pressure, waves, current, sedimentation) – Type of superficial underground (e.g. plain concrete, pavement, grassland) – Wear between product and superficial underground – Geotechnical characteristics – Type of vertical connections (wall/tubes) Stability – Flood action (water pressure, waves, current, sedimentation) – Type of superficial underground (e.g. plain concrete, pavement, grassland) – Wear between product and superficial underground – Geotechnical characteristics Readiness – Type of equipment used – Number of personnel – Location of storage place – Logistics
Testing conditions
Laboratory tests were conducted in the testing facility of the Technical University Hamburg-Harburg (TUHH) (Fig. 2). The test facility is a basin made of watertight concrete with the dimensions 20 m length, 15 m width and 2 m hight. The ground of the testing facility is characterised by an even and smooth concrete ground. The testing facility is enclosed by even rectangular concrete walls with an opening of 3 m at the front side to enable easy transportation of testing material into the basin. The opening can be closed by demountable flood barriers made of aluminium beams. Furthermore, two water storage tanks are

located in the testing facility, which are also enclosed at two sides by demountable flood barriers. For dynamic impact load tests, the right hand segment wall can be dismounted to offer a sufficiently long acceleration distance for flotsam load testing.

For load tests fresh water is pumped out of the storage tanks into the testing tank. The total leakage rate, i.e. leakage rate underneath the structure, between single elements of the structure, between structure and basin walls as well through the structure itself, can be measured by a dimensioned pump sump with a size of 50x50x50 cm³ (Fig. 3).

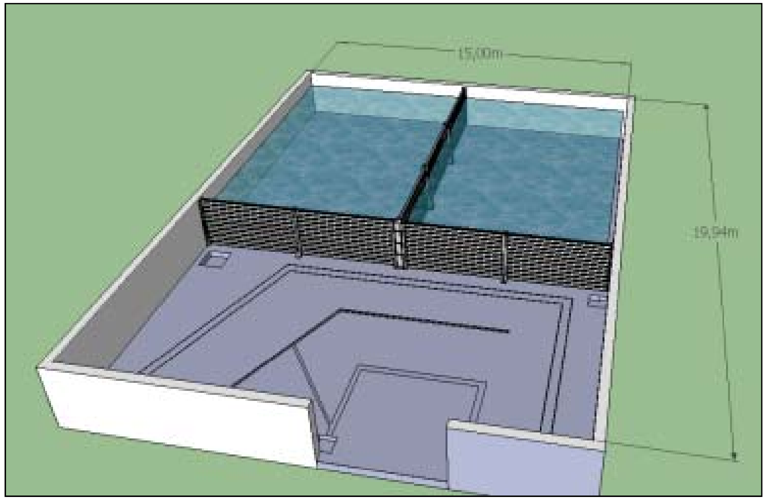

Fig. 2: Testing facility of the TUHH in Hamburg-Wilhelmsburg[9]


Fig. 3: Pump sump for leakage measurement[3 oben3]

Product configuration

Different product configurations have been tested.

First, a configuration according to the FM Approval[10] of the United States has been chosen recommending a minimum length of 18 m for the installed flood abatement system. Additionally, the FM Approval demands two corners, two with an angle of 90° and the other one with 60° (Fig. 4). Both ends of the flood abatement system need to be connected to a permanent straight structure, e.g. a concrete wall. In this arrangement, the flood abatement system behaves as a free-standing system. The length of the system and the curves and corners are a good basis for assessing the stability, the water tightness (impermeability) and the flexibility of the system. For this kind of testing four corner elements with an angle of 45° have been manufactured by the company DAEDLER (Fig. 5).

[9] Gabalda, V.; Daemrich, K.F., 2011: Performance of the Daedler and Optimal Flood Abatement System. TU Hamburg-Harburg, Mai 2011

[10] FM-Approval: Approval Standard for Flood Abatement Equipment, Class Number 2510, December 2006, FM Global

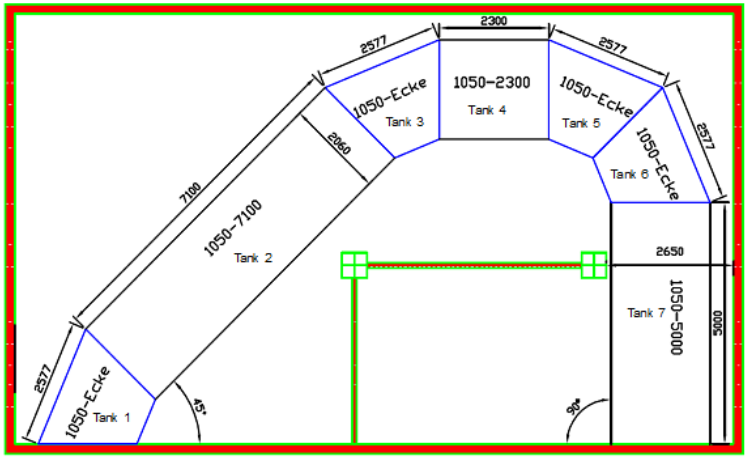

Fig. 4: Product configuration according to the FM Approval in the testing facility of the TUHH in Hamburg-Wilhelmsburg[11]

Fig. 5: Product configuration of the system DAEDLER according to FM Approval in the testing facility of the TUHH in Hamburg-Wilhelmsburg[12]

[11] Gabalda, V.; Daemrich, K.F., 2011: Performance of the Daedler and Optimal Flood Abatement System. TU Hamburg-Harburg, Mai 2011

In a second test series a straight product line of 15 m consisting of two single elements with a length of 7.5 m have been tested (Fig. 6). Underneath the elements different foamed plastic mats have bean placed to increase the wear between product and underground.

Fig. 6: Straight product configuration of the system DADLER in the testing facility of the TUHH in Hamburg-Wilhelmsburg[13]

Type of testing

Assessment of watertightness

– Hydrostatic load tests including leakage rate measurements for different system and/or product configurations as well as different water levels

Hydrostatic load tests have been carried out with different water levels. The highest water level for testing was defined by system failure, i.e. high degree of displacement of the system.

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[12] Photo: Manfred W. Jürgens made within the research project HWS-Mobile executed in 2009 to 2011 at the Leuphana University Lüneburg with financial assistance of the German Ministry for Economy and Technology on the basis of a resolution of the German Parliament

[13] Photo: Bärbel Koppe made within the research project HWS-Mobile executed in 2009 to 2011 at the Leuphana University Lüneburg with financial assistance of the German Ministry for Economy and Technology on the basis of a resolution of the German Parliament

Stability Assessment

- Hydrostatic load tests including displacement measurements for different system and/or product configurations as well as different water levels
- Hydrostatic load tests up to system failure (high degree of displacement) for different system and/or product configurations
- Dynamic impact load / current load executed by a heavy water outfall at one side of the structure
- Dynamic load impact / debris load tests with different debris weights, impact angles and a fixed water level

Dynamic load tests have been carried out by a water level of approx. 43% of the system height and with two different flotsam weights of 225 kg and 400 kg, impact angles in the range of 70° to 90°, and impact velocities of 0.8 to 2.0 m/s.

Readiness Assessment

- Mounting and demounting of the system, partly including time measurement

Result assessment

Results of testing in term of performance

The intention of the executed tests was the improvement of the product characteristics including enlargement of product dimensions, changes in the coupling technology as well as of wand connections. Furthermore different foamed plastic mats have been tested underneath the structure to increase the wear between product and underground.

The research group developing the trapezoidal tube system DAEDLER has been able to improve the performance of the system.

The executed dynamic load tests showed generally a good behaviour of the structure, as the leakage rates increased only shortly in conjunction with the impact itself. After the successful execution of 11 dynamic load tests with different flotsam weights and impact velocities damage occurred during the twelfth test. As the flotsam was not released after impact but was towed into the element the plastic mantle of the structure cracked. After damage no sudden failure occurred but the system stability could be ensured at the testing water level of 0.45 m (Fig. 8).

The executed tests demonstrated that the assembly of the system must be competent and accurate to realize low leakage rates. Especially wall connections as well as connections between the single elements have to be installed carefully.

Fig. 8: Straight product configuration of the system DADLER in the testing facility of the TUHH in Hamburg-Wilhelmsburg[14]

Suggestion for improvement

- Selection of appropriate frictional mats for placement underneath the structure
- Selection of appropriate sealing material to decrease the leakage rate in case the system is used on pavements

Input for WP4

As the system DAEDLER is still in development no failure height and water level dependent leakage rates can be delivered for the use in HOWAD and FLORETO.
Due to the testing facility seepage into the underground could not be taken into account.
It must kept in mind that the executed tests are only valid for a real situation of the same characteristics, e.g. the use of the system on the same superficial underground like in the test basin. The model hypothesis should take this into account.

[14] Photo: Bärbel Koppe made within the research project HWS-Mobile executed in 2009 to 2011 at the Leuphana University Lüneburg with financial assistance of the German Ministry for Economy and Technology on the basis of a resolution of the German Parliament

Input for Objective 2.3
The executed tests demonstrate that: – The standardization of the testing is not possible because of the diversity of the products. – The performance is depending on many conditions, which implies that a performance is not associated to a "product" but to a "product tested at defined conditions" – It would be advantageous if different underground characteristics could be tested in the test basin like e.g. plain concrete ground, pavement, grassland

Appendix 2.3:

Summary of the FRe Technologies Testing MOBILDEICH (27.01.2012)

General product description

Product description (type of product, stability characteristic, sealing characteristics, drawings, pictures, …)

Mobildeich MD93-2

Mobildeich is a temporary perimeter flood barrier consisting of tubes filled with water (Fig. 1).

Fig. 1: Modildeich MD93-2 installed at the water basin of the TUHH

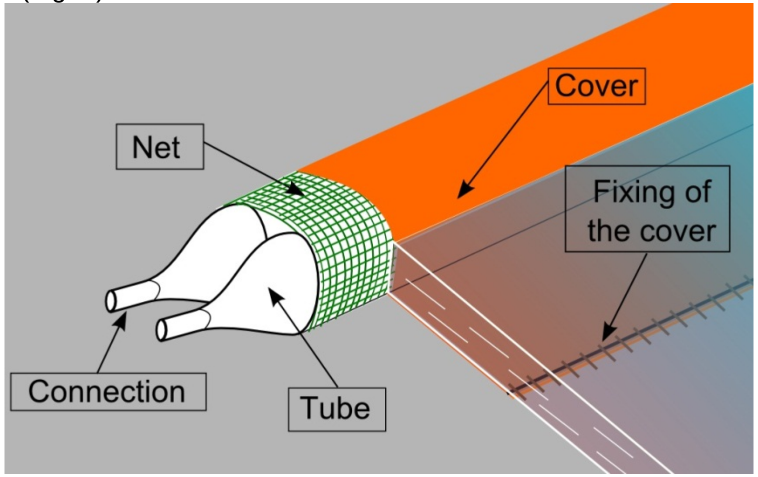


Fig. 2: The barriers are closed

During the flood warning the system is placed on site to form a perimeter around the area to be protected. It is then filled with water and a cover is placed on it. The cover can be fixed to the ground in different manners dependent on the surface characteristics.

The stability of the system (Fig. 2) results from the combination of the weight of water within the tubes and the cover fixed to the ground. The latter accounts for the sealing capacity of the overall system. The tubes are produced in different sizes (in terms of length and diameter) and can be connected to each other. Every module consists of two tubes, which are bound together by means of a net. The net has the function of holding the tubes together and to absorb the shear forces.

Functionalities expected by this product

Water tightness: It is expected that the product limits the water penetration

Stability: It is expected that the product remains stable

Readiness: It is expected that the product will be ready in time

What are the main sale arguments of the product?
The system manufactured by Mobildeich GmbH substitutes conventional sandbag constructions, which are highly demanding with respect to building material, employment and deployment time, number of staff and transport efforts. The main sale arguments of the system are associated to the readiness functionality: – Low consumption of resources – Short installation time – Small number of personnel required – Deployable at different undergrounds without any destructive installations
Field of use and limitation
– The water-filled tube system Mobildeich shall serve as an emergency system for linear flood protection but can be used also in construction sites in the near of water bodies to keep the working area dry. – For geotechnical reason, the temporary product shouldn't be used for expected water level higher than 0,6m (according to the BWK booklet[15]) if no ground analysis is previously done. If the ground analysis is done water levels up to 1,2 meter are possible. Further substructures are normally not required, but the ground must – be stable to bear structural and hydraulic loads, – offer a sufficient static friction between the system ground / tube to enable a stable position and – not show any sharp edges (to avoid damages of the tube materials) nor big irregularities (to avoid points of discontinuity)

General Testing Description
Functionalities tested
Water tightness Stability Readiness
Performance criteria
The functionalities were qualitatively and quantitatively assessed. The quantitative analysis was based on the following performance criteria: Criterion water tightness: Leakage rate (l/h/m) Criterion stability: Only a qualitative analysis was performed (observation of product displacement and failure) Criterion readiness: Qualitative analysis coupled with quantitative analysis based on the mounting time
List of conditions effecting the performance
Water tightness: – Flood action (water pressure, waves, current, sedimentation)

[15] BWK, 2005: "Mobile Hochwasserschutzsysteme - Grundlagen für Planung und Einsatz". Merkblatt 6, Bund der Ingenieure für Wasserwirtschaft, Abfallwirtschaft und Kulturbau (BWK) e.V., Sindelfingen.

- Type of ground surface (e.g. plain concrete, pavement, grassland)
- Wear between product and superficial underground
- Geotechnical characteristics
- Type of vertical connections (wall/tubes)

Stability
- Flood action (water pressure, waves, current, sedimentation)
- Type of foundation (e.g. plain concrete, pavement, grassland)
- Wear between product and superficial underground
- Geotechnical characteristics

Readiness
- Type of equipment used
- Number of personnel
- Location of storage place
- Logistics

Test facility description

Laboratory tests were conducted at the climate change research centre (KLIFF) of the Technical University Hamburg-Harburg (TUHH) (Fig. 3). The test facility includes a water basin made of watertight concrete, which has the dimensions of 20 m long, 15 m wide and 2 m high. The testing facility is characterized by a flat and smooth concrete ground and is enclosed by rectangular concrete walls with an opening of 3 m at the front side to enable easy transportation of the testing material into the basin. The opening can be closed by a demountable flood barrier made of aluminium. The half of the basin opposite to the opening is enclosed by demountable flood barriers to form two storage tanks. For the dynamic load tests, the right hand segment wall is dismounted to have an acceleration corridor for the debris loads.

For the hydraulic tests the water is pumped out of the storage tanks into the testing area. The total leakage rate, i.e. leakage rate underneath the structure, between single elements of the structure, between structure and basin walls as well as through the structure itself, can be measured using a pump sump with a size of 50x50x50 cm^3 equipped with a scale in which water volume variation can be read (Fig. 4).

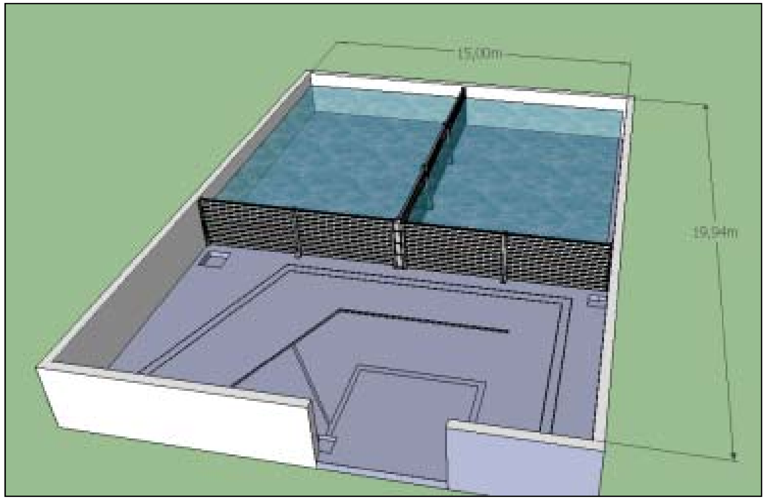


Fig. 3: Water basin of the TUHH

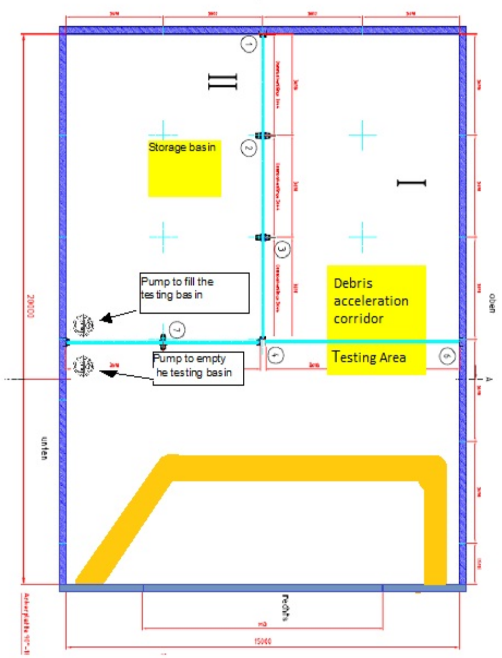

Fig. 4: Pump sump

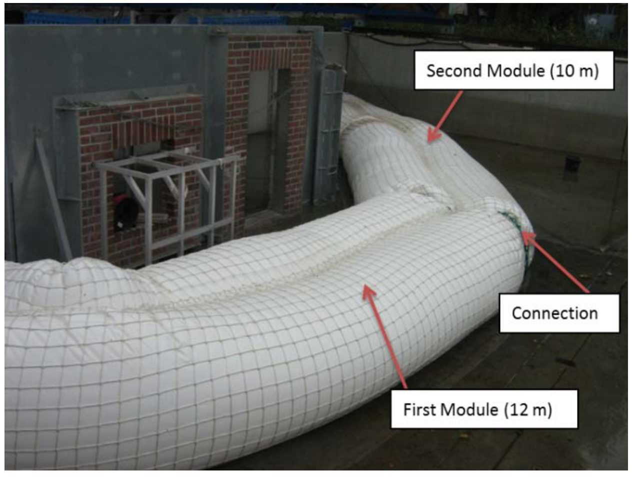
Product configuration

The installation of the system has been carried out following the configuration suggested by the FM Approval[16] which recommends a minimum length of 18 m including two corners, one with an angle of 90° and the other one with 60° (Fig. 5).

Both ends of the system need to be connected to a permanent straight structure, e.g. a concrete wall. In this arrangement, the barrier behaves as a free-standing system. The length of the system and the bendings are a good basis for assessing the stability, the water tightness and the flexibility of the system. For this test two modules (each module consisting of two tubes) were used respectively 10 m and 12 meters long with a diameter of 93 cm (Fig. 6).

[16] FM-Approval: Approval Standard for Flood Abatement Equipment, Class Number 2510, December 2006, FM Global





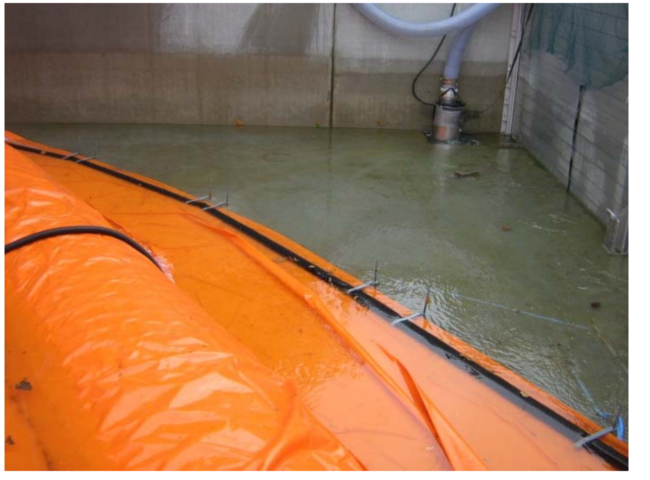


Fig. 5: Configuration of the Mobildeich using steel dowels

Fig. 6: Modules used for the test

Fig. 7: Fixing of the cover

The cover was fixed to the ground using tubular elements pressed by steel dowels (see figure 7).

Testing conditions

Assessment of water tightness and stability

- Hydrostatic load test including leakage rate and displacement measurements for different water levels
- Hydrodynamic load test including leakage rate and displacement measurements at a water level of 70 cm carried out using a propeller which generated a jet of 20 cm with a current of 2 m/s parallel and orthogonal to the system over a period of one hour
- Impact test including displacement measurements at a water level of 70 cm using a wooden log of 400 kg

Readiness Assessment

- Mounting and demounting of the system done by one instructor and three assistants

Result assessment

Results of testing in term of performance

The hydrostatic load test was carried out at eight different water levels up to the height of 80 cm. After 22 hours the test was repeated at a water level of 75 cm. Hardly any deformation of the system could be detected during the testing. No backward sliding was detected, showing a good stability of the system.
The leakage rate rose up to 7 l/min/m at the highest water level during the first test. At the two ends of the dike higher leakages were observed. Nevertheless, after the steady state was reached, at a water level of 75 cm, the leakage rate measured was not higher than 3.5 l/min/m.
Regarding the hydrodynamic load test, in both positions, parallel and orthogonal to the system, the deformation was not more than that recorded in the hydrostatic load test. The leakage rate did not change throughout the whole testing procedure.
In the debris load test the Mobildeich was subjected to the impact of a log with velocities between 1 m/s and 2.5 m/s. The deformation only occurred during the impact. After the impact the Mobildeich returned to its former position. No sliding of the system over the ground was detected.
Both mounting and dismounting were done in about 30 min/10 m. The most critical tasks during the mounting process were the proper positioning of the tubes at the corners and the placement of the cover on top of the tubes. During the dismounting process, the most critical tasks were found to be the reeling back of the tubes and the folding of the cover.
Regarding the durability test, the system was erected and dismounted 100 times on different ground surfaces and filled at different water pressures. Neither the increasing roughness nor the high pressure inside the tubes affected the dike in terms of damage.

Suggestion for improvement

- Smaller cover for an easier handling
- A stripe of gasket on the part of the cover to be fixed to the ground for application on asphalt or concrete surfaces
- Rounded and colored cap of the dowel to make them more visible and less dangerous

Appendix 2.4:

Summary of the FRe Technologies Testing – System Sandbags

General product description

Product description (type of product, stability characteristic, sealing characteristics, drawings, pictures, …)

Flood Protection System Sandbags - Category: Temporary flood barriers / Sandbags

The sandbag flood protection system is a temporary system made of jute bags filled with sand. The cross section of the flood protection dam can be designed individually.

The size of the tested empty sandbag is 35 x 60 cm resulting in a filled sandbag size of 25 x 50 cm. It is possible to construct any user-defined dam cross-section and dam length by sandbags.

Sandbag systems are not watertight but offer some water retention and the height of the seepage line is lowered over the structure width (Fig. 1). The leakage rate is dependent on:

- Structure width (the larger the widths to lesser the leakage rate)
- Filling material (large leakage rate in case of coarse filling material)
- Filling grade of the sandbags (the larger the filling rate of the single sandbag the larger the leakage rate)
- Packing tightness of the filled sandbags

To achieve minor leakage rates the waterside of the sandbag dam may be covered with a watertight plastic sheet.

No additional anchorage like pegs and end constructions are necessary. The fixation of the construction is done only by its mass effect, which consequently does not require any permanent construction. Nevertheless, it is important to avoid any gaps between flood protection dam and structure. Indeed, this would result in water leakage and, depending on the erosion stability of the ground, in a washout out of soil leading to system instability.

Because of its flexibility, sandbag systems are able to follow uneven grounds. However, problems occur if smaller gaps and joints exist as e.g. in case of paved surfaces. These potential water passages cannot be sealed totally by the structure itself. Additional tests on pavements are necessary for evaluation.

All radius curves and corners are easy to realize with sandbag systems.

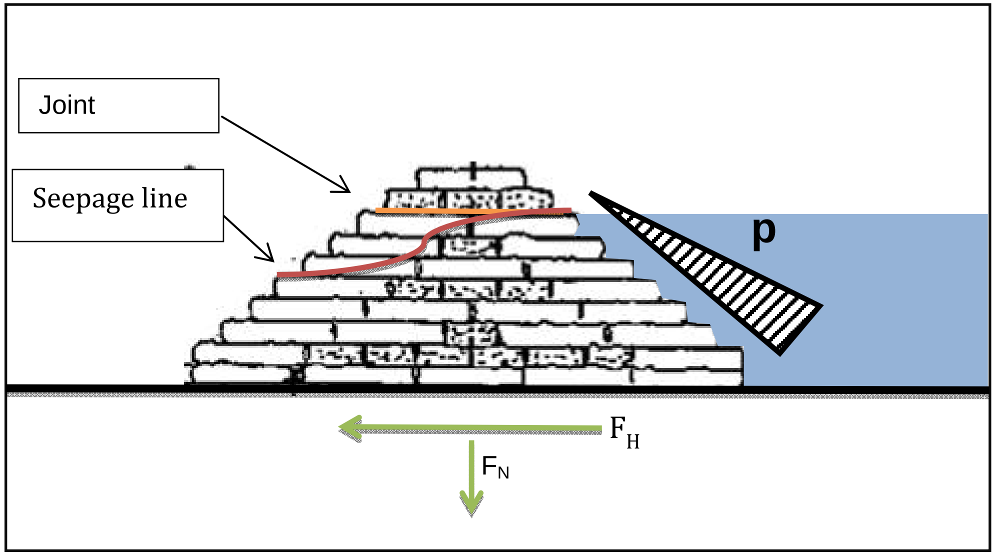


Fig. 1: Possible seepage line in a sandbag dam[17]
Functionalities expected by the product
Stability: It is expected that the product remain stable Water retention: It is expected that the product limits the water penetration; significant leakage rates have to be expected in case no watertight plastic sheet is in use at the outer slope of the structure
What are the main sale arguments of this product?
Advantages of sandbag systems: – Sandbag systems are widely in use – They can be installed by semi-skilled workers, but some guidance for tight packing should be available – They offer flexible structural design – They are deployable at different undergrounds without any destructive installations
Field of use and limitation
Field of use of sandbag systems: – Sandbag systems serve as an emergency system for (linear) flood protection. – For geotechnical reasons, the temporary product should not be used for expected water level higher than 0,6m (according to the BWK booklet[18]) in case no ground analyses are previously done. Further substructures are normally not required, but the ground must be stable to bear structural and hydraulic loads. (Disadvantages of sandbag systems) – Huge amounts of sandbags and sand are required – Long employment and deployment time – Large number of staff for employment and deployment required – Huge transport efforts required

[17] Modified graphic from: Meyer, O., 2011: Untersuchung und Bewertung mobiler Deichsysteme für Hochwasser- und Katastrophenschutz. Student research project at the Technical University Hamburg-Harburg, 16.11.2011.

[18] BWK, 2005: "Mobile Hochwasserschutzsysteme - Grundlagen für Planung und Einsatz". Merkblatt 6, Bund der Ingenieure für Wasserwirtschaft, Abfallwirtschaft und Kulturbau (BWK) e.V., Sindelfingen

General Testing Description

Functionalities tested

Watertightness

Stability

Readiness

Performance criteria

The functionalities were qualitatively and quantitatively assessed. The analyses were based on the following performance criteria:
Criterion watertightness: Leakage rate (l/h/m)
Criterion stability: Only a qualitative analysis was performed (observation of product failure)
Criterion readiness: Qualitative analysis coupled with quantitative analysis based on the mounting time

List of conditions effecting the performance

Watertightness:

- Flood action (water pressure, waves, current, sedimentation)
- Type of superficial underground (e.g. plain concrete, pavement, grassland)
- Wear between product and superficial underground
- Geotechnical characteristics
- Type of vertical connections (wall/sandbags)

- Structure width (the larger the widths to lesser the leakage rate)
- Filling material (large leakage rate in case of coarse filling material)
- Filling grade of the sandbags (the larger the filling rate of the single sandbag the larger the leakage rate)
- Packing tightness of the filled sandbags

Stability

- Flood action (water pressure, waves, current, sedimentation)
- Type of superficial underground (e.g. plain concrete, pavement, grassland)
- Wear between product and superficial underground
- Geotechnical characteristics

Readiness

- Type of equipment used
- Number of personnel
- Location of storage place
- Logistics

Testing conditions

Laboratory tests were conducted in the testing facility of the Technical University Hamburg-Harburg (TUHH) (Fig. 2). The test facility is a basin made of watertight concrete, which has the dimensions 20 m long, 15 m wide and 2 m high. The ground of the testing facility is characterised by an even and smooth concrete ground. The testing facility is enclosed by even rectangular concrete walls with an opening of 3 m at the front side to enable easy transportation of the testing material into the basin. The opening can be closed by demountable aperture flood barriers made of aluminium. Furthermore, two water storage tanks are located in the testing facility, which are also enclosed at two sides by demountable flood barriers. For dynamic impact load tests, the right hand segment wall is dismounted to have an acceleration area for flotsam load testing.

For load tests fresh water is pumped out of the storage tanks into the testing tank. The total leakage rate, i.e. leakage rate underneath the structure, between single elements of the structure, between structure and basin walls as well through the structure itself, can be measured by a dimensioned pump sump with a size of 50x50x50 cm^3 (Fig. 3).

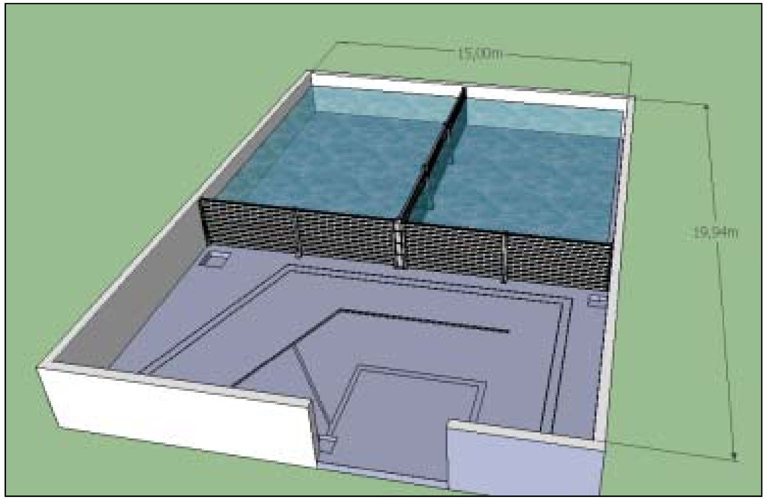


Fig. 2: Testing facility of the TUHH in Hamburg-Wilhelmsburg[19]

Fig. 3: Pump sump for leakage measurement[3 oben3]

Product configuration

A product configuration according to the FM Approval[20] of the United States has been tested recommending a minimum length of 18 m for the installed flood abatement system. Additionally, the FM Approval demands two corners, one with an angle of 90° and the other one with 60° (Fig. 4). Both ends of the flood abatement system need to be connected to a permanent straight structure, e.g. a concrete wall. In this arrangement, the flood abatement system behaves as a free-standing system. The length of the system and the curves and corners are a good basis for assessing the stability, the water tightness (permeability) and the flexibility of the system.

In testing a structural cross section was chosen according to the guideline of the German Technical Relief Organisation THW[21] (Fig. 1).

[19] Gabalda, V.; Daemrich, K.F., 2011: Performance of the Daedler and Optimal Flood Abatement System. TU Hamburg-Harburg, Mai 2011

[20] FM-Approval: Approval Standard for Flood Abatement Equipment, Class Number 2510, December 2006, FM Global

[21] THW, 2006: Deichverteidigung und Hochwasserschutz (Dyke defence and flood protection). Deutsches Technisches Hilfswerk (German Technical Relief Organisation)

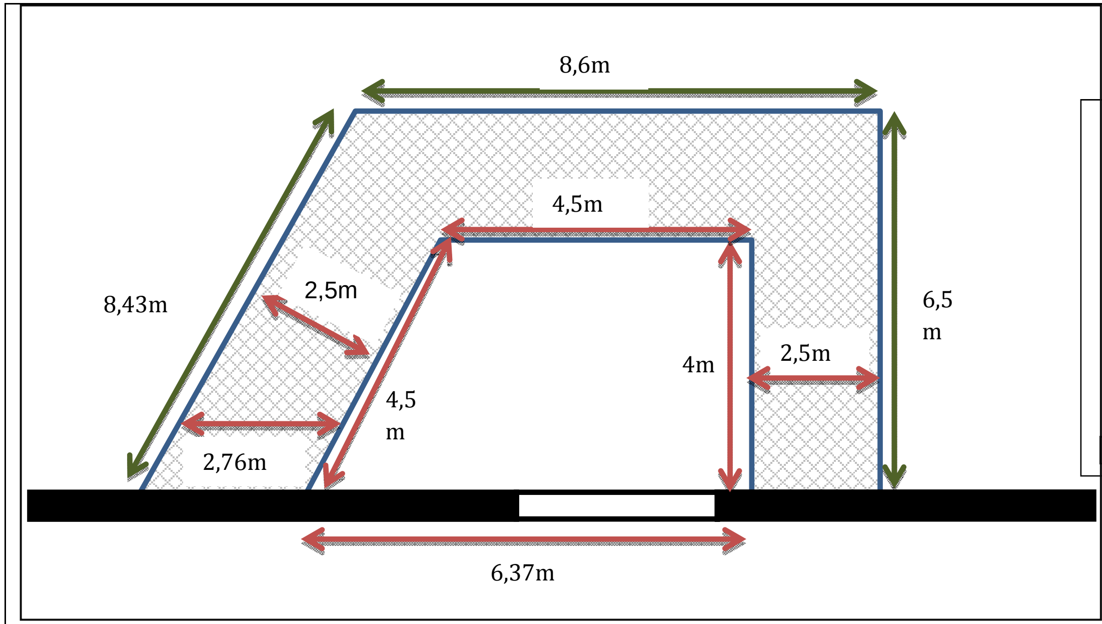


Fig. 4: Product configuration according to the FM Approval in the testing facility of the TUHH in Hamburg-Wilhelmsburg[22]

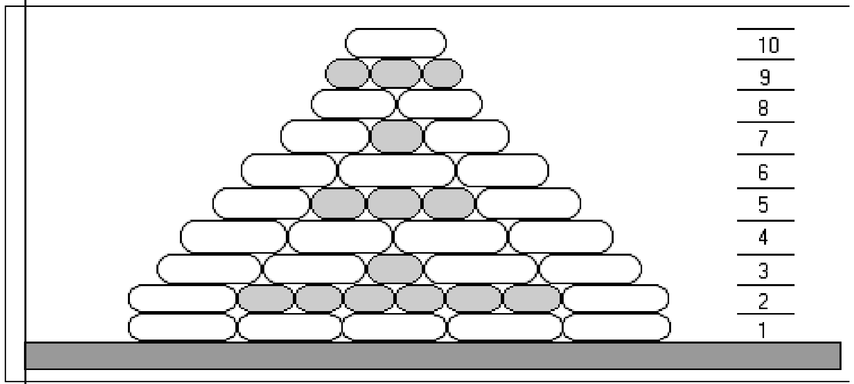


Fig. 5: Laying technique of a sandbag dam; cross section, grey parts: transverse laid sandbags[21]

Type of testing

Assessment of watertightness

– Hydrostatic load tests including leakage rate measurements for different water levels. The highest water level for testing was defined by the available pump performance during overflow tests.

Stability Assessment

– Hydrostatic load tests including displacement observations for different water levels
– Dynamic impact load test with current load parallel and vertical to the sandbag dam axis. Parallel current load tests have been conducted with water levels of 75% and 82% of the system height (water levels of 0.80 m and 0.88 m) and current velocities of 1.6 and 2.0 m/s. Vertical load tests have been executed with a water level of 82% of the system height (water level of 0.88 m) and with current velocities up to 2.6 m/s.

[22] Meyer, O., 2011: Untersuchung und Bewertung mobiler Deichsysteme für Hochwasser- und Katastrophenschutz. Student research project at the Technical University Hamburg-Harburg, 16.11.2011.

– Dynamic load impact / flotsam load tests with different flotsam weights of 225 kg and 400 kg, impact angles in the range of 70° to 90°, a water level of 66% of the product height (water level of 0.70 m) and impact velocities in the range of 1.0 to 2.6 m/s.

Readiness Assessment

– Mounting and demounting of the system, partly including time measurement

Result assessment

Results of testing in term of performance

The tests have been used for the assessment of product characteristics.

The filled sandbags have been placed on pallets directly in front of the installation place (Fig. 6). Approx. 44 pallets with 70 filled sandbags each were available (in total 3,080 sandbags).

Fig. 6: Filled sandbags on pallets and built sandbag dam according to FM Approval in the testing facility of the TUHH in Hamburg-Wilhelmsburg[22]

The mounting time of the sandbag dam with a length of 18.3 m and a mean dam height of approx. 0.9 m and a basis width of 2.5 m (Fig. 7) was 185 minutes. 19 persons were involved in the construction work.
The most time-consuming working step is the correct positioning and pressing of the sandbags. This working step is mainly responsible for stability and leakage rate of the structure.

The executed static load tests showed that the sandbag system is able to withstand overflowing water levels of up to 5 cm. Due to limited pump performance a dam length of 1.6 m was lowered for overflow testing (Fig. 8).
For measuring leakage rates at different water levels it takes approx. half an hour until the dam is soaked through and the leakage rate is more or less stable.

