Current European Research Relevant to Reservoir Safety: The FloodProBE and UrbanFlood Projects

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SYNOPSIS. The European FloodProBE (www.floodprobe.eu) and UrbanFlood (www.urbanflood.eu) projects started in 2009, run for several years and contain components of research that are likely to be of interest to reservoir safety managers.

The FloodProBE project focuses on flooding in urban areas, with research into the resilience of the built environment to flooding and the performance of flood defences, such as embankments. Processes such as internal erosion, structure transitions and the performance of grass cover are investigated.

The UrbanFlood project is developing a framework of 'smart' sensors, connected to the Internet and providing real time data for use within systems supporting routine asset management, early warning and emergency event management. Linked with a touch table system to support emergency response event management, this system offers a glimpse of what could soon be available to support the management of dam incidents.

This paper provides an overview of the two projects, highlighting some of the aspects of research considered most relevant to reservoir safety and where more detailed information can be accessed.

INTRODUCTION

Research into flood risk assessment and management can provide useful concepts, tools and approaches that may also be used within the more specialised field of reservoir safety management. Over the past decade, EU projects such as CADAM, IMPACT and FLOODsite have contributed to a better understanding of failure processes and modelling tools for breach and inundation mapping. More recently, the EU FloodProBE and UrbanFlood projects have been initiated, each of which will advance capabilities in the field of flood risk analysis, assessment and management, hence supporting aspects of reservoir safety management.

The FloodProBE and UrbanFlood projects are introduced in the following sections, and aspects of the research work most relevant to reservoir safety are highlighted. Guidance is provided on how to access more information on each of these projects.

THE EU FLOODPROBE PROJECT

FloodProBE is a European research project with the objective of providing cost-effective solutions for flood risk reduction in urban areas. FloodProBE is developing technologies, methods and tools for flood risk assessment and for the practical adaptation of new and existing buildings, infrastructure and flood defences leading to a better understanding of vulnerability, flood resilience and defence performance.

This research supports implementation of the Floods Directive through the development of more effective flood risk management strategies. The work is being undertaken in close partnership with industry, and is utilising pilot sites across Europe, to help provide practical industry guidance and cost effective construction solutions. The research is being undertaken by a team from 16 different organisations, drawn from seven different countries. In the UK, pilot site work is focussed around Hull and the Humber estuary along with case study material from the 2007 floods in Gloucester.

The research programme is structured around a number of core work packages, as described below:

- WP2 Vulnerability of the urban environment
- WP3 Reliability of urban flood defences
- WP4 Construction technologies and concepts for flood defences and flood resilience

Project coordination and dissemination / stakeholder involvement is covered under WP1 and WP6 respectively, with science integration, pilot testing and overall guidance produced under WP5.

ASPECTS OF RESEARCH MOST RELEVANT TO RESERVOIR SAFETY

The scope of work under each of work packages 2, 3, 4 and 5 are outlined below, explaining in more detail the areas of work likely to be of greater interest and relevance to reservoir safety practitioners.

Vulnerability of the urban environment (WP2)

There are three research areas here: the first looking at risk and vulnerability analysis from a Norwegian perspective; the second assessing urban network vulnerability to flooding and the third assessment of individual building vulnerability to floods. Here, the term ‘network’ is taken to mean urban system networks such as sanitation, drinking water supply, electricity supply etc.

The research into network vulnerability is likely to be of most interest to utility companies using dams for electricity or water supply, for business risk analysis and in providing support for emergency planning. The network analysis research is developing a GIS based model for mapping the extent of different, interrelated systems and their subsequent response during a flood event. For example, interdependencies between electricity supply, pumping stations and water supply mean that if part of one of these systems is lost, parts of the other systems may also become inoperable. Whilst there may be redundancies designed within the system(s), are there sufficient redundancies within all of the systems for all reasonable flood risk conditions?

