Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Programme

Performance and Reliability of Flood and Coastal Defences

R&D Technical Report FD2318/Project Record

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Preface

This document reports the findings of research into the “Performance and reliability of flood and coastal defences”- Phase I” - Project FD2318 in the Risk Theme of the Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Programme. This project has explored ways to assess the performance and reliability of flood and coastal defences in order to make better assessments of risk. It directly supports Defra and Environment Agency policies, strategies and new decision-making tools for flood and coastal risk management. In particular:

- it provides information to assess the effectiveness of flood defences in reducing risk
- it provides information to support decision-making on how to manage the performance of flood defences
- it provides methods to help to assess flood and erosion risk including performance of defences under extreme loads.

The project reviewed a range of methods for assessing the reliability of different types of defences, including their deterioration in time. It then focussed on developing practical methods for assessing reliability[1] using ‘fragility curves’. A fragility curve summarises information about the probability of failure of an engineering system such as a flood defence, in response to a specific range of loads (eg high water levels or waves). This report presents the main findings of the project including the methodology developed to construct fragility curves.

This report is aimed at those carrying out, or with an interest in, flood and coastal risk assessment. It describes the scientific and practical basis for fragility curves, and their role in the risk and performance based management framework (Ref: FD2318/TR). The report is intended to inform and assist those involved with managing flood and coastal defences, and assessing risk associated with flood defence structures and systems. FD2318/TR2 compliments this report by providing a more in-depth technical background including the mathematical equations of failure processes that were used for fragility calculation.

[1] Reliability is the complement of failure probability. For example a defence may have a reliability of 0.99 or a failure probability of 0.01 per year - the meaning is the same

Executive summary

This document describes the documents and associated materials produced during the project “Performance and Reliability of Flood and Coastal Defences – Phase I”; project FD 2318 in the Risk Evaluation and Understanding of Uncertainty Theme of the Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Programme.

The project has explored ways to assess the performance and reliability of flood and coastal defences in order to make better assessments of risk. It directly supports Defra and Environment Agency policies, strategies and new decision-making tools for flood and coastal risk management. In particular:

- it provides information to assess the effectiveness of flood defences in reducing risk

- it provides information to support decision-making on how to manage the performance of flood defences and,

- it provides methods to help to assess flood and erosion risk including performance of defences under extreme loads.

Background research and technical information is reported in four documents which have then been refined and compiled into two guidance documents. A workshop was conducted to disseminate latest thinking to practitioners, which was very successful. For completeness the workshop guidance is included in this project record.

The project reviewed a range of methods for assessing the reliability of different types of defences, including their deterioration in time. It then focussed on developing practical methods for assessing reliability using ‘fragility curves’. This summarises information about the probability of failure of an engineering system such as a flood defence, in response to a specific range of loads, such as high water levels or waves.

The research work was prepared by Foekje Buijs during her research based at HR Wallingford, Silvia Segura Domínguez, Michael Wallis, Paul Sayers and Jonathan Simm of HR Wallingford, and supported by Steve Oldfield of RMC Consultants. The project Director was Colin Fenn of HR Wallingford. (The HR Wallingford job number was CDS0718). The client project officer was Ian Meadowcroft.

This project record is part of an R&D output and no part of this report or the documents reviewed within it constitute formal Agency or Defra policy or process.

Acknowledgements

This Defra-funded project FD2318 was commissioned under the Risk Evaluation and Understanding of Uncertainty Theme of the Joint Defra / Environment Agency Flood and Coastal Defence R&D programme. This report was prepared by Foekje Buijs during her research based at HR Wallingford and Silvia Segura Domínguez, Paul Sayers, Jonathan Simm and Michael Wallis of HR Wallingford, and supported by Steve Oldfield of RMC Consultants. Research contributors included Fola Ogunyoye (failure and deterioration indicators), Philip Smith (geotechnical issues) and Jaap-Jeroen Flikweert (international review and failure case studies) of Royal Haskoning, and Prof. Mark Dyer (geotechnical failure processes) of the University of Strathclyde. The Project Director was Colin Fenn of HR Wallingford. The client project officer was Ian Meadowcroft.