Depending on the water level behind the dam different leakage rates have been measured:

- Water level 0.30 m above ground, leakage rate of approx. 1,500 l/h or approx. 80 l/(m*h)
- Water level 0.60 m above ground, leakage rate of approx. 5,100 l/h or approx. 280 l/(m*h)
- Water level 0.80 m above ground, leakage rate of approx. 10,500 l/h or approx. 570 l/(m*h)
- Water level 0.90 m above ground, leakage rate of approx. 14,400 l/h or approx. 790 l/(m*h)

The executed dynamic load tests showed a good behaviour of the structure. No damages occurred at the system during parallel current load tests and only minor damages have been observed during vertical current load tests up to current velocities of approx. 2 m/s. Higher current velocities lifted single sandbags leading to permanent damages. The flotsam load tests have been executed without showing permanent damages at the structure.

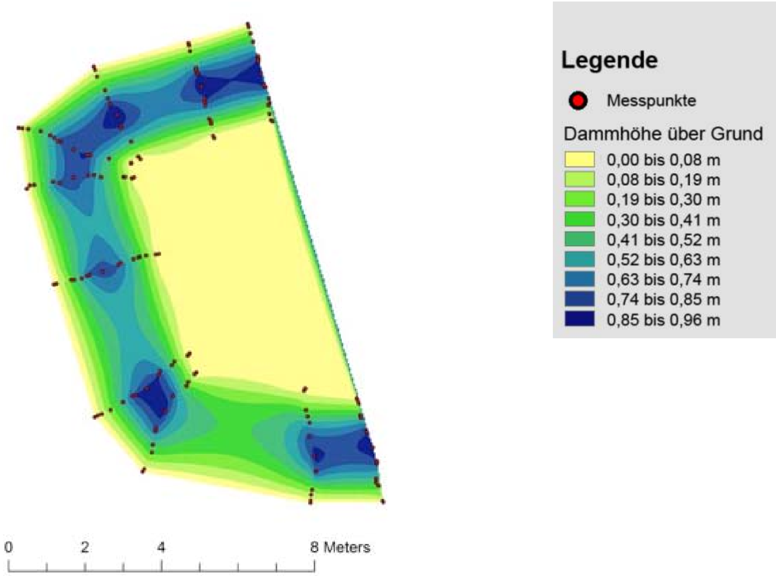


Fig. 7: Shape of the tested sandbag dam[22]

Fig. 8: Overflow test in the testing facility of the TUHH in Hamburg-Wilhelmsburg[22]

Suggestion for improvement

- Sandbags should be filled only up to 2/3 of their maximum filling capacity as higher filling rates result in higher permeability of the structure (formation of gaps between the sandbags)
- The packing of sandbags should be executed by skilled personnel as tight packing results in more structural stability and lower leakage rates
- Wall connections should be built with low-filled sandbags ensuring a better adaptation to existing structures
- The leakage rate of a sandbag dam can be reduced by the use of a watertight plastic sheet at the waterside slope of the dam.

Appendix 2.5:

Summary of the FRe Technologies Testing – System Aqua-Stop Damm

General product description

Product description (type of product, stability characteristic, sealing characteristics, drawings, pictures, …)

Aqua-Stop Damm - Category: Demountable flood barrier. According to manufacturers can be used as temporary flood barrier on earthy ground. The following work studies the product as demountable flood barrier.

The Aqua-Stop Damm is classified as demountable flood barrier since it needs a preliminary preparation of the ground. It is composed of 6 main components:

- Connection frames between wall and fences (figure 1)
- Fences (figure 2)
- Connection frame between fences (figure 3)
- Anti-sliding plates with their associated screws and washers (Connection fences/ground) (figure 4)
- Sand bags or gravel bags (figure 5)
- Cover (figure 6)

Figure 3: Connection frame between fences





Figure 4: Anti-sliding plates with their associated screws and washers

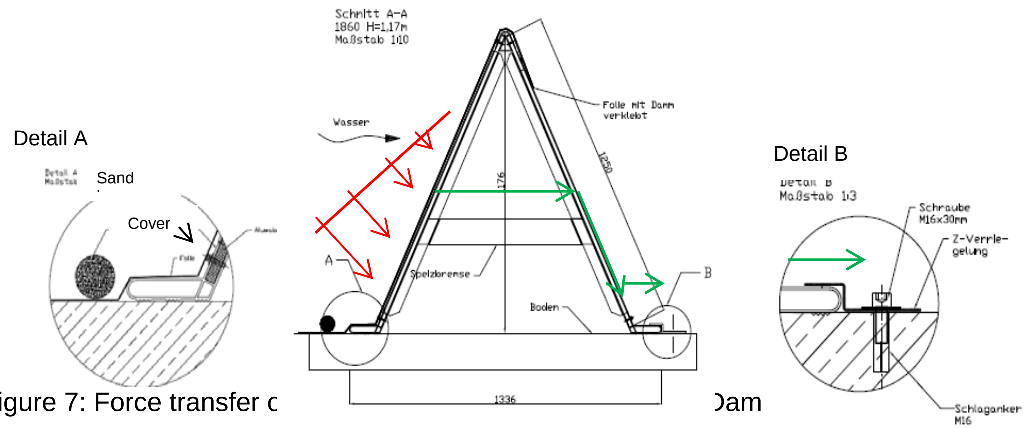
FigureFigure 6: Cover bags

Stability:

The stability is assured by the material resistance. The flood forces (example: hydrostatic forces as shown in figure 7) are transferred to the anti-sliding plate and the ground by the frames.

Sealing:

The sealing functionality is assured by the cover installed on the fences. This cover is fixed on the ground using sand or gravel bags and on the fence using tape.



Forces transferred
Hydrostatic forces

Figure 7: Force transfer c … Dam

Mounting:

The product requires the equipment (shown in figure 8) to be mounted. The mounting steps are:

- Frame fixation on the wall
- Installation of the frames and fences
- Fixation of the anti-sliding plates
- Setting up the cover on the fence

Fixation of the cover with sand bags and tapes

Figure 8: equipment required for mounting

Two types of fence were tested:

Hexagonal plastic comb panel "MonoPan PP80 TN[23]"
Heat-formed fence
Fence length: 2m
Fence Height: 1m / 1,3m / 1,5m [24]
special cut at the factory and possibly also on site

Hexagonal Aluminium comb panel „ALUCORE 15[1]" + Aluminium coating
Fence length: 2m
Fence height: 1m until 1,4m (Standard 1,17m; Weight ca. 55kg)
special cut at the factory

23 Material produced by the company WIHAG Composite
http://www.monopan.ca/docs/MonoPan.pdf
24 data provided by the manufacturers, available on the company website:
http://www.aquastop.de/produkte/katastrophenschutz-damm/

Functionalities expected by this product
Watertightness: It is expected that the product limits the water penetration Stability: It is expected that the product remain stable Readiness: It is expected that the product will be ready in time
What is the main sales argument of this product?
The main sales arguments of the system AQUA-STOP Damm are quoted in the company Website[25]: " • quick and easy handling • no foundation work • easy transportation and flexible • durable • rotproof and against vandalism • Stable • Easy to clean • Secure stability on all kind of hard ground • Secure against debris load "
Field of use and limitation
• For geotechnical reason, the product should not be used for expected water level higher than 0,6m (according to the BWK booklet[26]) if no ground analysis were previously done.

General Testing Description
Functionalities tested
Watertightness

[25] http://www.aquastop.de/produkte/katastrophenschutz-damm/

[26] Flood abatement Systems- Fundamentals for planning and Applications-December 2005

Stability Readiness
Performance criteria
The functionalities were qualitatively and quantitatively assessed. The quantitative analysis was based on the following performance criteria: Criterion watertightness: Leakage rate (l/h/m) Criterion stability: qualitative analysis (observation of product failure) coupled with quantitative analysis based on the deformation Criterion readiness: Qualitative analysis coupled with quantitative analysis based on the mounting time
List of conditions which have an effect on the performance
Watertightness: – Flood action (water pressure, waves, current, sedimentation) – Type of superficial underground (e.g. plain concrete, pavement, grassland) – Geotechnical characteristics – Installation of the cover – Wind Stability – Flood action (water pressure, waves, current, sedimentation) – Type of superficial underground (e.g. plain concrete, pavement, grassland) – Product wear – Geotechnical characteristics Readiness – Number of personnel – Location of storage place – Logistics
Testing conditions
Laboratory tests were conducted in the testing facility of the Technical University Hamburg-Harburg (TUHH) (Figure 9). The test facility is a basin made of watertight concrete, which has the dimensions 20 m long, 15 m wide and 2 m high. The ground of the testing facility is characterised by an even and smooth concrete ground. The testing facility is enclosed by even rectangular concrete walls with an opening of 3 m at the front side to enable easy transportation of the testing material into the basin. The opening can be closed by demountable aperture flood barriers made of aluminium. Furthermore, two water storage tanks are located in the testing facility, which are also enclosed at two sides by demountable flood barriers. For dynamic impact load tests, the right hand segment wall is

dismounted to have an acceleration area for debris load testing.

For load tests fresh water is pumped out of the storage tanks into the testing tank. The total leakage rate, i.e. leakage rate underneath the structure, between single elements of the structure, between structure and basin walls as well through the structure itself, can be measured by a dimensioned pump sump with a size of 50x50x50 cm³ (Figure 10).

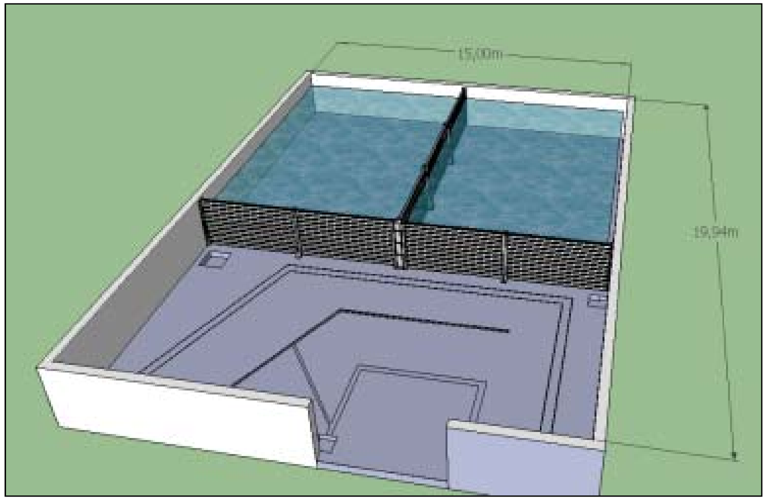


Figure 9: Testing facility of the TUHH in Hamburg-Wilhelmsburg[27]

Figure 10: Pump sump for leakage measurement[3 oben3]

Product configuration

Different product configurations have been tested.

First, a configuration according to the FM Approval[28] of the United States has been chosen recommending a minimum length of 18 m for the installed flood abatement system. Additionally, the FM Approval demands two corners, one with an angle of 90° and the other one with 60° . Both ends of the flood abatement system need to be connected to a permanent straight structure, e.g. a concrete wall.

This configuration was built with Alucore (height: 1,17m) and with Monopan (height: 1,31m) as shown in the figure 11.

A second configuration (see figure 12) only made of Alucore consisted on a U-shape with two 90° angles and two wall connections. The two middle fence (height: 1,00m) were smaller than the other fences (height: 1,17m).

[27] Gabalda, V.; Daemrich, K.F., 2011: Performance of the Daedler and Optimal Flood Abatement System. TU Hamburg-Harburg, Mai 2011

[28] Approval Standard for Flood Abatement Equipment, December 2006

Figure 11: Configuration 1

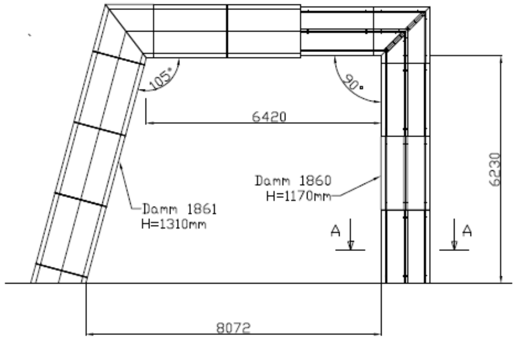
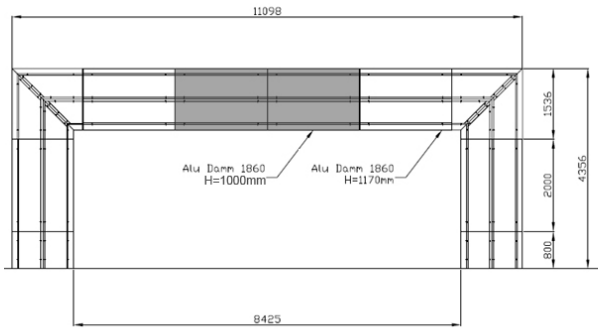


Figure 12: Configuration 2



Type of testing

Assessment of watertightness

- Hydrostatic load tests including leakage rate measurements for different system and/or product configurations as well as different water levels
- Hydrodynamic load / current load executed parallel to the barrier - Qualitative analysis
- Hydrodynamic load / current load perpendicular to the barrier at low water depth - Qualitative analysis
- Dynamic load impact / debris load tests with different debris weights, impact angles and at a fixed water level - Qualitative analysis

Stability Assessment

- Hydrostatic load tests including displacement measurements for different system and/or product configurations as well as different water levels
- Overtopping test up to 2,5 cm on two fences - Qualitative analysis
- Dynamic load impact / debris load tests with different debris weights, impact angles and a fixed water level - Qualitative analysis

Dynamic load tests have been carried out by a water level of approx. 70% of the system height and with two different debris weights of 225 kg and 400 kg and impact angles in the range of 75° to 90°.

Readiness Assessment

- Mounting and demounting of the system, partly including time measurement

Result assessment

Results of testing in term of performance

Configuration 1:

- Hydrostatic load tests including leakage rate measurements for different system and/or product configurations as well as different water levels

Result leakage see figure

Failure of the system due to a high deformation see figure 13 of the Monopan fences

Fig drostatic test

Configuration 2:

– Hydrostatic load tests including leakage rate measurements for different system and/or product configurations as well as different water levels
Result of leakage rate to see on figure 14. It was noticed that the sealing performance can be very different from one case to another. The leakage tests carried out for three different mounting, showed complete different results. Which prove that the product sealing is highly depending on the mounting.

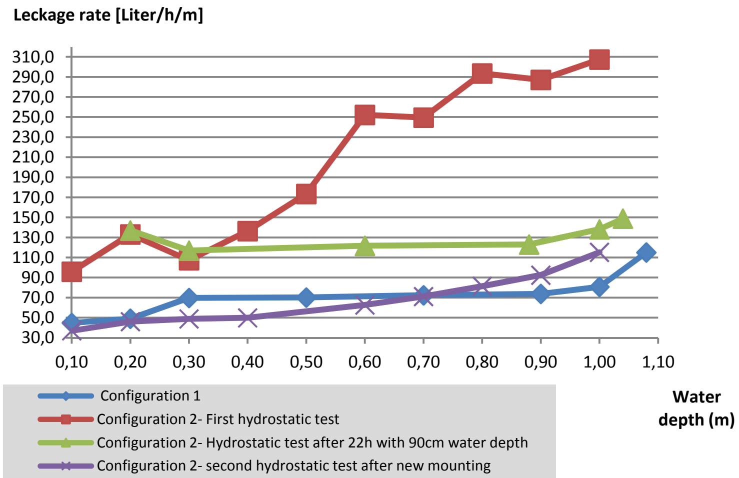


Figure 14: Leakage rate results

– Hydrodynamic load / current load executed parallel to the barrier - Qualitative analysis
No deformation nor leakage increase were observed
– Hydrodynamic load / current load perpendicular to the barrier at low water depth - Qualitative analysis
Displacement of the sand bags (see figure 15) and the cover which may cause some sealing lacks.

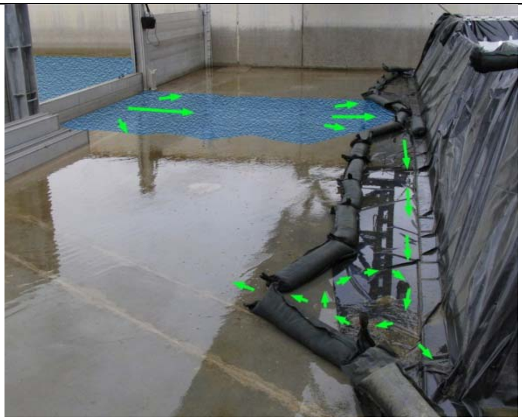


Figure 15: Product state after current load perpendicular to the barrier at low water depth

- Dynamic load impact / debris load tests with different debris weights, impact angles and at a fixed water level - Qualitative analysis
  Deformation of the fences and tear of the cover causing an increase of the leakage rate (from 300 L/h to 800L/h)
  At the impact area a stronger cover deliver by the company was place. No tear were observed on this cover,

- Overtopping test up to 2,5 cm on two fences - Qualitative analysis
  No unstability observed

Configuration 1 and 2:

- Mounting and dismounting of the system, partly including time measurement

Result based on mounting of a 9,8m long barrier with one wall connection and of 90° angle by two workers, with foundation already prepared.

- Mounting of the structure by two workers with foundation already prepared: 2h48min for 100 meters
- Mounting of the cover by two workers: 3h13min for 100 meters
- Total Mounting by two workers: 6h01min for 100 meters

Suggestion for improvement

- For the Monopan the fixation on the ground should be done on the dry and side
- For the mounting, a more explanative and easy reading mounting manual was suggested instead of the existing one
- For the fixation of the cover, sand bags on the barrier are more secure than tapes especially in case of windy weather
- In case of impact, a stronger cover is required

Appendix 2.6:

Summary of the FRe Technologies Testing – Aquafence V1200

General product description

Product description (type of product, stability characteristic, sealing characteristics, drawings, pictures, …)

Aquafence V1200[29]- Category: Demountable flood barrier. According to manufacturers can be used as temporary flood barrier on earthy ground. The following work studies the product as demountable flood barrier.

The Aquafence is classified as demountable flood barrier since it needs a preliminary preparation of the ground. The temporary part is a foldable module with almost all components integrated. Only the connecting element between brackets and foundation and the protection shield are separated. Two states are possible the folded state (see figure 1) for storage purpose and the unfolded state (see figure 2). The integrated components identified in figure 2 and their functions are the following:

1. The boards are the main flood fence. These parts are made of laminated plywood
2. Stabilizer Rods aim to keep the board folded.
3. Canvas is the membrane which aims to seal the joints between the modules. They are made of fiber reinforcing PVC
4. Vertical and horizontal clamps aim to press the canvas on the board for sealing purposes
5. Eccentric lock aim to fix the modules together
6. Fixing brackets aim to connect the boards to the foundation
7. Gasket aims to seal the joints between ground and the board. It is made of a foam plastic with sealed cells.

Stability:

The system take profit of the innate force of the flood water to stabilize it (see figure 3). However for low water depth the water pressure is not enough to press the bottom sealant and stabilize the module thence a foundation is required.

Sealing:

The sealing at the joints is assured by the bottom gasket and the canvas

[29] Information and drawings taken from company document: A4_1800 description Aquafence

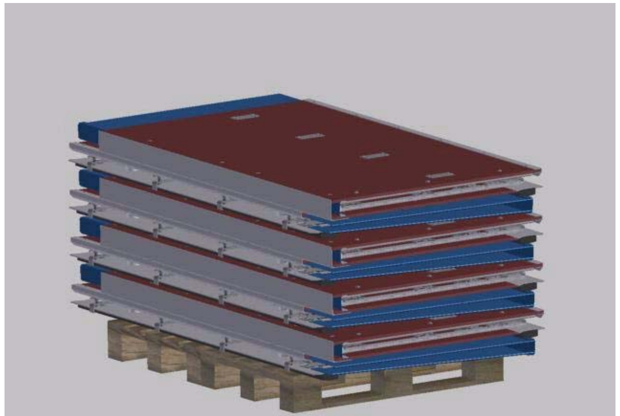


Figure 1: Four folded modules on a pallet

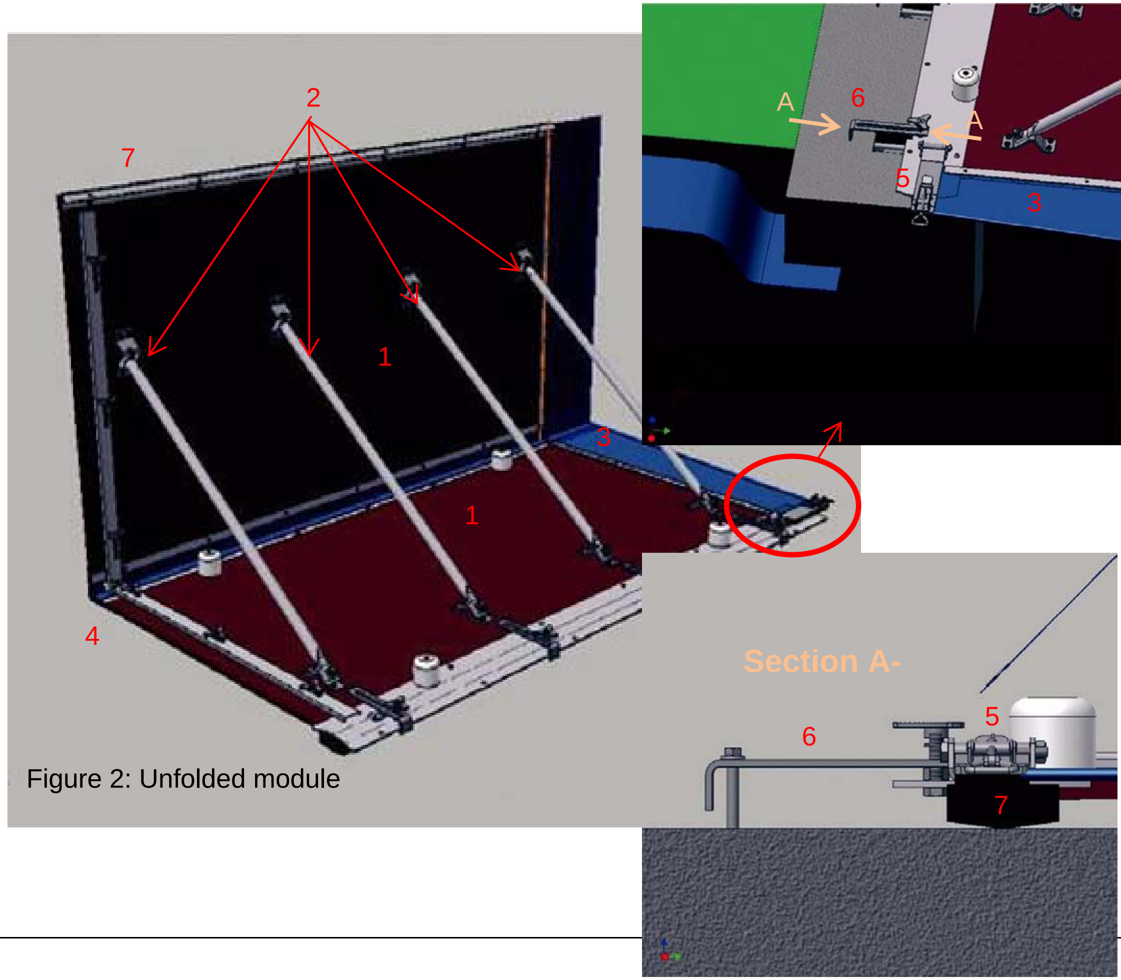


Figure 2: Unfolded module

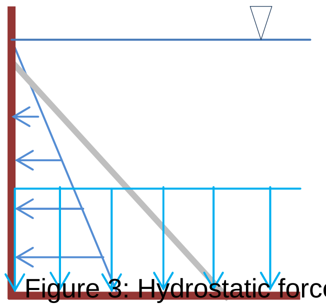


Figure 3: Hydrostatic forces distribution

Functionalities expected by this product
Watertightness: It is expected that the product limits the water penetration Stability: It is expected that the product remain stable

Readiness: It is expected that the product will be ready in time

What is the main sales argument of this product?

The main sales arguments of the system Aquafence are quoted in the company Website[30]:
"

- Low-lifetime Cost
- Non hazardous
- Fast deployment
- flexible "

Field of use and limitation

- For geotechnical reason, the product should not be used for expected water level higher than 0,6m (according to the BWK booklet[31]) if no ground analysis were previously done.

General Testing Description

Functionalities tested

Watertightness

Stability

Readiness

Performance criteria

The functionalities were qualitatively and quantitatively assessed. The quantitative analysis was based on the following performance criteria:
Criterion watertightness: Leakage rate (l/h/m)
Criterion stability: qualitative analysis (observation of product failure) coupled with quantitative analysis based on the deformation
Criterion readiness: Qualitative analysis coupled with quantitative analysis based on the mounting time

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[30] http://www.aquafence.com/benefits.html

[31] Flood abatement Systems- Fundamentals for planning and Applications-December 2005

List of conditions which have an effect on the performance
Watertightness: – Flood action (e.g. water pressure, waves, current, sedimentation) – Type of superficial underground (e.g. plain concrete, pavement, grassland) – Geotechnical characteristics Stability – Flood action (water pressure, waves, current, sedimentation) – Type of superficial underground (e.g. plain concrete, pavement, grassland) – Product wear – Geotechnical characteristics Readiness – Number of personnel – Location of storage place – Logistics
Testing conditions
Laboratory tests were conducted in the testing facility of the Technical University Hamburg-Harburg (TUHH) (Figure 9). The test facility is a basin made of watertight concrete, which has the dimensions 20 m long, 15 m wide and 2 m high. The ground of the testing facility is characterised by an even and smooth concrete ground. The testing facility is enclosed by even rectangular concrete walls with an opening of 3 m at the front side to enable easy transportation of the testing material into the basin. The opening can be closed by demountable aperture flood barriers made of aluminium. Furthermore, two water storage tanks are located in the testing facility, which are also enclosed at two sides by demountable flood barriers. For dynamic impact load tests, the right hand segment wall is dismounted to have an acceleration area for debris load testing. For load tests fresh water is pumped out of the storage tanks into the testing tank. The total leakage rate, i.e. leakage rate underneath the structure, between single elements of the structure, between structure and basin walls as well through the structure itself, can be measured by a dimensioned pump sump with a size of 50x50x50 cm^3 (Figure 10).

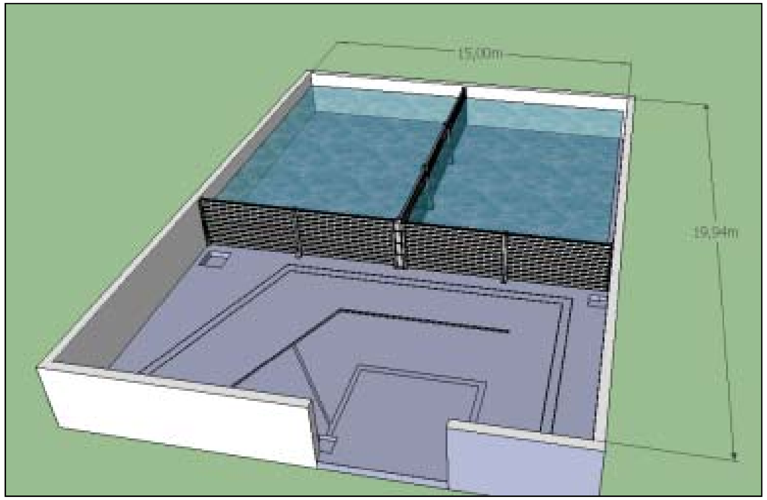


Figure 9: Testing facility of the TUHH in Hamburg-Wilhelmsburg[32]


Figure 10: Pump sump for leakage measurement[3 oben3]

Product configuration

The configuration according to the FM Approval[33] of the United States has been chosen recommending a minimum length of 18 m for the installed flood abatement system. Additionally, the FM Approval demands two corners, one with an angle of 90° and the other one with 60° . Both ends of the flood abatement system need to be connected to a permanent straight structure, e.g. a concrete wall. The type of module tested was 1,20 meter high.

At both ends the wall elements are connected to the concrete wall of the test basin via the adapters which have been mounted at the concrete wall with bolts. The remaining gaps between concrete wall and adapter have been filled with silicon sealing paste.

Type of testing

Assessment of watertightness

- Hydrostatic load tests including leakage rate measurements
- Hydrodynamic load / current load executed parallel (see Figure 4) and perpendicular (see Figure 5) to the barrier- Qualitative analysis
- Dynamic load impact / debris load tests (see Figure 6) with different debris weights, impact angles and a fixed water level - Qualitative analysis

Stability Assessment

[32] Gabalda, V.; Daemrich, K.F., 2011: Performance of the Daedler and Optimal Flood Abatement System. TU Hamburg-Harburg, Mai 2011

[33] Approval Standard for Flood Abatement Equipment, December 2006

– Hydrostatic load tests including displacement measurements for different water levels
– Dynamic load impact / debris load tests with different debris weights, impact angles and a fixed water level - Qualitative analysis

Dynamic load tests have been carried out by a water level of approx. 70% of the system height and with two different debris weights of 225 kg and 400 kg and impact angles of 70°.

Readiness Assessment

– Mounting and demounting of the system, partly including time measurement

Durability Assessment

– Wear Test/ 100 cycles of mounting and dismounting of the product with check of the movable parts every cycle

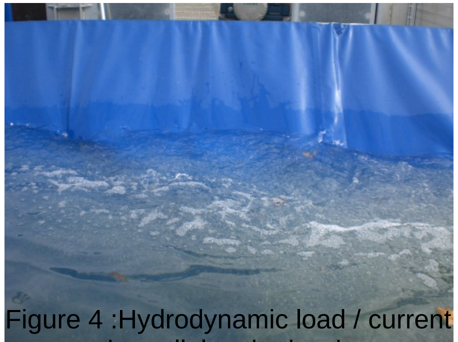


Figure 4 :Hydrodynamic load / current load executed parallel to the barriers

Figure 5 :Hydrodynamic load / current load executed perpendicular to the barriers

Figure 6 : Impact test

Result assessment

Results of testing in term of performance

<u>Load resistance:</u>

Hydrostatic:	Tested for maximum water depth 90 cm
Hydrodynamic:	Tested for maximum current of 2 m/s
Debris load:	Wooden log of 50x50 cm², 0,4 t weight with maximum approach velocity of 2,4 m/s
In all load tests:	No permanent deformation Elastic deformation less than 4 cm Leakage rate: < 65 l/h/m.

<u>Durability</u>

Minimum life cycle:	60 deployments for all Aluminium components, canvas and gaskets 100 cycles for the plywood wall

Deployment	
Deployment time:	With workforce of 4 people: 200 min/100 m of wall elements (average)

Suggestion for improvement

- Improvement of the documentation
- Extension of the horizontal clamp with an eccentric lock

Appendix 2.7:

Summary of the FRe Technologies Testing – IBS Mobile Wall System

General product description

Product description (type of product, stability characteristic, sealing characteristics, drawings, pictures, …)

IBS Mobile Wall System - Category: Demountable flood barriers / Dam Beams

The IBS Mobile Wall System is a demountable segment wall system consisting of an upright supporting system in between which aluminium beams are positioned. For watertightness of the system the beams are equipped with seals and a pressing tool is placed on the upper beam to guarantee sufficient pressure for sealing. Anchor plates made of stainless steel are permanently installed system elements in which the upright supporting posts are mounted.

Large construction heights of 4 m above ground level or more can be achieved in case of sufficient bearing capacity and watertightness of the underground. The latter can be achieved by the permanent installation of sheet pile walls. Furthermore, the system elements must be designed according to expected system height and consequent loading forces.

Corners and curve radiuses can be realized by the use of special corner and curve elements.

Functionalities expected by the product

Watertightness: It is expected that the product limits the water penetration

Stability: It is expected that the product remain stable

Readiness: It is expected that the product will be ready in time

What are the main sale arguments of this product?

Advantages of the IBS Mobile Wall System:

- Large product heights available
- Stable construction
- Low consumption of resources
- Short installation time
- Small number of personnel required

Field of use and limitation

Field of use of IBS Mobile Wall System:

- Planned use on a defined site with permanent elements for load transfer
- Substitution of permanent dikes and flood protection walls in urban areas with limited space and high demands concerning view and traffic connections
- In case of proper ground preparation system heights of up to 5 m are possible

General Testing Description

Functionalities tested

Watertightness

Stability

Readiness

Performance criteria

The functionalities were qualitatively and quantitatively assessed. The analysis was based on the following performance criteria:
Criterion watertightness: Leakage rate (l/h/m)
Criterion stability: Only a qualitative analysis was performed (observation of product failure)
Criterion readiness: Qualitative analysis coupled with quantitative analysis based on the mounting time

List of conditions effecting the performance

Watertightness:
- Flood action (water pressure, waves, current, sedimentation)
- Geotechnical characteristics

Stability
- Flood action (water pressure, waves, current, sedimentation)
- Geotechnical characteristics

Readiness
- Type of equipment used
- Number of personnel

– Location of storage place
– Logistics

Testing conditions

Laboratory tests were conducted in the testing facility of the Technical University Hamburg-Harburg (TUHH) (Fig. 3). The test facility is a basin made of watertight concrete, which has the dimensions 20 m long, 15 m wide and 2 m high. The ground of the testing facility is characterised by an even and smooth concrete ground. The testing facility is enclosed by even rectangular concrete walls with an opening of 3 m at the front side to enable easy transportation of the testing material into the basin. The opening can be closed by demountable aperture flood barriers made of aluminium. Furthermore, two water storage tanks are located in the testing facility, which are also enclosed at two sides by demountable flood barriers. For dynamic impact load tests, the right hand segment wall is dismounted to have an acceleration area for flotsam load testing.

For load tests fresh water is pumped out of the storage tanks into the testing tank. The total leakage rate, i.e. leakage rate underneath the structure, between single elements of the structure, between structure and basin walls as well through the structure itself, can be measured by a dimensioned pump sump with a size of 50x50x50 cm³ (Fig. 4).

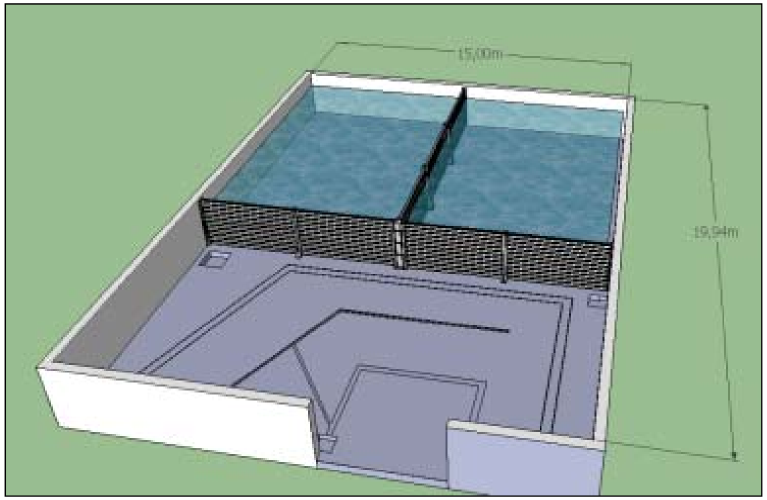
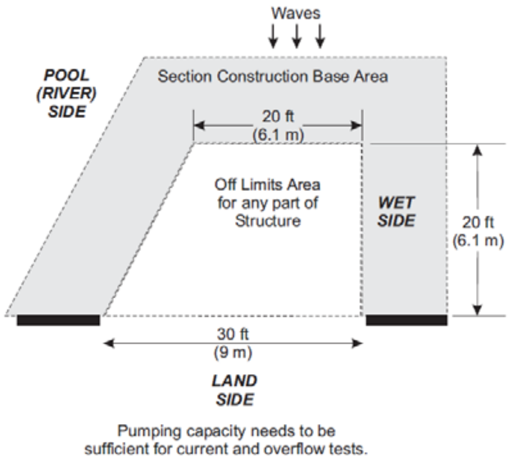


Fig. 3: Testing facility of the TUHH in Hamburg-Wilhelmsburg[34]

Fig. 4: Pump sump for leakage measurement[3 oben3]

[34] Gabalda, V.; Daemrich, K.F., 2011: Performance of the Daedler and Optimal Flood Abatement System. TU Hamburg-Harburg, Mai 2011

Product configuration
A product configuration according to the FM Approval[35] of the United States has been tested recommending a minimum length of 18 m for the installed flood abatement system. Additionally, the FM Approval demands two corners, one with an angle of 90° and the other one with 60° (Fig. 5). Both ends of the flood abatement system need to be connected to a permanent straight structure, e.g. a concrete wall. In this arrangement, the flood abatement system behaves as a free-standing system. The length of the system and the curves and corners are a good basis for assessing the stability, the water tightness (permeability) and the flexibility of the system.  Fig. 5: Product configuration according to the FM Approval in the testing facility of the TUHH in Hamburg-Wilhelmsburg
Type of testing
Readiness Assessment – Mounting and demounting of the system, partly including time measurement

[35] FM-Approval: Approval Standard for Flood Abatement Equipment, Class Number 2510, December 2006, FM Global

Assessment of watertightness

– Hydrostatic load tests including leakage rate measurements for different water levels. The highest water level was 0.95 m above ground and corresponds to the manufacturers highest loading water level for a system height of 0,95 m.

