Title: Testing Innovative Technologies to Manage Flood Risk

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Summary

The move towards multi-faceted approaches to flood risk management is cemented in the EU Floods Directive (Directive 2007/60/EC). Across Europe, resources are diverted towards softer interventions such as using the planning system to control developments in flood risk areas, and citizens are encouraged to live with floods. Damage mitigation nevertheless remains important and, thus, a market has been developing for technologies that help to manage flood risk at the receptor scale, such as door and window guards and perimeter barriers. However, little empirical research has been undertaken that analyses how such technologies might fit with holistic flood risk management strategies.

This paper reports on a multi-disciplinary research project which investigated, developed and tested innovative technologies to protect buildings and urban infrastructure from floods. The paper discusses testing parameters, the limitations of technologies, and the barriers that impede their uptake.

Introduction

Two-thirds of the reported European damage costs from natural disasters between 1980 and 2012 can be attributed to hydro-meteorological events such as storms, floods, and landslides. Climatological events such as extreme weather account for twenty per cent of these damage costs and this has increased by EUR 4 billion over the same period (EEA, 2012a). Exposure to flooding has increased, particularly in urban areas, because of a rising proportion of sealed surfaces, the pressure on drainage systems posed by rising urban populations, and climate change (EEA, 2012b; Douglas *et al.*, 2010). The uncertainty engendered by a changing climate, combined with the experience and cross-border nature of recent floods, seems to hold significant implications for our quality of life now and in the future (EEA, 2012b).

Large flood defences designed to hold water back have traditionally been used to manage flooding. Whilst such defences will remain important in creating resilient places, the efficacy of that approach is undermined by continuing flood events and a greater understanding of the nature of floods and those at risk from it (White, 2013). Recent policies at European and national levels reflect the uncertainty by encouraging flood risk managers and citizens to 'learn to live with rivers', make 'room for the river' and 'make space for water' (Institution of Civil Engineers, 2001; Rijkswaterstaat Ruimte voor de Rivier, 2007; Defra, 2005). The European Floods Directive (2007) reinforces a more holistic approach by focussing on prevention, protection, and preparedness, in addition to more effective emergency responses and recovery plans (Commission Directive 2007/60/EC).

National states are no longer the dominant stakeholder in flood risk management that is implemented at a variety of scales and across geographic boundaries. Stakeholders include emergency planners, property owners, water companies, the insurance industry along with municipal and national governments. Property owners are one group who are given extra responsibilities to prepare for floods and it has been demonstrated that some are willing to protect their own domains when given sufficient support (Botzen *et al.*, 2009; Kreibich *et al.*, 2011).

Recent years have seen a number of technologies emerging onto the market in order to mitigate the damage to properties. In terms of the source-pathway-receptor-consequence model (S-P-R-C), these technologies can be defined as measures that may reduce exposure to flooding at the receptor level, where the built environment and people are considered as receptors. They must also be combined with ongoing efforts including managing flooding at both source and pathway (Zevenbergen and Gersonius, 2007). Their novelty means that the route to market for these products across Europe is uncertain and there are questions over how they fit within flood risk management strategies.

This paper draws upon the EU-FP7 funded Smart Resilience Technologies, Systems and Tools (SMARTeST) project that investigated, developed, and disseminated knowledge on flood resilient technologies in seven European countries: Cyprus, France, Germany, Greece, Spain, the Netherlands, and the United Kingdom. The multi-disciplinary team included engineers and social sciences in order to understand the extent to which flood resilient technologies could become integrated into flood risk management and the barriers that have prevented them from doing so. This paper focusses on the testing protocols developed in order to address the perceived barriers and concerns identified in stakeholder workshops. Beginning with an overview of the technologies, the paper presents the results of a desk-based review of existing protocols and findings from stakeholder workshops that helped to shape the testing protocols. Consequently, the case for codified European standards is presented. The next section categorise the range of technologies considered in the project.