Contents

1. Introduction

This project record contains the findings of a research and development project (FD2318), 'Performance and Reliability of Flood and Coastal Defences – Phase I'. The research documents contained herein record the major work elements and development of thinking within this study area and represents an accurate account of the project. The project reports that constitute the project record have been recorded to compact disc which is attached to the back cover of this report. The CD contains:

- This project record
- The Literature Review report
- Review of Flood and Coastal Defence Failures and Failure Processes report
- Evaluation of the Applicability of The Concept of Fragility to Risk Assessment of Flood and Coastal Defences report
- TR 1 - Development and Use of Fragility Curves in Flood and Coastal Defence
- TR 2 - Development and Use of Fragility Curves in Flood and Coastal Defence – Annexes.
- The presentations used in the workshop

1.1 Aims and objectives

The objectives of the study overall were:

- To explore the available approaches to characterising the reliability of flood and coastal defences.
- To develop scientifically underpinned fragility curves capturing information about the performance of structures under a variety of loading conditions.
- To provide clear best practice guidance on the concepts of characterising defence performance, including the presentation of existing knowledge on the performance of all types of linear defences.

Specific aims within the study included:

- To identify, compare and contrast existing methodologies for analysing the reliability of defence structures (walls and embankments), not only on flood defences but also on methodologies employed by other industries and other countries.
- *To assess whether the characterisation of defences developed under the Risk Assessment for Strategic Planning High Level Methodology (RASP HLM) R&D project is suitable for performance management in practice.*
- *To test the failure and deterioration modes identified within the literature review with what is observed in practice and to identify the key failure modes.*
- *To provide a review of geotechnical issues affecting the performance and failure of defences.*

- *To evaluate the applicability of the concept of fragility to coastal and flood defences.*
- *To define the role of the concept of fragility in flood and coastal risk assessments. To explore the types of risk that the concept of fragility represents and the extent to which it can serve to provide information about the reliability of the defences.*
- *To define for which flood and coastal defence types and failure modes associated with them it is possible in a practical sense to construct fragility curves.*

Research Documents

The research documents pertaining to this project are:

1. Literature Review (R&D Interim Technical Report)
2. A Review of Flood and Coastal Defence Failures and Failure Processes (R&D Interim Technical Report)
3. Evaluation of the Applicability of the Concept of Fragility to Risk Assessment of Flood and Coastal Defences (R&D Interim Technical Report)
4. Performance and Reliability of Flood and Coastal Defences FD2318/TR1 (R&D Technical Report)
5. Performance and Reliability of Flood and Coastal Defences FD2318/TR2 (R&D Technical Report)

1.2 Literature review (R&D Interim Technical Report)

This report firstly defines and lists the components of performance appraisal. It then gives an overview of the lessons learned from other industries with respect to performance and condition assessments. The next chapter discusses the current UK methods of assessment and contrasts those employed in other countries. A summary of limit state functions and the statistical approach is given before conclusions and recommendations are given to support the evaluation of the applicability of the concept of fragility to express reliability of flood and coastal defences.

1.3 A review of flood and coastal defence failures and failure processes (R&D Interim Technical Report)

This study assessed the use of the characterisation of defences developed under the Risk Assessment for Strategic Planning – High Level Methodology (HLM) R & D project, within performance management. It also set out to test the failure and deterioration modes identified within the literature review with what is observed in practice by practitioners and also to identify key failure modes. A review of geotechnical issues affecting the performance and failure of defences was made and a summary of an international review of defence failure carried out for the study is given. The report however, only considers linear defences and does not include point structures.

The primary purpose of this document was to assist the project team with the development of further phases of the project, although it does contain useful information for the flood and coastal defence practitioner.

Figure 1 Overtopping and erosion of bank material led to this breach of a river embankment

Figure 2 Failure of the toe of the channel lead to collapse of this revetment

1.4 Evaluation of the applicability of the concept of fragility to risk assessment of flood and coastal defences (R&D Interim Technical Report)

The report evaluates the applicability of the concept of fragility to coastal and flood defence reliability and risk assessment. It also investigates for which failure modes associated with defences it is practical to construct fragility curves. This investigation included; embankments, slope protection from erosion, vertical walls, dunes and shingle beaches, pumps and gates. Limitations of the approach to capture time-dependent reliability are also discussed.