Stability Assessment

– Hydrostatic load tests including displacement observations for different water levels
– Dynamic impact load test with current load parallel and perpendicular to the barrier axis with a water level of 0.95 m and current velocities up to 2.0 m/s
– Dynamic load impact / flotsam load tests with different flotsam weights of 200 kg and 400 kg, impact angle of approx. 90°, a water level of 0.95 m and impact velocities in the range of 1.2 to 3.3 m/s.

Durability test

– The durability of the single elements have been tested by mounting and demounting of the mobile wall system 100 times

Result assessment

Results of testing in term of performance

The tests have been used for the assessment of product characteristics.

The mounting time of a 3 m wide and 0,95 m high field of the IBS Mobile Wall System including the mounting of 1 supporting post was 7.5 minutes for two people. The other required supporting post was permanently installed. The demounting time of the field was 7 minutes for two people.

The executed static load tests showed that the IBS system is able to withstand water levels of 0.95 m without any displacements or damages.

Depending on the water level behind the barrier different leakage rates have been measured:

– Up to a water level of 0.30 m above ground no leakage occurred
– Leakage started with a water level of 0.40 m above ground
– Water level 0.95 m above ground, leakage rate of approx. 192 l/h or approx. 10 l/(m*h)
– Water level 0.95 m above ground, leakage rate of approx. 128 l/h or approx. 7 l/(m*h) after a deployment time of 23 hours

The leakages occurred mainly at the connections between beam and supporting post (Fig. 2).

The executed dynamic load tests showed a good behaviour of the structure. No damages occurred at the system during parallel and vertical current load tests (Fig. 3 and Fig. 4). Also no permanent but only elastic displacement occurred during flotsam load tests (Fig. 5 and Fig. 6).

Fig. 2: Leakage at the supporting post[36]

Fig. 3: Dynamic load tests – parallel current load[36]

Fig. 4: Vertical current load[36]

Fig. 5: Flotsam at the guidance rope[36]

Fig. 6: Impact of flotsam at the IBS Mobile Wall System[36]

Results of the durability test

[36] Pasche, E., 2010: Testbericht für das IBS Hochwasserschutzsystem. Client: IBS – Industriebarrieren und Brandschutztechnik Thierhaupten. Technische Universität Hamburg-Harburg, March 2010.

The following seals damages (at the bottom and at the beam) were caused by an improper mounting. In fact the beams should be inserted without contact to the already installed beams. The last few centimeters to press the beams down has to be done in a horizontal position. During the test the beams were inserted but cut in one end in the seal of the already installed beam causing deformation und damage to the seal.

- The seals at the beams start to loose from the beam after 10 repetitions. Until the end of the test (100 repetitions) the seal started to stuck between beam and post seal (Fig. 7)
- The required force for the lifting of beams during dismantling increased with increasing number of repetition due to jammed seals
- After 20 repetitions all seals at the beams have been stretched (Fig. 8)
- The ground seal was cracked at the end of the durability testing (Fig. 9)
- After each 10 cycles the system was flooded. No changes of the leakage rate was observed even after 100 repetitions

Fig. 7: Loose seals at the end of the destructive testing[36]

Fig. 8: Stretched seals after 15 repetitions[36]

Fig. 9: Cracked ground seal at the end of the destructive testing[36]

Suggestion for improvement

- The beams should first be inserted without contact to the already installed beams and second be pressed together in a horizontal position.
- To avoid jamming of the seals, the company advises to use a lubricant.

Appendix 2.8:

Summary of the FRe Technologies Testing –Spring Dam System

General System description

System description (type of System, stability characteristic, sealing characteristics, drawings, pictures, …)

Spring Dam System - Category: Pre-installed flood barrier- Manually Folding Stand-by

The Spring Dam is a pre-installed perimeter flood barrier characterized by a passive state (see figure 1) and an active state (see figure 2).

Figure 1: Spring Dam at the passive state

Figure 2: Spring Dam at the active state

Between flood warnings the flood protection system is in its passive state. The barrier is installed the ground level and does not disturb the environment functionally or aesthetically.

The stability of the system is ensured by props, which transfer the forces acting on the barrier to the frame and consequently to the ground (see figure 3). Each unit is has two demountable props.

The watertightness is ensured at the horizontal junction between the frame and the barrier by a permanent Ethylene-Propylene-Diene-Monomer (EPDM) seal, which is glued onto the frame. In its active state the barrier transfers load to the seal leading to an increase in watertightness of the system. At the barriers and wall/barriers junction, a demountable seal is inserted vertically. Four bolts with wingnuts compress the seal on the barrier ensuring the watertightness at these junctions.

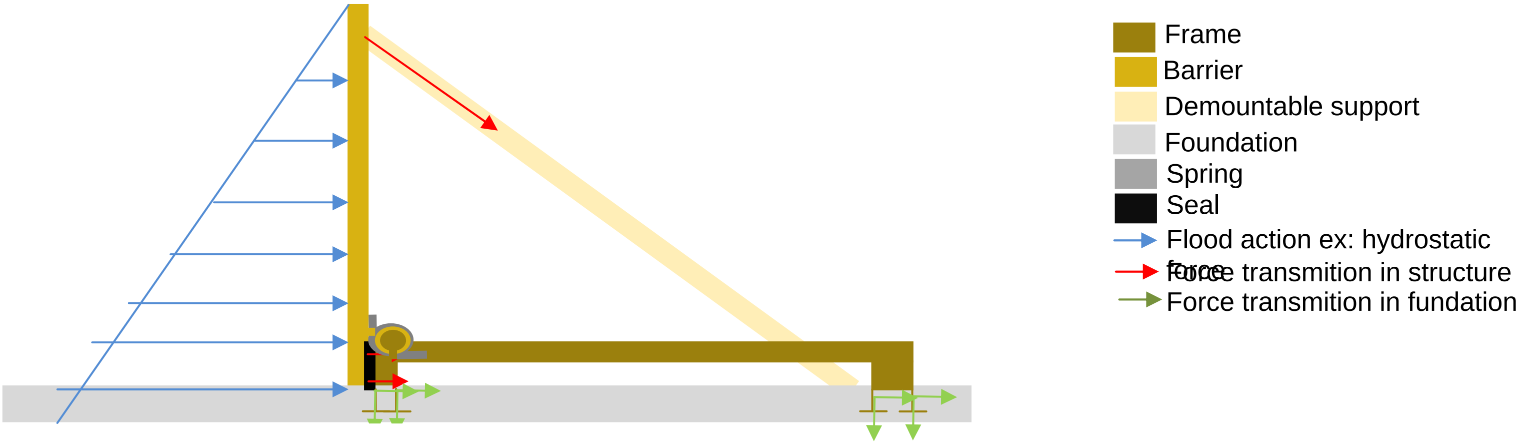


Figure 1: Force transmission principle

The opening mechanism is a flap system. As the weight of the used steel material is important, springs at the rotation axis enable an easier mobilisation process by hand. The spring effect can be adjusted thanks to a mechanism which varies the energy transmitted by the spring.

Functionalities expected by this product

Watertightness: It is expected that the product stops the water penetration

Stability: It is expected that the product remains stable

Readiness: It is expected that the product will be ready in time

What is the main sales argument of this product?

The main sales argument of the Spring Dam system is associated to the readiness functionality:

- Easy to mobilise
- Short mobilisation
- No logistic issues (no offsite storage, not labour intensive, no transportation risks, no damage risks in handling)

Spring Dam stresses the adaptability of the product to its environment at its passive as well as active state.

Field of use and limitation

The Spring Dam is an engineering solution. It can be designed for different type conditions but should theoretically and physically prove its functionalities.
It can be built up to a height of 2,50m. However, a geotechnical analysis is required to investigate the ground stability for a Designated Maximum Water Depth

exceeding 0,6m.

General Testing Description

Functionalities tested

Watertightness

Stability

Readiness

Performance criteria

The functionalities were qualitatively and quantitatively assessed. The quantitative analysis was based on the following performance criteria:
Criterion watertightness: Leakage rate (L/h/m)
Criterion stability: Mainly qualitative analysis was performed (observation of product defect/damage or failure) coupled with quantitative analysis based on deformation/displacement measurements
Criterion readiness: Qualitative analysis coupled with quantitative analysis based on the mobilisation time

List of conditions which have an effect on the performance

Watertightness:

- Flood action (i.e. water pressure, waves, current, sedimentation)
- Product Wear
- Environment (i.e. salt, chemical reaction)
- Geotechnical characteristics

Stability

- Flood action (i.e. water pressure, waves, current, sedimentation)
- Product Wear
- Geotechnical characteristics
- Environment (i.e. salt, chemical reaction, …)

Readiness

- Number of personnel
- Logistics
- Environment

Testing conditions

Laboratory tests were conducted in the testing facility of the Technical University Hamburg-Harburg (TUHH) (Figure 4). The test facility is a basin made of watertight concrete, which has the dimensions 20 m long, 15 m wide and 2 m high. The base of the testing facility is characterised by an even and smooth concrete ground. The testing facility is enclosed by rectangular concrete walls with an opening of 3 m at the front side to enable easy transportation of the testing material into the basin. The opening can be closed by demountable aperture flood barriers made of aluminium. Furthermore, two water storage tanks are located in the testing facility, which are also enclosed at two sides by demountable flood barriers. For dynamic impact load tests, the right hand segment wall is dismounted to have an acceleration area for debris load testing.

For load tests fresh water is pumped out of the storage tanks into the testing tank.

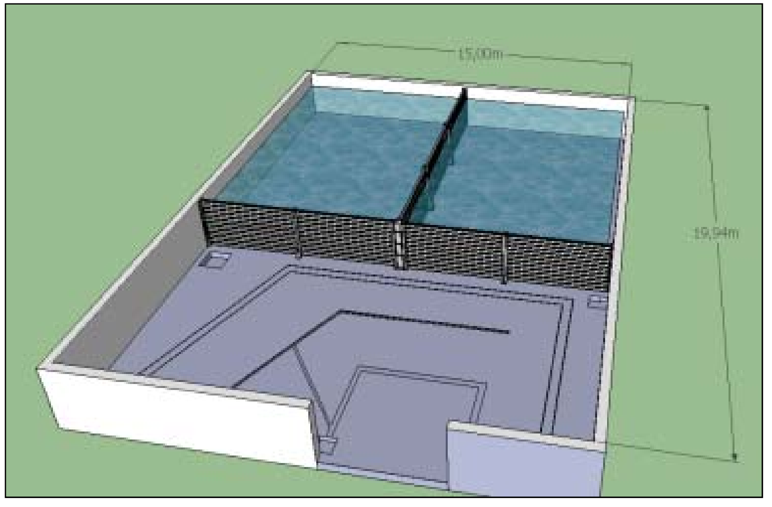


Figure 4: Testing facility of the TUHH in Hamburg-Wilhelmsburg

Product configuration

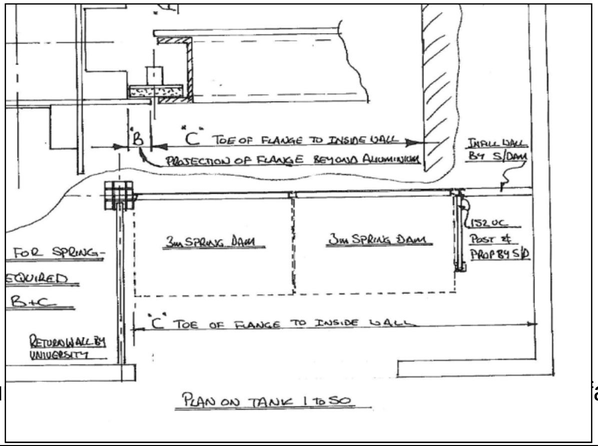
The product configuration adopted was planned to be representative of the system. It contains all the characteristic joints and elements of Spring Dam.

It was decided to test two Spring Dam barriers with a total of two wall/barrier connections and one intermediate joint (see figure 5). Each flood barrier is 3 m wide and 1,80 m high. However the height of the product is not corresponding to the Designated Maximum Water Depth (DMWD). Indeed, two aspects have to be taken into account:

- The product is normally stored in a 0.20 m deep compartment in the ground. The reference being the ground level, the DMWD will result in a height of 1,80-0,20= 1,60m.
- One of the vertical seal components was 1,60m high, i.e. 20 cm shorter than the other. Consequently the DMWD was only 1,60m-0,20m=1,40m.

The barriers were connected at one side with another demountable system closing the measurement area at that side (see figure 6). The other side was adjacent to an inner wall (wall between the basin wall and the Spring Dam shown in figure 5).

It was not possible to recess the system into the concrete floor of the test basin. The product was consequently installed on the concrete surface (see figure 6).



Figu facility

Figure 6: Spring Dam configuration

Type of testing

Assessment of watertightness

– Hydrostatic load tests including leakage rate measurements for different water levels until the Designated Maximum Water Depth (DMWD) of 1,40m.
– Hydrodynamic load / current load executed parallel to the barrier or perpendicular to the barrier at the proximity of the “critical” points of the system and at a fixed water level - Qualitative analysis
– Dynamic load impact / debris load tests with different debris weights, impact angles and at a fixed water level - Qualitative analysis

Stability A

Figure 2: Plan of product configuration in test facility

– Hydrostatic load tests including displacement measurements for different water levels until the Designated Maximum Water Depth (DMWD) of 1,40m - Qualitative and quantitative analysis
– Hydrodynamic load / current load executed parallel to the barrier or perpendicular to the barrier at the proximity of the “critical” points of the system and at a fixed water level - Qualitative analysis
– Dynamic load impact / debris load tests with different debris weights, impact angles and at a fixed water level - Qualitative analysis

Dynamic load tests have been carried out at a water level of approx. 80% of the system height and with two different debris weights of 200 kg and 400 kg and impact angles in the range of 70° to 90°.

Readiness Assessment

– Mounting and demounting of the system, including time measurement

Durability Assessment

– Wear Test/ 100 cycles of mounting and demounting of the system with a check of the movable parts every cycle and a check of the sealing functionality every 20 cycles

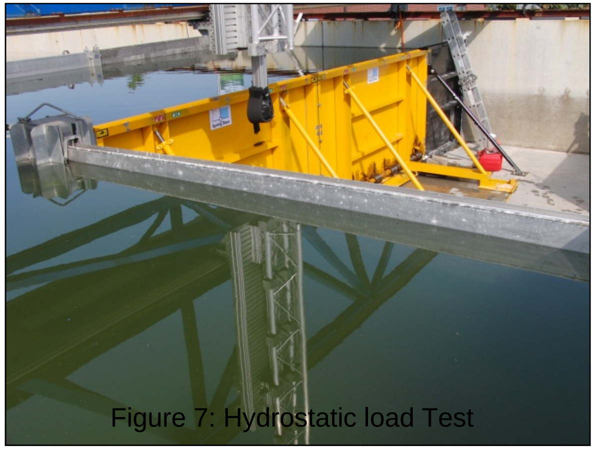


Figure 7: Hydrostatic load Test

Figure 8: Parallel current Test

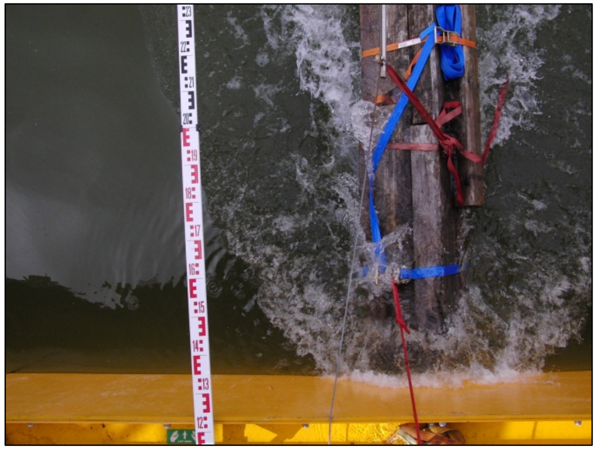


Figure 9: Debris impact test

Result assessment

Results of testing in terms of performance

Regarding the stability, the Spring Dam withstood the loads applied during the tests without instability, damages or defects, which is critical for the good functionality of the barrier.

Regarding the waterproofing no leakage was found with the Spring Dam system but a small leak did occur at the connection (about 11L/h for 1,60m water depth) with the test tank temporary wall nearby.

Regarding the mobilisation test, the system was easy to mobilise but the two test dam units had inadvertently been supplied without their vertical adjusters which resulted in the dam head over travelling when in the raised position. As a result of this some difficulty was experienced aligning the fixed wall to Spring Dam seals at each end. We have been assured by Spring Dam that this will not occur again.

Whilst the wear tests presented mainly a robust technology, the vertical seals were, due to the lack of the verticality adjusters mentioned in the last paragraph, exposed to a misalignment that caused damage that should not have occurred if the mating channels had been in their designed position. Given that this element is essential to the waterproofing functionality the correct adjustment of the dams to the vertical is very important. The adjusters should correct this issue.

Suggestion for improvement

1. Combine the oversized washer with the vertical seal tightening wing nut so that the items work as one.

2. Ensure the vertical dam adjustment is provided to all subsequent installations.

Appendix 3 – Summary of testing of Flood Aperture barriers

Appendix 3.1
Summary of the FRe Technologies Testing of the Aquastop flood aperture barriers(<10 pages)

General product description
Product description (type of product, stability characteristic, sealing characteristics, drawings, pictures, …)
Aqua-Stop: Pre-installed - Automatically operated flood barriers The automatically operated flood barriers manufactured by the company Aqua-Stop consist of three elements respectively for doors, windows and basement windows (Fig. 1), which are installed directly at the openings and are activated by a central control mechanism. As the water reaches the designed level, the barriers close (Fig. 2).

Fig. 1: Door, window and basement window barriers

Fig. 2: The barriers are closed

The three elements work in different ways. The barrier for the basement windows consists of a window made of an acrylic sheet (Perspex). It is closed by a rolling mechanism which pulls the window from its upper side. The barrier for the window consists of a rolling shutter which rolls down while the door element consists of a wooden plate which is lifted upward. Door and window barriers are equipped with a rubber tube placed between the barrier and the frame. Once the barrier is closed, the tube is inflated by an air compressor to press the elements against the gaskets to produce the sealing effect.

Functionalities expected by this product

Water tightness: It is expected that the product limits the water penetration

Stability: It is expected that the product does not suffer any damage caused by hydraulic pressure

Readiness: It is expected that the product will be ready in time

What are the main sale arguments of the product?

The main sale arguments of the system Aqua-Stop are associated with the readiness functionality:

- The elements are already installed
- Automatically operated system, no need of manpower
- Reduction of logistic (no offsite storage, not labour intensive, no transportation risks, no damage risks in handling)

Field of use and limitation

The main field of installation of the automatically operated flood barriers for doors, windows and basement windows are new constructions as the system

installation has to be taking into account already in the planning stage of the building.
Before installing the system in existing building some stability analysis should be carried out to prove the capacity of the walls and of the ground to withstand high water levels.
Thanks to its automatic nature, the system is recommendable in those situations where a building is not always under supervision.
The system is designed to absorb only hydraulic loads thus its application is not recommended when floating objects are expected.
The system works with electric power; it should therefore not be used in case of possible power breakdowns.

General Testing Description

Functionalities tested

Water tightness

Stability

Readiness

Performance criteria

The functionalities were qualitatively and quantitatively assessed. The quantitative analysis was based on the following performance criteria:
Criterion water tightness: Leakage rate (L/h)
Criterion stability: Mainly qualitative analysis was performed (observation of product defect/damage or failure) coupled with quantitative analysis based on deformation/displacement measurements
Criterion readiness: Qualitative analysis based on the time needed to close the barriers

List of conditions which have an effect on the performance

Water tightness:
- Flood action (i.e. water pressure, waves, current, sediments)
- Product Wear
- Climate (ice)

Stability
- Flood action (i.e. water pressure, waves, current, sedimentation)
- Product Wear
- Climate (ice)

Readiness
- Maintenance

Test facility description

Laboratory tests were conducted at the climate change research centre (KLIFF) of the Technical University Hamburg-Harburg (TUHH) (Fig. 3). The test facility includes a water basin made of watertight concrete, which has the dimensions of 20 m long, 15 m wide and 2 m high. The testing facility is characterized by a flat and smooth concrete ground and is enclosed by rectangular concrete walls with an opening of 3 m at the front side to enable easy transportation of the testing material into the basin. The opening can be closed by a demountable flood barrier made of aluminium. The half of the basin opposite to the opening is enclosed by demountable flood barriers to form two storage tanks. For hydraulic tests the water is pumped out of the storage tanks into the testing area. For measuring the leakage rate, three aluminium plates were used to collect the water seeping through the openings (Fig. 4).

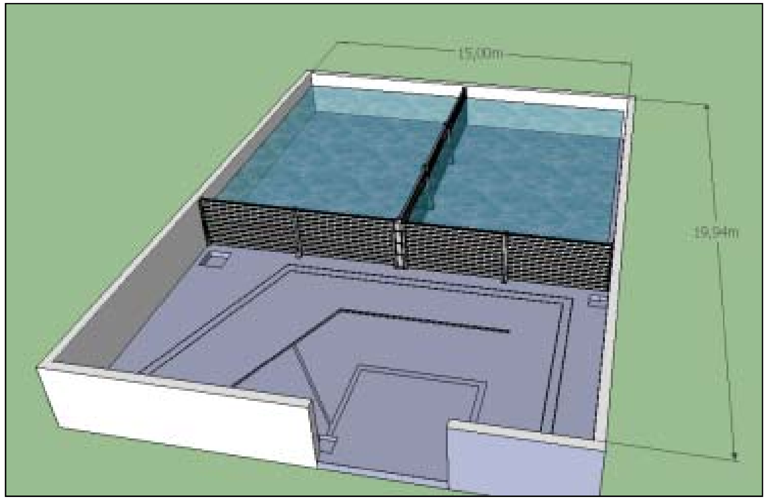


Fig. 3: Testing facility of the TUHH in Hamburg-Wilhelmsburg

Fig. 4: Aluminium plates to measure the leakage

Product configuration

For the purpose of the test a ready-mixed concrete wall (see Fig.6) with three openings respectively for door, window and basement window was installed between two aluminum pillars inside the water basin. The three elements were then installed at the wall (Fig. 6). At the side of the frame, which is placed at the wall, runs a gasket which ensures water tightness at the interface. Prior to the installation, silicon was spread over this gasket (Fig. 7).

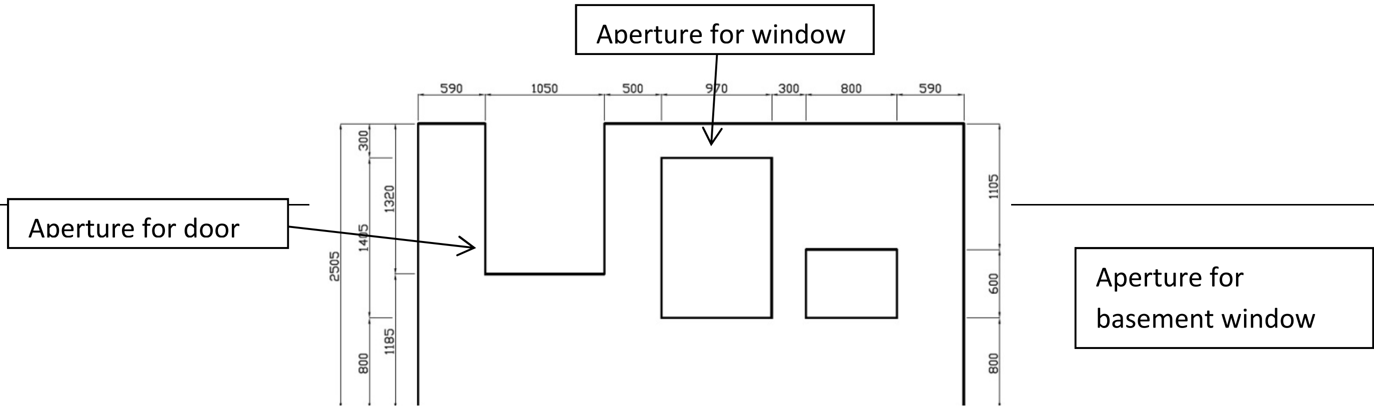


Fig. 6: House wall


Fig. 6: Installation of the barriers


Fig. 7: Silicon spread over the gasket

Type of testing

Assessment of water tightness and stability

– Hydrostatic load test including leakage rate and displacement measurements for different water levels

Readiness Assessment

– Closing of the barriers

Result assessment

Results of testing in term of performance

The hydrostatic load test was carried out at eight different water levels up to the height of 80 cm above the lower edge of the basement window. The lower edge of the window and the door are 15 cm and 40 cm above the one of the basement window respectively. Hardly any deformation of the system could be detected during the testing. The basement window showed an irregular behavior i.e. the higher the water level the lower the leakage up to the upper edge. From this point on a sudden increase was recorded. This was caused by an incorrect functioning of the barrier, which was not completely closed (see Fig. 7 and Fig. 8).

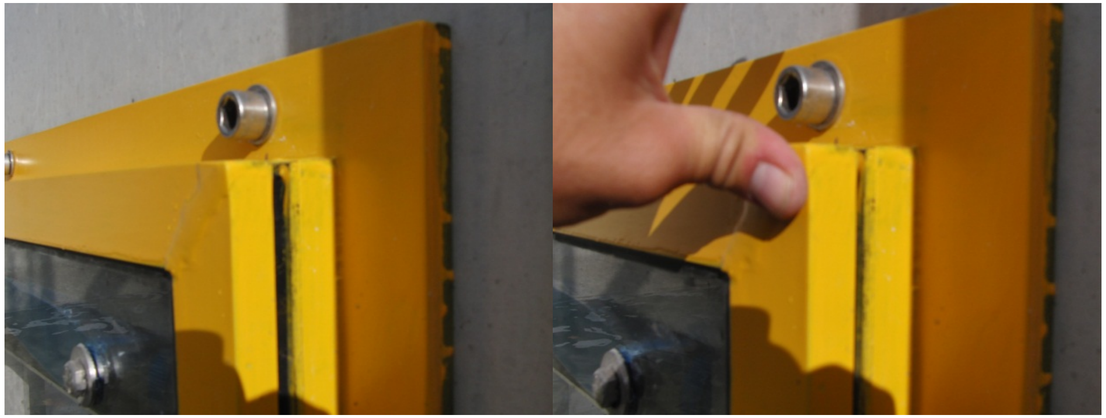


Fig. 7 (left) and Fig. 8 (right): The barrier for the basement window does not close properly

The leakage rate of the window barrier showed a linear behavior. With a water level of 65cm above the lower edge, the leakage rate was 3 l/h. Due to the test configuration, the door barrier was tested up to a water level of 40 cm. No leakage was detected apart from some droplets.

Suggestion for improvement

The two major problems observed during the tests were the closing mechanism of the basement window and the inflating mechanism for the tubes of the window and door barriers.

- For the first problem a possible solution could be to create two tracks within the roll to allow the pulling bands to be always in the right position. In fact, these bands were somehow displaced after rolling up and down several times. This led to a play at the upper part of the barrier.
- The second problem regards the whole inflating system. It is not automated and once the tubes are inflated, the pressure within them does not remain constant due to air losses in the connections. To keep the air pressure constant a person has to supervise the inflating system, in this case a regular air compressor. This means that, at this point of the development the system has a good potential in terms of water tightness but still need some improvements in the automation. The tubes need better connections and the air compressor should be automatically operated and ensure constant pressure inside the tubes.

Input for WP4

Since these products are in development, the performances measured could be improved. Consequently these results are not representative of the product performances.

Input for Objective 2.3

The executed tests demonstrate that:

- The standardization of the testing is not possible because of the diversity of the products. The application of the standard aperture would not be adapted for all products.
- The unity of the leakage rate measurement s is here in L/h. However it would be more representative to bring this in L/h/m.

Appendix 3.2

Summary of the FRe Technologies Testing
Flood barriers Collad'eau

General product description

Product description (type of product, stability, sealing, drawings, pictures, …)

"Collad'eau" – Category : Building aperture technology

The water-tightness of "Collad'eau" is ensured by an inflatable tube located between the rim of the barrier and the wall. The tube is protected by a butyl rubber envelope (cf. fig. 1). The dimensions of the panels are as follows: width between 0,73 to 1,03 m; height 0,976m and thickness 21 mm. Adjacent elements are placed to fill the building opening. Elements with customised dimensions can be made. The water tightness depends on the air pressure in the inflatable tube (typically 2.5 - 3 bars), controlled with a manometer. For the protection of openings wider than 1 meter, metallic reinforcements are added to ensure the stability of the system (cf. fig. 2).

Figure 1 : Flood barrier Collad'eau

Figure 2 : Hydrostatic test on flood barrier Collad'eau (width 3m)

At the bottom of panels, elements are blocked either with punctual or linear metallic angle brackets. On the top of panels, links between panel/support and between panels are assured by sliding bolts and fastening devices.

Figure 3 : Flood barrier Collad'eau-
Low fastening devices

Figure 4 : Flood barrier Collad'eau -
Top fastening devices

Figure 5 : Flood barrier Collad'eau -
Sliding bolts

Expected functionalities of this product

Water tightness: It is expected that the product limits the water penetration
Stability: It is expected that the product remains stable
Readiness: It is expected that the product to be ready on time

What is the main sales argument for this product?

The main sales argument of the "Collad'eau" barrier are :

- Easy to install
- Light and small size of elements
- Adaptable to minor defects of the opening surface (orthogonality, flatness)

Field of use and limitation

Mainly individual houses and more generally other types of buildings.
Products are sold either individually or with civil engineering to ensure a good adaptation to the structure.
The maximum water height is 90 cm.

General Testing Description

Functionalities tested

- Water tightness
- Stability
- Deployment/implementation

Performance criteria

The functionalities were qualitatively and quantitatively assessed. The quantitative analysis was based on the following performance criteria:

- water tightness: leakage rate (Litre/hour/meter of barrier width: L/h/m) before and after impact test
- stability: qualitative analysis (visual observations) coupled with quantitative analysis based on elements displacement measurements
- readiness: measurement of mounting time

List of conditions which have an effect on the performance

Water tightness:

- Flood action (i.e. water pressure, current)
- Impacts resistance
- Nature of the support (concrete, steel)
- Openings dimensions
- Peripheral fastening (linear / punctual…)

Stability:

- Flood action (i.e. water pressure, current)
- Impacts resistance
- Openings dimensions
- Peripheral fastening (linear / punctual…)

Readiness:

- Required manpower

Testing conditions

Tests have been performed at the Centre Scientifique et Technique du Bâtiment (CSTB).
The test rig for water tightness and shocks assessment consists of a support representing an opening (door, French window, garage door). Two opposite barriers can be mounted simultaneously (Figure 6). This support consists of a horizontal foundation beam and two vertical columns. The surface of columns can be concrete (form removal aspect) or steel.

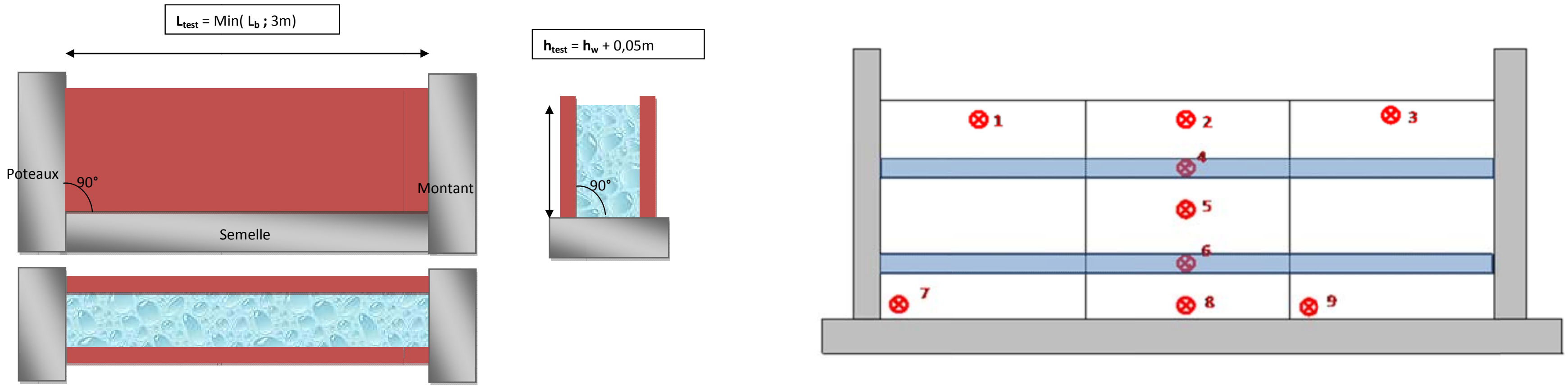


Figure 6 : Water tightness test rig and positioning of deflection measurements points

The **water load** is the sum of the static water height hw and of the static equivalent of the dynamic pressure resulting from a of 1m/s water flow: h_{test} = hw + 5 cm.
Water leakage is measured over a 24 hour period. During this period, displacements at the head and at the foot of the tested panel are recorded. The water height remains constant and the leakage water flow is estimated. The 600 J shock simulates the impact of a craft hitting the flood barrier during docking.

The **bending test,** under a monotonous increasing load, is carried out up to the rupture of the model. (Figure 7)

Figure 7 : Bending test rig

Product configurations
Four configurations of the "Collad'eau" barrier were assessed.

Configuration n° 1 : punctual peripheral locking in 2 points, locking on columns and knee brace on columns

This flood-barrier configuration is as follows:

- 3 panels with dimensions L x H x e : 1036 x 976 x 21 mm with sliding bolts;
- 2 intermediate columns, in steel (thickness 3 mm) of section 40x40mm and 1100mm high, each including reinforcement (knee brace) and two fastening devices (**settling by locking** on the top).
- Corners, in PVC of dimensions 35x35x30mm, used to ensured water tightness, are settling with silicone at the base of the support and intended to avoid risks of leakage at the angles partly low of the panel

Figure 8 : configuration n°1

Configuration n° 2 : uninterrupted peripheral locking, clamping on columns and horizontal reinforcement

This flood-barrier configuration is as follows:

- 3 panels with dimensions L x H x e : 1036 x 976 x 21 mm with sliding bolts;
- 2 intermediate column, in stell (thickness 4 mm) of section 40x40mm and of height 1140mm, each including two fastening devices (**settling by clamping** on the top) Every post is situated in its support by blockage quarter turn ;
- Corners, in PVC of dimensions 35x35x20mm, used to ensured water tightness, are settling with silicone at the base of the support and intended to avoid risks of leakage at the angles partly low of the panel ;
- 3 Metallic angle setting on the concrete/masonries support and on the vertical column intended to avoid any displacement of panels during their functioning ;
- 2 horizontal reinforcements positioning in front of the vertical column as high as 45 and 85 cm. Support of both horizontal reinforcements is performed by two supports sealed in column.

Figure 9 : configuration n°2

Configuration n° 3 : punctual peripheral locking, clamping on columns and horizontal reinforcement

This flood-barrier configuration is as follows:

- 3 panels with dimensions L x H x e : 1036 x 976 x 21 mm with sliding bolts;
- 2 intermediate column, in steel (thickness 4 mm) of section 40x40mm and of height 1140mm, each including two fastening devices (**settling by clamping** on the top) Every post is situated in its support by quarter turn locking;
- Corners, in PVC of dimensions 35x35x20mm, used to ensured water tightness, are settling with silicone at the base of the support and intended to avoid risks of leakage at the angles partly low of the panel ;
- **7 Metallic elements (stopping window)** among which 3 settle on the concrete support in the middle of the panel and on the vertical posts (2 on each height) intended to avoid any displacement of panels during their functioning.
- 2 horizontal reinforcements positioning in front of the vertical column as high as 45 and 85 cm. Support of both horizontal reinforcement is performed by two supports sealed on column.