Dry-proofing Technologies

In technical terms, technologies that address flooding at the building scale can be known as "resistance" (or dry-proofing), which aim to keep water out of structures, and "resilience" (or wet-proofing), which allow for water entry into a structure (CLG, 2007). The SMARTeST project tested products that fall into three categories: aperture technologies, perimeter technologies and building technologies (see Figure 1). Though the SMARTeST project dealt with products in all categories, this paper concentrates on the first two types, which are examples of "resistance" or "dry-proofing", since the testing concerns are similar. This paper refers to these technologies as "dry-proofing" for the sake of consistency.

Figure 1: Categorisation of technologies. Shaded areas are the categories covered in this paper. Source: Authors

Perimeter technologies are available in three categories: temporary, demountable and pre-installed. Temporary perimeter flood barriers consist of complete removable components, which can be assembled when a flood warning is issued and demounted after the end of a flood warning. These barriers remain stable without any additional foundation. Their stability is ensured by:

- the internal weight of the product caused by its own product weight or by additional weight by filling material like water or sand; or
- By external forces like hydrostatic pressure of flood water levels.

Where stability is ensured by internal forces, the following types of products can be distinguished:

- Barriers where stability is ensured by the weight of the barrier; for example, tube products made of synthetic, flexible material which may be filled with water or sand; or
- Tank products consisting of containers, which may be filled with weighty material. Different designs exist on the market: for example, rigid structures or frames (wood or steel) supporting a flexible impermeable or permeable membrane.

In the case of stability ensured by external forces, two types of products can be distinguished:

- Trestle products that form a low angle with the ground. They benefit from the vertical component of the hydrostatic force of flood water levels.
- Set-square products work in a similar fashion to trestle products but instead are composed of a vertical fence to stop the water and a horizontal fence to stabilise the product. This is formed in such a way that the floodwater pressure transfer consolidates the structure and strengthens the fencing rather than weakening it.

Demountable perimeter flood barriers consist of a combination of removable and pre-installed permanent components. The system can be erected when a flood warning is issued and demounted after the end of a flood warning. Due to the pre-installed components, these barriers can only be used at a specific site. Generally, the demountable components are composed of pillars, which can be fixed after a flood warning to the pre-installed ground components. The stability of this type of barrier relies on the barrier itself as well as on the foundation. Therefore, the foundation should be designed to avoid geotechnical failures such as sliding, bearing, collapsing, and internal erosion

Pre-installed perimeter flood barriers consist of pre-installed moveable components. Between flood events, the product is in a passive state without any flood protection functionality. The product may be concealed in an underground compartment or an adjacent structure. When the product is in a functional state during a flood event, the barrier is automatically erected using flood buoyancy and mechanically erected systems using hydraulic cylinders. Such products can also be manually activated.

Aperture flood barriers can also be classified into three categories depending on their method of installation. Temporary aperture flood barriers, which do not require preinstalled parts, minimally interfere with the appearance of a property. The products remain stable by different fixation methods. Door and windows guards and flexible covers for airbricks are examples in this category. Traditional sandbags may be included in this category too and it is the same for other products based on this principle, such as bags filled with water absorbent material.

Demountable aperture flood barriers require both permanent parts and elements that have to be installed when a flood warning is issued. These elements are generally beams or plates that are inserted between permanent vertical parts fixed on the aperture. However, some of these technologies can be directly fixed to walls or to windows or doors frames. These products can be adapted to different openings such as doorways, windows, and garage doors.

Pre-installed aperture barriers can be activated automatically or manually when a flood warning is issued. Due to their passive nature, some of the products have integrated functions. Examples here include flood doors that combine flood protection with the traditional function of opening and closing a door.

Review of Existing Standards and Approvals

Given the uncertainty surrounding the depth, velocity, duration, and timing of flood events, the integration of dry-proofing technologies into a wider flood risk management system needs to be underpinned with an up-to-date assessment of vulnerability and an understanding of the conditions when dry-proofing technologies could potentially exceed their performance expectations. This implies that the products should be tested to determine their performance limits. In order to establish a test procedure, a desktop review of existing standards was undertaken (Table 1).

FM Global is an international company that deals with property insurance and loss. FM Global has a protocol for flood abatement equipment, which presents the compounds and material testing methodology for temporary perimeter flood barriers and aperture barriers (FM Global 2006).