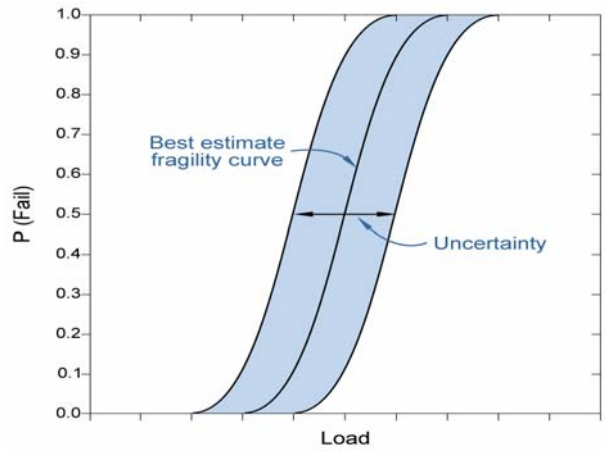


Figure 3 A Generic Fragility Curve

1.5 Performance and Reliability of Flood and Coastal Defences (Reports TR1 & TR2)

These reports consist of findings from those described above and a methodology for constructing fragility developed during the study.

The reports aim to assist:

- Those involved with managing flood and coastal defences, and assessing risk associated with flood defence structures and systems
- The further development of Defra and Environment Agency policies, strategies and decision-making tools for flood and coastal risk management.

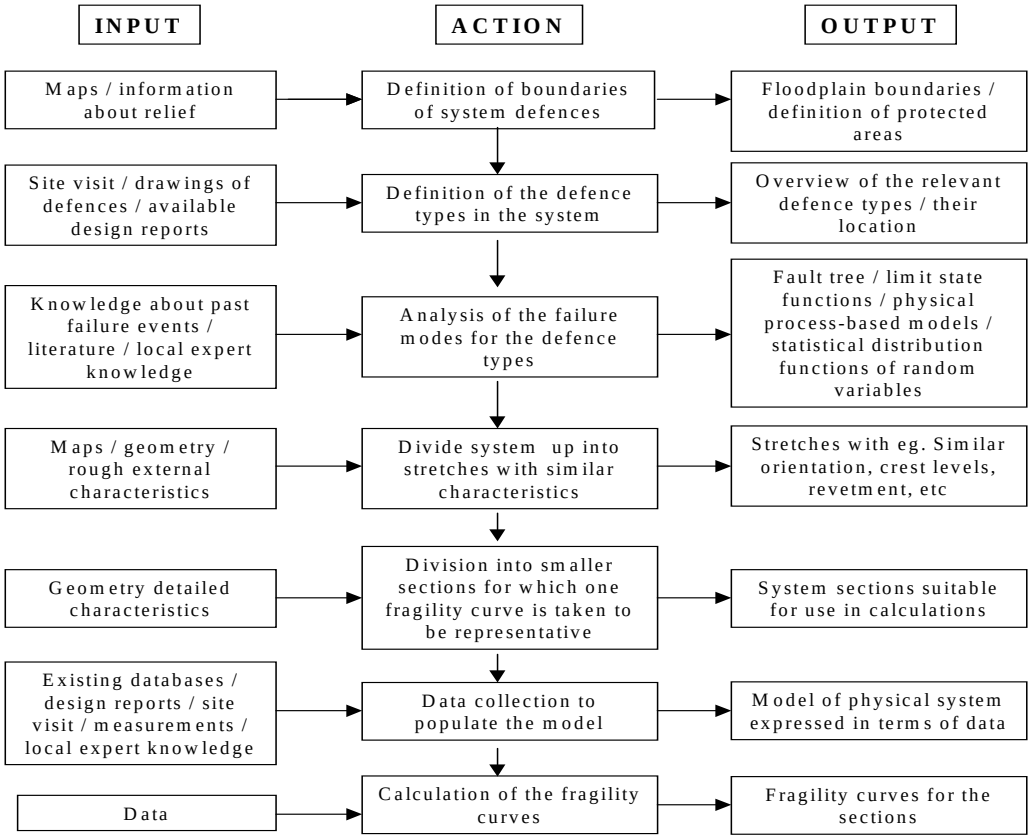
The use of fragility is valuable to analysts, practitioners, managers, planners and strategists as it provides a common approach to assessing the performance and reliability of flood defences under load, which is a valuable tool in flood and coastal defence management decision-making throughout the tiered approach to planning flood and coastal erosion management measures.

