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SID 5 Research Project Final Report

- **Note**

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  A SID 5A form must be completed where a project is paid on a monthly basis or against quarterly invoices. No SID 5A is required where payments are made at milestone points. When a SID 5A is required, no SID 5 form will be accepted without the accompanying SID 5A.

- This form is in Word format and the boxes may be expanded or reduced, as appropriate.

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Project identification

1. Defra Project code: FD2318

2. Project title: Performance and Reliability of Flood and Coastal Defences

3. Contractor organisation(s): HR Wallingford Ltd
   Howbery PArk
   Wallingford
   Oxon. OX11 9UZ

4. Total Defra project costs: £ 118718.00

5. Project: start date .... 01 November 2003

   end date .... 30 September 2005

6. It is Defra's intention to publish this form.
   Please confirm your agreement to do so...**YES** ☒ **NO** ☐

   (a) When preparing SID 5s contractors should bear in mind that Defra intends that they be made public. They should be written in a clear and concise manner and represent a full account of the research project which someone not closely associated with the project can follow.

   Defra recognises that in a small minority of cases there may be information, such as intellectual property or commercially confidential data, used in or generated by the research project, which should not be disclosed. In these cases, such information should be detailed in a separate annex (not to be published) so that the SID 5 can be placed in the public domain. Where it is impossible to complete the Final Report without including references to any sensitive or confidential data, the information should be included and section (b) completed. NB: only in exceptional circumstances will Defra expect contractors to give a "No" answer.

   In all cases, reasons for withholding information must be fully in line with exemptions under the Environmental Information Regulations or the Freedom of Information Act 2000.

   (b) If you have answered NO, please explain why the Final report should not be released into public domain

Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

Present challenges in flood risk management include:
 - assessing flood and coastal erosion flood risk
 - assessing the performance of flood and coastal defence systems under a range of conditions and
 - understanding the benefits (in terms of risk reduction) of various management interventions available. IN order to help the flood and coastal erosion risk management community meet these challenges this project set out to address the following;

- To establish
  - the available approaches to characterising the performance and reliability of flood and coastal defences in other industries and other countries.
  - the main defence failure processes associated with the main flood and coastal defence types
  - the appropriateness of the concept of fragility to capture those main failure processes and to inform decision-making.
- To develop scientifically based 'fragility curves' capturing information about the performance of structures under a variety of loading conditions,
- To provide clear guidance on the concepts of characterising defence performance, including the presentation of existing knowledge on the performance of all types of linear defences.

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'. 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 (e.g. high water levels or waves). It was found that fragility methods can be used effectively to express the probability of failure of a defence given a range of loading conditions, and to summarise information about its reliability.

A methodology for constructing fragility curves for this purpose was devised and described during the project. (A workshop for practitioners was held to introduce the concept). This application of the 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. The project has also shown that it is possible to construct a fragility computer model 'tool' which could aid interpretation, understanding and management – decision-making.

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:
   - the scientific objectives as set out in the contract;
   - the extent to which the objectives set out in the contract have been met;
   - details of methods used and the results obtained, including statistical analysis (if appropriate);
   - a discussion of the results and their reliability;
   - the main implications of the findings;
   - possible future work; and
   - any action resulting from the research (e.g. IP, Knowledge Transfer).

This research set out to identify methods and provide guidance on best practice approaches for assessing the reliability of flood and coastal defence structures (linear structures, pumps and gates) and their deterioration in time. The outputs sought were to directly support the overall joint R&D programme objective of developing improved risk-based management / engineering.

Specific objectives.
The specific objectives of the project were;

1. To explore the available approaches to characterising the reliability of flood defences, including linear defences, point structures (pumps, gates) and identify methods that best support the overall programme objective of supporting improved risk-based management / engineering.

2. To develop or collate and compile ‘fragility curves’ which capture information about the performance of linear load defence structures under a variety of loading conditions.

3. 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.

The intended format of the output was written guidance in the form of a well-structured R&D Technical Note on the concept of defence fragility and the methodologies behind the development of fragility curves, and a more detailed R&D project report outlining the findings of the project and recommendations for future developments.

Evidence of completion of the objectives is the ‘Project Record’ submitted as the final deliverable under the contract. This includes interim reports that investigate existing literature on the subject, expert knowledge (interviews with practitioners served to gather experience-based knowledge about known defence failures), and also discuss the concept of fragility and its applicability in this arena. The document produced for the stakeholder workshop is also included as well as the final technical reports that summarise this information. The final report also describes and demonstrates a methodology by which fragility can be calculated and just as importantly – how to interpret the results. Knowledge gaps and limitations have also been highlighted.