The British Standards Institution (BSI) is the national standards body in the UK and produces standards on a wide range of products, services, and processes. BSI also represents UK interests within international and European standards organisations such as ISO or CEN. A Publicly Available Specification (PAS) was developed in 2003 to cover flood protection products. This is not a formal standard but responds flexibly to industry demands for standards in the UK.

The Centre Scientifique et Technique du Bâtiment (Scientific and Technical Centre for Building, CSTB) is the French national organisation that provides research and innovation, consultancy, testing, training, and certification services for the construction industry in France. CSTB is a member of EOTA and it is an approval body nominated to issue ETA (European Technical Agreement). In 2004, France's Department of Infrastructure requested a protocol to help users gain a better understanding of the performance of aperture barriers.

Deutsches Institut für Normung (German Institute for Standardisation - DIN) 19569 is a German national standard relating to wastewater treatment plants, which includes descriptions of design principles for structures and technical equipment (Beuth Verlag 2000). Although not intended to be used for flood protection products, some German companies assess the water-tightness of their products according to the Part 4 of DIN 19569, which covers specific principles for shut-off devices including penstocks, sluice gates, and stop-logs.

Table 1: Types of testing standards.

These four standards differ in a number of distinct ways. Flood perimeter barrier layout testing is described in detail in FM Global. PAS 1188-2 and PAS 1188-4 do not specify length or layout; but specify intermediate joints and internal and external corners, if they form part of a flood resilience system. Specified test durations vary from 22 to 48 hours, a parameter which could be significant in case of creep. The type of surface of the support for aperture technologies also differs: masonry for PAS 1188-1, concrete for FM Global Protocol, and concrete/steel for CSTB protocol.

The acceptable leakage rate varies depending on the standards body. Under the PAS 1188 standards, the permissible leakage rate for perimeter barriers is 40l/h/m whereas under the FM Global Protocol this rises to 45 l/h/m. Yet DIN 19569-4 takes an entirely different approach by distinguishing five sealing classes, which are defined with respect to leakage rates as shown in Table 2.

Table 2: Sealing classes according to DIN 19569-4

Hydrodynamic load tests are also variable. The characteristics of wave-induced tests and currents tests differ slightly between PAS 1188 and the FM Global protocol. Meanwhile, for aperture technologies, wave and current tests are considered in PAS 1188-1 but not in FM Global and CSTB protocols. Security is assessed by impact tests in the CSTB protocol whereas it is indirectly determined by deformability for the FM Global protocol and PAS 1188. Impact tests are not specified in PAS 1188.

Having established the variability between standards and protocols, stakeholder views on dry-proofing technologies were to refine the observations on testing standards.

Stakeholder Views

Technological products, regardless of how well they perform, should not be considered without reference to the social factors that inhibit or facilitate uptake. Technologies shape socio-economic contexts and are, in turn, shaped by them (Bijker and Law, 1992; Guy, 2006). Workshops, which demonstrated different technologies and tools, were held with property owners, decision makers, insurers, and flood risk management professionals in each partner country. A number of common concerns regarding how flood protection technologies perform in practice were identified. In countries where aperture and perimeter technologies were in use, such as the UK and Germany, decision-makers were generally aware of the technologies but admitted that they did not fully appreciate the range of technologies and their different design parameters.

Even where stakeholders were aware of technologies and testing protocols in place, there was an evident lack of trust in their efficacy in a flood situation, particularly from end users and the insurance industry. These concerns mainly pertained to manually deployed products, as it was unclear whether there was sufficient expertise and knowledge to do this correctly. It was also noted that aperture and perimeter technologies must be conceived of in relation to the wider flood risk management system: non-automated technologies are reliant on adequate flood warning systems. In countries where dry-proofing technologies were not well-known or used, such as Greece, Spain and Cyprus, there was a fear that warning systems and flood risk assessments were not well-embedded enough to support the use of flood resilient technologies.