This work is split into two technical reports, TR 1 and TR 2.

TR 1: The Development and Use of Fragility Curves in Flood and Coastal Defence (R&D Technical Report)

TR 1includes:

- The conceptual reasoning behind the application of the fragility curve method
- A step by step guide to the construction of fragility curves plus additional guidance and recommendations



Figure

Firstly the investigation into the existing knowledge on the main failure modes and deterioration processes of the main structure types is summarised which included a desk study of process based models and interviews with experts. An over view of failure and deterioration processes of the main structure types and their indicators is given in tabular form. The most prominent failure processes for each structure type are presented.

The concept of fragility is introduced. Existing approaches to construct fragility are discussed. The most suitable approach is chosen to characterise fragility. Different views on fragility are discussed and the concept of fragility is evaluated, both in terms of its role in coastal and flood risk management, and in the practicality of constructing fragility for each structure type.

Guidelines are provided on how to build fragility curves for prominent failure modes. Example fragility curves are provided in the appendices for all 61 defence types according to the NFCDD characterisation.

Any knowledge gaps in this methodology have been identified where apparent and recommendations made for further development.

TR 2: Development and Use of Fragility Curves in Flood and Coastal Defence - Annexes (R&D Technical Report)

TR 2 describes fragility curves for National Flood Risk Assessment (NaFRA) and for intermediate and detailed levels of risk assessment together with indicative failure modes for a range of coastal and fluvial defences. The equations and the decisions about statistical representations and data requirements are also included.

2. Workshop

2.1 The application of fragility methods: background information & further reading

This document was written to accompany and compliment the workshop event held on the 3rd February 2005 at HR Wallingford. Each delegate was issued with an A4 binder containing the workshop materials including a copy of presentations made on the day. A copy of the agenda for the day is included in the appendix.

The report described the background to the concept of defence reliability including the range of approaches to characterising reliability and the appropriateness of different defence types. A summary of existing equations describing particular failure and deterioration processes was also given. Guidelines were provided on how to build fragility curves and the data requirements for their construction was listed. Fragility curves for some linear defences were provided.

2.2 List of delegates

A total of 45 delegates registered for the workshop event of which 42 attended from a range of organisations, both public and private sector, and from academia.

William Allsop	HR Wallingford Ltd
Joshua Arnold	Environment Agency
Richard Ashley	University of Sheffield
Mathew Balkham	Atkins
Mervyn Bramley	Independent
Mark Brown	Black & Veatch
Foekje Buijs	Newcastle University
Paul Burgess	RMS
Paul Canning	Atkins Water
Andrew Coen	Environment Agency
Cathrine Cooper	Environment Agency
Simon Cox	Environmemnt Agency
Ian Dalgleish	Atkins
Dave Denness	Environment Agency
Robert Doe	University of Portsmouth
Mark Dyer	University of Strathclyde
Nicola Eastley	Environment Agency
Colin Garwood	Floodgaurds Systems
John Goudie	Defra Flood Management Division
Jim Hall	University of Newcastle
Dominic Hames	University of East London
Gavin Johnson	Capita Symonds
Peter Kite	Peter Kite Associates
Richard Knight	Environment Agency

Michael Law	Weetwood Ltd
Gavin Long	Nottingham University
Martin Marriott	University of East London
Michael Mawdesley	Nottingham University
Ian Meadowcroft	Environment Agency
Edward Morris	Environment Agency
Mark Morris	HR Wallingford Ltd
Ian Nunn	Environment Agency
Shakirudeen Oduwuga	Department of Geography
Fola Ogunyoye	Posford Haskoning
Timothy Phillips	University of Newcastle
James Porter	Kings College London
Adrian Saul	University of Newcastle
Alma Neelije Antcnia Schellart	University of Sheffield
Jonathan Simm	HR Wallingford Ltd
Roy Stokes	Environment Agency
Owen Tarrant	Environment Agency
Ana Ulanovsky Ambrogi	Environment Agency
Mike Wallis	HR Wallingford Ltd
Tim Wells	Halcrow Group Ltd
John Wicks	Halcrow

A hands-on practical session for the delegates was arranged for the afternoon during which they used specially designed software to demonstrate the use of fragility curves to assess defence reliability. This consisted of a simple spreadsheet interfaced with more detailed reliability analysis software. The software incorporated a number of failure mechanisms including erosion and geotechnical failure.

