Assessing and managing risks with transitions in flood defence infrastructure

Project overview

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This report is the result of research commissioned and funded by the Joint Flood and Coastal Erosion Risk Management Research and Development Programme. The Joint Programme is jointly overseen by Defra, the Environment Agency, Natural Resources Wales and Welsh Government on behalf of all risk management authorities in England and Wales: Flood and Coastal Erosion Risk Management Research and Development Programme

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Dr Robert Bradburne
Chief Scientist

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Executive summary

This report is the final technical report of the ‘Assessing and managing risk with transitions in flood defence infrastructure’ project and presents a complete summary of research carried out, the research outcomes and the research outputs.

The individual research outputs are reported in detail as 4 separate reports:

Report 1 (Section 4): Prioritisation of transitions: Development of top-down methods for identifying and prioritising asset transitions based on risk

Report 2 (Section 5): Inspection: Framework for onsite inspection and evaluation of asset transitions

Report 3 (Section 6): Fragility curves: Quantifying the probability of failure at asset transitions

Report 4 (Section 7): Transitions guidance: Design and management guide for fixing transitions

1 Introduction

1.1 Project inception

This research and development project was commissioned by the Environment Agency in May 2018. The target audience for the work is the flood risk management authorities operating in England and Wales and their sponsoring governmental departments. Within the Environment Agency, the project will support the work of the following national and area teams:

- FCRM Asset Performance and Engineering
- National Operations Asset Management
- Area Asset Performance Teams
- Area Partnership and Strategic Overview Teams
- Area Field Teams

Although originally envisaged to be completed by September 2019, the project encountered a number of delays relating to staff changes, Covid, and amendments to the project scope as initial outcomes of the research became clear and as the business needs of the Environment Agency evolved.

1.2 The project team

This work has been led by HR Wallingford and carried out in close collaboration with Royal HaskoningDHV (RHDHV) and a supporting consortium of team members built from members of a previous European Commission project called FloodProBE. The overall focus of the FloodProBE project (see www.floodprobe.eu) was to support provision of cost-effective flood protection for the built environment through investigations into processes, technology and solutions covering transitions, grass performance, geophysics, remote sensing and the integration of data from multiple sources. HR Wallingford and RHDHV have expert UK knowledge and experience with respect to risk-based asset inspection and management. The supporting consortium members were drawn from across Europe and the USA to ensure the research reflects current international knowledge and practice on transitions. The team is described below:

HR Wallingford (HRW)

- Project lead and lead for reports 1 and 3.
- HRW carried out the original work on transitions within FloodProBE, and has developed fragility curves and risk-based methods and tools for the assessment of flood defence asset performance.
- HRW has specific hydraulic expertise.

Royal HaskoningDHV

- Lead for reports 2 and 4.
- RHDHV has practical experience of assessing flood defences for the Environment Agency, developing asset management procedures (including inspection procedures) and industry guidance.
- RHDHV has specific hydraulic and geotechnical expertise.

Deltares

- Coordinated the original FloodProBE project and has since implemented further research into transitions processes.
- Deltares has specific hydraulic and geotechnical expertise.

IRSTEA (National research institute of science and technology for environment and agriculture)

- IRSTEA led the original FloodProBE work on transitions and continues to address these issues in France in collaboration with government ministries.
- IRSTEA has specific hydraulic and geotechnical expertise.

US Army Corps Engineers (USACE)

- Mike Sharp (geotechnics) and Chris Neutz (levee embedments) have key relevant background and expertise on current USACE knowledge and practice relevant to transitions.

Électricité de France (EDF)

- Jean Robert Courivaud is a recognised industry expert on asset performance and management, including transitions.

1.3 Project objectives

Transition zones are areas of potential weakness within an overall system of flood defences. They can be found at any location, on or within a flood defence where there is a change in flood defence structure, material, geometry, orientation, subsoil, or of protection revetment (slope or crest, road), in internal cross section or in construction or foundation materials. The transition zone is at the interface between 2 volumes or a line between 2 surfaces, where there is often inherently less resistance to the failure processes of erosion (internal and external) and/or where loadings may be increased locally. If these processes are undetected, or left unchecked, they can ultimately lead to flood defence failure and breach. Transitions of concern generally involve a link to an earth embankment, and that has been the focus of this project. Connections between structural flood walls and embankments (see Figure 1.1), and crossings of utility infrastructure such as culverts or pipes through or over an embankment are examples of transitions.