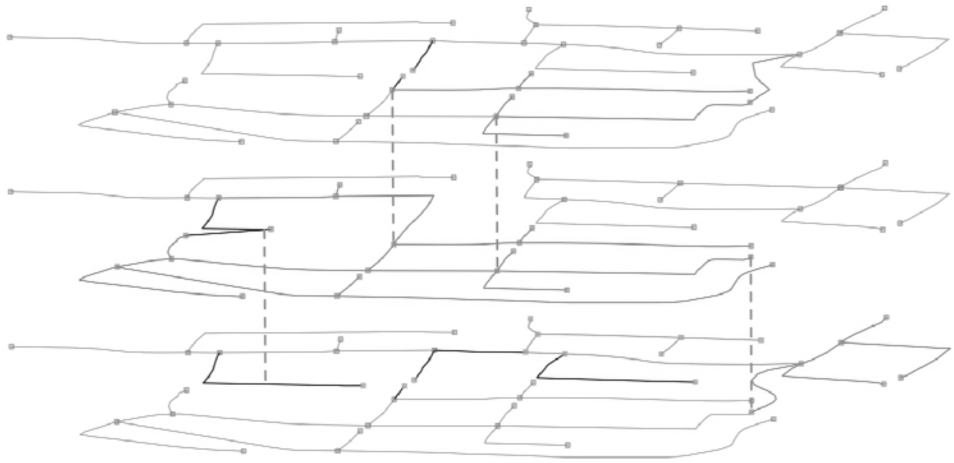

Figure 1. Example of three networks linking drinking water distribution, electricity supply and sanitary network (FloodProBE, 2012).

Reliability of urban flood defences (WP3)

There are six specific research actions under this area of the project looking at the performance of urban flood defences – primarily levees – hence much of the research is also relevant to the analysis of earth embankment dams. The six research areas are:

- Internal and surface erosion processes
- Structure transitions
- The performance of grass cover
- Rapid, non intrusive geophysical methods for assessing dikes
- Remote sensing (high density LiDAR)
- Combination of information sources for dike (performance) diagnosis

Internal and surface erosion processes
This research advances the current state of knowledge on internal erosion processes and is closely linked with the team developing the ICOLD bulletin on internal erosion. Different erosion processes are defined, along with consideration of susceptibility of different soils to different processes and methods for testing soils.

Structure transitions
This looks at how transitions within levees (or dams) can pose weak points within a system of flood defences. Transitions can be created by changes in profile, design, embedded or buried structures, revetments etc. A typology of transitions is presented and summary information provided for each type detailing associated failure processes, problem indicators (visible during field inspection) and guidance on design or post construction remedial measures to reduce the risks.

The performance of grass cover
Concerns have previously been raised regarding the suitability of the CIRIA 116 report guidance on the performance of grass cover when used for breach and reliability analyses (Morris *et al*, 2010). This research analyses the problem further, confirming the earlier concerns and considers how the performance of grass might be better predicted. A key conclusion is that the CIRIA Technical Note 71 performance data rather than the later CIRIA 116 data should be used for breach or reliability analysis.

Rapid, non intrusive geophysical methods for assessing dikes
This research provides consensus views from a range of different geophysics experts on the applicability and use of different geophysical techniques for the rapid through to detailed assessment of dike integrity. This may be of interest where long lengths of earth dam require monitoring or assessment.

Remote sensing (high density LiDAR)
This research looks at how high density LiDAR can be used to map and identify features along a levee system, including within urban areas. Guidance and examples are provided upon accuracy and different ways in which the data may be analysed to extract useful performance information.

Combination of information sources for dike (performance) diagnosis
This research looks to the future and ways in which a wider range of data types and sources might be combined to provide greater insight into the performance of levees. Different examples are considered including updating of performance models (assessments) based upon visual observations, measured data etc. This type of analysis would be of interest to dam owners undertaking detailed reservoir risk assessments – for

example a Tier 3 level of analysis under the new reservoir risk assessment methodology (FloodProBE, 2012).

Construction technologies and concepts for flood defences and flood resilience (WP4)

This research area focuses upon construction solutions for flood defences and buildings, and provision of guidance on their application. Whilst research covers a range of things including multifunctional flood defence structures, solutions for damage mitigation and improving building resilience (to flooding) the item of most interest to dam owners is likely to be the research and guidance on the use of bio-technology for the strengthening of flood embankments against erosion; particularly internal erosion. Here, bacteria are used within the "BioGrout" system to convert loose sand into sandstone, so preventing internal erosion but having little effect on permeability. Injection of the treatment into the levee or dam soil means that the BioGrout method can be used without needing substantial excavation works and the system automatically focuses on areas where seepage is occurring.

Figure 2 BioGrout research: laboratory testing (left); field testing (centre); prevention of pipe channel growth (right) (FloodProBE, 2012)

Further information

To find out more about the FloodProBE project in general, visit www.floodprobe.eu or attend the FLOODrisk 2012 conference in Rotterdam (www.floodrisk2012.net) where the project is a supporting initiative and a range of more detailed papers will be presented.