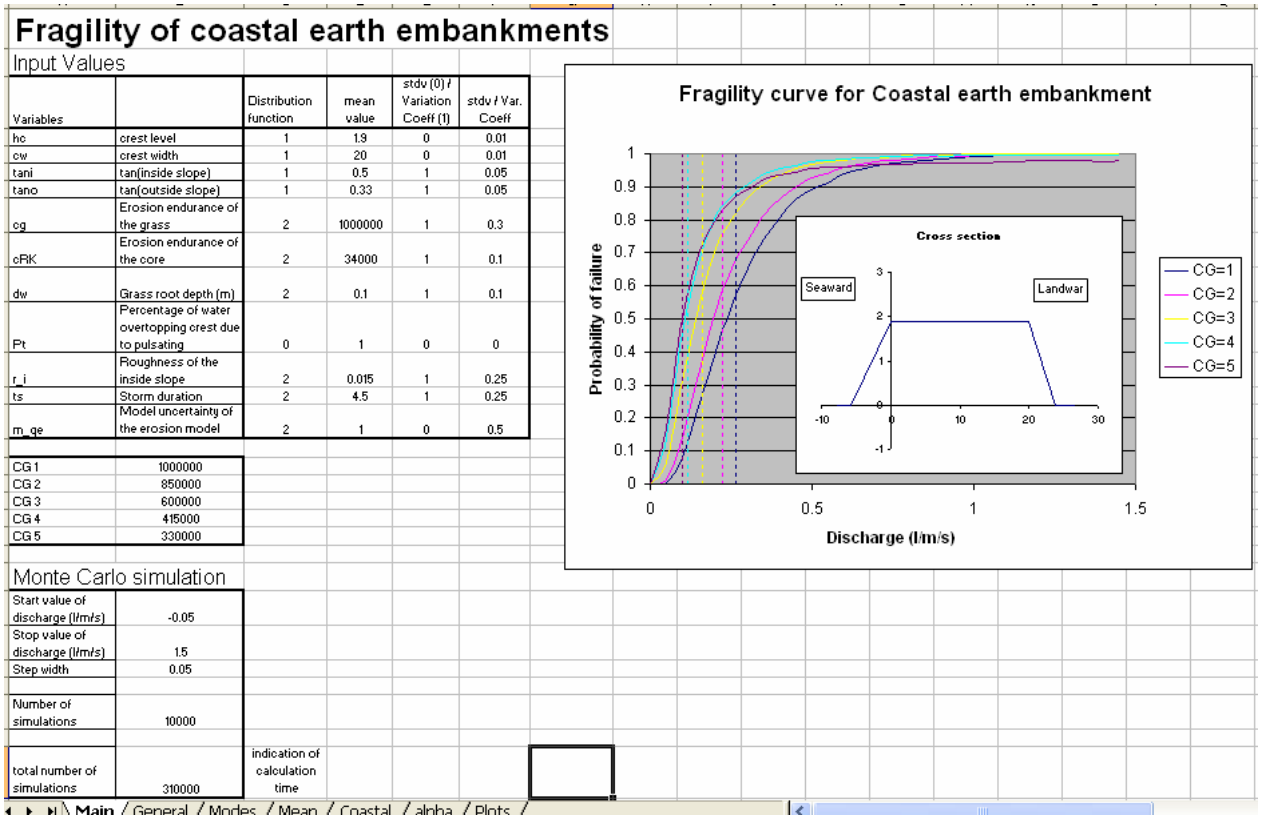


Figure 5 A screenshot of the demonstration software

3. Dissemination

3.1 Web site

The web site address is http://www.prfcd.org.uk/ and was used to publicise the project and make outputs available during the project via a password protected facility.