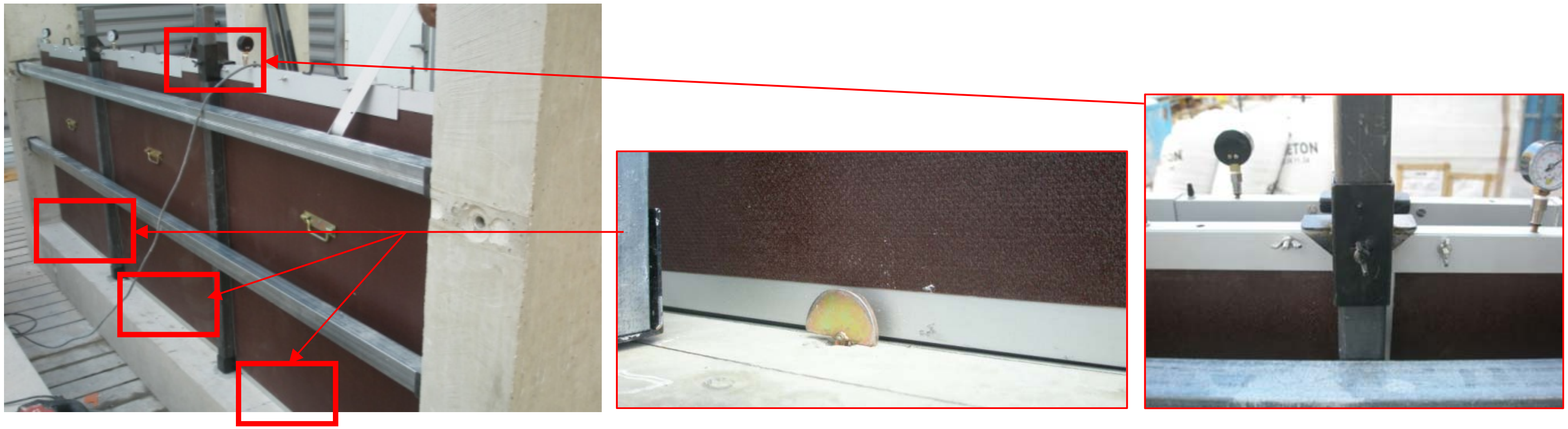


Figure 10 : configuration n°3

<u>Configuration n° 4 :</u> uninterrupted peripheral locking, locking on columns and horizontal reinforcement

This flood-barrier configuration is as follows:

- 3 panels with dimensions L x H x e : 1036 x 976 x 21 mm with sliding bolts;
- 2 intermediate column, in steel (thickness 4 mm) of section 40x40mm and of height 1140mm, each including two fastening devices (**settling by locking** on the top) Every post is situated in its support by quarter turn locking;
- Corners, in PVC of dimensions 35x35x20mm, used to ensured water tightness, are settling with silicone at the base of the support and intended to avoid risks of leakage at the angles partly low of the panel ;
- **3 Metallic angle** setting on the concrete/masonries support and on the vertical column intended to avoid any displacement of panels during their functioning ;
- 2 horizontal reinforcements positioning in front of the vertical column as high as 45 and 85 cm. Support of both horizontal reinforcement is performed by two **supports sealed** on column.

Type of testing

The following tests program is the same for each type of contact surface (concrete, metallic) on which is the tested panel is installed

<u>Water tightness and shocks tests consists on:</u>

- Support preparation by the manufacturer
- Installation of the flood barrier by CSTB and manufacturer
- Instrumentation of the tested panel for displacements measurement during the water tightness test
- Water filling with leakage observation and displacements measurements during 24 hours
- Emptying before 600J shock test
- Water filling with leakage observation and displacements measurements during 24 hours

<u>Bending test</u> for the determination of the maximum of load capacity, consisting of a 4 points bending test on the barrier taken up in its support.

Result assessment

Results of testing in term of performance

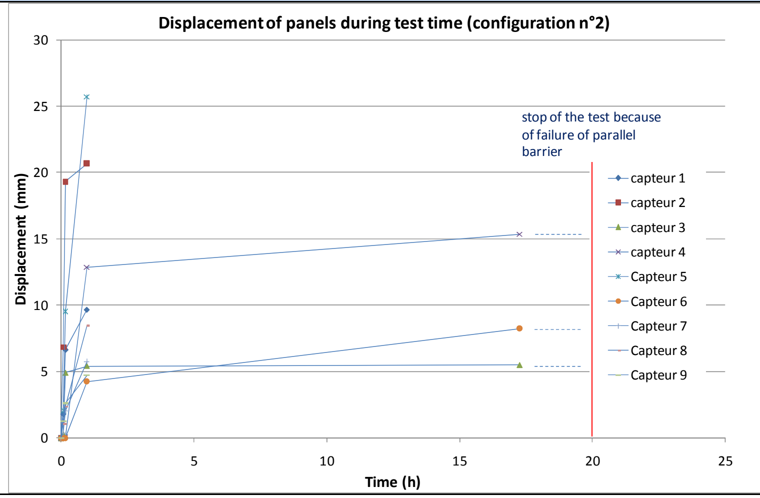
<u>Readiness assessment :</u>

- Weight of one panel to be manipulated: 16,5 kg - Manipulation by one person, made easier by the presence of two handles (facade and upper rim)
- Time of installation of the system (support preparation + barrier installation) and number of persons: 5 hours (for the implementation of 2 barriers facing in) or about 2 h 30 by implement with 3 persons. The setting can be accomplished by a single person (not assessed length of assemblage).
- Necessary equipment: Drilling machine with drills (max diameter = 50 mm)– Screw gun - Accessory (concrete screw) – Silicone
  Note: Many specific pieces which may be lost
- Presence of an instruction sheet: Yes, stuck to some panel
- Particular attention: Cleaning of the support and in particular cleaning of the permanent holes in the support to fasten the barrier (no protection cap provided for the holes)

<u>Water tightness and impact test : configuration n°1 + metallic support</u>

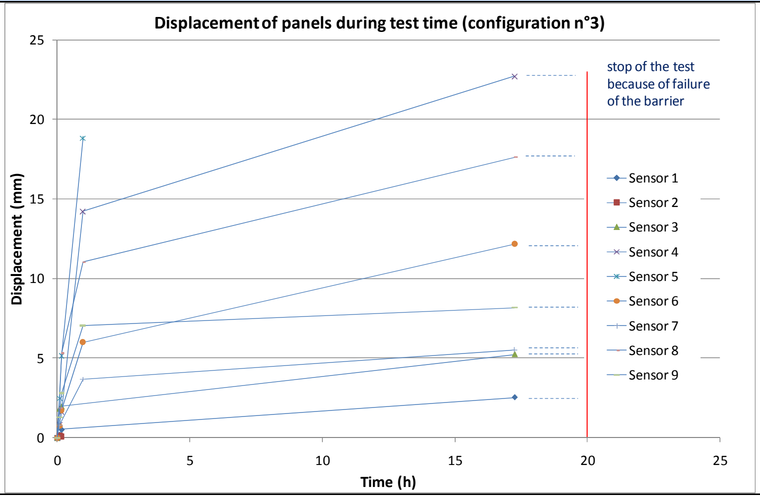
phase N°	Report		
1	**Application of the water load (80+5 cm during 24 hours)**		
	Displacements at the bottom of the barrier (points 7, 8 et 9) :		
	Panel 1 (pressure : 2,2 bars)	17 mm (initial) and 24 mm (after 24 h)	
	Panel 2 (pressure : 2,4 bars)	14 mm (initial) and 22 mm (after 24 h)	
	Panel 3 (pressure : 2,6 bars)	5 mm (initial) and 16mm (after 24 h)	
	<u>Report :</u> low leakage (0,5 l/h/m) at the low fastening devices		
2	**Emptying and 600 joules impact of "floating objects"**		
	Movement of all the 3 panels, without visual damage.		
3	**Application of the water load (80+5 cm during 24 hours)**		
	Displacements at the bottom of the barrier:		
	Panel 1 (pressure : 2,5 bars)	18 mm (initial) and 19 mm (after 24 h)	
	Panel 2 (pressure : 2,5 bars)	23 mm (initial) and 26 mm (after 24 h)	
	Panel 3 (pressure : 2,5 bars)	9 mm (initial) and 13 (after 24 h)	
	<u>Report :</u> leakage (1,0 l/h/m) at the low fastening devices and at the base of the barrier		

Water tightness and impact test : configuration n°2 + concrete support

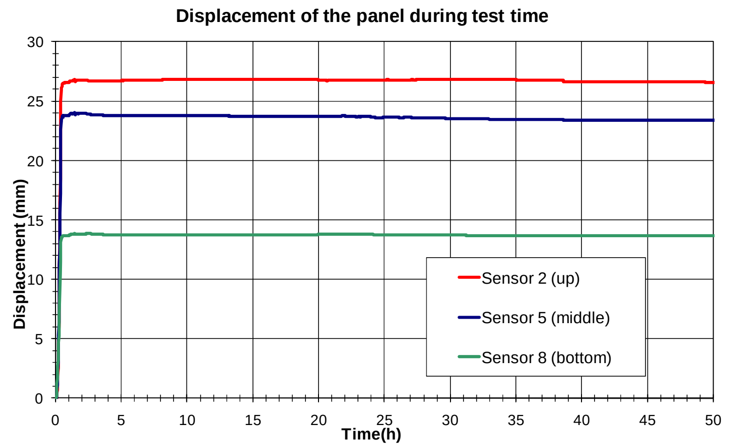
<table>
<tr><th>phase N°</th><th>Report</th><th></th></tr>
<tr><td>1</td><td>Application of the water load (80+5 cm during 24 hours)
Displacements at the bottom of the barrier (points 7, 8 et 9) :
Panel 1 (pressure : 2,5 bars) — 5,8 mm (initial) and unmeasured (after 24 h)
Panel 2 (pressure : 2,5 bars) — 8,5 mm (initial) and unmeasured (after 24 h)
Panel 3 (pressure : 2,5 bars) — 4,7 mm (initial) and unmeasured (after 24 h)
<u>Report :</u> After 17 hours of test, low leakage (0,7 l/h/m) on the low fastening devices of the barriers and between two panels. Pressure was increase to 3 bars on the bets.
Test have been stopped after 20 hours, after damage of the opposite barrier (configuration n°3)</td><td>


</td></tr>
<tr><td>2</td><td>Emptying and 600 joules impact of “floating objects”
NOT REALISED</td><td rowspan="2">Because of failure of parallel barrier during phase 1, these tests have not been realised</td></tr>
<tr><td>3</td><td>Application of the water load (80+5 cm during 24 hours)
NOT REALISED</td></tr>
</table>

Water tightness and impact test : configuration n°3 + concrete support

<table>
<tr><th>N° phase</th><th colspan="2">Report</th><th></th></tr>
<tr><td rowspan="5">1</td><td colspan="2">Application of the water load (80+5 cm during 24 hours)
Displacements at the bottom of the barrier (points 7, 8 et 9) :</td><td rowspan="5">
</td></tr>
<tr><td>Panel 1 (pressure : 2,5 bars)</td><td>3,7 mm (initial) and 5,5 mm (after 17 h)</td></tr>
<tr><td>Panel 2 (pressure : 2,5 bars)</td><td>11,0 mm (initial) and 17,6 mm (after 17 h)</td></tr>
<tr><td>Panel 3 (pressure : 2,5 bars)</td><td>7,1 mm (initial) and 8,2 (after 17 h)</td></tr>
<tr><td colspan="2"><u>Report:</u> After 17 hours of test, low leakage (0,7 l/h/m) on the low fastening devices of the barriers and between two panels. Pressure was increase to 3 bars on the bets
After 20 hours of test, explosion of the inner tube of the central panel. After dismantling of the barrier, we report of vertical movement of 7 mm of the panel (sliding of the top fastening device on the post in spite of the tightening)</td></tr>
<tr><td>2</td><td colspan="2">Emptying and 600 joules impact of “floating objects”
NOT REALISED</td><td rowspan="2">Because of failure of the barrier during phase 1, these tests have not been realised</td></tr>
<tr><td>3</td><td colspan="2">Application of the water load (80+5 cm during 24 hours)
NOT REALISED</td></tr>
</table>

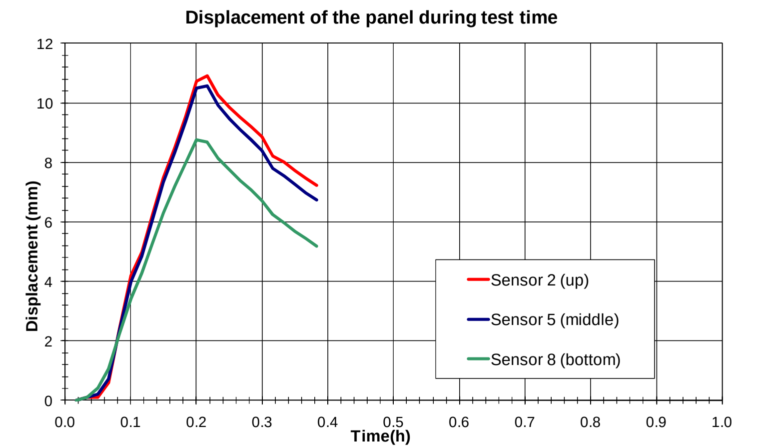
Water tightness and impact test : configuration n°4 + concrete support

<table>
<tr><th>N° phase</th><th>Report</th><th></th></tr>
<tr><td>1</td><td>Application of the water load (90+5cm during 24 hours)
Displacements of the central panel (initial pressure: 3 bars):
<table>
<tr><td>Sensor 2 – head of panel</td><td>23,8 mm (initial) 23,7 mm (after 24 h) et 23,4 mm (after 48 h)</td></tr>
<tr><td>Sensor 5 – middle of panel</td><td>26,5 mm (initial) 26,8 mm (after 24 h) et 26,6 mm (after 48 h)</td></tr>
<tr><td>Sensor 8 – bottom of panel</td><td>13,7 mm (initial) 13,8 mm (after 24 h) et 13,7 (after 48 h)</td></tr>
</table>
<u>Report:</u> After achieving test water height (95 cm), low leakage (less than 0,1l/h/m) on the low fastening devices of the barriers and between two panels.
After 48 hours of test, decreasing of the inner tube pressure (0,1 to 0,2 bar on first and third panels, 0,5 bar on central panel). Low leakage (less than 0,1l/h/m) on the low fastening devices of the barriers and between two panels.</td><td>
</td></tr>
<tr><td>2</td><td>Emptying and 600 joules impact of “floating objects”
<u>Impact n°1</u> : at 80% of water height (h = 72 cm) on central panel
Weak deformation at the position of impact point
<u>Impact n°2</u> : closed to the connection with concrete column, at low height
Deformation and failure of the panel, partial displacement of the inflatable tube out of the rim
<u>Impact n°3</u> : at the position of the connection between two panels, at low height
Deformation of the panel and the aluminium rim, failure of one of the both panels

</td><td>Impact point 1 :

Impact point n°2 :

Impact point n° 3 :
</td></tr>
</table>

<table>
<tr><td rowspan="6">3</td><td colspan="2">Application of the water load (90+5 cm during 24 hours)
Displacements of the central panel :</td><td rowspan="6">
</td></tr>
<tr><td>Sensor 2 – head of panel</td><td>7,2 mm (initial)</td></tr>
<tr><td>Sensor 5 – middle of panel</td><td>6,7 mm (initial)</td></tr>
<tr><td>Sensor 8 – bottom of panel</td><td>5,2 mm (initial)</td></tr>
<tr><td colspan="2"><u>Report :</u> After achieving test water height (95 cm), leakage rate (13,2 l/h/m) was so important that hydrostatic loading couldn't be kept constant. Leakage's locations correspond to areas damaged by impact tests.</td></tr>
</table>

<u>Bending test: configuration n°1 + metallic support</u>

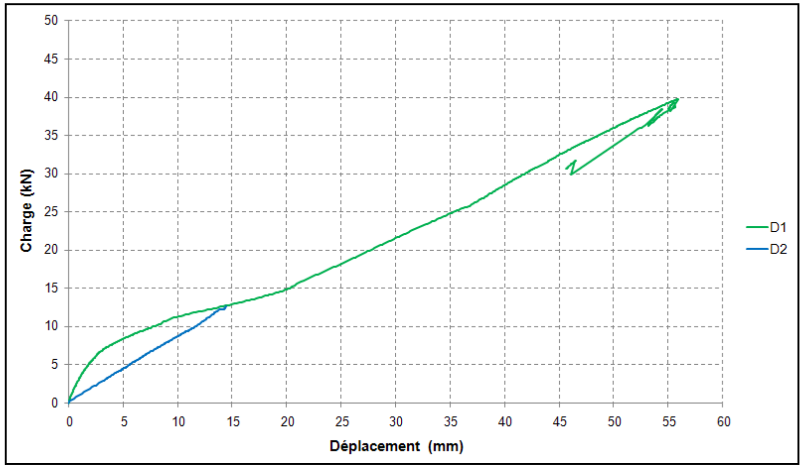


Figure 11 : load-deformation curve on panel P1

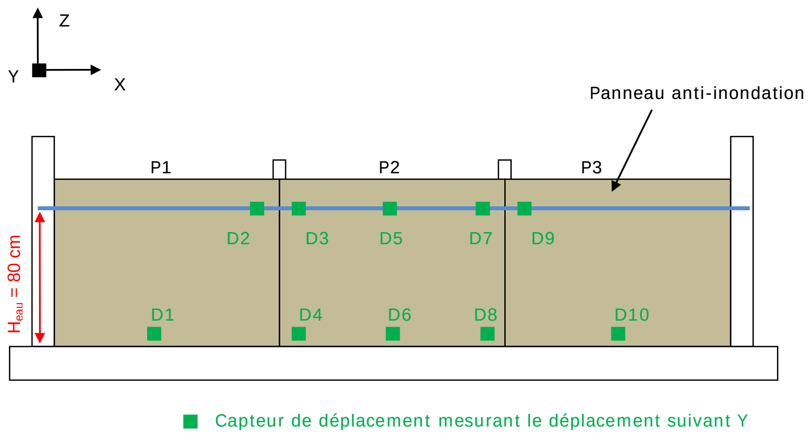


Figure 12 : disposition of the measurement key points

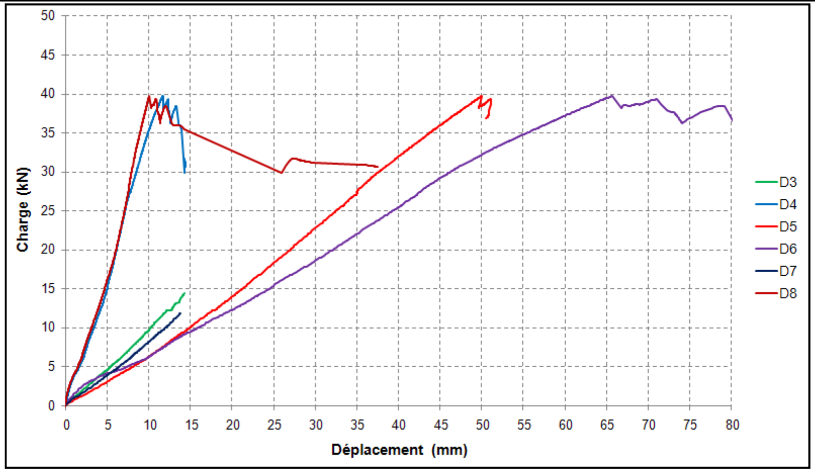


Figure 13 : load-deformation curve on panel P2

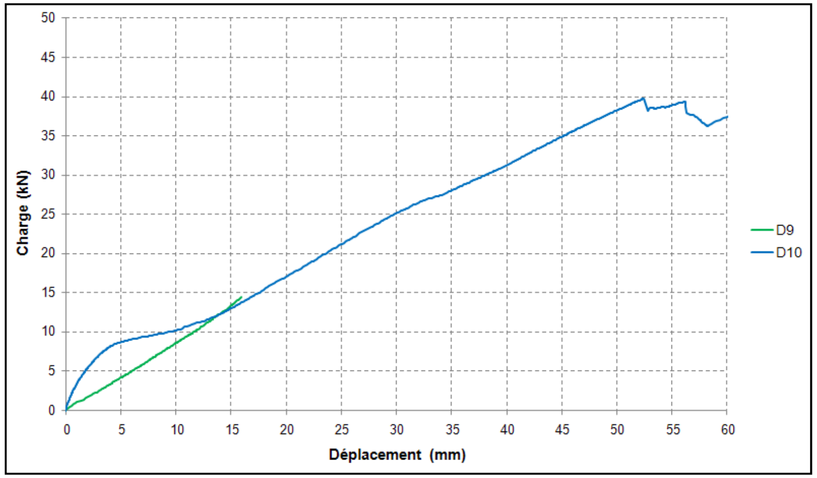


Figure 14: load-deformation curve on panel P3

Figure 15 : rupture of the barrier

Suggestion of improvement
- The connection by locking on top of the panel, as used for the configuration n°1, seems to provide a better performance (no vertical sliding). The same idea of connection was used for configuration n°4 by modifying clamping system (drilling of the column at the point of locking). - The horizontal reinforcement (configurations 2, 3 and 4) instead of knee brace needs less floor space requirement. - Blocking the panel with a linear abutment on the support (configurationsn°2 and 4) avoids local pinch of the inner inflated tube. - Providing protection cap for permanent holes in the support (in particular for large holes 50 mm diameter). - Risk that some pieces may be lost because there are many.
Input for WP4
Leakage rate measurement
Input for Objective 2.3
<u>Guide of testing</u> Various types of connection between panels and support were tested. The importance of these choices of connections was demonstrated. The SMARTeST test guidance will highlight the need to consider the whole system: panels + connections.

Appendix 3.3

Summary of the FRe Technologies Testing
Flood barriers « Barrier n°3 »

General product description

Product description (type of product, stability characteristic, sealing characteristics, drawings, pictures, …)

"Barrier n°3" – Category : Building aperture technology

This "Barrier n°3" barrier is composed in one PVC element. PVC used is 100% recycle and 100% recyclable. Element is 0,8m high and 40 mm thick. Its length depends on the opening's width (0,9 to 2,5m). Element is fitted between two PVC columns, screwed to the walls. The water tightness is ensured by using foam Ethylen-Propylen-Dien-Monomer (EPDM) seal band at the base of the PVC barrier and between PVC columns and the vertical support. The seal band compression is made with:

- Two lateral presses to press the columns against the support, to reinforce the water tightness of columns,
- Two other presses, one on each column, at the head of the barrier, to vertically compress EPDM bottom seal band.

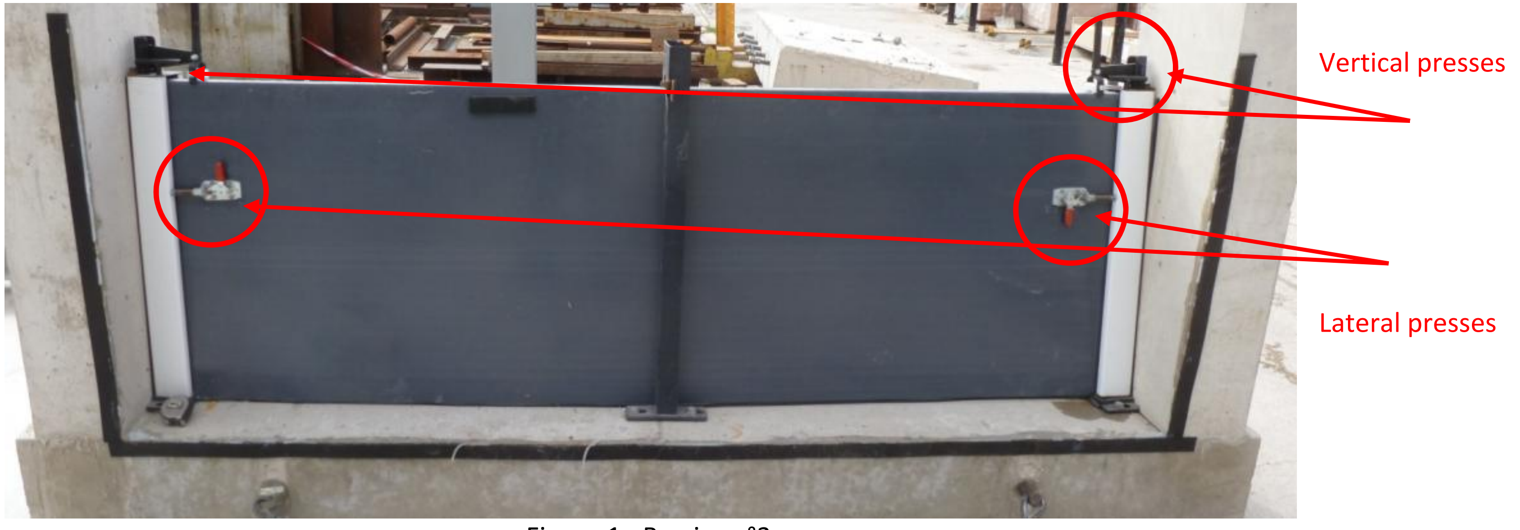


Figure 1 : Barrier n°3

Functionalities expected by this product
Water tightness: It is expected that the product limits the water penetration Stability: It is expected that the product remains stable Readiness: It is expected that the product to be ready on time
What is the main sales argument of this product?
The main sales argument of the " Barrier n°3" are : • Light and robust • Environment friendly • Likely to be customized
Field of use and limitation
Mainly individual houses and more generally other types of buildings The maximum water height is 75 cm.

General Testing Description

Functionalities tested

- Water tightness
- Stability
- Deployment/implementation

Performance criteria

The functionalities were qualitatively and quantitatively assessed. The quantitative analysis was based on the following performance criteria:

- water tightness: leakage rate (Litre/hour/meter of barrier width: L/h/m) before and after impact test
- stability: qualitative analysis (visual observations) coupled with quantitative analysis based on elements displacement measurements
- readiness: measurement of mounting time

List of conditions which have an effect on the performance

Water tightness:

- Flood action (i.e. water pressure, current)
- Impacts resistance
- Nature of the support (concrete, masonry, …)
- Openings dimensions
- Peripheral fastening (linear / punctual…)

Stability:

- Flood action (i.e. water pressure, current)
- Impacts resistance
- Openings dimensions
- Peripheral fastening (linear / punctual…)

Readiness:

- Required manpower

Testing conditions

Tests have been performed at the Centre Scientifique et Technique du Bâtiment (CSTB).

The test rig for water tightness and shocks assessment consists of a support representing an opening (door, French window, garage door). Two opposite barriers can be mounted simultaneously (Figure 2). This support consists of a horizontal foundation beam and two vertical columns. The surface of columns can be concrete (form removal aspect), masonry or steel.

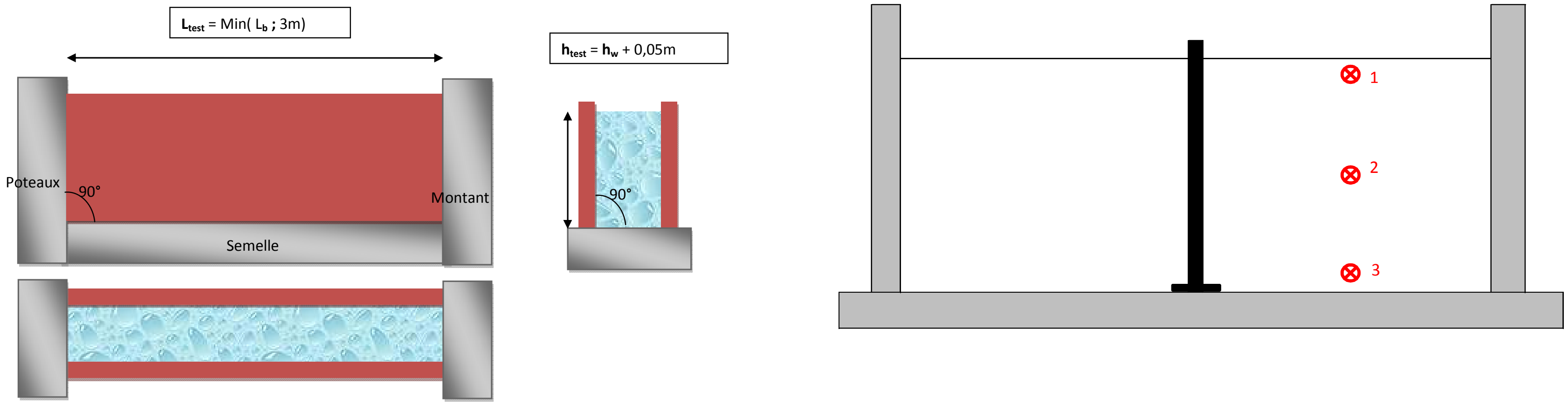


Figure 2 : Water tightness test rig and positioning of deflection measurements points

The **water load** is the sum of the static water height hw and of the static equivalent of the dynamic pressure resulting from a of 1m/s water flow: h_{test} = hw + 5 cm. Water leakage is measured over a 24 hour period. During this period, displacements at the head and at the foot of the tested panel are recorded. The water height remains constant and the leakage water flow is estimated.

The 600 J shock simulates the impact of a craft hitting the flood barrier during docking.

Product configuration

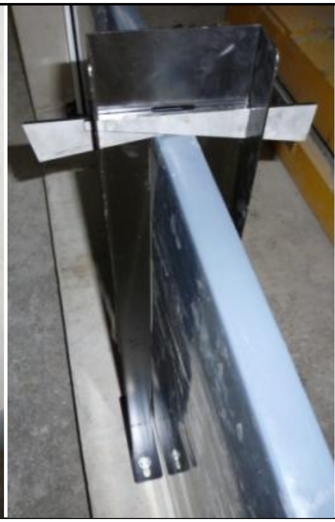
The tested configuration for "Barrier n°3" is characterised by: length of the elements = 2400 mm, length of the opening = 2500 mm, total height = 0,8 m. This technology is as follows:

- 1 honeycomb structure PVC board 40 mm thick with global dimensions L x H x e : : 2400 x 800 x 40 mm,
- An auto-adhesive EPDM seal band to be cut at the appropriate length and fix, at the bottom of the board (40 mm wide and 10 mm thick);
- 2 steel frame, with their auto adhesive EPDM seal band (40 mm wide and 10 mm thick) which has to be cut with the appropriate length;
- 1 intermediate steel frame;
- 2 PVC columns, with their auto EPDM seal band (40 mm wide and 10 mm thick) which has to be cut with the appropriate length. Each steel frames have to be put into one column;
- 2 steel bars Ø14 mm;
- 2 lateral presses which have to be screwed to the PVC board
- 2 vertical presses which have to be connected to the steel frame
- Hardware, accessories, which is needed for connection and water-tightness.

Installation of column with its steel frame and fixation with 2 anchors at the base of the steel frame, to create steel reinforced PVC column.

Installation of the PVC board after cutting if necessary and fixation of the lateral presses by screwing in the PVC panel. Auto adhesive seal band is put at the base of the PVC panel



	Installation of the intermediate steel frame and fixation with 4 M12 anchors in the concrete support
	Installation of the steel bar into the column
	Installation of the vertical presses at the head of the panel
	Installation of steel pieces on the intermediate steel frame to vertically compress the bottom seal band in central area

Type of testing

The following tests program is the same for each type of contact surface (concrete, masonry) on which is the tested panel is installed

<u>Water tightness and shocks tests consists on:</u>
- Support preparation by the manufacturer
- Installation of the flood barrier by CSTB and manufacturer
- Instrumentation of the tested panel for displacements measurement during the water tightness test
- Water filling with leakage observation and displacements measurements during 24 hours
- Emptying before 600J shock test
- Water filling with leakage observation and displacements measurements during 24 hours

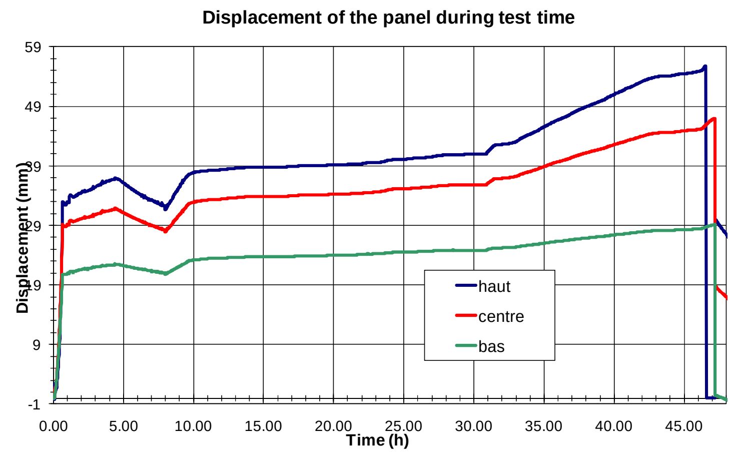
Result assessment

Results of testing in term of performance

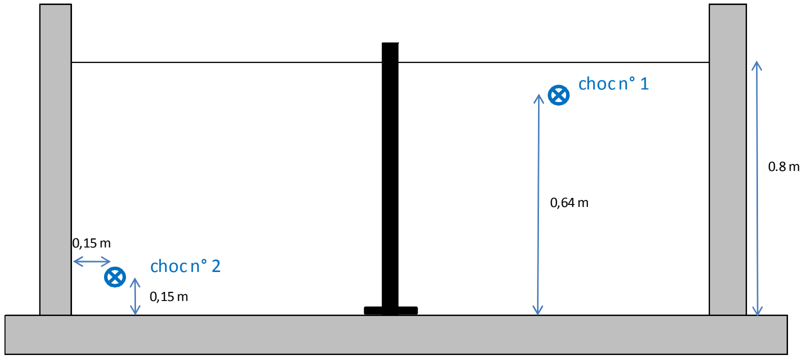
Readiness assessment :

- Weight of the tested panel to be manipulated: 16 kg (6,4 kg/m)
- Time of installation of the system (support preparation + barrier installation) and number of persons: around 1,5 hours with 2 people for the first installation
- Necessary equipment: Drilling machine with drills – Screw gun - Accessory (concrete screw) – Silicone
  Note: Many specific pieces which may be lost
- Presence of an instruction sheet: Yes
- Particular attention: Cleaning of the support and in particular cleaning of the permanent holes in the support to fasten the barrier (even if protection caps are provided) + flatness of vertical and horizontal contact surfaces
- Cut the PVC panel to adapt it to support dimensions is not so easy (PVC with cells, stiffness).

Water tightness and impact test : concrete support

phase N°	Report	
1	**Application of the water load (75 + 5 cm during 24 hours)** Displacements (points 1, 2 et 3) : Sensor 1 – head of the barrier: 33 mm (initial) 40 mm (after 24 h) 55 mm (after 45h) Sensor 2 – middle of the barrier: 29 mm (initial) 35 mm (after 24 h) 46 mm (after 45h) Sensor 3 – bottom of the barrier: 21 mm (initial) 25 mm (after 24 h) 29 mm (after 45h) Report : Many leakage points (10l/hour) located: - At lateral presses, where screwing were made to fix them - On column, at bottom between PVC columns and concrete support Test time was increased untiil 45h because displacement of the panel was not stable at 24h. at 45h, stability not achieved too and large deformation was observed. Note: test was carried on barrier installed six month ago and stocked outside during winter period. Then all the EPDM bands were damaged by climatic conditions and by long term compression	
2	**Emptying and 600 joules impact of "floating objects"**	 

<table>
<tr><td></td><td><u>Impact n°1</u> : at 80% of water height (h = 64 cm)
Displacement of the panel with sliding of the PVC column and deformation of intermediate steel frame until failure of the welding
<u>Impact n°2</u> : closed to the connection with concrete column, at low height
Damages of the impact n°1 are increased by impact n°2



</td><td></td></tr>
<tr><td>3</td><td>Application of the water load (75 + 5 cm during 24 hours)
NOT REALISED</td><td>This test was not realised because the panel was too damaged by impact test (phase 2)</td></tr>
</table>

Water tightness and impact test : masonry support

<table>
<tr><th>phase N°</th><th>Report</th><th></th></tr>
<tr><td>1</td><td>

Application of the water load (75 + 5 cm during 24 hours)

Displacements (points 1, 2 et 3) :

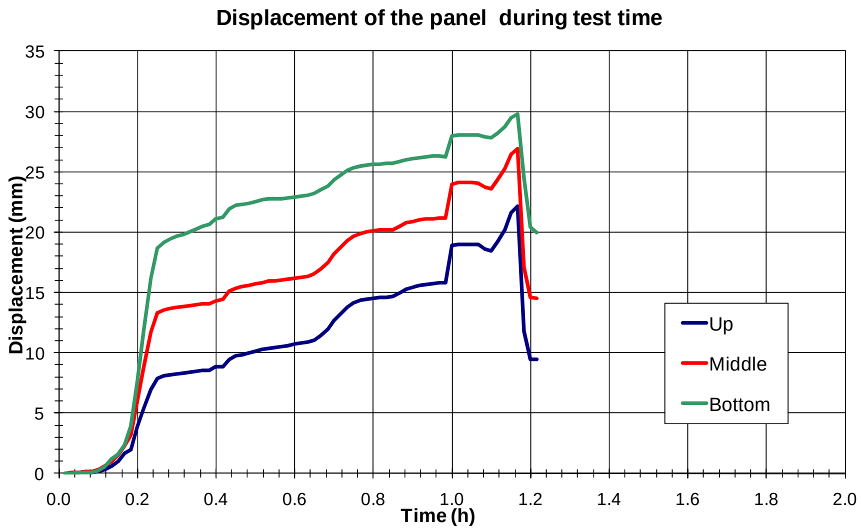
Sensor 1 – head of the barrier	22 mm (h_{eau}=0,7 m)
Sensor 2 – middle of the barrier	27 mm (h_{eau}=0,7 m)
Sensor 3 – bottom of the barrier	30 mm (h_{eau}=0,7 m)

Report:

High leakage (420 l/h) at the base joint between the panel and the horizontal support. High deformation of the panel and the intermediate column. High displacement at the bottom of the panel with sliding and unsticking of the joint.
The test was stopped after 1h because of the high leakage.

Note : For this test, all the critical points where leakage was observed during previous test was treated with silicone : at the bottom of the aluminum columns and at the vertical connection with the masonry columns (see photos below).