There are operational considerations too. Property owners who had installed dry-proofing technologies indicated that they seldom checked their technologies and some were unsure of how they might be deployed in a flood situation. One further complication was a lack of professional expertise within the wider sector: potential specifiers, such as surveyors, did not always have flood risk knowledge. Information regarding the technical parameters of products, and with regard to how they may be integrated into broad flood risk management systems, was identified as being particularly pertinent.

There are relatively few current applications of dry-proofing technologies and the potential market opportunities are not yet fully exploited across Europe. The user workshops indicated that one of the implementation obstacles is a lack of clarity about performance requirements and testing procedures. Moreover, the variability of different testing standards globally was thought to inhibit the transfer of technologies and knowledge between national contexts.

Testing Procedures

The wide technical range of available products, combined with insights from the review of existing standards and stakeholder workshops, meant that it was challenging to work out any fixed evaluation procedure. It was necessary to ensure that many of the variable elements of existing testing schemes were taken into account. Moreover, the scale and extent of testing depended upon the available facilities and the time and resources available for testing. Two testing facilities for perimeter and aperture technologies were available. A test tank at the Technische Universität Hamburg-Harburg (TUHH) was used for hydrostatic, hydrodynamic, and impact load tests in a 1:1 scale of building aperture and perimeter technologies. A building aperture facility at the Centre Scientifique et Technique du Bâtiment (CSTB) was used for hydrostatic and static load tests (impact tests) in a 1:1 scale of building aperture technology.

A total of thirteen perimeter barriers and four building aperture barriers were tested. When undertaking the tests, the project tried to integrate concerns about actual deployment and how the product may function in a real flood event; which was a key concern for stakeholders. Thus, the main aspects of the test procedures were the following:

- A ‘readiness’ assessment measured the time taken to install and demount a flood protection system.

- A stability and water-tightness assessment included the following:
    - o Hydrostatic load tests including leakage rate measurements for different system and/or product configurations as well as different water levels;
    - o Hydrostatic load tests including displacement measurements for different system and/or product configurations as well as different water levels;
    - o Hydrostatic load tests up to system failure (high degree of displacement) for different system and/or product configurations;
    - o Dynamic impact load/current load executed at one side of the structure;
    - o Dynamic load impact/debris load tests with different debris weights, impact angles and a fixed water level;
    - o Overflow test/observation of the product stability in an overtopping situation.
- An assessment of the effect of wear to establish durability included 100 cycles of installing/demounting of the product with a check of the movable parts every cycle.
- A failure load test determined the behaviour of the barrier under the action of a distributed load and the safety factor of the product.

Limitations of Testing

When analysing product performances, the testing conditions were taken into account. The testing showed that product performances are highly dependent on the conditions during testing. Two examples will illustrate the point. Firstly, the water-tightness of products was assessed according to the leakage rate. The leakage rate is dependent on how the product is sealed as well as on external conditions; for example, the geotechnical characteristics of the ground, topography, type of ground surface and flood actions. The products were tested in purpose-built test tanks made of smooth and flat concrete. These conditions may be described as 'ideal' with respect to the watertightness of the ground and the absence of gaps between the ground and the barrier. However, the smooth concrete results in a very low friction co-efficient between the ground surface and the protection structure, which meant that constructions such as temporary tube systems were rendered less stable in the test situation than they might be when deployed in practice. Secondly, the time to install the product was assessed in metres per hour. During the testing phase, the transportation timescales were short and the weather conditions were fair. This may be different to real situations.

Test standardisation means that the same test conditions, procedures, and variables are set for comparable products. This process may cause one product to be viewed more favourably than others may whereas in a 'real' flood situation both may perform equally well. Potential end users will need to know how the selected product will perform under their specific on-site conditions.

To ensure precise results, products should be tested according to their design and relevant deployment situations. Therefore, it is first necessary to identify the variables that influence the functionality of a product and how they influence that product (Table 3).

During the execution of the tests, it became clear that the system architecture, and the expected system functionality, differ significantly between products. Therefore, it was impossible to define a strict testing procedure given the range of products selected for testing. Thus, specific product features were taken into account during the testing phase. 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 consider this restriction and to test the system as a linear perimeter system.