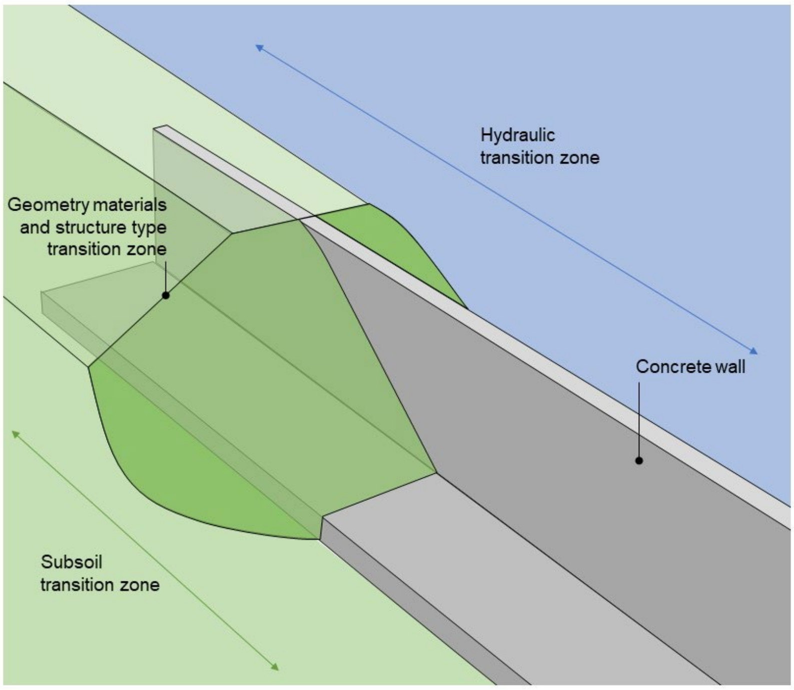


Figure.1.1 Diagram of a transition zone between a flood wall and earth embankment

Current guidance in England and Wales on the visual inspection of flood defence assets to determine condition does not explicitly account for the potential effects of transitions on defence performance. Similarly, risk analysis methods also currently fail to explicitly account for transitions. In these risk analyses, flood defence performance is captured via a fragility curve that relates the load on the defence (a water level relative to defence crest level or an overtopping discharge) to a probability of failure. The presence of transition zones is not uniquely accounted for and the performance of, for example, a flood embankment is simply based on an assessment of its geometry and condition along a specified length. As such, where transitions do increase the probability of defence failure above that of the adjoining defence assets, the associated risks are missed from local, regional and national flood risk assessments.

Therefore, the objective of the project is to develop tools and guidance to help Risk Management Authorities (RMAs) asset managers to:

- consider the presence of transitions during flood defence condition assessment
- quantify the effects of transitions on defence performance and flood risk
- manage the risk associated with transitions with improved design and retrofitted solutions for existing defences

The benefits from the outputs of the project will be:

- raised awareness of transitions and the potential risk that they may pose among asset inspectors, catchment engineers, and asset managers

- early identification of possible performance issues at transitions, through targeted inspection and evaluation, allowing maintenance and repair to be programmed pro-actively
- a greater understanding of the likely impact of transitions on localised defence performance, allowing maintenance and repair work to be prioritised more effectively, taking account of these potential weak points in the defence system
- good practice in the design, maintenance and repair is shared widely, ensuring work is carried out efficiently

1.4 Project outputs and their contribution to transition asset management

The original terms of reference for this research specified the development of 4 principal products:

- improved guidance for identifying and inspecting transition zones
- new methods and tools for the reliability analysis of flood defences with transitions
- new methods to account for transitions in flood risk systems analysis such as the Environment Agency's National Flood Risk Assessment (NaFRA)
- new guidance supporting the design, maintenance and repair of transitions

The project outputs have been continuously reviewed, as the research has progressed, and following practical learning secured from pilot study applications of methods. As a result, a number of additional outputs were commissioned during the project and some of the project outputs have been adjusted. These scope changes followed multiple workshops between the project and Environment Agency client team, and lessons learned from the first (and subsequently commissioned second) pilot studies. The changes were agreed with the Environment Agency client team and Project Board.

1.5 Purpose and structure of this report

This report presents a complete summary of research carried out, the research outcomes, and the research outputs for each of the reports. The report is structured as follows:

Section 2 introduces the different types of transition.

Section 3 describes the different flood defence asset failure mechanisms relevant to transitions.

Section 4 summarises the research reports and the research activities contributing to the development of each report.

The envisaged users of this report are professionals in the Environment Agency, Natural Resources Wales and other organisations seeking an overview of the significance of flood defence transitions and how they can be assessed and managed. It is also expected to be useful to anyone taking the research development further in the future.

The individual outputs created by the research are contained or described within separate stand-alone reports, which are described and referenced in the following sections.

2 Types of transition considered by the research and their prevalence

A project workshop held in London in October 2018 provided the opportunity to gather experiences and views about transitions from stakeholders involved in asset flood risk management. The stakeholders were mostly from the UK, but also included representatives from the US, France and the Netherlands. The feedback identified the most frequent and vulnerable types of transitions to be:

- between levees and flood walls or hard point assets
- at culvert and pipeline crossings of levees
- between soft and hard revetments

To support these initial findings, a spatial analysis of the Environment Agency flood defence database for England, named AIMS (Asset Information and Maintenance System), was carried out. This was to secure a high-level quantitative estimate of the number and type of possible flood defence to flood defence transitions in England. The study concluded that the total number of transitions between FCRM assets is 167,500. The analysis identified 20,709 transitions involving an earth embankment. Of those, 40% corresponded to transitions between different types of embankment, 38% to transitions between embankments and high ground, and 22% to transitions between embankments and hard structures. This combined evidence was used to focus the research project on the study of 4 specific types of transition, listed below.