</td><td>



</td></tr>
<tr><td>2</td><td>

Emptying and 600 joules impact of “floating objects”
NOT REALISED

</td><td rowspan="2">These tests were not realised because of the high deformation of the panel.</td></tr>
<tr><td>3</td><td>

Application of the water load (75 + 5 cm during 24 hours) after impact
NOT REALISED

</td></tr>
</table>

Suggestion of improvement

- Systematic laying of silicone should be recommended at all the drilling points (especially, to install lateral presses)
- Provide solution to correct high flexibility of the panel either by reinforcing panel or by limiting the width of the aperture to protect.
- Reinforcement of the intermediate steel frame, which the weakest point in case of impact
- Foam EPDM seal bands seem to be not enough water tight efficient if deformations of the barriers are large. The choice of the seal band could be corrected to be compatible with the level of deformation of barriers and the rate of compression of the joints.
- If PVC columns were fixed at their head to vertical support, sliding observed during impact test could be avoided
- Metal parts can corrode if stored outdoors (especially lateral press)




- Permanent installation is not recommended because of the decreasing of joints compression
- Outdoors storage without protection is not recommended (deterioration of the properties of the different joints, corrosion of steel parts)
- Risk that some pieces may be lost because there are many.

Input for WP4

Leakage rate measurement

Input for Objective 2.3

<u>Code of practice</u>:
Highlight the importance of storage conditions of the elements but also the need for uninstalling technologies after flooding within a reasonable time to avoid possible damage.

Appendix 3.4

Summary of the FRe Technologies Testing
Flood barriers « Barrier n°4»

General product description

Product description (type of product, stability characteristic, sealing characteristics, drawings, pictures, …)

"Barrier n°4" – Category : Building aperture technology

The "Barrier n°4" barrier is composed of horizontal aluminium elements. Elements are 0,25 m high and 80 mm thick. The number of elements and their length depends on the protection height (1 m max.) and the opening's width (0,5 to 6 m). They are stacked on each other between aluminium columns anchored in support (see figure 1). The water tightness is ensured by using :

- Ethylen-Propylen-Dien-Monomer (EPDM) seal bands between elements (one horizontal seal band at the bottom, 6 horizontal ones between panels, 8 vertical ones for columns),
- Two vertical presses (see figure 2), one on each side of the barrier, in order to compress the EPDM bands.

Figure 1 : Barrier n°4 elements stacked between columns

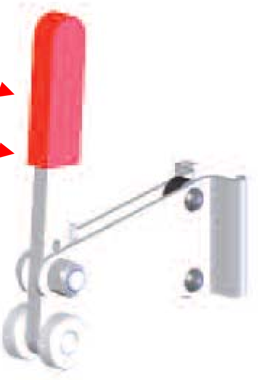


Figure 2 : Vertical press

Functionalities expected by this product

Water tightness: It is expected that the product limits the water penetration Stability: It is expected that the product remains stable Readiness: It is expected that the product to be ready on time
What is the main sales argument of this product?
The main sales argument of the " Barrier n°4" are : • Quality • Robustness • Durability
Field of use and limitation
Mainly industrial, commercial building, and more generally other types of buildings This product can be used as perimetric barriers too, but has not been tested at CSTB into this field. The maximum water height is 100 cm.

General Testing Description

Functionalities tested

- Water tightness
- Stability
- Deployment/implementation

Performance criteria

The functionalities were qualitatively and quantitatively assessed. The quantitative analysis was based on the following performance criteria:

- water tightness: leakage rate (Litre/hour/meter of barrier width: L/h/m) before and after impact test
- stability: qualitative analysis (visual observations) coupled with quantitative analysis based on elements displacement measurements
- readiness: measurement of mounting time

List of conditions which have an effect on the performance

Water tightness:

- Flood action (i.e. water pressure, current)
- Impacts resistance
- Nature of the support (concrete, masonry)
- Aperture dimensions
- Internal and peripheral fastening (linear / punctual…)

Stability:

- Flood action (i.e. water pressure, current)
- Impacts resistance
- Aperture dimensions
- Internal and peripheral fastening (linear / punctual…)

Readiness:

- Required manpower

Testing conditions

Tests have been performed at the Centre Scientifique et Technique du Bâtiment (CSTB).

The test rig for water tightness and shocks assessment consists of a support representing an opening (door, French window, garage door). Two opposite barriers can be mounted simultaneously (Figure 3). This support consists of a horizontal foundation beam and two vertical columns. The surface of columns can be concrete (form removal aspect), masonry or steel.

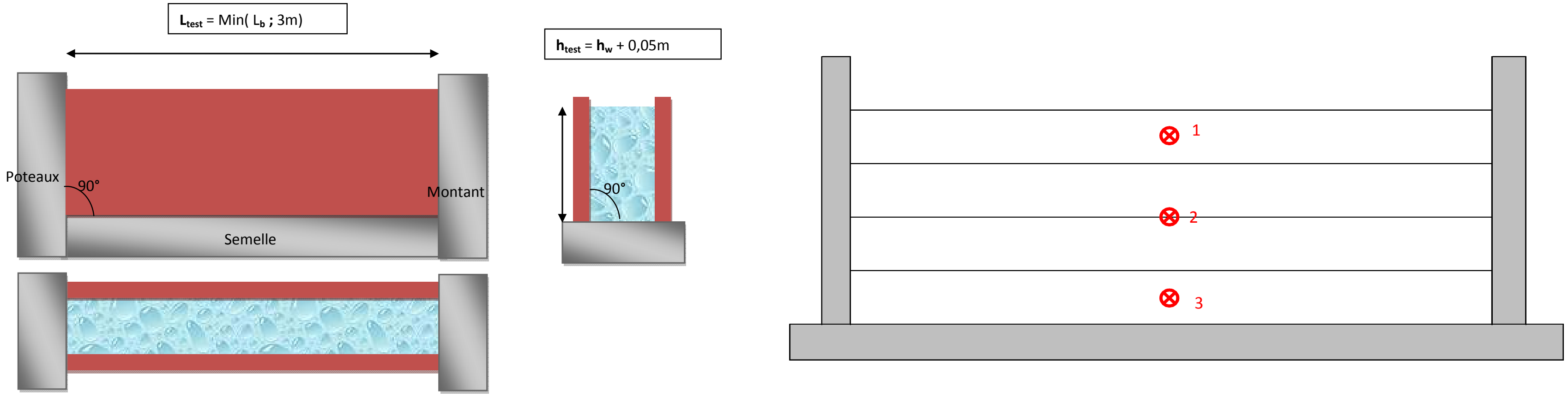


Figure 3 : Water tightness test rig and positioning of deflection measurements points

The **water load** is the sum of the static water height hw and of the static equivalent of the dynamic pressure resulting from a of 1m/s water flow: h_{test} = hw + 5 cm. Water leakage is measured over a 24 hour period. During this period, displacements at the head and at the foot of the tested panel are recorded. The water height remains constant and the leakage water flow is estimated.

The 600 J shock simulates the impact of a craft hitting the flood barrier during docking (Figure 4).

Figure 4 : Impact test rig

Product configuration

The tested configuration for "Barrier n°4" is characterised by: length of the elements = 2915 mm, length of the opening = 3000 mm, total height = 1,06 m. This technology is as follows:

- 4 aluminium boards (4 mm thick) with global dimensions L x H x e : 2915 x 250 x 80 mm ;
- 2 aluminium columns, with U section 130 x 87,5 mm and height equal to 1209mm.
- EPDM seal bands : one at bottom, two inserted between two sheet piles, 4 vertical ones for each column ;
- Hardware, accessories, which are needed for connection and water-tightness.

Installation of columns: connection to support with 3 anchor for each column

Installation of the 4 horizontal panels.
The first one is equipped with an extra joint at bottom.

Installation of the vertical press (one for each column)

Clamping of the device to compress the seal bands

Type of testing
The following tests program is the same for each type of contact surface (concrete, masonry) on which is the tested panel is installed. <u>Water tightness and shocks tests consists on:</u> - Support preparation by the manufacturer - Installation of the flood barrier by CSTB and manufacturer - Instrumentation of the tested panel for displacements measurement during the water tightness test - Water filling with leakage observation and displacements measurements during 24 hours - Emptying before 600J shock test - Water filling with leakage observation and displacements measurements during 24 hours

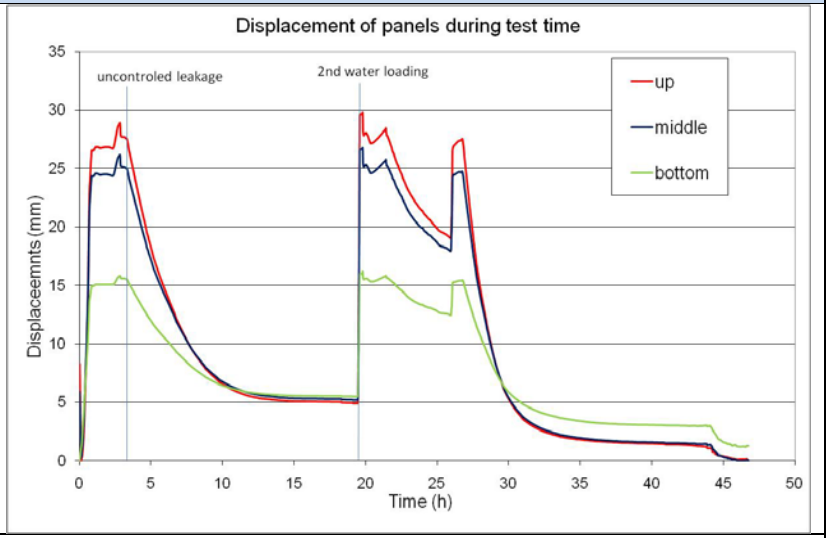
Result assessment

Results of testing in term of performance

Readiness assessment :

- Weight to be manipulated: 18,7 kg/board (6,5 kg/m) - Two people are needed to transport and install panels
- Time of installation of the system (support preparation + barrier installation) and number of persons: around 1,5 hours with 2 people.
- Necessary equipment: Drilling machine with drills – Screw gun - Accessory (concrete screw) – Silicone
- Presence of an instruction sheet: Yes
- Particular attention: Cleaning of the support + flatness of the support

Water tightness and impact test : concrete support

phase N°	Report	
1	**Application of the water load (100+5 cm during 24 hours)** Displacements (points 1, 2 et 3) : Sensor 1 – head of the barrier: 27 mm (initial) and 29 mm (after 3 h) Sensor 2 – middle of the barrier: 24 mm (initial) and 26 mm (after 3 h) Sensor 3 – bottom of the barrier: 15 mm (initial) and 16mm (after 3 h) Report : Many leakage points (more than 1l/minute) located: - On column, at vertical joint between aluminium and concrete columns - On column, at bottom between aluminium columns and concrete support - Inside the aluminium columns, at vertical joint between panels and columns - At horizontal connection between panels (drop by drop) Note: First test was carried on barrier installed six month ago and stocked outside during winter period. Then all the EPDM bands were damaged by climatic conditions and by long term compression. After installation of new joints, second test was carried on but quickly stopped because of high leakage rate, mainly at the bottom of columns and at vertical joint.	
2	**Emptying and 600 joules impact of "floating objects"** NOT REALISED	These test were not realised because of high leakage rate observed during phase 1
3	**Application of the water load (100+5 cm during 24 hours)** NOT REALISED	

Water tightness and impact test : masonry support

phase N°	Report
1	**Application of the water load (100+5 cm during 24 hours)**

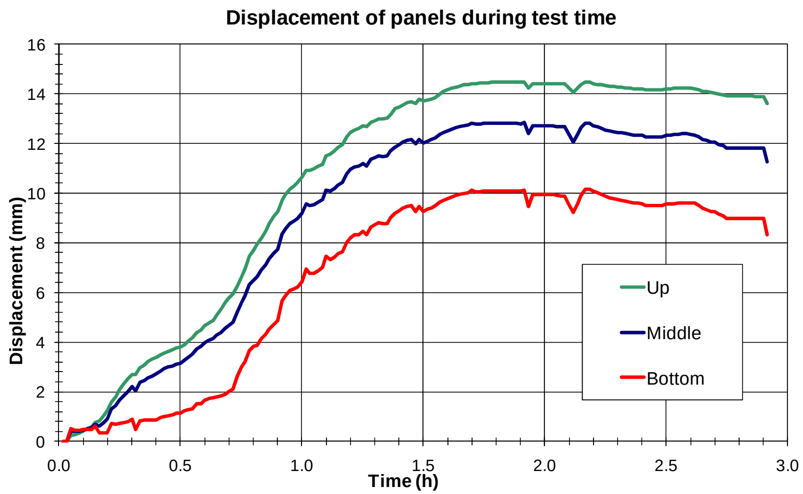
Displacements (points 1, 2 et 3) :

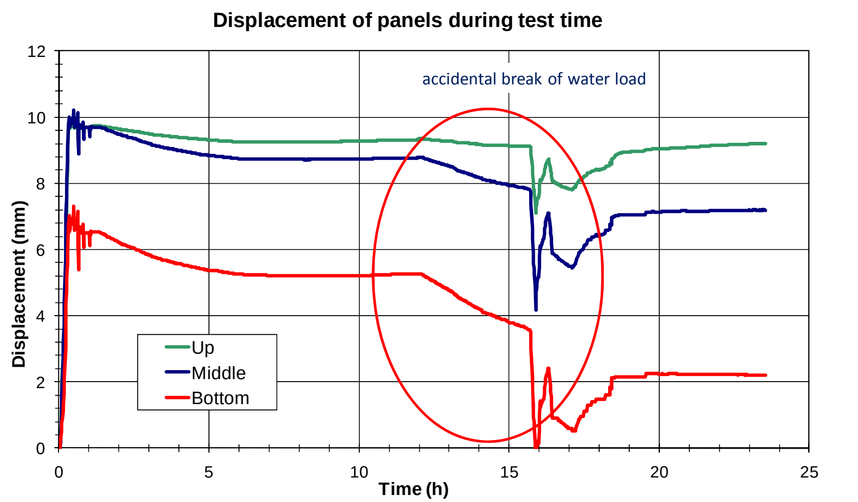
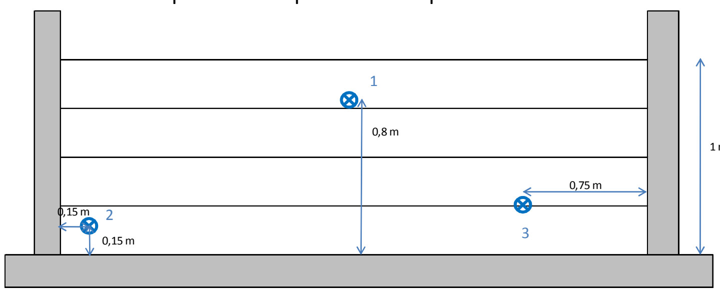
Sensor 1 – head of the barrier	10 mm (initial) and 11 mm (after 3 h)
Sensor 2 – middle of the barrier	12 mm (initial) and 13 mm (after 3 h)
Sensor 3 – bottom of the barrier	14 mm (initial) and 15 mm (after 3 h)

Report:

High leakage rate between masonry elements and between masonry columns and horizontal concrete support. Leakage through masonry columns: those leakages are not linked to the tested technology.
Leakage at the bottom joint between the first panel and the concrete support.
The test was stopped because of the defects of the test rig.

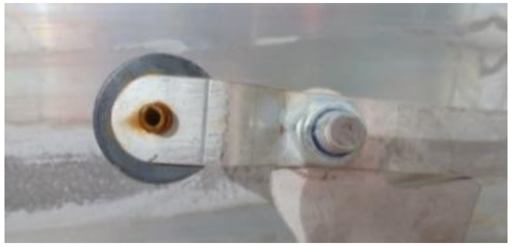
Note : For this test, all the critical points where leakage was observed during previous test were treated with silicone : at the bottom of the aluminum columns (in and out the column) and at the vertical connection with the masonry columns (see photos below).



<table>
<tr>
<td>1bis</td>
<td>Application of the water load (100+5 cm during 24 hours) – Repeated test
Displacements (points 1, 2 et 3) :
<table>
<tr><td>Sensor 1 – head of the barrier</td><td>7 mm (initial) and 5 mm (after 12 h)</td></tr>
<tr><td>Sensor 2 – middle of the barrier</td><td>10 mm (initial) and 9 mm (after 12 h)</td></tr>
<tr><td>Sensor 3 – bottom of the barrier</td><td>10 mm (initial) and 9 mm (after 12 h)</td></tr>
</table>
<u>Report :</u>
High leakage between masonry elements and between masonry columns and horizontal concrete support. Leakage through masonry columns: those leakages are not linked to the tested technology.
Weak leakage at the bottom joint between the first panel and the concrete support.</td>
<td>
</td>
</tr>
<tr>
<td>2</td>
<td>Emptying and 600 joules impact of “floating objects”
<u>Impact n°1</u> : at 80% of water height (h = 80 cm) on central panel
Weak deformation at the position of impact point (1 à 1.5 cm) with a gap at the connection between panels, disclamping of the presses
<u>Impact n°2</u> : close to the connection with concrete column, at low height
Deformation at the position of impact point (~ 1 cm)
<u>Impact n°3</u> : at the position of the connection between two panels, at low height
Weak deformation of the panel at the position of impact

</td>
<td>
Impact point n°1

Impact point n°2

Impact point n°3</td>
</tr>
<tr>
<td>3</td>
<td>Application of the water load (100+5 cm during 24 hours) after impact
NOT REALISED</td>
<td>This test was not realised because of difficulties to distinguish leakage linked to test rig from leakage linked to tested technologies.</td>
</tr>
</table>

Suggestion of improvement
- Systematic laying of silicone should be recommended between aluminium columns and support - The arrangement of the joints between the horizontal at the base of the column and the vertical joints should be corrected. There is indeed a gap which is not closing when joints are compressed. During test with masonry, this gap was partially filled with silicone. Mechanical connection between column and bottom horizontal support, like realised in use for perimetric barrier, may allow to limit this origin of leakage. - Clamping of the columns to the wall is necessary to ensure water tightness. If not, rotation of columns is possible and leads to leakage. Emphasize this point in the instructions sheet. - Metal parts can corrode if stored outdoors (especially vertical presses)   - Permanent installation is not recommended because of the decreasing of joints compression - Outdoors storage without protection is not recommended (deterioration of the properties of the different joints, corrosion of steel parts)
Input for WP4
Leakage rate measurement
Input for Objective 2.3
<u>Code of practice</u>: Highlight the importance of storage conditions of the elements but also the need for uninstalling technologies after flooding within a reasonable time to avoid possible damage. <u>Guide of testing</u>: Definition of masonry type used to build the test rig to precise.

Appendix 4 – Summary of testing of Water resistant material and anti-corrosion material

Appendix 4.1

Summary of the FRe Technologies Testing - GAIRECOM

General product description

Product description (type of product, stability characteristic, sealing characteristics, drawings, pictures, …)

Category: local sealing materials

Gairecom MMA 2010 M is a last generation two component methylmethacrylate (MMA) structural adhesive. In previous research (D2.1), the following main fields of application for GAIRECOM were pointed out:

- Joints:. innovative qualities:
    - local waterproofing sealings
    - joint mechanical reinforcement
- Anchors. Innovative qualities:
    - enhanced resistance at the contact ground matrix / barrier

This product aims to restore the waterproofing properties of the original structure rather than being waterproofed material itself. This way, this local adhesive enhances the flood resilience of primary FRE solutions. For this reason, the evolution of the Gairecom's properties at the contact with water has been tested, but not its watertightness. Unlike others traditional adhesives, its short curing time provide to this product a Flood Resilient relevance.

Physico-chemical characteristics

- First reagent presentation: colourless gel
- Second reagent presentation: green gel
- Mixing ratio (both weight and volume) first/second component: 1/1

• Density (after mixing) (20 °C): 1,10 ± 5% g.cm-3
• Pot-life (initial temperature 20 °C): 28 ± 10 min
• Exothermal peak (initial temperature 20 °C): 110 ± 20°C

Mechanical properties at 20 °c (after 2 days at room temperature)
• hardness (type: Shore A): 100
• Tensile strength: 20 ± 5 MPa
• Elongation at break: 5 ± 10%
• Elastic modulus: 1.100 ± 10 MPa
• Fracture toughness (KIC): 1,54 ± 0,10 MPa.$m^{1/2}$
• Fracture energy (GIC): 2,56 ± 0,20 kJ.m^{-2}
• Lap shear strength (see next Table) [megapascals]

	FRP	EPOXY	ALUMINIUM	STEEL	ABS	PVC	POLYSTYRENE
FRP	> 10*						
EPOXY		>10					
ALUMINIUM			15-20				
STEEL				20			
ABS					>8*		
PVC						>8*	
POLYSTYRENE							>5*

(*) Cohesive failure of substrate [MPa]

Functionalities expected by this product

In order to provide flood resilience to a given vulnerable element, It is possible to point out the following GAIRECOM functionalities:

• short curing time of the product

- the response time against floods is not always very high
- chemical inertia in presence of water
  - the product shall maintain its structural behavior in presence of water
- mechanical resistance
  - tensile strength
  - high deformation at break

What is the main sales argument of this product?

Within the FRe market, GAIRECOM is a particularly competitive product for the following reasons:

- short curing time (no standardized test so far)
- user friendly and supplied in cartridge
- high mechanical properties
- high chemical inertia: available at the contact ground matrix / barrier

Field of use and limitation

- **range of application:**
- Gairecom can be applied both under dry and wet conditions
- Compatible with a wide range of substrates
- **limitations:**
- The pot-life is limited. (Fig. 1)
- Gairecom MMA 2010 M half-life depends strongly on storage conditions. Its expiry date, at 20 ºC and protected from UV radiation, is approximately 6 months from its manufacture.

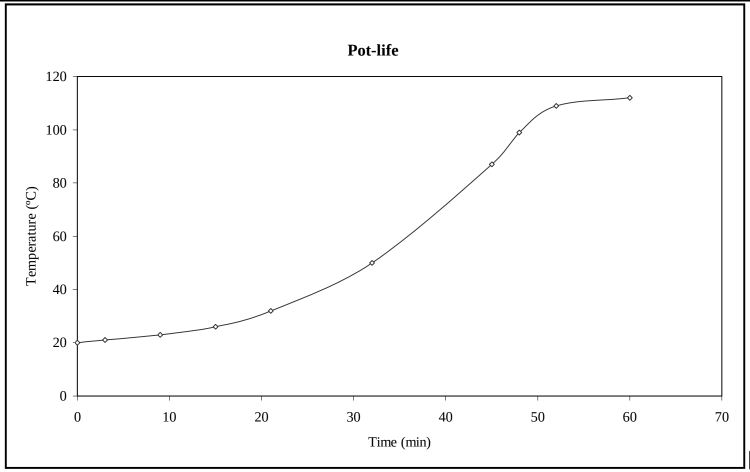


Figure 1: Pot - life

General Testing Description

Functionalities tested

GAIRECOM's main functionalities can be highlighted through the following properties:

- local waterproofing sealings
  - water absorption
  - evolution of mechanical properties in presence of water
- joint mechanical reinforcement and enhanced resistance at the contact ground matrix / barrier:
  - elastic modulus
  - elongation at break
  - tensile strength

Performance criteria

GAIRECOM main properties can be highlighted through the following criteria:

- local waterproofing sealings
  - water absorption (mass, [kg])
  - evolution of mechanical properties in presence of water (indirectly tested through the evolutions of other properties)
- mechanical reinforcement:
  - elastic modulus [N/mm^2]
  - elongation at break [mm]
  - tensile strength [N/mm^2]

List of conditions which have an effect on the performance

Mechanical properties:

- presence of water
  - water absorption
  - temperature highly influences the water absorption
- adhesion:
  - nature substrate

- regularity of the product’s surface

- actions dynamics (speed of the imposed deformation)
- temperature

Type of testing, testing conditions and product configuration

Laboratory tests were conducted in the testing facility of Gairesa Company. The tested properties have been: elastic modulus, elongation at break and tensile strength. These tests include three steps:

- determination of mechanical properties of specimens (elastic modulus, elongation at break and tensile)
- immersion of specimens until saturation in water at two different temperatures (room temperature and 60ºc)
- analysis of tensile properties of specimens after reaching water-uptake equilibrium

The determination of the elastic modulus is relevant for the assessment of the mechanical properties of the product (joint mechanical reinforcement and resistance at the contact ground matrix / barrier). Elongation at break offers an idea of the product’s ductility, this is, its mechanical resilience. Since GAIRECOM can be used both under wet or dry conditions, it is necessary to carry out tests under both conditions.

- **Determination of mechanical properties of specimens**

  - Test specimens: sheet, plate and molded plastics. Test specimens shall be prepared by machining operations, or die cutting, from material in sheet, plate, slab or similar form. Materials thicker than 14 mm must be machined to 14 mm. Specimens can also be prepared by molding the material to be tested. All surfaces of the specimen shall be free of visible flaws, scratches or imperfections. Marks left by coarse machining operations shall be carefully removed with a fine of abrasive and the field surfaces shall then be smoothed with abrasive paper. The finish sanding strokes shall be made in a direction parallel to the long axis of the test specimen. All flash shall be removed from a molded specimen, taking great care not disturb the molded surfaces. In machining a specimen, undercuts that would exceed the dimensional tolerances shall be scrupulously avoided. Care shall also be taken to avoid other common machining errors. If it is necessary to place gage marks on the specimen, this shall be done with a wax crayon that will not affect the material being tested. Gage marks shall not be scratched, punched, or impressed on the specimen. When testing materials that are suspected of anisotropy, duplicate sets of test specimens shall be prepared, having their long axes respectively parallel with, and normal to, the suspected direction of anisotropy.
  - Number of test specimens: Test eleven specimens.
  - Speed the imposed deformation for testing: 3 mm/min
  - Conduct the tests at 23 ± 2°C and 50 ± 5 % relative humidity. Reference testing conditions, to settle disagreements, shall apply tolerances of ±1°C and ±2 % relative humidity.

Figure 2 Lloyd Instruments. Testing facilities of mechanical properties test for rectangular speciments(3-5 mm and 20mm ±10%)

- **Immersion of specimens until saturation in water at two different temperatures (room temperature and 60ºC)**

  - number of test specimens: Test eleven specimens.
  - three types of conditionement for specimens shall be prepared as follows:
  - specimens of materials whose water-absorption value would be appreciably affected by temperatures round 110°C (230°F), shall be dried in an oven for 24 h at 50 ± 3°C, cooled in a desiccator, and immediately weighed with a tolerance of 0.001 g.
  - specimens of materials, such as phenolic laminated plastics and other products whose water-absorption value has been shown not to be appreciably affected by temperatures up to 110°C , shall be dried in an oven for 1 h at 105 to 110°C .
  - when data for comparison with absorption values for other plastics are desired, the specimens shall be dried in an oven for 24 h at 50 ± 3°C , cooled in a desiccator, and immediately weighed to the nearest 0.001 g.

- **Analysis of tensile properties of specimens after reaching water-uptake equilibrium**

  - test specimens: sheet, plate and molded plastics. Test specimens shall be prepared by machining operations, or die cutting, from material in sheet, plate, slab or similar form. Materials thicker than 14 mm must be machined to 14 mm. Specimens can also be prepared by molding the material to be tested. All

surfaces of the specimen shall be free of visible flaws, scratches or imperfections. Marks left by coarse machining operations shall be carefullyremoved with a fine of abrasive and the field surfaces shall then be smoothed with abrasive paper. The finish sanding strokes shall be made in a direction parallel to the long axis of the test specimen. All flash shall be removed from a molded specimen, taking great care not disturb the molded surfaces. In machining a specimen, undercuts that would exceed the dimensional tolerances shall be scrupulously avoided. Care shall also be taken to avoid other common machining errors. If it is necessary to place gage marks on the specimen, this shall be done with a wax crayon that will not affect the material being tested. Gage marks shall not be scratched, punched, or impressed on the specimen. When testing materials that are suspected of anisotropy, duplicate sets of test specimens shall be prepared, having their long axes respectively parallel with, and normal to, the suspected direction of anisotropy. o number of test specimens: Test eleven specimens. o speed of testing: 3 mm/min
Product configuration
Please, refer to the previous “testing conditions” part.
Type of testing
Please, refer to the previous “testing conditions” part.

Result assessment
Results of testing in term of performance

Even if temperature is in important parameter that influences GAIRECOM properties, to date, tests have only been performed at 60ºC.

• **Determination of mechanical properties of specimens (elastic modulus, elongation at break and tensile) (to 60ºC).**

	Elastic mod. (MPa)	Max. extension (%)	Elongation at break (%)	Max. Tension (MPa)	Energy released at break (KJ/m3)	Wide specimen (mm)	Thickness specimen (mm)
Average	1094	3.673	4.218	19.05	501.7	14.06	3.970
Standard deviation	74.30	0.257	0.511	0.610	101.2	0.195	0.0104

• **Immersion of specimens until saturation in water at two different temperatures (room temperature and 60ºC)**

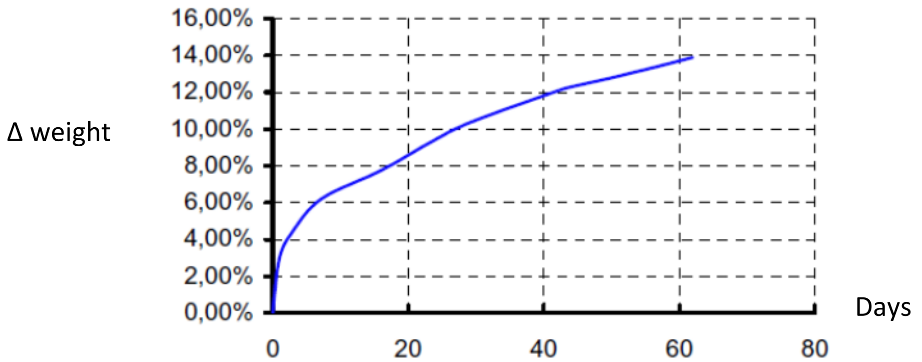


Figure 3:Results to 60ºC

• **Analysis of tensile properties of specimens after reaching water-uptake equilibrium (to 60ºC)**

	Elastic mod. (MPa)	Max. extension (%)	Elongation at break (%)	Max. Tension (MPa)	Energy released at break (KJ/m3)	Wide specimen (mm)	Thickness specimen (mm)
Average	836.8	2.470	2.470	11.86	136.9	14.79	4.467
Standard deviation	115.3	0.366	0.346	1.380	39.58	0.132	0.225

The determination of the elastic modulus is relevant for the assessment of the mechanical properties of the product (joint mechanical reinforcement and resistance at the contact ground matrix / barrier). Elongation at break offers an idea of the product's ductility, this is, its mechanical resilience. Properties are presented for both a dry product and after reaching the water-uptake equilibrium in order to highlight the evolution of mechanical properties at the water contact (flood resilience).
Suggestion for improvement

Appendix 4.2

Summary of the FRe Technologies Testing – SIKALASTIC

General product description
Product description (type of product, stability characteristic, sealing characteristics, drawings, pictures, …)

Category: liquid membranes

Sikalastic®-425 is a cold-applied, one-component solvent free liquid applied waterproofing membrane. The product is based on hybrid technology getting an optimum combination of different polymers to obtain a product with unique properties.

Figure 4 Application of Sikalastic 425. Ref: Sika

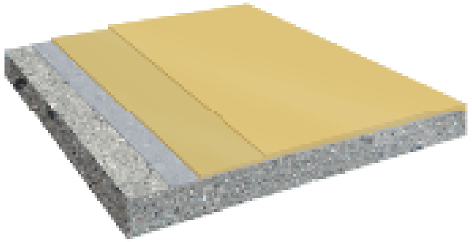


Figure 5 Basic System. Ref: Sika

Figure 6 System reinforce with mesh to improve durability and mechanical resistance. Ref. SikaThe product is stable during 12 months from date of production if stored properly in original, unopened and undamaged sealed packaging in dry conditions at temperatures between +5°C and +30°C.

Functionalities expected by this product
In order to provide flood resilience to a given vulnerable element, It is possible to point out the following SIKALASTIC functionalities: • waterproofing of horizontal and subhorizontal surfaces (SIKALASTIC 425) • waterproofing of vertical surfaces (others SIKALASTIC applications) Others relevant, but accessory, functionalities to be mentioned: • high elasticity (deformable) • crack bridging (continuous membranes: applications with no joints) • water vapor permeability • adhesion to different substrates

What is the main sales argument of this product?
Liquid membranes is a technological field subject to an intense innovative process; in this context, SIKALASTIC outstands through the following properties: • environmental aspects: o solvent free o improve the energy efficiency of buildings • workability (user friendliness): o easy to apply, one component ready to use o long shelf life (12 months) o wide range of application: even if SIKALASTIC 425 is only available for sub-horizontal surfaces, other SIKALASTIC solutions are also available for vertical surfaces o provided in packaging in 20 an 5 Kg container and supply in wide range of color (white, gray, red, terra-cotta….) o highly crack-bridging • durability (resilience): o highly elastic and crack-bridging o UV resistance

Field of use and limitation

Range of application:
 	
• superficial waterproofing:
  o both for new construction and refurbishment projects
  o cost efficient life cycle extension at failing roofs
  o resistance to wind loads is tested indirectly through the tensile and elongation at break tests
• for vertical wall waterproofing solutions in both new construction and refurbishment projects (sikalastic 830 N and sikalastic 353)
 	
Nevertheless, the following conditions gets beyond the field of application of SIKALASTIC 425:
• substrates with rising moisture
• shall not be applied directly on insulation boards
• not recommended for pedestrian traffic
  o in such cases, SIKALASTIC membrane shall be covered with appropriate elements such as tiles, stone plates or wooden panels

General Testing Description
Functionalities tested
SIKALASTIC 425’s main functionalities can be highlighted through the following properties: • waterproofing: o watertightness o water vapor diffusion resistant • mechanical properties: o adherence to the substrate o mechanical properties ✓ elongation at break ✓ maximum tensile strength o resistance to dynamic and static indentation o crack bridging • durability: o resistance to fatigue movement o resistance to heat ageing o resistance to UV radiation in presence of moisture o resistance to hot water ageing o indirectly tested through the evolution of others properties under hot water submersion

Performance criteria

These tests have been done pursuant to the EOTA procedures. SIKALASTIC 425 main properties can be highlighted through the following criteria:

- waterproofing:
  - watertightness: water leakage rate
  - water vapor diffusion resistant: vapor water transmission rate

- mechanical properties:
  - adherence to the substrate [N/m^2]
  - resistance to wind loads: stress [Pa] recorded in a tensile testing machine
  - mechanical properties: to assess indirectly resistance to wind loads, among others
    - ✓ elongation at break [mm]
    - ✓ maximum tensile strength [Pa]
  - resistance to dynamic and static indentation: visual recognition of the existence of perforations
    - ✓ static indentation: nature of the indentor [steel]
    - ✓ dynamic indentation: magnitude of the impact energy [J]
  - crack bridging: visual recognition after an imposed crack width [mm] to the substrate

- durability:
  - resistance to fatigue movement
    - ✓ visual recognition
    - ✓ waterproofing properties evolution: water leakage rate
  - resistance to heat ageing
    - ✓ indirectly tested through the evolution of others properties against rising temperatures
  - resistance to UV radiation in presence of moisture
    - ✓ indirectly tested through the evolution of others properties under UV radiation
  - resistance to hot water ageing
    - ✓ indirectly tested through the evolution of others properties under hot water submersion

List of conditions which have an effect on the performance

All properties of the product depends first of all on the quality of the product installation (temperature and relative humidity of curing). The substrate preparation is crucial to ensure highly durable quality.

- waterproofing:
  - watertightness
    - ✓ water pressure
  - water vapor diffusion resistant
    - ✓ air pressure

- mechanical properties:
  - adherence
    - ✓ nature of the substrate (concrete has been tested)
  - resistance to wind loads (waterproofed membranes are obstacle to the wind stream)
    - ✓ speed of the imposed deformation
  - resistance to dynamic and static indentation (visual recognition [perforated or not perforated])
    - ✓ static indentation: nature of the indentor [steel]
    - ✓ dynamic indentation: magnitude of the impact energy [J]
  - crack bridging
    - ✓ crack width

- durability:
  - resistance to fatigue movement
    - ✓ speed of the actions
    - ✓ amplitude
    - ✓ temperature (-10 ± 2 °C.)
    - ✓ nature of the substrate
    - ✓ dimensions of the gap
  - resistance to heat ageing
    - ✓ temperature
  - resistance to UV radiation

- ✓ presence of moisture
- ✓ intensity of the irradiance of the fluorescent UV artificial weathering apparatus
- ✓ temperature and relative humidity

- o resistance to hot water ageing
  - ✓ temperature
  - ✓ water depth

Testing conditions & type of testing

WATERTIGHTNESS

Type of testing & testing conditions

Watertightness is determined by applying a specified water pressure to the exposed side of the installed product by means of a hydrostatic head of water for a fixed period of time and detecting any water leakage. The product shall be cured at (23 ± 2) °C and (50± 5)% relative humidity. The cured test specimens shall be then conditioned at (23 ± 2) °C and (50± 5)% relative humidity for a period of at least 16 hours.