Table 3: Influence of variables on functionality

Discussion

The testing experiences showed that the guidance for testing mobile perimeter flood barriers should include the evaluation of the product characteristics for the specific tested product. The test conditions, such as lengths and geometry of tested devices, testing ground characteristics, contact walls, and load characteristics have to be clearly stated and need to be taken into account in a performance and functionality assessment.

The variables identified in Table 3 may be interpreted by testing institutes, in collaboration with manufacturers, as either test conditions set according to the known intended use of the product and/or test variables where the effect of one parameter on the product performance is assessed.

The review of standards and the appreciation that site characteristics affect performance means that the performance assessment of perimeter technology cannot simply be based on fixed testing routines. Instead, testing schemes will differ with respect to both the tested products and the functionalities expected at potential flood sites. It is therefore not possible to compare the test results of different technologies. Any evaluation scheme that aims to compare different technical solutions should take account of a multitude of parameters for different flood barriers and specific site characteristics. This evaluation scheme has to be adapted based upon 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 product and the building is the weakest system. This also underscores a need for testing and approval procedures to appreciate the whole system; that is, on the panels as well as on the connection points. Moreover, multiple tests have to be executed for the assessment of product performance. The stakeholder workshops also emphasised that an added consideration is an analysis of the whole flood risk management system: if there are insufficient flood warning mechanisms in place, there is little worth to be gained in implementing aperture or perimeter technologies.

Current approval procedures mainly decide based on product performance based upon pass/fail criteria. This is not always appropriate for flood barriers because performance is so dependent on external conditions. Pass/fail criteria allows for an industry-defined permitted amount of leakage, which can be confusing for consumers particularly when products are labelled as "protection". Instead, performance may be classified on a scale of leakage rate, which gives purchasers more information from which to make an informed decision. For aperture barriers, this ranges between 0 and 5 litres per hour per metre of the edge length (Table 4). For perimeter barriers, this ranges from 0 to 100 litres per hour per metre of the barrier length (Table 5).

Table 4: Leakage rates for aperture barriers, building sealing

Table 5: Leakage rate classifications for perimeter barriers

Currently there are no European standards for building aperture or perimeter technologies and, as established above, testing regimes vary significantly between verification bodies. Standardisation may assist emergent technologies in a number of ways (Blind, 2013). Standardising is not the only method to address perceived barriers; one could leave it simply to the market to decide. However, the consequences of product failure are too severe (the loss of lives or livelihoods) to warrant exploring this option. A harmonised European standard (or set of standards) could benefit manufacturers, installers and address the concerns of stakeholders. In particular, a standard protocol for establishing testing may help to demonstrate to the end-user that products work within given parameters. This may be similar to the EU Environmental Technology Verification programme (http://iet.jrc.ec.europa.eu/etv/), in which environmental innovations are tested via a protocol agreed between the manufacturer and a verification body in order to examine performance claims.

Consistent with harmonisation, a CE mark could indicate that a product was compliant with EU legislation and assessed before coming to the market. National bodies in EU member countries could supervise the allocation of CE marking to ensure that manufacturers have had their product independently verified, where applicable. In addition, such national bodies should ensure that manufacturers have verified that their product complies with all relevant requirements in a specific directive, for example health and safety or environmental conditions.

Combined with an understanding of the technological barriers faced, the research concluded that testing should cover all aspects of the technologies from design, through to installation, operation, and decommissioning. This means identifying the functions expected, the characteristics of these functions and the variables influencing the performances. Given the technological barriers reported by stakeholders, it will be crucial to ensure that the results of testing and the variabilities in performance are properly communicated to specifiers and end-users who must be advised of the need to prepare for a flood event that may exceed expected performance.

Implications for Civil Engineers:

- Aperture and perimeter technologies may be considered as part of the source-pathway-receptor-consequence model (S-P-R-C) to help to reduce exposure to flood risk to people and the built environment at receptor scale.
- No fixed testing scheme can be defined for the performance assessment of the huge variety of perimeter technologies available, but a testing matrix should 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;
- Harmonised European standards could help the route to market and encourage further innovation through sharing knowledge and practice.

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