The only amendment to the original objectives was the provision of best practice guidance. It was apparent to the project board by the drafting stage that the final report(s) could not constitute ‘best practice guidance’ as the methodology, although sound, had not at the time been established or demonstrated sufficiently through application to enable such guidance to be written. It was agreed that the final reports should be presented as technical reports.

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

Process-based models of failure are in most cases available but with various degrees of complexity, ranging from ‘one-line equations’ to detailed finite element models. Although a lot of research has already been done, these process-based models are subject to continuous improvement. For example the physics of geotechnical failure modes needs to be developed much further and validation is required of the simpler equations that are available against the more complex finite element models.

The different levels of detail of process-based models fit well into a tiered risk assessment structure – be it national, regional and defence scheme scale decision-making, or design projects with decision-making concerned with the feasibility, preliminary and detailed design stages. The underlying failure processes of coastal and flood defence types remain the same for all tiers. The choice of process-based model and number of failure modes can be tailored to the tier of decision-making and data availability in that tier.

Deterioration processes affect the properties of coastal and flood defences and therefore affect the failure modes of those defences. Deterioration can thus trigger failure modes not necessarily related to a storm event. Process-based models for deterioration processes are much less organised and developed than those for the main failure modes. Methods to account for the unpredictability in time of the deterioration source, (e.g. animal infestation), as well as the physical processes caused by it are still poorly understood.

An investigation was carried out into methods utilised to construct fragility for flood defences in other countries (mainly the Netherlands, Germany and USA) and other industries (nuclear, seismic and mechanical engineering). Subsequently, structural reliability methods are recommended for constructing fragility for flood and coastal defences. These methods simulate defence failures based on the best available knowledge and data about the physical processes, aided by expert judgement to fill in the gaps. These processes are represented by process-based models that are conventionally applied in practice to assess the performance of structures.

The quality of the fragility results therefore hinges on the quality of:

- the underpinning process-based models;
- the representation of the uncertainties in those models and data;
- the data availability;
- the accuracy of the chosen calculation methods.

Although the structural reliability method is also subject to judgement-based influences, the underlying process-based or probabilistic models make the results more accessible to external scrutiny.

Two main issues were considered in the applicability of fragility to coastal and flood defences:

1. *The role of the concept of fragility in risk assessments containing different defence types.*

The concept of fragility is suitable to capture structural performance of flood and coastal defences. Fragility also allows insight in the sensitivity of the probability of failure to the characteristics of the defence. The quality of fragility depends on the quality of the process-based models.

Fragility is currently heavily founded on hydraulic loading conditions leading to flooding. Coastal and flood defence systems also contain elements that have functions other than delivering flood and coastal protection. Neglecting these other functions might underestimate the importance of certain defence types or point structures in the system. Also, fragility sometimes needs extra attention to ensure that the likelihood of the failure process correctly corresponds with the consequences in the risk term. A good example is coastal erosion, where failure of the coastal revetment can happen during a storm while the consequences are caused by an additional erosion process. The likelihood of the different developments in time of the erosion process must be considered as well.

Fragility maps the structural reliability of different failure modes and defence sections onto a uniform measure. This allows the comparison of the importance of different failure processes and defence sections. This can be used in tandem with information about the existing properties of the defence to efficiently inform decisions about maintenance, repair and improvement options.

Condition assessments should be linked to the failure modes of the coastal or flood defence. Rather than focusing on one dominant failure mode, the condition assessment should take all failure processes into account. In addition, the condition assessment should attempt to focus on the defence properties appearing in the process-based models. For visual condition assessments it is expected that the indicators used will have indirect relations with the properties relevant in the failure processes. These indirect relations should preferably be quantified as much as possible. The indirectness also reflects on the confidence about the quantification of the properties in the process-based models.

2. *To what extent the concept of fragility is applicable to process-based models associated with different defence types.*

The following comment is generally applicable - 'as physical understanding of failure processes progresses, the quality of fragility improves'.

Even if good quality process-based models are available, it is clear that ways to construct fragility are not straightforward for all failure processes. Examples are geotechnical failure modes, failure modes between storms or vertical walls triggered by deterioration processes, and time-dependent processes in general.

The evaluation of the concept of fragility for defence point structures pointed out that point structures should be considered in the wider system-based context. Extreme local water levels are caused by several factors such as afflux, as well as the total capacity of the system of watercourses and the duration of the rainfall. Such an approach allows attention to be focused on the most influential defence point structures. After targeting the most important point structure the individual fragility can be investigated to get clues about how to improve it.

This application of fragility methodology to flood and coastal defence assessment is a new and rapidly developing area of research. Advances should 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.

The 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.

References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

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.

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