WATER VAPOR PERMEABILITY

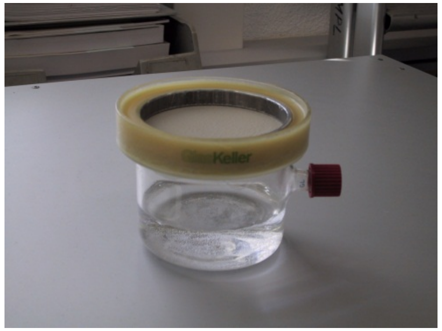


Figure 7: Water vapor permeability

Type of testing

Water vapor permeability is measured by determination of vapor water transmission rate (figure 4).

RESISTANCE TO WIND LOADS

Type of testing & testing conditions

Resistance to wind loads is determined by placing the test specimen, attached between a stiff plate and a fixed rigid substrate, in a tensile testing machine and pulling it apart at a given speed. The recorded maximum force, corresponding to the cohesion of the test specimen divided by the cross sectional area of the test specimen gives the delamination strength.

MECHANICAL PROPERTIES (elongation at break, tensile strength, adhesion and crack bridging)

Type of testing

Mechanical properties determined are the elongation at break and the maximum tensile strength (figure 9), adhesion and crack bridging. Adhesion at different substrates is tested according to a traditional "pull-off" test (figure 8). Pull-off adhesion testers measure the force required to pull a specified diameter of coating away from its substrate. This measured pull-off force provides a direct indication of the strength of adhesion between the coating and the substrate. Crack bridging is assessed through the visual recognition of the membrane's behavior after having been applied to a substrate with a crack of a given width. This test is carried out under different temperature and crack width, pursuant to UNE-EN 1062-7:2004.

Testing conditions

Mechanical properties are determined in a tensile testing machine and pulling it apart at a given speed. The testing conditions were a temperature of 23ºC and a relative humidity of 50%.

Testing specimens

For the tensile strength and elongation at break, the specimens were the following:

- dumb bell test pieces: type s2
- free clamping length: 42mm
- rate of traverse: 200mm/min
- dry film thickness: 0.8 mm (av.)

For the pull-off testing (adhesion), the tested specimen is a 2000 µm thick dry film. The specimen was rolled when tested.

For the crack bridging test, three layers of the specimen are applied on the cracked concrete substrate (the first layer of product with a 10% of water, and the other two layers with a consumption of 07 kg/m2)., obtaining a total thickness of the membrane of 600 µm thick in the break zone.

Figure 8: Mechanical properties. Instron. Ref: Sika

Figure 8: Mechanical properties. Sattec. Ref: Sika

RESISTANCE TO DYNAMIC AND STATIC INDENTATION

Type of testing

The dynamic indentation is determined by applying an impact energy of 5.9 J by means of a given steel indentor on the exposed side of the installed product, perforation is identified by a visual recognition. Static indentation is determined by applying a given static load by means of a steel indentor to the exposed side of the product for a period of 24 hours and investigating whether the test specimen is perforated or not.

Testing conditions

The installed product shall be cured at (23 ± 2) °C and at a relative humidity of (50 ± 5) % for at least the period as prescribed by the applicant. The cured test specimens shall be conditioned at a temperature of (23 ± 2) °C and a relative humidity of (50 ± 5) % for a period of at least 16 hours.

RESISTANCE TO FATIGUE MOVEMENT

Type of testing

Resistance to fatigue movement is determined by applying the product on a specified substrate with a specified gap and investigating, after opening and closing the gap at a given speed, amplitude and temperature, the effects on the product both visually and by determining the watertightness at the area over the gap in the substrate.

Testing conditions
The test shall be carried out at a temperature of (-10 ± 2) °C.

RESISTANCE TO HEAT AGEING

Type of testing & testing conditions (figure 6)
The test is performed by exposing samples to 70ºC during 200 days in order to determine the possible effect of this exposure on various characteristics of the product, by comparative testing.

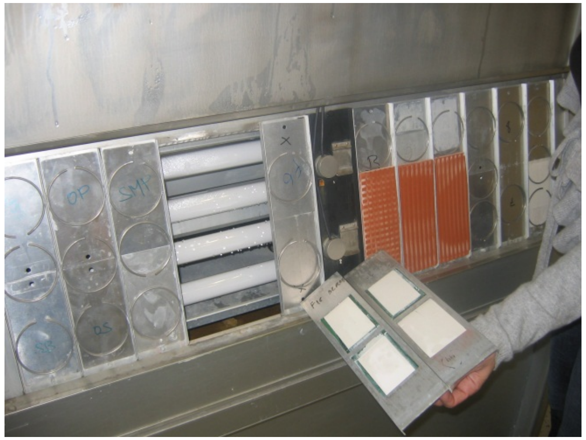


Figure 9: Resistance to heat ageing. Ref: Sika

RESISTANCE TO UV RADIATION IN PRESENCE OF MOISTURE

Type of testing & testing conditions (figure 7)
Samples are exposed in a fluorescent UV artificial weathering apparatus at a specified irradiance, black and white standard temperature, relative humidity and spray cycles. Changes in other performances are determined after 2000 hours.

Figure 10: Resistance to UV radiation in presence of moisture. Ref: Sika

RESISTANCE TO HOT WATER AGEING

Type of testing

Resistance to hot water ageing is determined by exposing the upper weathering surface of the test specimen to water at 90ºC during 30 days in order to determine the possible effect of this exposure on various characteristics of the product, by comparative testing.

Testing conditions

Attach the reservoir to the test specimen by clamping or bonding use a silicon sealant to ensure a watertight seal to the test specimen. Introduce water to a depth of 100 mm over the specimen and ensure that the water surface is covered with means to prevent evaporation. Place the test specimen and attach reservoir into the oven at the required temperature. Maintain the required temperature and the water level during the specified period of time. At the end of the exposure period remove the test specimen from the oven, discharge the water and bring the specimen back to ambient temperature. Remove the reservoir from the test specimen and maintain the test specimen at ambient temperature for 24 hours before further testing.

Product configuration
Please refer to the “testing conditions and type of testing” part.

Type of testing
Please refer to the “testing conditions and type of testing” part.

Result assessment
Results of testing in term of performance

General characteristic of the product SIKALASTIC 425 CET:

- Density: 1,35 Kg/l (according to ISO 2811-1)
- Viscosity at 20ºC: 4800 cps
- Solid content (by weight): 65% (according to ISO 3251)

List of results having been obtained within SMARTeST:

- waterproofing: no test results have been obtained within the project
  - watertightness
  - water vapor diffusion resistant

- mechanical properties:
  - adherence to the substrate
  - mechanical properties
    - ✓ elongation at break
    - ✓ maximum tensile strength
  - resistance to dynamic and static indentation: no test results have been obtained within the project
  - crack bridging

- durability:
  - resistance to fatigue movement: no test results have been obtained within the project
  - resistance to heat ageing
  - resistance to UV radiation in presence of moisture
  - resistance to hot water ageing

indirectly tested through the evolution of others properties under hot water submersion

Workability (SIKA's internal tests)
Those tests are so trivial that they have not been described hereabove.

- shelf live: 12 months
- solvent content: ok
- application: roll, brush and spray
- application temperature: 2 to 50°c
- substrate temperature: 2 to 50°c
- substrate moisture content: > 4%
- drying times at 20°c, 70% R.H.
    - rain resistant: 2 h
    - foot traffic: 5 h
    - total cure: 24 h

MECHANICAL PROPERTIES:

Elongation at Break (2000 µm dry film)	UNE 104302	390 %
Elongation at Break (film with Fleece 120)	UNE 104302	60%
Crack bridging	Internal test, pursuant to ETAG	passed
Water uptake (42/15/42days) (not described in this document)		5,3%
Capillary absorption (not described in this document)	EN10623	0,0128 $kg/m^2h^{1/2}$
Adherence on dry and wet concrete		2,7 N/m^2

crack bridging (pursuant to UNE-EN 1062-7:2004)

Thickness of the crack when it is the first alteration (µm)			
	-20ºC	-10 ºC	- 5ºC
Specimen 1	2566	2702	2745
Specimen 2	2592	2649	2722
Specimen 3	2552	2664	2729
Average	2570	2672	2732

Classification by EN 1504-2

Class	**Thickness of the covered crack (µm)**	
A1	>100	--
A2	>250	0.05
A3	>500	0.05
A4	>1250	0.5
A5	>2500	0.5

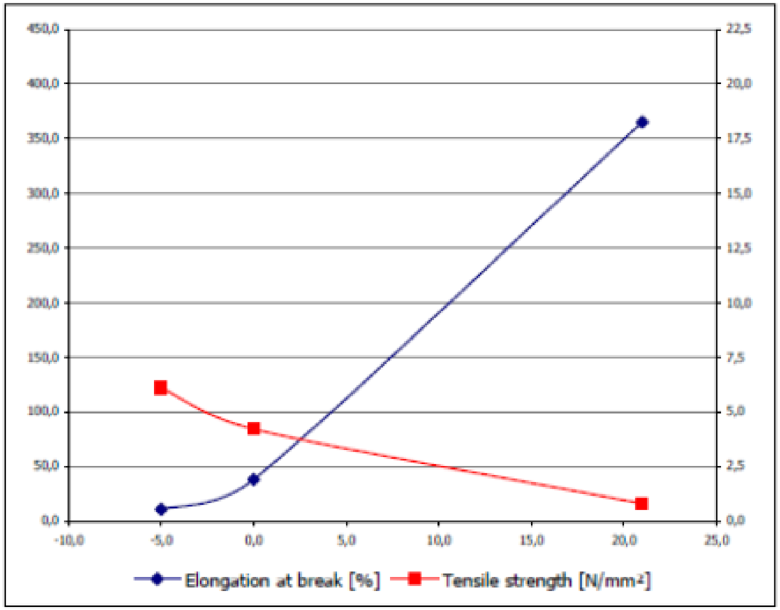
Elongation at break and tensile strength (evolution of mechanical properties against temperature)

Property	Storage (23ºC/50% rH) (days)	Test Temperature (°C)		
		-5,0	0,0	21,0
Elongation at break [%]	7	11	38	365
Tensile strength [N/mm²] 7 6,1 4,2 0,8	7	6.1	4.2	0.8
Elongation at break [%]	31	18	42	380
Tensile strength	31	7.7	4	1.2

[N/mm²]				
Elongation at break [%]	90	6	25	300
Tensile strength [N/mm²]	90	14.1	8	1.6

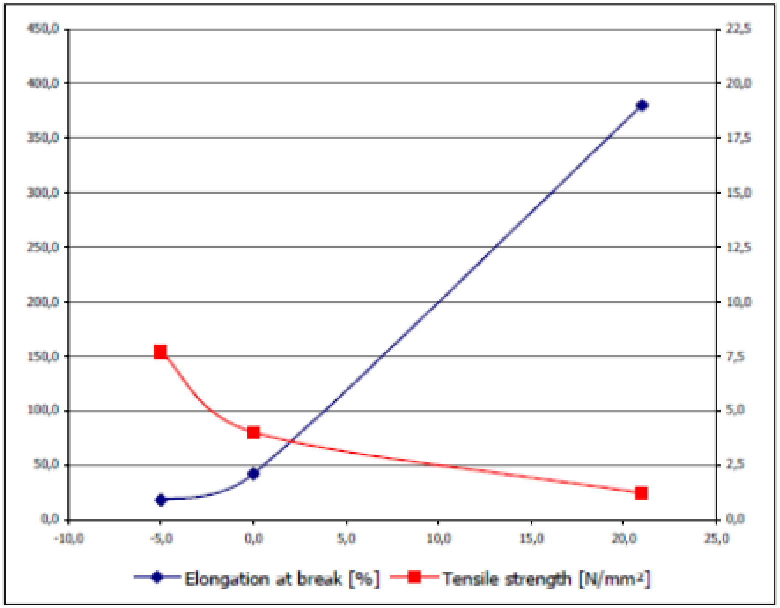
Tensile strength after 7d at 23°C / 50% rH

Test Temperature [°C]	-5,0	0,0	21,0
Elongation at break [%]	11,0	38,0	365,0
Tensile strength [N/mm²]	6,1	4,2	0,8



Tensile strength after 31d at 23°C / 50% rH

Test Temperature [°C]	-5,0	0,0	21,0
Elongation at break [%]	18,0	42,0	380,0
Tensile strength [N/mm²]	7,7	4,0	1,2



Tensile strength after 90d at 23°C / 50% rH

Test Temperature [°C]	-5,0	0,0	24,0
Elongation at break [%]	6,0	25,0	300,0
Tensile strength [N/mm²]	14,1	8,0	1,6

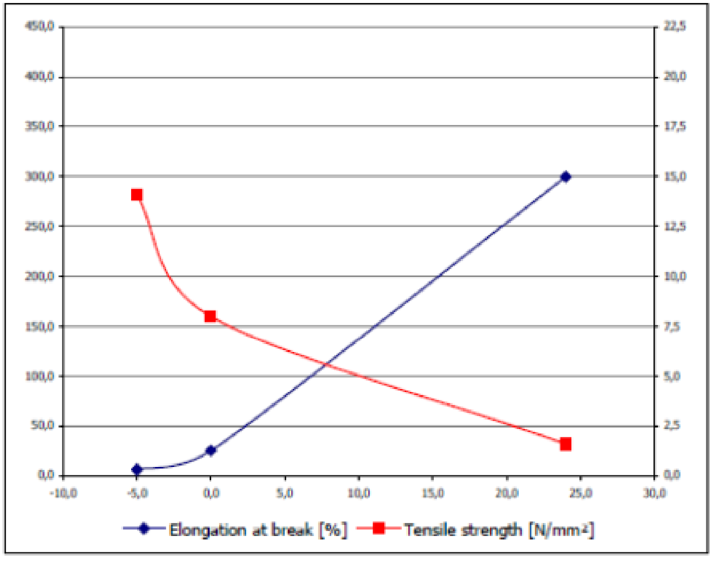


Figure 10: Climatic camera. Ref: Sika

 **Figure 11: Climatic cameras. Ref: Sika**
Suggestion for improvement

Appendix 4.3
Summary of the FRe Technologies Testing - TEIMLAM

General product description
Product description (type of product, stability characteristic, sealing characteristics, drawings, pictures, …)
Category: solid membrane/ polymer and cured composites materials. TEIMLAM is a FRe Building Technological Product made from several macromolecules of different nature and obtained from different manufacturing processes. It has been designed to constitute solid horizontal membranes, for roofs or ceilings, concrete treatment (i.e. dam repairs) and in general when waterproofing/structural resistance is required. TEIMLAM is presented as a two component liquid product (epoxy prepolymer and curing agent) or epoxy matrix, glass fiber (as reinforcing material) and optional primers and gel coats, when necessary. The glass fiber is impregnated with the epoxy matrix, after mixing both components, to obtain a weight ratio matrix/fiber of about 1/1. During a period of time between 12-24 h (it depends on temperature) the composite epoxy/glass fiber is obtained and ready to use as barrier. This particular material will be proposed for testing regarding to this application. It can also be applied to vertical barriers, if properly pre-manufactured, requiring in that case special anchors and joints depending on its particular application. Continuous rolled system, resulting from an "*in situ*" liquid Epoxy Resin impregnation of glass fiber textiles. Its polymerization, at ambient temperature, gives a solid, rolled, continuous product. Available to conform autonomous FRe panels.

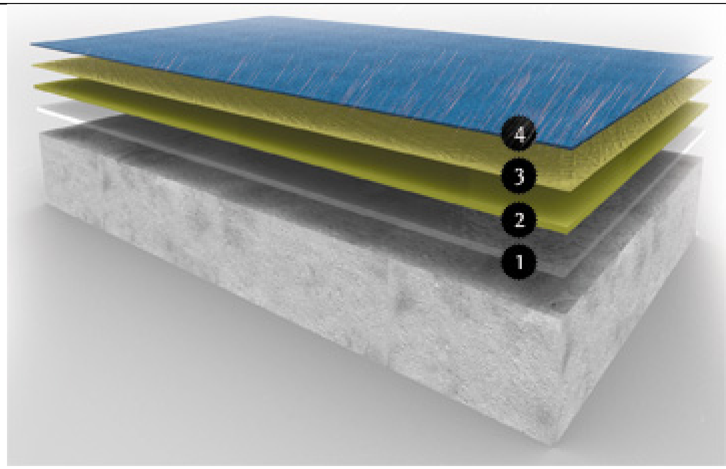


Figure 11. Teimlam1. adhesion: polymeric bond

2. elastic layer

3. epoxy- fiberglass

4. auto protection layer

Functionalities expected by this product

In order to provide flood resilience to a given existing vulnerable element, It is possible to point out the following TEIMLAM's functionalities:

- waterproofing of horizontal and subhorizontal surfaces
  - traffic loads resistant
- conform autonomous polymeric panels for barriers

To fulfill those goals, the following functionalities shall be expected from this product:

- constant elastic modulus, elongation at break and tensile strength with water
- prick resistant (traffic and foot loads)
- watertightness: It is expected that the product limits the water penetration
- water vapor diffusion resistant: to determine the water vapor transmission properties of flexible sheets for waterproofing

Others relevant but accessory functionalities to be mentioned: • adhesion: to determinate the resistance to delamination of an installed liquid applied roof waterproofing kit, partially or fully bonded to a substrate. • hot water resistant: to determine the possible effect of this exposure on various characteristics of the installed product, by comparative testing.
What is the main sales argument of this product?
TEIMLAM offers a high range of application, since it can be used as a horizontal waterproofing membrane or as an autonomous structural polymeric panel for barriers and it has even been successfully applied to dam reinforcement [see "*The use of epoxy systems in civil engineering: dam repairs*". Proceedings of the International Conference held at the University of Dundee, Scotland, UK, 11-13 September 1990. Senén Paz and others] Its composite nature reinforces highly its mechanical properties, so: • when applied as a horizontal waterproofing membrane, it shall be resistant to traffic loads • when applied as autonomous panel, it shall fulfill the tests required for barriers • it can be applied as a waterproofed reinforcement for dams (see the last reference)
Field of use and limitation
In the huge field of application of this product lies precisely the main sales argument of this product, so, please refer to this part. In short, applications range from new constructions, reparations and special constructions (dams, bridges…).Teimlam can also be use like polymeric barrier panel (prefabricated). Service life: 25 years.[1]

1 Tests have been done for a service life of 25 years.

General Testing Description
Functionalities tested

TEIMLAM's main functionalities can be highlighted through the following properties:
• waterproofing
  o watertightness
  o water vapor diffusion resistant (m, mass [mg])
• structural mechanical reinforcement:
  o adhesion (Tensile testing machine [MPa])
  o evolution of mechanical properties in presence of (hot) water (indirectly tested)

Performance criteria

TEIMLAM's main properties can be highlighted through the following criteria:
• waterproofing
  o watertightness: visual recognition with moisture indicator
  o evolution of mechanical properties in presence of water is indirectly tested at different temperatures through:
    ✓ adhesion to concrete: pull-off stress [KPa]
    ✓ static-prick resistant (not tested within SMARTeST)
  o water vapor diffusion resistant: mass of the moisture flow rate [m]
• structural mechanical reinforcement:
    ✓ adhesion: pull-off stress [KPa]

List of conditions which have an effect on the performance

Water presence:
• water pressure
  o hydrostatic loads varies with water pressure
• water state (liquid, vapor)
  o FRe membranes shall prevent liquid water transfer but allow vapor water evacuation (otherwise, indoor moisture problems may appear)

- water temperature
  - even if flood waters are usually at ambient temperature, in some specific conditions, hot water floods are imaginable
  - anyway, flood resilience tested against hot water is more adverse than ambient temperature floods

Mechanicial properties:

- anisotropy of composite materials (axes disposition during testing)
- speed of deformation (flood types dynamic/static stresses)
- temperature (specially through water absorption)
- product preparation and elaboration
- water presence

Water vapor diffusion resistance:

- thickness of the specimen (mechanical gauge)
- relative humidity and temperature (constant-temperature, constant-humidity chamber)
- air pressure

Adhesion:

- nature of the substrate
- stress speed
- temperature
- relative humidity

Type of testing, testing conditions and product configuration

Laboratory tests were conducted in the testing facility of Gairesa Company and Instituto de las Ciencias de la Costruccion Eduardo Torroja.

WATER VAPOR DIFFUSION RESISTANCE

Type of testing

In short, the water vapor diffusion resistance is tested according to a weight assessment (analytical balance) of the moisture flow rate through the test specimen. The test specimen is sealed to the open flange of a test cup containing a desiccant. The assembly is then placed in an atmosphere with a controlled temperature and humidity. When mass take-up is linear over a period of time, the assembly is weighed periodically to determine the density of moisture flow rate through the test specimen into the desiccant.

Testing facilities

- cups: use cups of pure, cold drawn aluminum of 1 mm thickness, which guarantee a free test area of 0,005 m2, total weight of specimen-mounted cup and desiccant must not exceed capability of the analytical balance used (accuracy *0,1 mg), as represented in Figure 3. “*Cups. BS EN 1931*”.

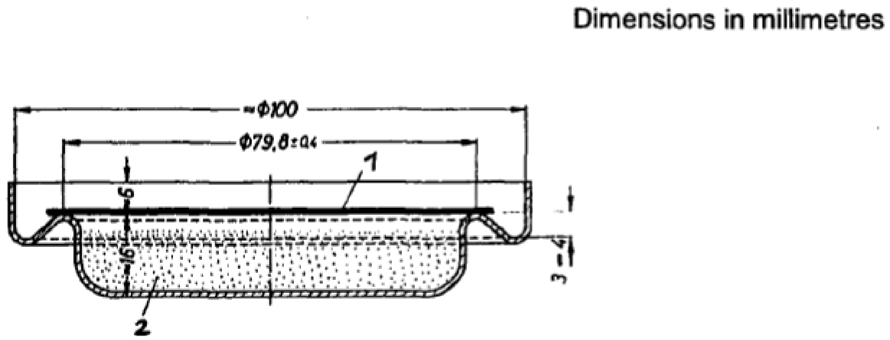


Figure 12 *Cups. BS EN 1931*

- mechanical gauge to determine the thickness d of specimen to the nearest 0,05mm ±0.I mg. (Figure 13 “*Mechanical gauge*”)

Figure 14 *Mechanical gauge*

- Analytical balance, capable of weighing the specimen-mounted cup with an accuracy of ± 0.1 mg

- Constant-temperature, constant-humidity chamber (Figure 5: “Evaporation atmosphere BS EN 1931”) capable of maintaining a relative humidity of 75±2% and a temperature of 23±1ºC. The relative humidity at the upper test specimen surface must be kept constant during test. An air movement of 0,02 m/s to 0,3 m/s in the vaporizing atmosphere shall be produced by a propeller

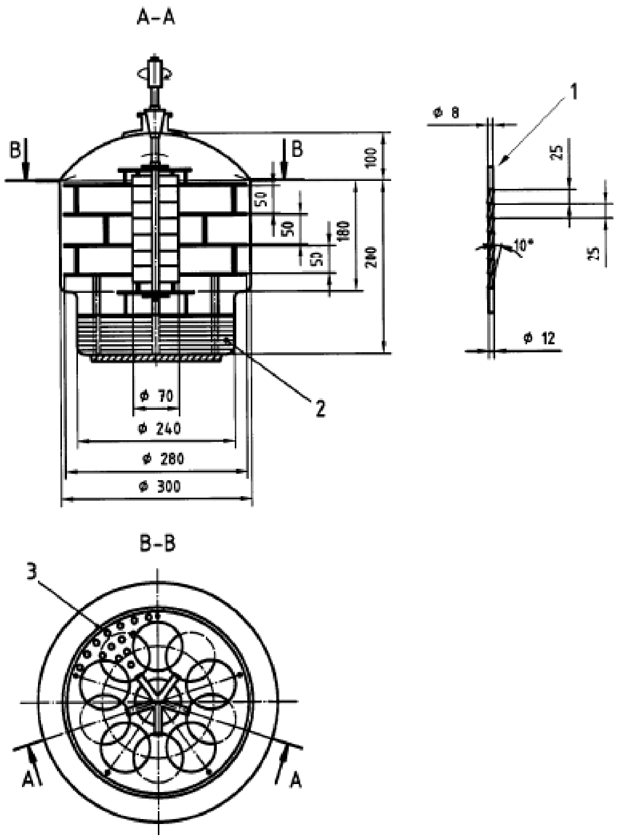


Figure 15 Evaporation atmosphere (BS EN 1931) 1 side view of the propeller with blades
2 saturated salt solution with remaining solid at the bottom
3 125 holes Φ 8 per plate

- Desiccator: for the transfer of test specimens
- Desiccant: Anhydrous calcium chloride with particles size of about 5 mm in diameter, free of fines that will pass a 600 µm sieve. The relative humidity in the cup atmosphere shall not exceed 1 %. During the test period the total mass increase of desiccant shall not be greater than 1.5 g per 25 cm3.
- Sealant: Sealing compound to create a vapour tight seal between the specimen and the cup (absorption atmosphere), e.g. extruded sealant, type Butyl or

Polyisobutylene or bituminous binder, paving grade bitumen 35/50 according to EN 12591.

- Template or sizing form: auxiliary device for the sealing procedure.
- If used during sealing procedure only, doutside = (79,8 ± 0,4)mm.
- If used also during test procedure, dinside = (79,8±0,4) mm.
- Barometer: capable of measuring barometric pressure with an accuracy of ±1 hPa.
- Number of specimens: three test specimens and one reference specimen.

Product configuration

- Circular test specimens, which are adjusted to the dimensions of the cup (d - 90 mm). The specified free surface of test specimen of 0,005 mz is equivalent to d = 79,8 mm.
- Conditioning of test specimens. After the test specimens are mounted on the cup, weigh the assembly to the nearest 0,l mg and then store at 23 "C / 75 % R.H. in the test chamber.

Testing conditions

The constant-temperature, constant-humidity chamber is used in order to ensure the following testing conditions:

- temperature: (23±1) ºC
- relative humidity: (75 ±2) %
- air convection: 0,02 to 0,3 m/s

WATERTIGHTNESS

Testing facilities

- Flanged box: To provide the requested hydrostatic pressure a metal circular flanged box is used with an aperture of 150 mm, connected to an open ended pipe or vessel which rises to a specified height or a pressure vessel. The flanged box includes a manometer and inlet and exhaust valves (Figure 16 Schematic diagram of flanged box. EOTA TR 003–). The flanged box is connected to a tap water with the addition of surfactants.

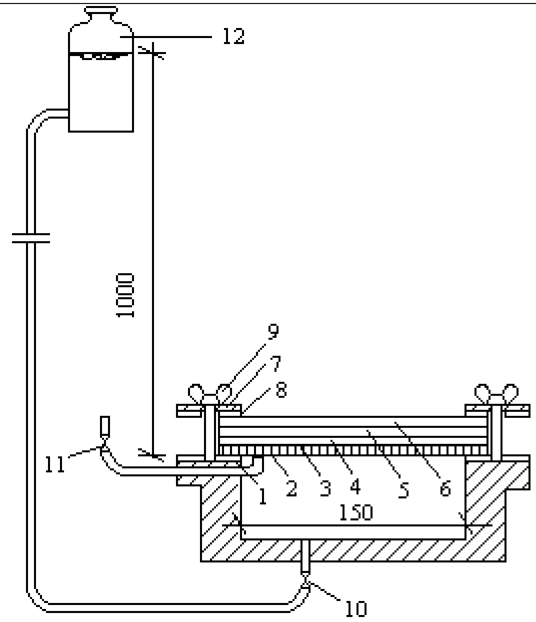


Figure 16 Schematic diagram of flanged box. EOTA TR 003–

1 – lower rubber sealing gasket; 2 - inserted test specimen; 3 – filter paper; 4 - moisture indicating mixture; 5 - filter paper; 6 – circular ordinary window glass sheet; 7 - upper rubber sealing gasket; 8 - steel clamping ring; 9 - wing nuts; 10 - water inlet valve; 11 – air exhaust valve; 12 - level / pressure indicator

- Clamping unit: Used to fix the test specimen to the aperture of the flanged box. It includes sealing gasket, steel clamping ring and wing nuts.
- Filter paper: Circular with diameter of (200 ± 2) mm.
- Moisture indicator: It is composed by a mixture of fine white (icing) sugar (99,5%) and methylene blue dye (0,5%) sieved over a 0,074 mm mesh and dried over calcium chloride in a desiccator.
- Cutter: Any suitable cutting device is used to cut circular test specimen with a diameter of (200 ± 2) mm.
- Inspection window: It is obtained by means of a circular glass sheet with a minimum thickness of 4 mm and a diameter of (200 ± 2) mm.

Product configuration

- Dimensions: The test specimen is a circular portion of the installed product having a diameter of (200 ± 2) mm.

- Number: The number of test specimens is three.

Test conditions

The product shall be cured at (23 ± 2) °C and (50± 5)% relative humidity for at least the period as prescribed by the manufacturer. The cured test specimens shall be then conditioned at (23 ± 2) °C and (50± 5)% relative humidity for a period of at least 16 hours. The test shall be carried out at (23 ± 2) °C unless otherwise specified. Place the test assembly consisting of sealing gasket, test specimen (exposed side to water), filter paper, moisture indicating mixture, filter paper, circular window glass sheet and sealing gasket respectively in the clamping unit.

ADHESION

Testing facilities

- Tensile testing machine: With suitable capacity and shall comply with EN ISO 527-1 and to a constant testing speed of (10 ± 1) mm/min. The tensile testing machine shall allow measurement of force with an accuracy of ± 1%
- Recording equipment: For measuring forces during the tensile operation
- Steel plate: with a thickness of10 mm (to resist deformation during the test)
- Accessories: Which permit self alignment of the test specimen and allow an equally distributed tensile stress
- Adhesive: Which is compatible with the roof waterproofing product and the substrate
- Cutter: A suitable cutting device is used to cut a test specimen from the installed product, with a diameter of (100 ± 1) mm

Product configuration

- Dimensions: The test specimen is the installed product including its rigid substrate and shall have a diameter of (100 ± 1) mm
- Number: The number of test specimens is five

Testing conditions

The test specimens shall be cured at (23 ± 2) °C and a relative humidity of(50 ± 5) % for at least the period as prescribed by the applicant.
After attaching the stiff plate to the test specimen the whole shall be conditioned at (23 ± 2) °C and a relative humidity of (50 ± 5) % for a period of at least 16 hours, to allow sufficient strength of the adhesive used. The test shall be carried out at a temperature of (23 ± 2) °C and a relative humidity of (50 ± 5) %, unless otherwise specified.

Figure 17 Lloyd Instruments . Test facility of adhesion test for rectangular speciments(wide:25mm ± 5% and long: 100mm±5%)
Velocity of test: 3 mm min-1

HOT WATER RESISTANCE

Flood resilient product are prone to withstand contact with water and this circumstance must be tested. Hot water contact is the most aggressive condition, specially for adhesion.

Hot water resistance is indirectly tested through the evolution of the its adhesive properties (to concrete) against different water temperatures.

Testing facilities

- Ventilated oven: Ventilated oven with temperature control in the range of 25 - 100°C to an accuracy of ± 2 °C
- Reservoir: Reservoir of a suitable size to contain the water
- Clamps: Clamps or other suitable means (e.g. adhesive and or sealant) to attach the reservoir to the test specimen
- Means to prevent evaporation: To reduce the rate of water loss

Product configuration

As explained here above, hot water resistance is indirectly tested through the evolution of the its adhesive properties (to concrete) against different water temperatures. So, regarding to the product configuration for this particular test, please refer to the adhesion testing.

APPENDIX: MECHANICAL PROPERTIES

Tested properties have been: elastic modulus, elongation at break and tensile strength. Even if the results for these tests have not been obtained within SMARTeST, the procedure to carry them out is described hereunder:

- **Determination of mechanical properties of specimens**
  - Test specimens: sheet, plate and molded plastics. Test specimens shall be prepared by machining operations, or die cutting, from material in sheet, plate, slab or similar form. Materials thicker than 14 mm must be machined to 14 mm. Specimens can also be prepared by molding the material to be tested. All surfaces of the specimen shall be free of visible flaws, scratches or imperfections. Marks left by coarse machining operations shall be carefully removed with a fine of abrasive and the field surfaces shall then be smoothed with abrasive paper. The finish sanding strokes shall be made in a direction parallel to the long axis of the test specimen. All flash shall be removed from a molded specimen, taking great care not disturb the molded surfaces. In machining a specimen, undercuts that would exceed the dimensional tolerances shall be scrupulously avoided. Care shall also be taken to avoid other common machining errors. If it is necessary to place gage marks on the specimen, this shall be done with a wax crayon that will not affect the material being tested. Gage marks shall not be scratched, punched, or impressed on the specimen. When testing materials that are suspected of anisotropy, duplicate sets of test specimens shall be prepared, having their long axes respectively parallel with, and normal to, the suspected direction of anisotropy.
  - Number of test specimens: Test eleven specimens.
  - Speed of testing: 3 mm/min
  - Conduct the tests at 23 ± 2°C and 50 ± 5 % relative humidity. Reference testing conditions, to settle disagreements, shall apply tolerances of ±1°C and ±2 % relative humidity

Figure 18 Lloyd Instruments. Testing facilities of mechanical properties test for rectangular speciments(3-5 mm and 20mm ±10%)

- **Immersion of specimens until saturation in water at two different temperatures (room temperature and 60ºC)**

  - Number of test specimens: Test eleven specimens of 76mm±10% x 25mm±10%.
  - Three specimens shall be conditioned as follows:
  - Specimens of materials whose water-absorption value would be appreciably affected by temperatures in the neighborhood of 110°C (230°F), shall be dried in an oven for 24 h at 50 ± 3°C, cooled in a desiccator, and immediately weighed to the nearest 0.001 g.
  - Specimens of materials, such as phenolic laminated plastics and other products whose water-absorption value has been shown not to be appreciably affected by temperatures up to 110°C , shall be dried in an oven for 1 h at 105 to 110°C .
  - When data for comparison with absorption values for other plastics are desired, the specimens shall be dried in an oven for 24 h at 50 $\pm$ 3°C , cooled in a desiccator, and immediately weighed to the nearest 0.001 g.

- **Analysis of tensile properties of specimens after reaching water-uptake equilibrium**

  - Test specimens: as in point 1 (Determination of mechanical properties of specimens)
  - Number of test specimens: Test eleven specimens.

- Speed of testing: 3 mm/min

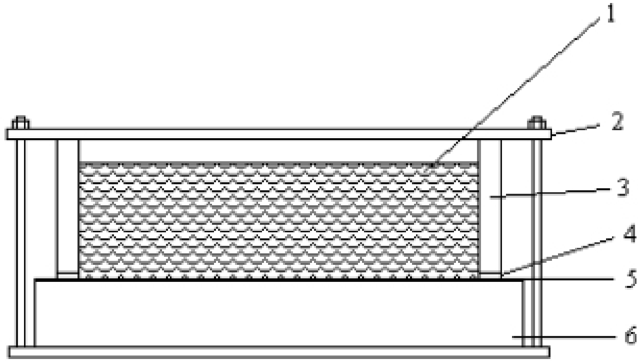


Figure 19. Schematic diagram of apparatus .EOTA TR 012
1 – water (anti-evaporation balls not shown); 2 – clamp; 3 –reservoir;
4 – sealant; 5 – liquid waterproofing system; 6 – substrate.

Product configuration

The test specimen is the installed products of the roof waterproofing kit, applied in accordance with the manufacturer's instructions to the appropriate substrate(s) having size of (300 + 50/0) mm x (300 + 50/0) mm.

Product configuration
Please refer to the “testing conditions and type of testing” part.
Type of testing
Please refer to the “testing conditions and type of testing” part.

Result assessment

Results of testing in term of performance

Water vapour diffusion resistant

- $\mu > 1.400$

Watertightness testing

- OK. It is watertight

Adhesion

- OK (>50KPa)

Hot water resistant

- After 60 days into water to 60ºC
- Adhesion to concrete: OK (>50KPa)
- Static-prick resistant

Max temperature on surface	Resistance level	
	Without protection	With protection
90ºC	L1	L3
80ºC	L2	L3
60ºC	L3	L4

Mechanical properties: the results are not available so far.

Suggestion for improvement

Appendix 4.4

Summary of the FRe Technologies Testing – MCI 2005

General product description

Product description (type of product, stability characteristic, sealing characteristics, drawings, pictures, …)

Category: corrosion inhibitor materials

Figure 20: Application of MCI 2005

MCI-2005 is a liquid concrete admixture that protects steel reinforcing, carbon steel, galvanized steel and other metals embedded in concrete from corrosion induced by carbonation, chloride and atmospheric attack. MCI-2005 protects concrete by the mean of a time-proven migratory corrosion inhibitor function (mitigation ionic transfers).

Functionalities expected by this product

In order to provide flood resilience to a given vulnerable element, It is possible to point out the following MCI 2005 functionalities:

- prevent material corrosion and deterioration under water presence
  - extend the life of all reinforced concrete structures
  - protect against the harmful effects of corrosion even in the densest concrete
  - increase the necessary electrolyte concentration required to start corrosion
- reduce the inward diffusion, water penetration, and the total effects of delaminating caused by freeze-thaw cycles on the concrete surface

What is the main sales argument of this product?

Within the FRe market, MCI-2005 is a particularly competitive product since it is highly user friendly. Its application is much quicker and easier compared to others anticorrosive products. This product, suitable even for the densest concretes, presents a versatile range of application ranging from new buildings to the reparation or refurbishment of existing structures.