THE EU URBANFLOOD PROJECT

Flood risk management issues currently affect more than two thirds of all European cities, and given the effects of climate change, this is only expected to worsen in the future.

The EU-funded UrbanFlood EWS project (www.urbanflood.eu) commenced in 2009 with the objective of designing an adaptable framework for the early warning of flood embankment (dike or levee) breaches in an urban environment (Pengel *et al*, 2010). Off-the-shelf digital sensors embedded in urban flood embankments are linked via the internet to continual monitoring systems with artificial intelligence (AI) to analyse data in real-time and predict where breaches will occur (Gouldby *et al*, 2011). This is then linked to emergency warning systems to alert human operators and to further breach and subsequent flood inundation and flood risk modelling. For example, the AI can utilise cloud computing processing power to prioritise and run complex modelling scenarios (Melinkova *et al*, 2011) and produce valuable flood inundation maps for immediate use by emergency responders.

The project team partners comprise:

- TNO (Netherlands) – Project Co-ordinator
- HR Wallingford (UK)
- University of Amsterdam (Netherlands)
- STOWA (Netherlands)
- Cyfronet (Poland)
- OOO Siemens (Russia)

The system developed is very adaptable and can incorporate any type of sensor that produces a digital output, thus allowing monitoring of the indicators of a wide variety of failure mechanisms. For example, vibrating wire piezometers, pore water pressure sensors, flow gauges, rain gauges, temperature sensors, inclinometers, seismographs, resistivity sensors, and GPS receivers could all be used to provide data for the monitoring system.

The project included use of data from induced breaches of real embankments at the Ijkdijk field laboratory in the Netherlands (www.ijkdijk.eu). This allowed validation and testing of many different types of sensors and of the overall EWS framework. This data was then used to develop the 'Virtual dike' modelling software that the AI can utilise to model breach effects (Melinkova et al., 2011).

Four pilot sites have been instrumented and are currently running in order to test and refine the AI monitoring systems. Sensor selection for these sites was constrained by budget, and based on previous positive experience from the Ijkdijk tests; the Geobeads unit manufactured by Alert Solutions was primarily used (Figure 3). These sensors detect tilt, temperature and pore water pressure. In addition two types of fibre optic cables (by TenCate (Figure 4) and GTC Kappelmeyer) were also used to measure relative strain and seepage (by sensing temperature change). All of these sensors offer maintenance free operation, high durability, are energy efficient and low in cost.

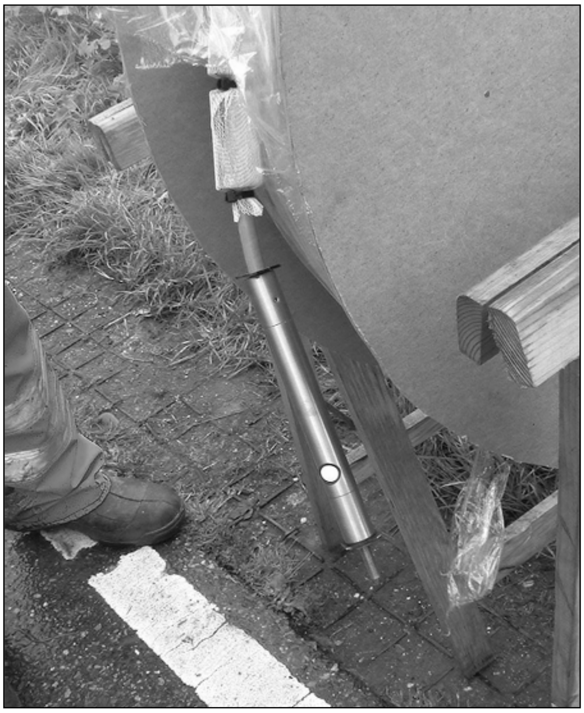

Figure 3. Geobead sensor by Alert Solutions

Figure 2. Fibre optic sensor cable by TenCate

The four pilot sites comprised:

1 - Grand Sluice, Boston, UK

This earthen flood embankment is operated by the Environment Agency and protects the town of Boston in Lincolnshire from river flooding. This particular location was chosen due to a tidal range in the river of up to 6m, and a history of embankment slope instability. Successful monitoring therefore needed to detect pore water pressure, deformations and (if possible) ground water flow near the toe.