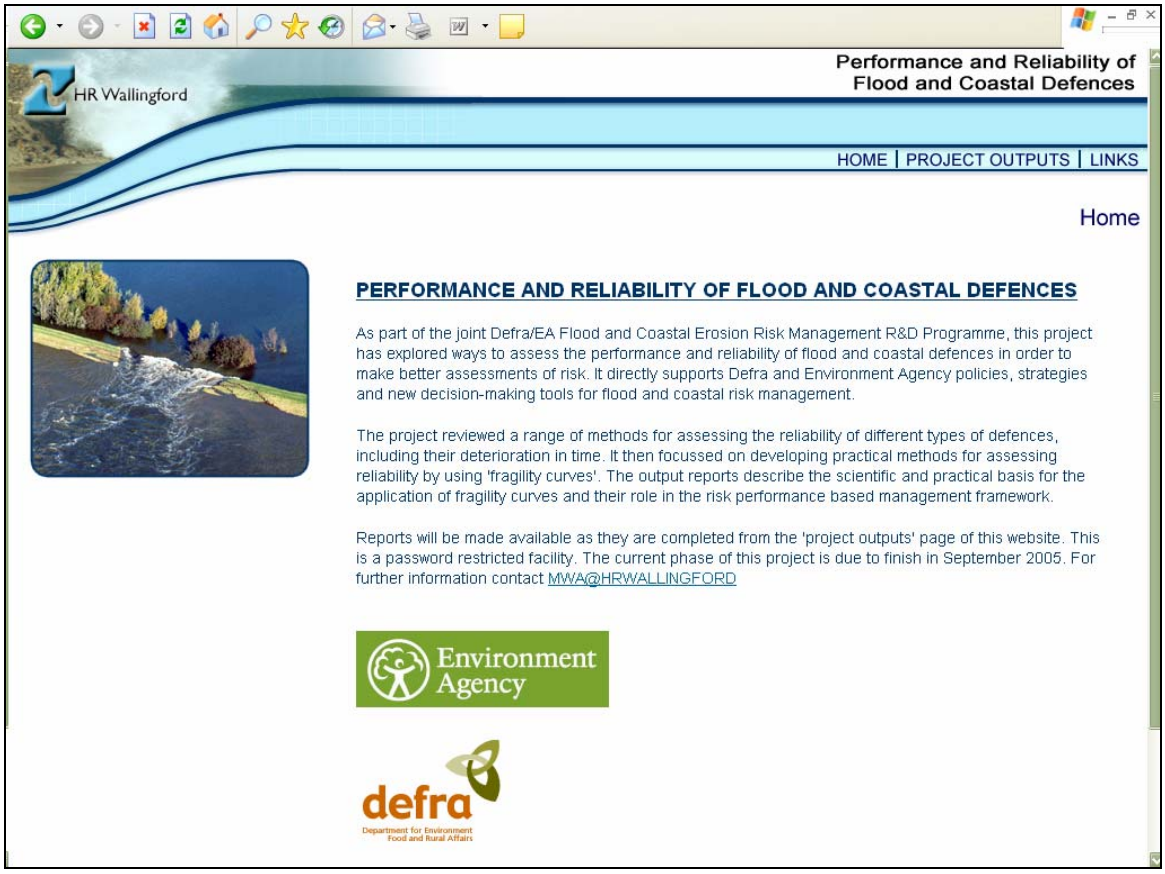


Figure 6 Screenshot of the front page of the project web site

Web links were provided to Defra, Environment Agency, HR Wallingford, FLOODRISKnet, and the Performance-based Asset Management System (PAMS) project.

3.2 Published papers and other dissemination

F.A. Buijs, S. Segura Domínguez, P.B. Sayers, J.D. Simm, J.W. Hall, (2005) *Tiered reliability-based methods for assessing the performance of coastal defences, (in press),* proc. Conf. Coastlines, Structures and Breakwaters in press, London, UK, April 20-22.

REUU newsletter April 04

Sayers P, *et al, (*2005) A Hierarchy of Risk-Based Methods and their Practical Application. Proc, 40th Defra Flood and Coastal Management Conf., Univ' York 5th- 7th July.

EA/Defra 'Research News' Issue No. 8, June 05. Article: *Got to Admit it's Getting Better.* Ian Meadowcroft.