Field of use and limitation

MCI® can provide solutions both to new structures (may be used for application in mass and on surface, depending on the geometry, and its use), and to deteriorated structures. In this last case, improvement are usually achieved applying to the total surface in order to stop existing corrosion processes that, excepting the removing of the coating structure, can hardly be stopped otherwise.

When incorporated into the concrete mix, Migrating Corrosion Inhibitors (MCI®) forms a corrosion inhibiting protective layer on metals. When used with repair mortars and grouts, MCI-2005 will migrate to undisturbed concrete providing effective corrosion protection to rebars already in place. MCI® used in the repair of structures affected by corrosion, allows them to have a longer life making the evolution of existing corrosion process suffers a significant delay in the same. In general, after the application of MCI®, forming a protective monolayer on the surface of the reinforcement.

General Testing Description

Functionalities tested

MCI 2005 ’s tested functionalities aims both to extend the life of reinforced concrete structures, and this effect has been assessed through two main tests:

- prevent material corrosion and deterioration under water presence (test: evolution of the corrosion current)
- protect against the harmful effects of corrosion even in the densest concrete (test: evolution of the concrete cracks)

Performance criteria

The determination of the Effect of Chemical Admixtures on the Corrosion of Embedded Steel Reinforcement in Concrete is according to ASTM G109 is determined through the following 2 performance criteria:

- crack width [mm]
- corrosion current [micro amps]

List of conditions which have an effect on the performance

The following conditions determine the "*Effect of Chemical Admixtures on the Corrosion of Embedded Steel Reinforcement in Concrete Flood action*":

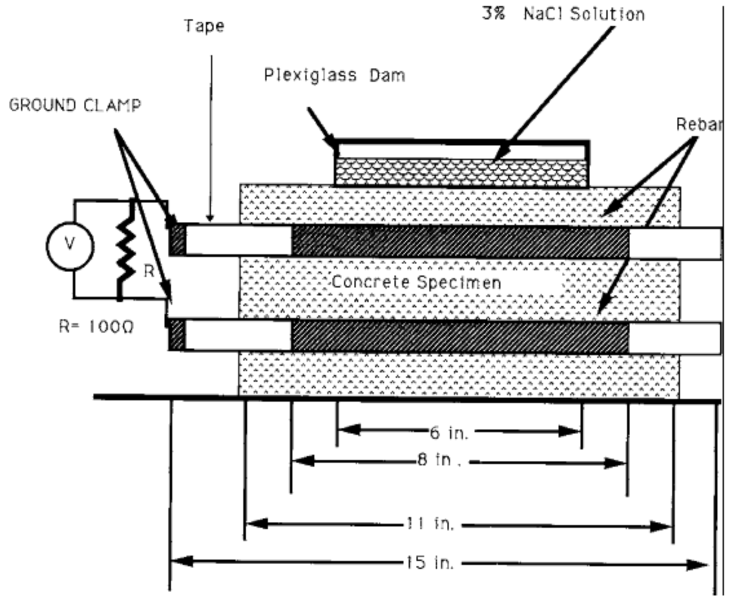
- the contribution of moisture and electrolyte (salt solution)
- the presence of oxygen
- the alternation of subaerial and sub aquatic cycles
- the type of cement
- the width of the concrete coating

Testing conditions

Laboratory tests were conducted in the testing facility of American Engineering Testing, INC. The test carried out has been the determination of the Effect of Chemical Admixtures on the Corrosion of Embedded Steel Reinforcement in Concrete Flood action

Apparatus

- The apparatus required for the evaluation of corrosion inhibitors includes a high impedance voltmeter (at least one Mohm) capable of measuring to 0.01 mV, a 100 Ω (65 %) resistor.
- Steel Reinforcement Bars, deformed, with a diameter between 10 mm and 16 mm, and a length of 360 mm (14 in.), drilled and tapped at one end to be fitted with coarse-thread stainless steel and nuts



NOTE—All measurements in inches (not to scale) (25.4 mm = 1 in.).

Figure 21. ***Concrete Beam (ASTM G109)***

Product configuration

Preparation of Test Specimens

- Power wire brush or sand blast the bars to near white metal, clean by soaking in hexane, and allow to air dry
- Drill and tap one end of each bar, attach a stainless steel screw and two nuts, and tape each end of the bar with electroplater's tape so that a 200-mm. portion in the middle of the bar is bare. Place a 90-mm. length of neoprene tubing, over the electroplater's tape at each end of the bar, and fill the length of tubing protruding from the bar ends with the two-part epoxy
- Specimen size is 280 x 150 x 115 mm .Place two bars, 25 mm from the bottom, and one bar at the top such that the distance from its top to the top surface of the specimen is twice the maximum aggregate size, as shown in figure 2

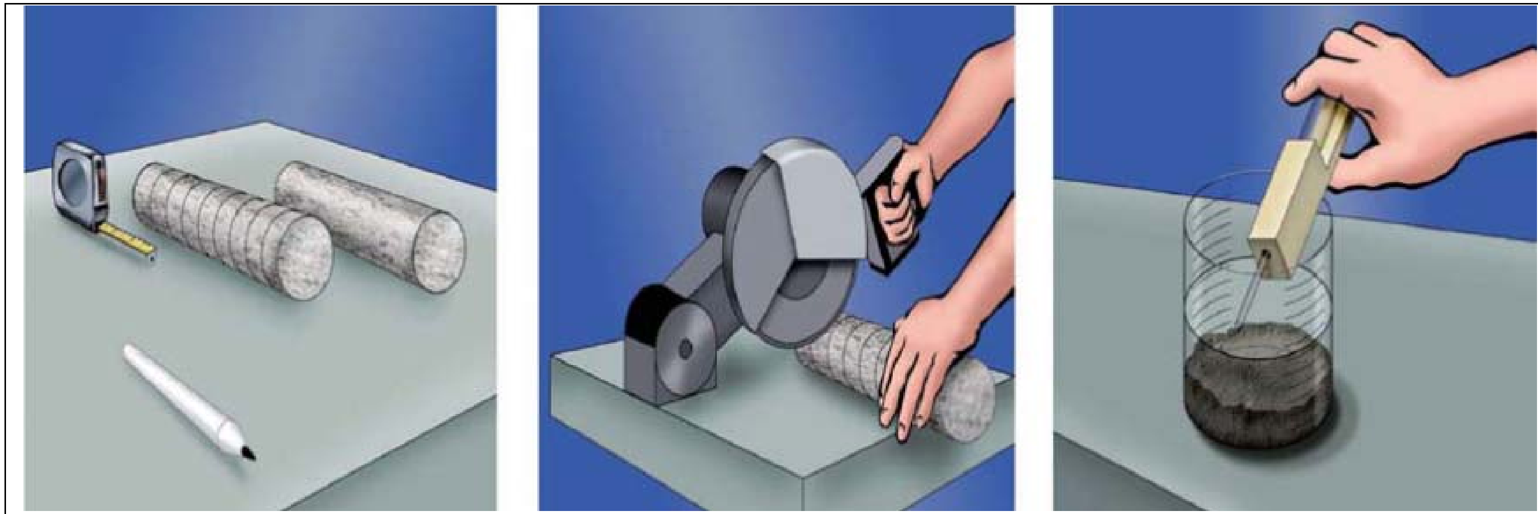


Figure 22: Test of ASTM G109. Ref: Quimilock

• Place the bars in the molds so that 40 mm of the bars are protected within each exit end from the concrete (minimizes edge effects). This will expose 200 mm of steel. Place the bars with the longitudinal ribs so that they are nearer the side of the beam, that is, both ridges are equidistant from the top or bottom of the specimen

Make the concrete specimens (controls and those with admixtures to be tested) in accordance with Practice ASTM C192/ASTM C192M, using the same source of materials. Determine the air content, using either Test Method ASTM C231 or ASTM C173/ASTM C173M. The water-to-cement ratio (w/c) shall not exceed 0.5. The minimum slump is 50 mm. Place and consolidates the concrete in the molds containing the bars in accordance with Practice C192/C192M

Support each test specimen on two nonelectrically conducting supports at least 13-mm (0.5-in.) thick, thus allowing air flow under most of the specimen. Start the test one month after the samples are removed from the 100 % RH atmosphere (moist room). Pond the specimens for two weeks at 23 6 3°C (73 6 5°F) with the salt solution, as described in 5.10. The volume of this solution is approximately 400 mL at a depth of 40 mm (1.5 in.). Use a plastic loose fitting cover to minimize evaporation. Maintain a relative humidity around the specimens of 50 6 5 %. After two weeks, vacuum off the solution and allow the samples to dry for two weeks. Repeat this cycle.

Connect the voltmeter between the reference electrode (ground or common terminal) and the bars.

Type of testing
The test consists in the measurement of the voltage across the resistor using the voltmeter. At the same time, the corrosion potential of the bars against a

reference electrode that is placed in the dam containing the salt solution shall be measured (see Practice G3 and Test Method ASTM C876).

Result assessment

Results of testing in term of performance

According to the 2 parameters selected to analyze the effect of anticorrosive, that we remind were:

- crack width [mm]
- corrosion current [micro amps]

the results of the Effect of Chemical Admixtures on the Corrosion of Embedded Steel Reinforcement in Concrete Flood action are:

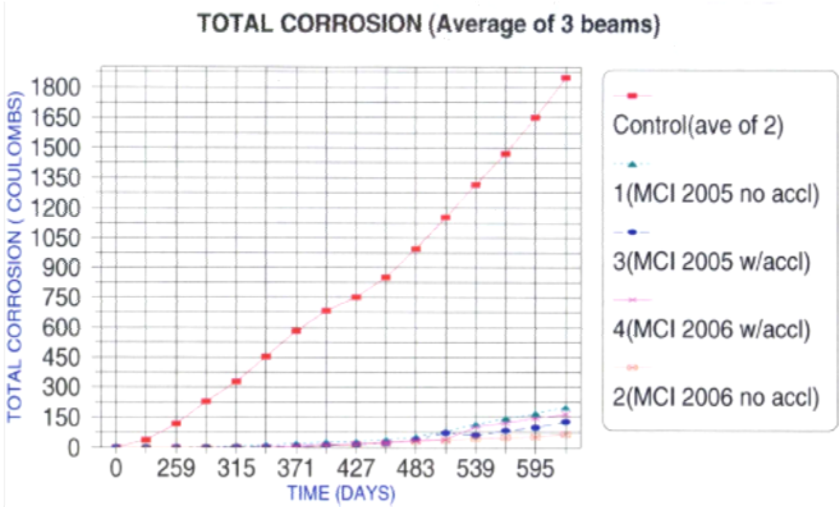
Concrete	Time to Corrosion, days	Corrosion Current, microamps
Control	259	57
MCI 2005	511	13
MCI 2005/accelerator	483	10

A longitudinal crack formed in a control concrete beam at 371 days. The cracks width has been monitored and was following data has been recorded:

Time (days)	Crack Width
371	< 0.001”
413	0.005”
486	0.010”
623	0.015”

No cracks are observed in the MCI concrete beams.

The test indicates MCI generally doubles the time to onset of corrosion. Once corrosion starts, the rate is for time less. The tests will be continued and we will provided additional information as it becomes available



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Suggestion for improvement

Appendix 5 – Summary of Testing of Infrastructure Technologies

Summary of the FRe Technologies Testing - Flood Angel Non Return Road Gully

General product description

Product description (type of product, stability characteristic, sealing characteristics, drawings, pictures, …)

An innovative product to alleviate flash flooding in urban areas by dealing with road flooding. The technology works using the power of floodwater to prevent water from backing up when roads suffer pluvial flooding. If water backs up in the pipe system, the flap closes, preventing it from passing any further. The non-return road gully is a permanently installed resilient technology that requires no human intervention or warning system.

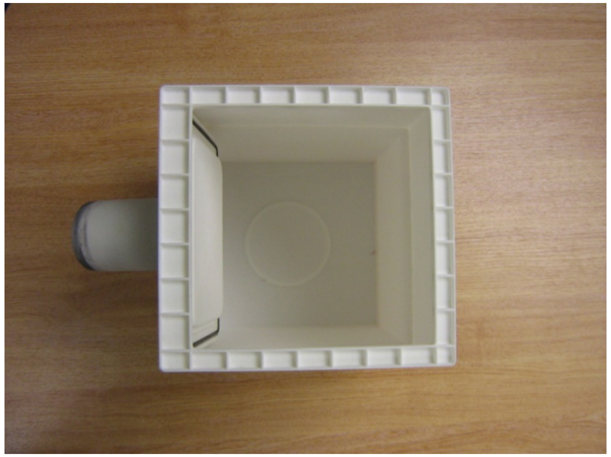

Figure 1: Non-return Road Gully in passive state

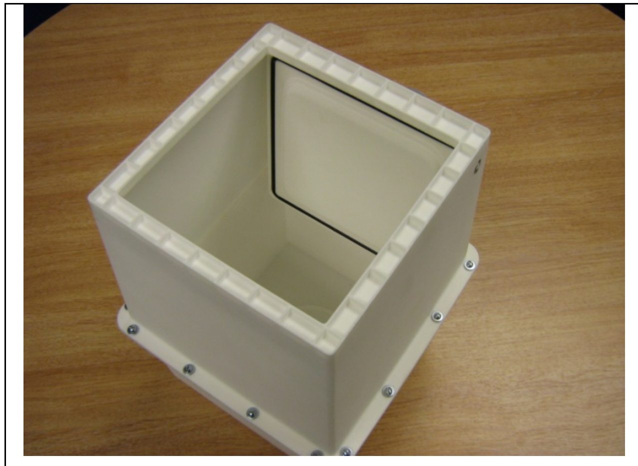

Figure 2: Non-return Road Gully in passive state

Figure 3: Non-return Road Gully in active state

Functionalities expected by this product
Water-tightness: It is expected that the product will be water tight when in its active state, preventing water from backing up in the pipe or sewer system. Stability: It is unlikely that the product is unstable if installed correctly. Readiness: Once installed, no further action is required in the event of a flood.

What is the main sales argument of this product?

The main sales argument is that it is a ‘fit and forget’ product. It is permanently installed and works automatically using the power of floodwater with no need for human interaction.

Field of use and limitation

The road gully is suitable for use in all road gullies where flooding is a potential problem.

General Testing Description

Functionalities tested

Water-tightness

Performance criteria

Water-tightness is determined by the ability for the non-return road gully to prevent water backing up in the sewer or pipe system. The closing valve and all other parts should remain watertight at all times.

List of conditions which have an effect on the performance

Water-tightness:

- Flood action (water pressure, wave, currents, sedimentation)
- Product wear
- Environment (i.e. salt, chemical reactions)
- Climate

Testing conditions

The Flood Angel Non-return Road Gully was tested at Environmental Enterprises Ltd. BSI approved test centre. The centre is capable of testing products in flood simulated conditions at depths of up to 1 metre, with wave simulation and water speeds of up to 1.5 metres/second.

Product configuration

The Non-return Road Gully was installed in a section of pipe work, as it would be in a ‘real’ situation.

Type of testing

Assessment of water-tightness:

- Static water test

During the static water test, slow rising flood waters are simulated to 300mm, 600mm, 900mm and 1000mm depth. At each level the water is allowed to stand for 72 hours. Leakage and visual inspections are carried out during this time and recorded at 18 hours, 48 hours and at the end of testing.

- Wave and current simulation test

During the wave and current simulation tests, at each of the above levels, a current is introduced to a maximum of 1.2m/s. This is measured using VS100 flow meters over a six hour period. At the above level, waves (height 100mm ±10mm) were also introduced for a period of six hours.

Result assessment

Results of testing in term of performance

During the static water test, no water passed through the non-return valve when it was sealed. No damage was seen to be done to any parts of the FARG as a result of the testing.

At the end of each cycle of wave and current simulation, records were taken and no leakage was observed.

The test operator was satisfied that the test conditions were more rigorous than the potential operation environment and as such the FARG would be suitably capable in a real flood event.

Suggestion for improvement

The Flood Angel Non-return Road Gully was seen to perform to above expected 'real' standards and as such no improvements are deemed necessary.

Input for WP4

For modelling of the FARG, no time for installation in the event of a flood would need to be considered. In a flood event, water would be prevented from backing up through the sewer system, but to model the flood depths effectively, the drainage capacity of the sewer system would have to be known.

If installed correctly, the FARG should not allow any water to back up, and can be said to watertight.

Input for Objective 2.3

The executed tests demonstrate that:

- This standardised approach could be used to test other drainage products.
- The test operator was satisfied that the test results were more rigorous than expected 'real' situations and by passing has shown that the FARG would remain watertight in a flood event.

I consent to the publication of the above summary of the testing of the **Flood Angel Non-Return Road Gully**, as part of the SMARTeST EU FP7 Project.

Name: FRANK KELLY

Signed:

Date: 15/08/2012.

Appendix 6 – Summary of Testing of Building elements

Report on laboratory testing of building constructions concerning their flood vulnerability

Leibniz-Institute for Ecological Urban and Regional Development

Content

1. Introduction

1.1 Background

Flood resilience strategies are becoming an increasingly important issue in flood risk management in Europe as they seek to mitigate the vulnerability of receptors exposed to flooding. Significant receptors within flood prone built-up areas are, amongst others, buildings with their many constructive forms. Building vulnerability thus has a strong effect on economic losses. Key criteria for the implementation of flood resilience measures (FRe M) are their potential to improve the resilience of building. For this purpose detailed knowledge about the effects of FRe M in terms of vulnerability mitigation is indispensible. Within the EU-research project "Smart Resilience Technology, Systems and Tools" (SMARTeST) innovative and smart flood resilience technologies have been identified and tested by experimental studies with regard to their reliability and level of performance. In addition laboratory investigations are undertaken to determine the physical vulnerability of selected wall and floor constructions to find appropriate engineering resilient solutions at property level. It is obvious, that no reliable data is available up to present date and that there is a lack of knowledge concerning this issue.

1.2 Purpose

The main purpose of this report is to provide baseline information on the flood resilience properties of selected building construction elements. Although there is a broad range of flood resilience technologies (FRe T) available at the market such as flood barriers and flood guards, which should avoid floodwater entering a building, there can be nevertheless a significant risk that constructions in flood-prone areas have to cope with floodwater. In this case the design of flood resilient constructions is an appropriate approach to mitigate flood damage. That means this report aimed at obtaining a basic understanding of how buildings behave when exposed to floodwater. Hence, this is a sound basis to give recommendations for the construction of new buildings as well as for a sustainable repair/refurbishment of existing buildings. In addition to susceptible building services like heating and electrics particularly external wall and floor constructions are the most relevant building constituents that have a high impact on the degree of flood damage (Naumann et al. 2009). Within a joint research project in UK between Communities and Local Government and the Environment Agency that was co-ordinated by the Department for the Environment, Food and Rural Affairs the resilience properties of selected wall and floor arrangements have been already analysed particularly for traditional English building constructions (Escarameia et al. 2006, Bowker 2007, Escarameia et al. 2007). A report of Gamerith and Höfler (2006) describes planning principles for new buildings in flood-prone areas and provides guidance on adapting existing buildings to mitigate their flood vulnerability. Of course there is a considerable amount of physical parameters on material properties such as water absorption in literature, but information on how the materials interact in composite construction is very sparse. It is obvious that the behaviour of a composite wall or floor construction cannot be analysed solely from the behaviour of its constituents. In addition, damage processes induced by flooding such as change in strength properties, change in modulus of elasticity, volume expansion due to freeze-thaw cycles, higher thermal conductivity, et cetera are often not analysed in detail. Therefore a first series of model test is undertaken in the hydraulic engineering laboratory[1] at the Dresden University of Technology covering common wall and floor constructions to determine their performance in case of flooding.

[1] Hubert-Engels-Laboratory

2. Potential damage processes due to flooding

Floodwater is often contaminated by untreated sewage, biological and chemical substances, or heating oil, which can considerably affect the performance of building construction. In order to reduce the diversity of damage processes, we authors focus in this section only on not contaminated floodwater. The identification and classification of relevant floor-induced damage processes is a fundamental requirement for a better understanding of material behaviour and for enhancing the resilience properties of building constructions. Hence, primarily the exploration of failure mechanisms in usual building materials is required. When building materials are exposed to flood water, they usually take on moisture, because of their capillary porous structure. Moisture can migrate by various modes of moisture transport, such as vapour transport, liquid transport, and phase changes. In principal, any moisture transport process depends on a potential difference as a driving force. Depending on the building material, the resulting moisture content can cause severe damage and can have a considerable negative influence on several material parameters such as change in strength properties, change in modulus of elasticity, volume expansion due to freeze-thaw cycles, or higher thermal conductivity. This can lead among others to stress cracking that in turn results in increased susceptibility to water penetration. There are very few building materials and composite constructions, which are not vulnerable to some form of moisture attack. The two columns in the middle of the scheme in Fig. 1 describe potential failure mechanisms; in contrast the right column refers to the failure effects. The complete causal chain from failure mechanisms to failure effects is called damage process. Through review on relevant literature the wide range of damage processes is confirmed (e.g. ATSM 1982). This systematic analysis of physical phenomena is a necessary basis for the development of engineering approaches to enhance the resilience particularly of composite building constructions such as wall and floor arrangements.

3. Description of test specimen

3.1 Overview

The detailed specifications of wall and floor arrangements, to be tested regarding their flood vulnerability, were proposed by the Leibniz-IOER. The following arrangements are all common constructive solutions that mean they are all representatives of usual construction practice and they are all standardized. Information on the specifications of the test specimen is obtained from relevant professional literature and from DIN-standard[2]. All arrangements consist of individual materials combined in composite wall and floor constructions. The tested set of wall arrangements is:

- **W1**: Double shell masonry of sand-lime bricks with heat insulation and air space
- **W2**: Single shell masonry of hollow bricks with external heat insulation and ventilated curtain façade

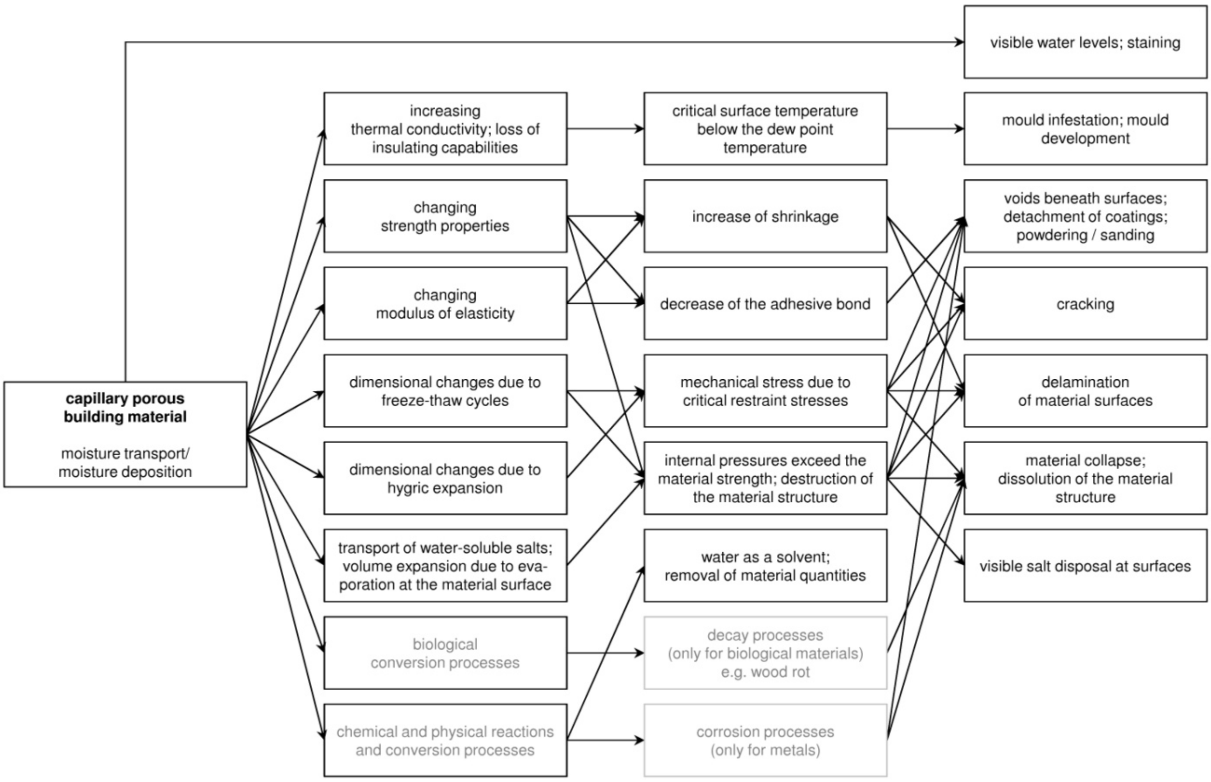

Fig. 1: Scheme of potential flood damage processes.

- **W3**: Single shell masonry of traditional solid bricks
- **W4**: Single shell wall of light (aerated) concrete blocks with thermal insulation composite system

The geometry of all four test specimen is 50x50 cm (width x high), whereupon the thickness of the composite construction depends only on structural and physical needs. In the following two sections the tested construction elements and their constituent materials are described in detail.

[2] DIN is the abbreviation for “Deutsches Institut für Normung” (German Institute for Standardisation)

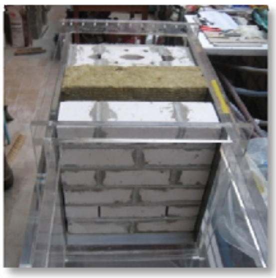

Fig. 2:
Wall arrangement W1

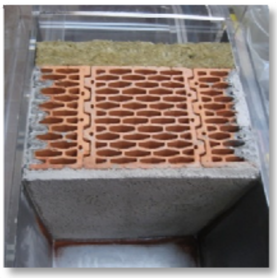

Fig. 3:
Wall arrangement W2

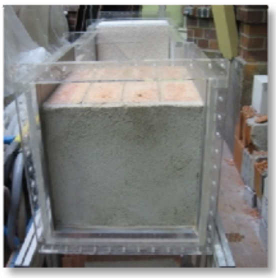

Fig. 4:
Wall arrangement W3

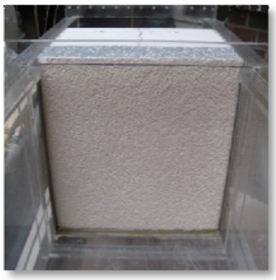

Fig. 5:
Wall arrangement W4

In addition two common floor types are tested:

- **F1**: Timber floor
- **F2**: Concrete floor

Fig. 6: Floor arrangement F1

Fig. 7: Floor arrangement F2

3.2 External wall constructions

3.2.1 Double shell masonry of sand-lime bricks with heat insulation and air gap

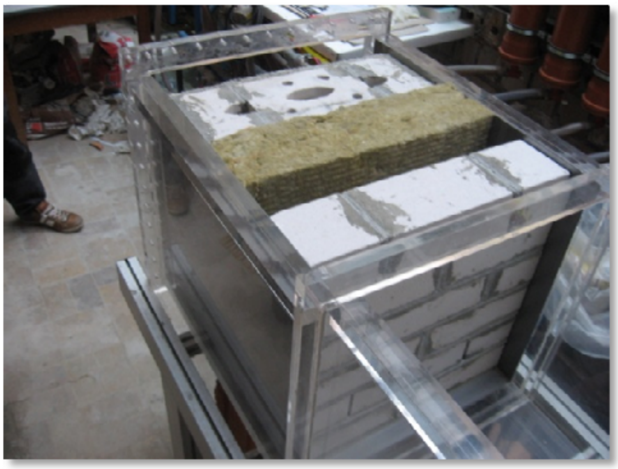

Fig. 8: Composite wall construction; double shell masonry of sand-lime bricks with heat insulation.

Double shell masonry is usually a rain-proof wall construction, even for higher driving rain loads. The restriction of moisture passing through the wall was initially the main reason for the development of this wall construction. The test specimen consists of an internal load bearing masonry of sand-lime bricks that have a width of 17.5 cm (cf. Fig. 8). On the inside of the wall a lime-cement plaster is applied. The exterior shell consists of fair-faced sand-lime brick masonry. This facing wall has a thickness of 11.5 cm. The butt joints of their first brick course are not all filled with mortar. These openings are provided for both the ventilation of the air space and the drainage of penetrated rain water. Following the German DIN 1053 standard the distance between the interior shell and the exterior shell must not be greater than 15 cm. For compliance with the requirements for thermal insulation, 11 cm thick mineral fibre insulation is used. To fasten the insulation in place appropriate fixings are used. The air gap between heat insulation an exterior shell has a width of 4 cm. The sand-lime bricks of the interior and exterior shells are bind together with cement mortar. A horizontal and vertical cross section of the composite construction is shown in Fig. 9.

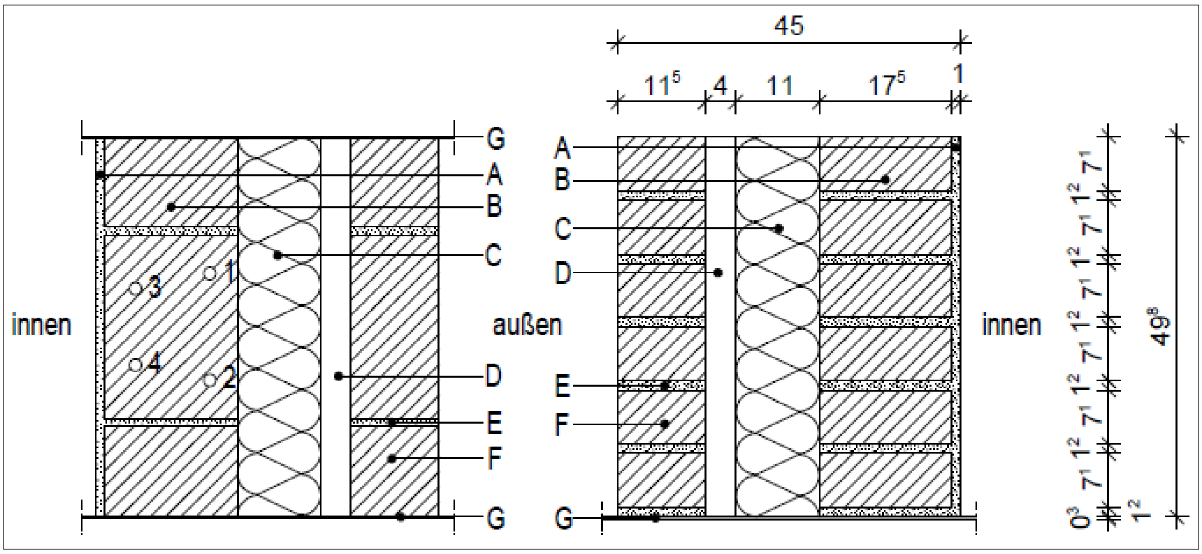

Fig. 9: Composite wall construction; double shell masonry of sand-lime bricks with heat insulation; Left: horizontal cross section, Right: vertical cross section (A) Lime-cement plaster, (B) Sand-lime bricks (interior shell), (C) Mineral fibre insulation, (D) Air gap, (E) Cement mortar, (F) Fair-faced sand-lime bricks (exterior shell), (G) Steel plate

3.2.2 Single shell masonry of hollow bricks with external heat insulation and ventilated curtain façade

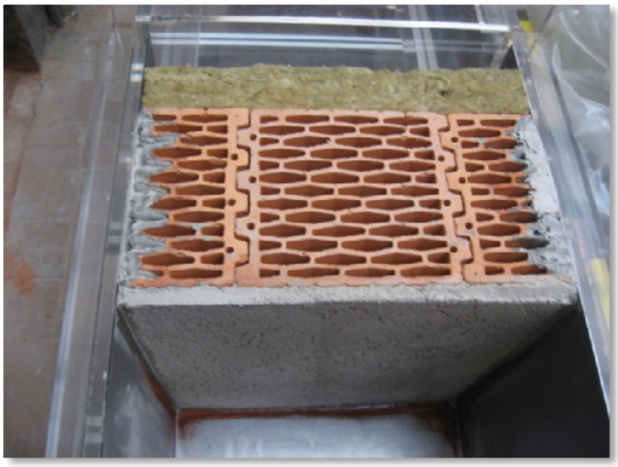

Fig. 10: Composite wall construction; single shell masonry of hollow bricks with external heat insulation and ventilated curtain wall; the curtain façade board is not yet mounted here.

The structural layer of this external wall construction consists of 24 cm thick hollow bricks. A non-structural, opaque curtain façade of fibre cement boards is covering the construction on the outside. The curtain wall is ventilated and has an air space of 3 cm. For compliance with the requirements for thermal insulation, 7 cm thick mineral fibre insulation is applied on the outside of the composite construction. The hollow bricks have the nominal size of 240x247x249 mm. A lime-cement plaster is used for the internal wall covering. The large-sized hollow bricks are bind together with thin bed masonry mortar, which is approximately 2 mm thick, to create a tight bond between the bricks. The hollow brick are joined together using a tongue and groove formation (cf. Fig. 10) – one brick side has a slot and the brick opposite will have a narrow groove that fit together. Hence, there is no need to mortar the butt joints. A horizontal and vertical cross section of the composite construction is shown in Fig. 11.

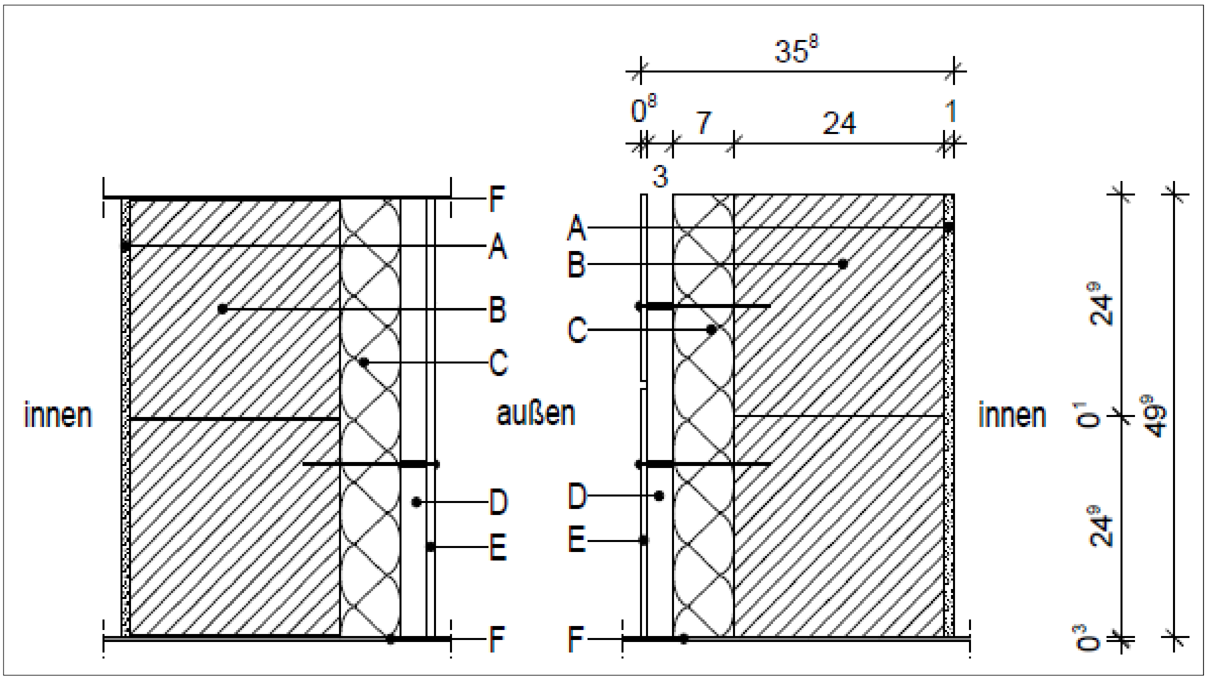

Fig. 11: Composite wall construction; single shell masonry of hollow bricks with external heat insulation and ventilated curtain wall;
Left: horizontal cross section, Right: vertical cross section
(A) Lime-cement plaster, (B) Large-sized hollow brick, (C) Mineral fibre insulation, (D) Air space, (E) Curtain wall (fibre cement board), (F) Steel plate

3.2.3 Single shell masonry of traditional solid bricks

This test specimen is a characteristic solid masonry wall construction for residential properties, which became common practice for the construction of exterior walls particularly between 1870 and 1914. The construction consists of traditional solid bricks with no cavity. The nominal size of the used bricks is 240x115x71 mm. The masonry has a thickness of two bricks that equates to a width of 50 cm. The pattern in which the bricks are laid here is called English bond. This is the most commonly used bond, for all wall thicknesses. The bond has two alternating courses of stretchers and headers, with the headers centred on the stretchers, and each alternate row vertically aligned (cf. Fig. 12). All bed and butt joints are filled with lime-cement mortar to create a tight bond between the bricks. Lime-cement plaster is used for coating the inside as well as the outside of the solid masonry wall. A horizontal and vertical cross section of the composite construction is shown in Fig. 13.

Fig. 12: Composite wall construction; single shell masonry of traditional solid bricks during the construction phase.