Geobeads (www.geobeads.com) provide data on inclination therefore indicating slope deformation, and temperature data from the Geobeads and the fibre optic cable indicate the locations and extent of water flow through the embankment. In addition, at this site two types of Shape Acceleration Arrays (SAAs) were installed. The first measures three-directional soil deformation profile, while the second measures pore water pressure.

2 - Stammerdijk, Amsterdam, Netherlands

This urban flood embankment was selected due to concerns over its stability when large ships navigate the adjacent canal. Two cross sections have been instrumented using a total of 19 Geobeads. In addition, three more traditional pore water pressure monitors have been installed in order to check the accuracy of the Geobeads.

3 – Ringdijk, Amsterdam, Netherlands

The Ringdijk is a typical urban flood embankment with visible signs of instability (Figure 5), and a recent failure to meet current stability standards. Three cross sections are instrumented with Geobeads, and these monitor the influence of the trees on the embankment, the influence of construction of office building basements nearby, and a control section where these influences are negligible.

4 – Rhine dike, Germany

This location was selected, partly due to existing ground profile data, but also because seepage had been previously noted at one section of the embankment during high flood levels in 2011. Geobeads were installed at two cross sections, along with a GTC Kappelmeyer fibre optic cable in the sand layer on the downstream toe side, in order to detect signs of seepage.

The four pilot sites are generating valuable monitoring data and allow demonstration of the monitoring, AI and early warning systems. Data collected to date shows some movement of the pilot site embankments and response of the embankment pore water pressures to changes in loading, including the passing of large ships. Responses so far have not been sufficient to trigger a failure prediction by the system; however, in the absence of live failure data, a simulated dike movement can be used to test the system response.

Figure 5. Crack indicating instability at Ringdijk site

Aspects of research most relevant to reservoir safety

The project was originally conceived to develop and test distributed sensor systems in support of real-time emergency warning systems. In this context, flood embankments were selected, but there are other environmental hazards that could also be monitored. Having implemented the project for flood embankments, the possibility and value of extending this to ongoing routine monitoring of water retaining embankments such as dams was soon recognised and is perhaps of greater significance for the UK reservoir safety community.

For example, a section of embankment dam with a history of slope failure could be monitored in this way so that the chance of predicting/catching the development of breach at an early stage is greatly increased. In a typical reservoir risk assessment, the difference between the likely loss of life (LLOL) predicted 'with warning' and 'without warning' can be quite significant, and have serious financial implications for an Undertaker (Morris *et al*, 2008).

Equally, monitoring a section of embankment dam where a wet patch has developed at the toe, could give quantifiable data of deterioration (or not) on which to justify an investment decision for costly remedial works.

A major advantage of the UrbanFlood EWS approach is that a bespoke monitoring system can be developed for each particular dam, taking into account the suspected issues (seepage, settlement, slips, etc) present and specifying relevant sensors to be used. The AI for this dam would then be 'trained' initially to understand normal sensor readings for that dam so as to spot exceptions.

Although current remote sensing techniques for leakage through dams do exist, these give only a snap shot of the situation at one moment in time and provide no long term real time monitoring and warning. To repeat this type of survey regularly would be cost prohibitive for most dam owners.

Although the exact costs and longevity of a typical UrbanFlood system will depend on exactly what sensors are installed, and in what quantity, by using inexpensive commercially available sensors such as 'Geobeads' it is currently estimated that initial set-up costs would be comparable to a one-off temperature or resistivity survey and that ongoing monitoring costs would be a small fraction of this per year.

Further information

The UrbanFlood EWS project team will be disseminating and publicising the project results and outputs in various ways over the coming year, including demonstration of a 'touch-table' user interface to support emergency event management. To find out more about the UrbanFlood project please visit www.urbanflood.eu or www.hrwallingford.com, or attend the FLOODrisk 2012 conference in Rotterdam (www.floodrisk2012.net).

CONCLUSIONS

The EU FloodProBE and UrbanFlood projects both have programmes of research which have aspects that are relevant to reservoir safety. Whilst both programmes of research are focussed on the performance of levees rather than dams, some of the concepts and solutions being developed would have direct application for dams. Of particular interest and relevance are likely to be:

FloodProBE research into:

- Network vulnerability to flooding
- Internal erosion processes
- Structure transition performance
- Grass cover performance
- Application of geophysics
- Use of high density LiDAR
- Performance analysis from combined data sources
- The use of BioGrout to prevent internal erosion

UrbanFlood research into:

- Use of networked sensors to monitor structure performance, supporting asset management, emergency planning and emergency event management
- Use of touch table technology to support emergency event management

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