3.3 Links to other projects and research

This project has promoted close links with several other projects and enabled invaluable development in flood and coastal risk management. Three key links include;

- The Flood Risk Management Research Consortium (FRMRC) – especially in the development of work package 4.3 – the development of a structured asset inspection methodology to enable better informed asset management decisions for reducing flood risk. The concept of 'failure modes' – used by fragility methodology – has provided a focus and a framework around which to construct a revised condition assessment and inspection methodology for the purpose of assessing flood and coastal defence performance.
- Performance-based Asset Management System (PAMS) – fragility is a central element of the PAMS methodology. It is an integrated part of the asset risk and performance assessment at both high and detailed levels. This project has enabled a level of detail to be added beneath the RASP high level method already established and used in national flood risk assessment (NaFRA). In doing so it has brought the concept within the bounds of the regional and local practitioner.
- Thames Estuary 2100 – is demonstrating this regional level application of fragility through a PAMS – type model. Also a version of the inspection methodology that the work on fragility has helped to develop is being used to gather data to update the model, which in turn should – through iteration – lead to better quality outputs.

This application of fragility methodology to flood and coastal defence assessment is a new and rapidly developing area of research. Advances will continue to be made for example in the understanding of failure processes and deterioration – developing the process based models on which fragility curves are constructed. For this reason it is important to ensure that future dissemination should be as contemporary as possible.

4. Conclusions

All seven of the project reports listed (i.e. not the published papers or news articles) can be downloaded from the project web-site (password protected) at http://www.prfcd.org.uk/.

These documents provide a comprehensive account of the research and investigations undertaken, and the developments made during the course of the project since its beginning in September 2004 through until July 2005.

The project record does not fully reflect the impact that developments made during the project have had (and will continue to have) on the flood management industry though its contribution to, and facilitation of, advances in associated projects such as PAMS. However the associated industry press articles such as the EA/Defra Research News provides a much better insight into these issues and reflects the importance and success of this work.

Project records of correspondence and data are held on file and archived at HR Wallingford.

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APPENDIX

Appendix Performance and reliability of flood and coastal defences - Application of fragility methods: Workshop Programme

Title of Workshop: **Performance and reliability of flood and coastal defences: Application of fragility methods**

Location **Organised by HR Wallingford and FloodRiskNet and to be held at HR Wallingford**

Date: **3rd February 2005 (1 day)**

This workshop is intended to disseminate the findings of research on the "Performance and reliability of flood and coastal defences"- Project FD2318 in the Risk Theme of the Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Programme. This project has explored ways to assess the performance and reliability of flood and coastal defences in order to make better assessments of risk. It directly supports Defra and Environment Agency policies, strategies and new decision-making tools for flood and coastal risk management. The project reviewed a range of methods for assessing the reliability of different types of defences, including their deterioration in time. It then focussed on developing practical methods for assessing reliability of using 'fragility curves'. This workshop will present the main findings of the project including the methodology developed to construct fragility curves. Further research on reliability methods of sewer systems and time dependent reliability will be introduced.

The workshop is aimed at those carrying out, or with an interest in, flood and coastal risk assessment. It will describe the scientific and practical basis for fragility curves, and their role in the risk and performance based management framework.

Time		Presenter	Comments
9:30	Registration		
10:00	Welcome / Introduction / General Overview	Ian Meadowcroft (EA Theme Leader)	
10:10	Risk and performance based management for flood and coastal defence - The context for fragility curves, their value for asset management and risk reduction	Mervyn Bramley (Engineering Theme)	10 minutes for questions
10:40	How well do assets perform? Experience from the field	Fola Ogunyoye (Royal Haskoning)	10 minutes for questions
11:10	Coffee break		
11:40	Asset management and inspections	Dave Denness (EA Operations)	10 minutes for questions
12:10	Construction of fragility curves	Jonathan Simm/ Foekje Buijs (HR Wallingford/Univ.	10 minutes for questions

		Newcastle)	
12:40	Summary of key points, general discussion and Introduction to afternoon workshop.	IM/JDS Chair (Foekje Buijs)	(10 mins) (10 mins)
13:00	Lunch		
13:45	Introduction and instructions for afternoon workshop	Jonathan Simm (HR Wallingford)	(5 minutes)
13:50	Working session – process of building a fragility curve. (Coffee at 14:30)		(60 mins)
14:50	Feedback		(10 mins)
15:00	FRMRC sewer performance vision	Adrian Saul (FRMRC)	
15:15	Time dependent reliability and flood defences systems	Foekje Buijs (Univ. Newcastle)	
15:30	Feedback and future steps: discussion and feedback on fragility curves as practical tools to support asset management and risk assessment and views about dissemination	JDS /IM (HR Wallingford/EA)	
16:00	Close	JDS/IM (HR Wallingford/EA)	