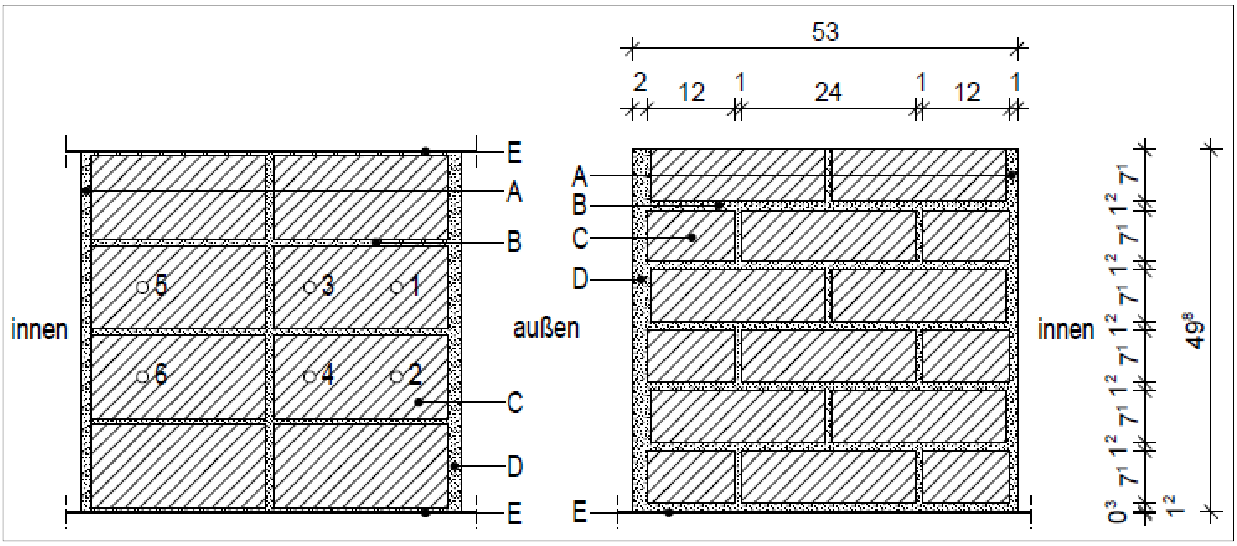

Fig. 13: Composite wall construction; single shell masonry of traditional solid bricks during construction
Left: horizontal cross section, Right: vertical cross section
(A) Lime-cement plaster, (B) Lime-cement mortar, (C) Solid bricks, (D) Lime-cement plaster, (E) Steel plate

3.2.4 Single shell wall of light (aerated) concrete blocks with thermal insulation composite system

Fig. 14: Composite wall construction; single shell wall of light (aerated) concrete blocks with thermal insulation composite system.

This exterior wall construction consists of light (aerated) concrete blocks, which have in this case a width of 17.5 cm. Although the aerated concrete blocks are highly thermally insulating, it is necessary to add an external thermal insulation composite system (ETICS) to comply with the actually requirements for thermal insulation. The ETICS consists of 10 cm polystyrene rigid insulation boards, basecoat mortar, fibreglass plaster reinforcing mesh, and finishing mortar. The large-sized hollow bricks are bind together with thin bed masonry mortar, which is approximately 2 mm thick, to create a tight bond between the bricks. The hollow brick are joined together using a tongue and groove formation (cf. Fig. 14) – one brick side has a slot and the brick opposite will have a narrow groove that fit together. Lime-cement plaster is used for coating the inside of the masonry wall. A horizontal and vertical cross section of the composite construction is shown in the following Fig. 15.

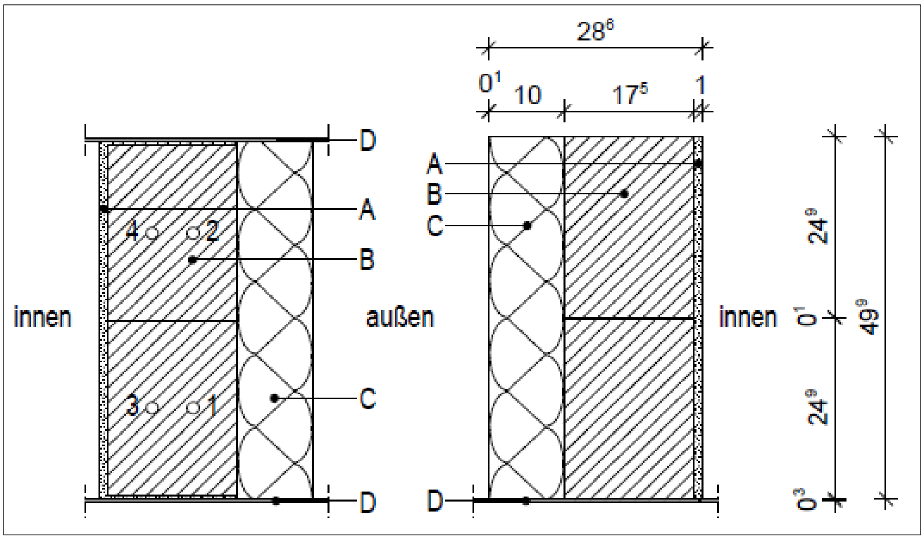

Fig. 15: Composite wall construction; single shell wall of light (aerated) concrete blocks with thermal insulation composite system.
Left: horizontal cross section, Right: vertical cross section
(A) Lime-cement plaster, (B) Aerated cement blocks, (C) Thermal insulation composite system, (D) Steel plate

3.3 Floor constructions

3.3.1 Timber floor

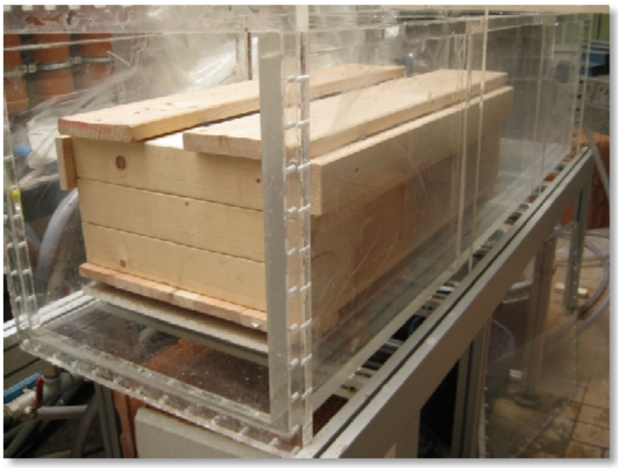

Fig. 16: Suspended timber floor; test arrangement consisting of structural joists, heat and sound insulation, plasterboard ceiling, and covering floor boards

Suspended timber floor constructions are often considered to be the most appropriate approach particularly for residential buildings, because of their low price, low dead loads, and well thermal insulation properties. Nevertheless timber floor constructions have been almost entirely supplanted by solid floors, even in residential construction, because of their insufficient sound insulation and fire safety. The tested floor arrangement represents a usual construction at the beginning of the 20th century. It consists of structural timber joists that have here a cross-sectional area of 10 cm by 24 cm. It was agreed to analyse one segment of the floor construction. The distance between two parallel floor joists is 80 cm (centres). The thermal (and sound) insulation is placed between the floor joists and is supported on boarding, which is in turn secured by to the joists by timber fillets. Floorboards, which have a thickness of 2.5 cm, are fixed on the joists and provide the walking surface. A suspended plasterboard ceiling is the finished surface concealing the underside of the floor construction. A vertical cross section of the composite construction is shown in the following Fig. 17.

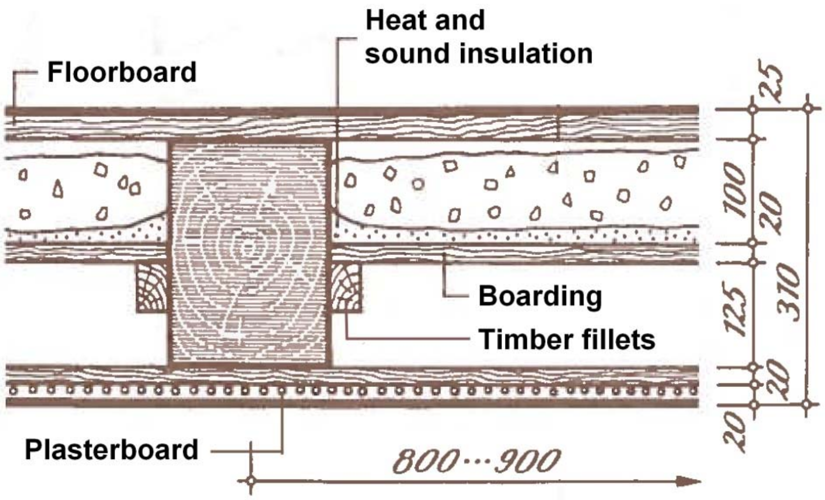

Fig. 17: Cross-section of the timber floor

3.3.2 Concrete floor

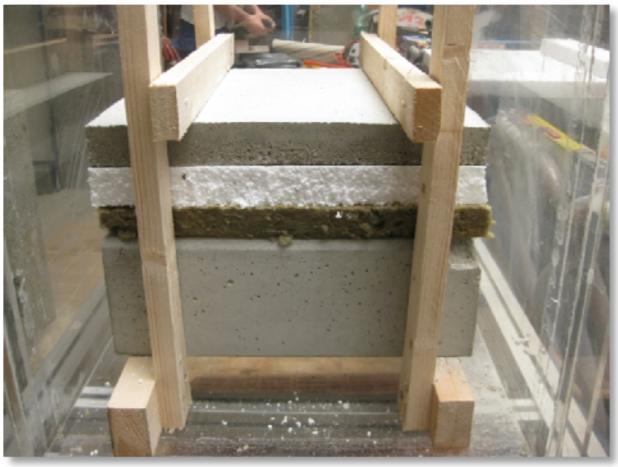

Fig. 18: Cross section of the tested composite floor construction; bottom-up: reinforced concrete floor, footstep sound and heat insulation, cement screed, carpet. The timber frame prevents the floating of constituents.

For decades, reinforced concrete floors represent the vast majority of all new built floor constructions and become standard, because they can be executed economically and it is easy to achieve the necessary fire safety and an adequate sound insulation. The tested floor arrangement has the dimension of 40 cm by 40 cm (base) and consists of a monolithic reinforced concrete slab having a thickness of 14 cm, which is responsible for the load transfer. The compressive strength class of the used concrete is C20/25[3]. The finished surface concealing the underside of the floor construction is made of a lime-cement plaster coating. 4 cm footstep sound insulation panels made of mineral fibre are arranged above the reinforced concrete slab. For compliance with the requirements for thermal insulation, 6 cm thick expanded polystyrene (EPS) rigid foam boards are applied underneath the 4.5 cm thick cement screed. The floor covering, which is applied over the floor structure and that provide a walking surface, is made of carpet. A vertical cross section of the composite construction is shown in the following Fig. 19.

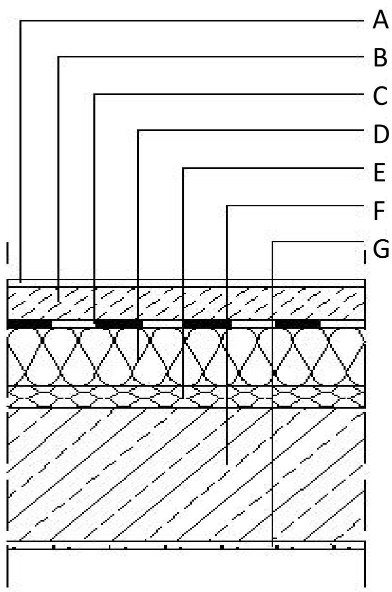

Fig. 19: Cross-section of the tested concrete floor;
(A) Floor covering (carpet), (B) cement screed, (C) Separation layer (PE-film), (D) heat insulation (EPS), (E) footstep sound insulation (mineral fibre), (F) reinforced concrete plate, (G) lime-cement plaster.

[3] Classes of compressive strength are defined in the European standard for concrete, EN 206-1. The cement, used for the production of this concrete, has the strength class 32.5 (cf. European standard for cement EN 197-1).

4. Test set-up

4.1 Test Facilities

The overall water-tight tank used for the tests is made of transparent acryl glass, so that processes such as seepage flow can be closely observed during the test runs. The specific geometry of the water tank enables to examine simultaneous two constructions per test run. Its design can be seen in the schematic diagram in Fig. 20. The inside of the water tank has a length of approximately 200 cm, a high of 50 cm, and a width of 50 cm. Two frames increase the rigidity of the tank construction. The front and back panel of the water tank can be removed for the in-situ construction and deconstruction of the test arrangements.

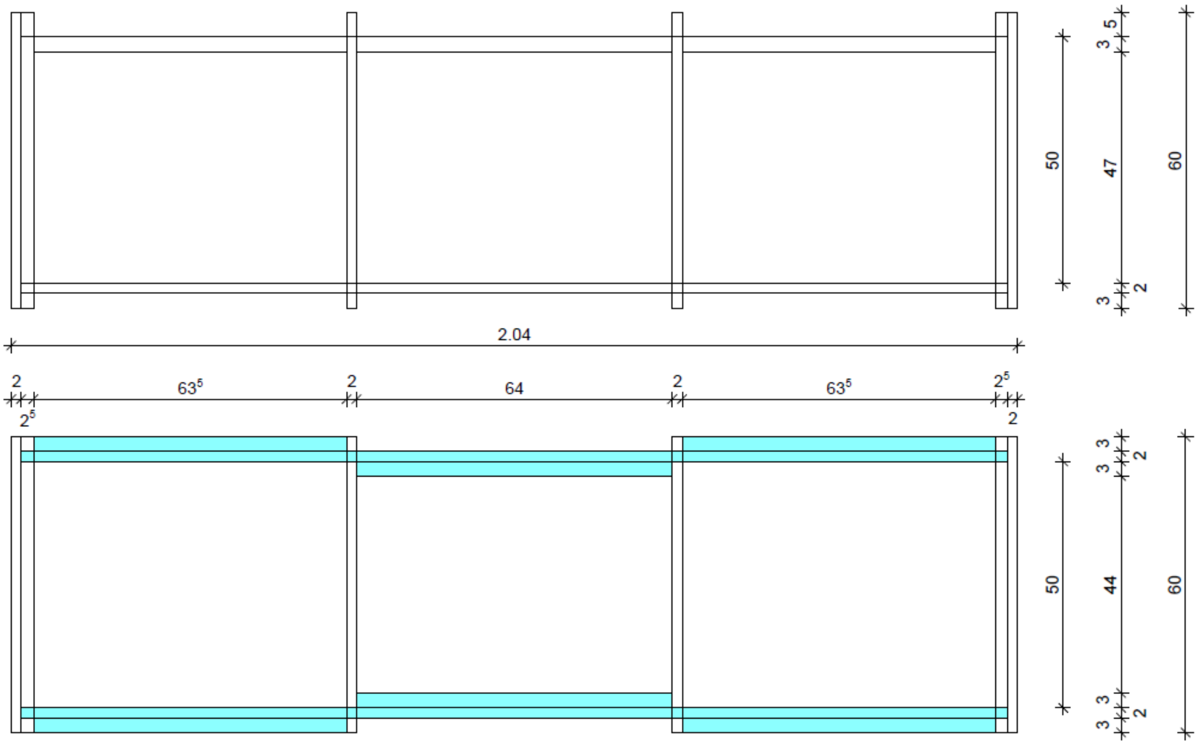

Fig. 20: Schematic of the water tank used for testing. Top: plan. Bottom: side elevation without frame.

Basically, the lateral connections between the edges of the tested wall constructions and the water tank have to be made watertight to simulate real building conditions. In order to ensure a sufficient lateral bonding, steel plates (thickness 3 mm) are adhered to the sidewalls of the water tank with silicon sealant (cf. Fig. 21). Then, the construction joints between the built test specimen and the steel plates are sealed with mortar. This task needs to be done very carefully to eliminate any leakage through the joints. After completing a test run the test specimens as well as the steel plates are removed from the water tank. Then, the silicone sealant is peeled off from the acryl glass tank and the steel plates are thoroughly cleaned to use them for the next test run.

4.2 Measuring equipment

A major objective of the test runs is to determine the water seepage through wall and floor constituents. To quantify this effect the laboratory tests clarify to what extent moisture penetrates the materials of each building construction. The material samples used for this purpose are obtained by using diamond-head core drills with a diameter of 68 mm. The samples are weighted on a precision balance with readout down to 1 mg. For the determination of their dry-mass, the samples are dried in a laboratory oven to constant mass at a specified temperature[4]. The air temperature and relative humidity in the laboratory was measured and recorded in regular intervals using a digital data-logger. The test runs were daily captured using a digital camera. The pictures document water levels in the tank as well as the system behaviour over the entire test period of seven days.

Fig. 22:
Digital data-logger to record air temperature and relative humidity in the laboratory at regular intervals. Picture: www.conrad.de

Fig. 23:
Precision balance with readout down to 1 mg.
Picture: www.kern-sohn.com

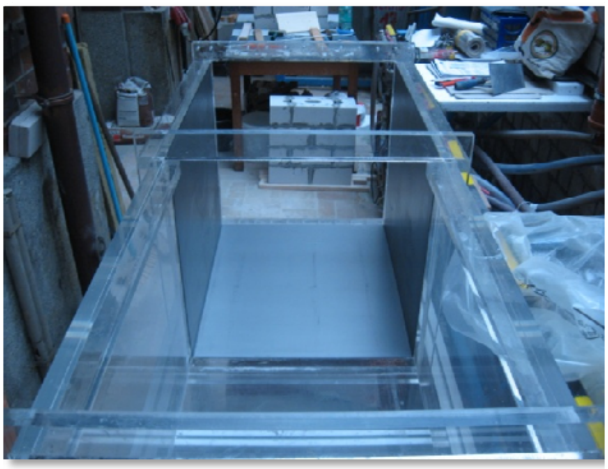

Fig. 21: Steel plates for the lateral connection

[4] The oven temperature is 105° C (WTA 2002).

5. Test procedure

5.1 General assumptions

5.1.1 Wall constructions

Building envelopes as well as floor constructions need to be adequately designed and constructed to cope with floodwater. To analyse their system behaviour, four common wall and two typical floor arrangements were tested in a water engineering laboratory at the Dresden University of Technology. The testing program envisaged simultaneously analysing two wall arrangements in each test run. Therefore, the front and the back panel of the water tank were removed to allow access for in-situ construction of the test specimens. The experimental work requires a number of model assumptions. (1) Caused by the small dimension of the tested wall panels and the lateral restraint at the edges of the water tank, the cracking behaviour is not the same as for real structures. (2) Because of a tight schedule of the testing program, the wall arrangements were left to cure only for 14 days. It is clear, that mortar (the same applies also for the plaster) reaches his strength value very close to its ultimate value at the end of 28 days, but after 14 days curing period the mortar achieved sufficient strength and bonding characteristics. (3) The testing protocol did not intend to observe long term drying shrinkage, which can also lead to cracking. Then, the test specimens were flooded on their external face with clean tap water to exclude the broad variety of damage processes that can be caused by contaminated water. Every day the water levels on both the internal and the external face of the wall constructions were measured and documented. To indicate the water seepage particularly through the structural layers of the exterior walls, a probe was inserted through boreholes from the top. After the flood duration of overall seven days, material samples were taken to obtain information about moisture content[5]. To quantify the moisture content and to determine the degree of saturation, the gravimetrical DARR-method is used. Moisture profiles illustrate the moisture distribution over the wall thickness. Testing results are the rate of leakage through the whole wall construction and the seepage through wall materials (represents by the degree of saturation).

Fig. 24: Water tank with two wall test arrangements that are under construction in-situ. In front: the double shell masonry of sand-lime bricks with heat insulation and air gap. In the background: the single shell masonry of hollow bricks with external heat insulation and ventilated curtain façade.

[5] The moisture content can be defined as either the mass of moisture per unit volume of the dry material, or the mass of moisture per unit mass of the dry material, or the volume of condensed moisture per unit volume of the dry material (Trechsel 2001). That means, the moisture content can be defined as the ratio, expressed as a percentage, of the mass of the pore water to the mass of the dry material.

5.1.2 Floor constructions

The test specimens were selected to cover two commonly used floor constructions simulating the floor arrangement about the basement. During the testing program both the timber floor construction as well as the concrete floor construction was precast in the laboratory, before they get installed in the water tank one after the other. The test specimens were fixed at the bottom plate of the water tank to prevent floating due to buoyancy forces. Then, the wetting phase lasts four days for each construction, before material samples were taken and analysed. Basically, the further procedure is the same as described for the wall arrangements.

5.2 Water depth

The wall arrangements were subjected to 40 cm depth of water. Due to the selected water level, structural failures of the test specimen were avoided. In addition, it was intended to simulate a flood situation in which object-related flood resilience technologies (FRe T)[6] can be reliably implemented at the building envelope. Basically it is assumed, that the depth of flood water should not be more than 1 m to prevent structural damage to the wall constructions induced by considerable horizontal hydrostatic forces, because of unequal floodwater levels on different sides of the exterior wall. Moreover, vertical buoyancy forces can cause severe structural damage to the entire building. Prior to the implementation of flood resilient technologies (FRe T), which prevent the ingress of water into the building, the stability of the building envelope must be verified by static calculations. There is evidence that structural failure can occur even below the limit of 1 m, depending on a number of factors, such as the length of the wall panel between vertical supports or joints and materials used. The two tested floor arrangements were completely inundated to simulate the case that flood water enters the building.

5.3 Flood duration

The testing program envisages duration of overall seven days for each test run. In the first phase the wall constructions were exposed to floodwater on the external face for 96 hours. Following that 4 day duration, additionally the internal face was flooded for three days in a second phase to analyse the impacts to building construction when floodwater is entering the building. However, the floor arrangements were tested for four days

5.4 Moisture determination

Almost all construction materials are porous in nature. Water continually undergoes several physical and chemical processes and interacts with nearly all materials (Trechsel 2001). Most of the constituents of the analysed wall and floor arrangements absorb water by capillary forces[7]. There is a set of different methods for analysing the moisture content of the applied building materials. In these laboratory studies the DARR-method (cf. WTA 2002) is used, which is a highly accurate procedure to quantify the moisture content of building materials. In this connection, moisture in a homogeneous sample is measured gravimetrically by determining the weight loss due to evaporation of water after it has been placed in an appropriate oven[8] and dried to constant mass[9] at 105° C[10]. A

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[6] Object-related flood resilience technologies are for example building aperture technologies, which prevent water ingress through windows and doors. These include amongst other door boards, flood guards, and flood shields.
[7] Building material absorbing water by capillary forces are called capillary active.
[8] The oven should be capable to maintain a temperature of 103° ± 2° C.

building material is dry when it contains no or only chemically bounded water. Based on the weight of the wet sample [m_{wet}] and the dry sample [m_{dry}], the mass related content of moisture [u_m] can be calculated using the following equation:

$$u_m = \frac{m_{wet} - m_{dry}}{m_{dry}} * 100\%$$

The degree of saturation specifies how much of the pore volume of a certain building material was filled with water when taking the samples. That means, the degree of saturation [S_w] indicates the ratio between the material moisture content [u_m] and the maximum moisture content [u_{max}] that can be attained by the material and is determined using the following equation:

$$S_w = \frac{u_m}{u_{max}} * 100\%$$

A detailed analysis of the degree of saturation is the basis for (1) assessing the susceptibility of applied building materials to moisture seepage and for (2) providing an effective redevelopment concept for enhancing the resilience properties.

Fig. 25: Building material test samples

Fig. 26: Building material test samples in the drying oven to determine their oven-dry mass.

5.5 Sampling

The used method for moisture determination requires taking core samples from building components. These material samples are obtained by using diamond-head core drills with a diameter of 68 mm. Regarding the requirements from WTA (2002), the weight of each collected sample must be greater than the minimum weight of 50 g. Both the selected core diameter as well as the minimum weight of the samples minimises the impact of heat, generated by drilling without cooling water, on the moisture content of the core samples. The samples are then vacuum-packed and labelled before their wet weight is determined in a materials testing laboratory. To visualise the quantity of water seepage in the cross section, moisture profiles were created.

[9] Constant mass has been achieved when less than 0.1 % of the test sample wet mass is lost during an additional exposure to the drying process.
[10] The drying temperature for gypsum and calcium sulphate containing building materials is only 40° C to remain chemically bounded water.

6. Evaluation of testing results

6.1 General conclusions for tested wall constructions

Basically, the system behaviour of a composite wall arrangement cannot be predicted solely from the behaviour of its components. Hence, the whole construction needs to be analysed to consider significant interactions between the wall constituents. The following conclusions can be drawn from the test results on walls:

- The test clearly proved that masonry walls using hollow brick blocks are very susceptible to flooding, firstly as the butt joints are not filled with mortar. The brick blocks are joined together using only a tongue and groove formation. Water seeps easily through the construction passing the brick blocks at the joints. This results in a significant rate of leakage. Secondly, as the tested wall is not-rendered at its external face, it offers no resistance against water penetration. The water uptake is very high and caused by the capillary porous material structure. The cavities of the bricks were quickly filled completely with water. The degree of saturation reached approximately 80 M.-%. There are considerable difficulties to dry the brickwork, because the cavities are not interconnected.
- Light (aerated) concrete blocks are highly insulating and consist of a closed-pore structure (up to 80% air). Hence, the determined water uptake of the material is minimal. But analogue to the hollow brick blocks the butt joints are not filled with mortar, so that water can pass the light concrete blocks and seep through the internal plaster. After three days a slow leakage rate was observed. As the external thermal insulation composite system (ETICS) was not fully adhered to the wall, water was easily running behind the ETICS and penetrated into the masonry.
- The mortar mixture has considerably influence on water seepage. Cement mortar joints are relatively more porous and are, hence, more susceptible to water seepage than the brick units. The type of mortar bedding selected can have a considerable effect on its bonding strength and workability, which in turn affects the water tightness of the joints.
- The used mineral fibre insulation absorbed a huge amount of water and became totally soaked and fragile to handle. It has lost its strength and dimensionally stability.
- A curtain façade element (cf. wall construction W2) can be removed after flooding, so that the insulating material underneath can be replaced particularly if mineral fibre insulation is used. Wall arrangements with a curtain façade have a good ability to dry out from the external face.
- The accumulation of water in the cavity of double shell masonry constructions is critical. Floodwater can built up in the cavity, saturate the insulation, and soak into the inner masonry shell. The cavity makes it difficult to dry out and the requirements for refurbishment are extensive. If mineral fibre or other water sensitive Floodwater can build up

6.2 General conclusions for tested floor constructions

Test results for floor constructions can be summarized as follows:

- mineral fibre insulation -> absorbed water -> the compression is irreversible
- gypsum plasterboard -> Gypsum plasterboard remained sound in appearance during the wet phase but disintegrated into small pieces when removed, only being held by the backing paper sheets

7. References

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Appendix 7 – Examples of benefit analysis for Mobile Perimeter Flood barriers

In the following example, the approach to a value benefit analysis is shown without referring to specific constructions and with only poor site information. For practical use, more information concerning site characteristics as well as features of specific construction details are required. For example, loading capacity and purchase costs of constructions often differ depending on the manufacturer.

The following site characteristics are given in example 1:

- site known in advance
- little space for flood protection, no conventional technical protection possible
- neighbouring regions are also endangered by flooding
- little unevenness of terrain, no slopes
- asphalted ground along the protection line
- medium scale access road to site
- early warning time of 24 hours
- winding alignment of protection line
- protection height of 0.60m above ground surface
- length of protection line is 50m
- protection line under observation during flooding
- limited financial means available, especially for purchase.

In Table 7- 1 weighting factors are given with respect to the example above. Attention is focussed on the system safety, followed by system characteristics and costs. Low weighting factors are attributed to logistics and special equipment because the protection line is accessible by road. The general safety is of minor importance as it is planned to observe the mobile protection line during flooding.

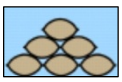
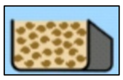
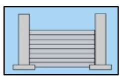
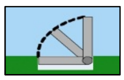
In Table 7- 2 a value benefit analysis is given for the use of selected mobile flood protection systems on a specified site. It is shown that according to analysis the flap system fits best to site characteristics with a score of 8.1 out of 10 possible points. Second is the beam dam system with a score of 7.3. The worst score of 5.6 is assigned to the sandbag system.

No. of main criterion	Weighting factor [%]	No. of sub criterion	Sub weighting factor [%], comments in brackets
1	40 %	1	20 % (this factor can only be assessed properly if the specific system is known)

No. of main criterion	**Weighting factor [%]**	**No. of sub criterion**	**Sub weighting factor [%], comments in brackets**
		2	10 % (asphalted site with little unevenness of terrain)
		3	10 % (a maximum allowed leakage rate between the elements is given and must be guaranteed – criterion for exclusion)
		4	0 % (no slopes)
		5	0 % (no slopes)
		6	40 % (important point)
		7	20 % (of minor importance, the maximum expected water level is defined)
2	20 %	1	10 % (site with little unevenness of terrain)
		2	50 % (short early warning time of 24 hours available)
		3	0 % (required protection height restricted to 0.6 m)
		4	5 % (required protection height restricted to 0.6 m)
		5	25 % (winding alignment)
		6	10 % (limited protection length of 50 m)
3	10 %	1	34 % (specific equipment can be used)
		2	33 % (specific equipment can be used)
		3	33 % (specific equipment can be used)
4	10 %	1	30 % (short early warning time of 24 hours available)
		2	15 % (prearrangements are possible)
		3	20 % (manpower shortage, neighbouring regions endangered)
		4	5 % (of minor importance, no time limitation after flooding)
		5	20 % (short early warning time of 24 hours)
		6	5 % (no specific storage problems)
		7	5 % (no specific storage problems)
5	15 %	1	40 % (for detailed cost analysis further information necessary)
		2	10 % (for detailed cost analysis further information necessary)
		3	20 % (for detailed cost analysis further information necessary)
		4	10 % (for detailed cost analysis further information necessary)
		5	10 % (for detailed cost analysis further information necessary)

No. of main criterion	**Weighting factor [%]**	**No. of sub criterion**	**Sub weighting factor [%], comments in brackets**
		6	10 % (for detailed cost analysis further information necessary)
6	5 %	1	50 % (both factors influence the reliability)
		2	50 % (both factors influence the reliability)

Table 7- 1: Weighting factors of mobile stationary and non-stationary flood protection systems depending on example site characteristics, example 1

			 Sandbag s	 Water-filled tube	 Water-filled cont.	 Sand-filled cont.	 Beam dam system	 Auto. flap system
	1	20%	7	7	7	8	10	10
1	2	10%	8	8	6	6	10	10
	3	10%	4	8	6	6	10	10
40%	4	0%	-	-	-	-	-	-
	5	0%	-	-	-	-	-	-
	6	40%	8	8	8	8	8	8

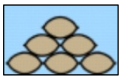
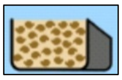
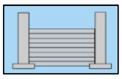
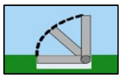
			 Sandbags	 Water-filled tube	 Water-filled cont.	 Sand-filled cont.	 Beam dam system	 Auto. flap system
	7	20%	8	0	0	5	5	5
2 20%	1	10%	10	10	8	8	10	10
	2	50%	0	9	8	3	6	10
	3	0%	-	-	-	-	-	-
	4	5%	10	5	5	5	5	2
	5	25%	10	9	7	7	8	8
	6	10%	8	0	0	5	6	8
3 10%	1	34%	0	7	6	2	5	10
	2	33%	0	7	6	2	5	10
	3	33%	5	5	5	4	10	10
4 10%	1	30%	8	7	6	6	8	10
	2	15%	10	10	10	10	4	0
	3	20%	0	8	7	4	6	10
	4	5%	2	8	7	2	8	10
	5	20%	0	8	8	3	10	10
	6	5%	7	7	7	7	5	10
	7	5%	0	7	6	4	5	10
5 15%	1	40%	9	7	7	7	4	0
	2	10%	0	8	8	5	10	10
	3	20%	0	9	9	2	10	10
	4	10%	0	8	8	4	6	10
	5	10%	4	7	6	3	8	10
	6	10%	2	7	7	4	5	10
6 5%	1	50%	9	7	7	10	4	4
	2	50%	10	0	0	10	8	8
Benefit value			5.6	6.8	6.3	5.8	7.3	8.1

Table 7- 2:Value benefit analysis of mobile stationary and non-stationary flood protection systems,example 1

The following site characteristics are given in example 2:

- site not known in advance, the possible deployment site is a larger administrative unit
- the administrative unit is located in the lowlands – no large slopes have to be expected
- early warning time in the administrative area of 48 hours
- protection height of 0.60m above ground surface
- protection line under observation during flooding
- sufficient finance available for purchasing products
- appropriate storage areas can be made available.

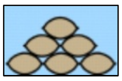
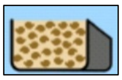
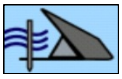
In Table 7- 3 weighting factors are given with respect to the site characteristics described above. The focus of attention is given to the system safety, followed by system characteristics and logistics. Low weighting factors are attributed to special equipment and costs. The general safety is of minor importance as it is planned to observe the mobile protection line during flooding.

In Table 7- 4 a value benefit analysis is given for the use of selected mobile flood protection systems on a specified site. It is shown that according to the analysis carried out, the water-filled tube system fits best to site characteristics with a score of 6.6 of 10 possible points. The worst score of 4.8 is assigned to the flap system.

No. of main criterion	**Weighting factor [%]**	**No. of sub criterion**	**Sub weighting factor [%], comments in brackets**
1	45 %	1	20 % (this factor can only be assessed properly if the specific system is known)
		2	10 % (deployment on different terrains)
		3	10 % (a maximum allowed leakage rate between the elements is given and must be guaranteed - criterion for exclusion)
		4	10 % (no larger slopes)
		5	0 % (no larger slopes)
		6	40 % (important point)
		7	10 % (of minor importance, the maximum expected water level is defined)
2	25 %	1	25 % (site not known)
		2	30 % (intermediate early warning time of 48 hours)
		3	0 % (required protection height restricted to 0.6 m)
		4	0 % (required protection height restricted to 0.6 m)

No. of main criterion	Weighting factor [%]	No. of sub criterion	Sub weighting factor [%], comments in brackets
		5	25 % (protection line not known)
		6	20 % (in emergency use desirable)
3	5 %	1	34 % (specific equipment can be used)
		2	33 % (specific equipment can be used)
		3	33 % (specific equipment can be used)
4	15 %	1	35 % (emergency use)
		2	0 % (no prearrangement is a requirement in case of emergency use)
		3	30 % (emergency use without detailed personnel planning in advance)
		4	5 % (of minor importance, no time limitation after flooding)
		5	20 % (generally important because of cost and time limitation)
		6	5 % (no specific storage problems)
		7	5 % (no specific storage problems)
5	5 %	1	40 % (for detailed cost analysis further information necessary)
		2	10 % (for detailed cost analysis further information necessary)
		3	20 % (for detailed cost analysis further information necessary)
		4	10 % (for detailed cost analysis further information necessary)
		5	10 % (for detailed cost analysis further information necessary)
		6	10 % (for detailed cost analysis further information necessary)
6	5 %	1	50 % (both factors influence the reliability)
		2	50 % (both factors influence the reliability)

Table 7- 3:Weighting factors of mobile non-stationary flood protection systems depending on example site characteristics, example 2

			 Sandbags	 Water-filled tube	 Water-filled cont.	 Sand-filled cont.	 Plat dam system	 Flap system
1 45%	1	20%	7	7	7	8	7	2
	2	10%	8	8	6	6	6	6
	3	10%	4	8	6	6	5	5
	4	10%	8	6	7	8	7	3
	5	0%	-	-	-	-	-	-
	6	40%	8	7	7	8	8	2
	7	10%	8	0	0	5	5	0
2 25%	1	25%	10	10	8	8	2	4
	2	30%	0	8	8	3	6	10
	3	0%	-	-	-	-	-	-
	4	0%	-	-	-	-	-	-
	5	25%	10	8	7	7	4	4
	6	20%	8	0	0	5	6	0
3 5%	1	34%	0	7	6	2	5	10
	2	33%	0	7	6	2	5	10
	3	33%	5	5	5	4	10	10
4 15%	1	35%	8	7	6	6	7	9
	2	0%	-	-	-	-	-	-
	3	30%	0	8	7	4	6	10
	4	5%	2	8	7	2	5	10
	5	20%	0	8	8	3	10	10
	6	5%	7	7	7	7	5	8
	7	5%	0	7	6	4	5	10
5	1	40%	9	7	7	7	5	10

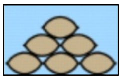
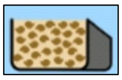
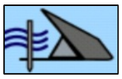
			 Sandbags	 Water-filled tube	 Water-filled cont.	 Sand-filled cont.	 Plat dam system	 Flap system
5%	2	10%	0	8	8	5	8	8
	3	20%	0	9	9	2	10	10
	4	10%	0	8	8	4	6	10
	5	10%	4	7	6	3	7	10
	6	10%	2	7	7	4	5	10
6 5%	1	50%	9	7	7	10	4	0
	2	50%	10	0	0	10	5	0
Benefit value			6.3	6.6	6.1	6.3	6.2	4.8

Table 7- 4:Value benefit analysis of mobile non-stationary flood protection systems, example 2