- Type 1 - Longitudinal transitions between embankments and 1) flood walls and 2) point assets (for example, stairs, flood gates) and between soft and hard embankment revetments
- Type 2 - Cross-sectional transitions in an embankment with a flood wall above
- Type 3 - Crossing infrastructure
- Type 4 - Longitudinal change in revetment type

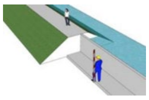
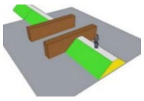
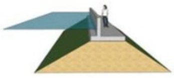
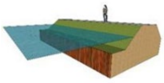
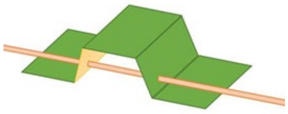
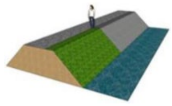
Longitudinal transitions	Cross-sectional transitions	Crossing infrastructure	Revetments
Type 1	**Type 2**	**Type 3**	**Type 4**
 Between embankment and flood wall  Between embankment and point asset	 Between embankment and crest wall  Between toe wall and embankment	 Between embankment and crossing structure	 Between soft and hard revetments

Figure 1.2 Transition type characterisation

It should be noted that transitions between flood defences and non-flood defence structures may not be evident from national flood defence databases. In the second pilot study in particular, the risks identified at transitions between flood defences and third party assets (for example, road support structures) were significant (see Figure 4).

Figure 1.3 Third party Type 4 (revetment) transition not identified by interrogation of the Environment Agency AIMS database

3 Failure mechanisms at transitions

The original scope for this project recognised that the presence of a transition zone may reduce the reliability (and increase the risk of failure) of the defence as a result of:

- increases in loadings on specific areas of the transition (resulting from the interaction of transition features with local flowpaths)
- reductions in the resistance of the defence to loadings due to additional points of weakness

Through literature review, stakeholder engagement and pilot site studies through the duration of the project, it has become clear that there are a range of impacts resulting from transitions that can influence either loadings or resistance. These are:

1. altered geometries (shorter seepage paths; steeper slopes; or irregular geometry causing turbulence)
2. differences in behaviour of materials (hydraulic separation; impeded grass root formation and shading; or gaps in filter structures)
3. impediments to construction and maintenance (poor compaction around transition elements; or impeded maintenance due to poor access and visibility)
4. preferred traffic paths causing deterioration (rutting and furrowing; animal burrows)

Through research carried out as part of the 'Quantifying the probability of failure at asset transitions' report (Environment Agency, 2022c) (the development of methods and tools to assess the reliability/performance of transitions), main failure mechanisms were studied and their relevance and significance to transition asset failure were identified. The outcomes of this research are summarised in section 3.1.

3.1 Evaluation of transition failure mechanisms

This section provides a description for each failure mechanism and its significance for transition assets.

3.1.1 External erosion

External erosion, also called surface erosion, may be caused by:

- overtopping or overflowing, leading to shear stresses on the landside slope of the earth embankment
- wave action on the waterside slope

At transitions, these actions can be larger due to changes in geometry or lower crest elevations of one of the assets. Furthermore, at transitions there can also be a strength reduction, for example, where there is weaker grass due to various transition impacts.

External erosion of the waterward levee slope was not considered by the research into transition reliability (Environment Agency, 2022c) due to its principal relevance for incision of banks on the outside of river bends leading to mass instability (which will be specific to the exact geometric arrangements at the site).

3.1.2 Internal erosion

Internal erosion involves the detachment of soil particles and their transport by seepage flow. There are 4 main internal erosion mechanisms (Morris and others, 2012, ICOLD, 2016, Tourment, 2015):

- **Contact erosion:** related to selective erosion of fine particles from the contact with a coarser layer
- **Backwards erosion:** occurring along a decompressed contact area as a result of seepage exiting an unfiltered surface; it leads to retrogressively growing soil piping and sand boils
- **Concentrated leak erosion:** related to the detachment of soil particles through a pre-existing path, such as a crack – given the largely clay composition of most UK flood embankments, this mechanism is believed to be the most important transverse internal erosion process for transitions between soil and hard structures
- **Suffusion:** related to the selective erosion of the fine particles from a matrix of coarse particles

The process of internal erosion can broadly be divided into 4 phases: initiation, continuation, progression to form an erosion piping zone (causing surface sloughing) and initiation of a breach. It can include one or more of the 4 internal erosion mechanisms (Morris and others, 2012).

Transitions can potentially be zones of preferred seepage paths where erosion can be initiated and develop. Hydraulic gradients across the structure, the driving loading factor causing seepage, may also be increased at transitions due to changes in geometry. Leakage from or into an embedded pipeline can also be a cause of internal erosion at the transition between pipeline and embankment.

The research into transition reliability (Environment Agency, 2022c) focused on concentrated leak erosion as the most relevant internal erosion mechanism, as this best represents both the hydraulic separation issues that arise at the interface between hard materials and earthen structures and the common issues with animal burrowing in UK levees, which lead to the potential for focused flow paths through embankments.

3.1.3 Slope and mass instabilities

Slope instability includes sliding and collapsing, while mass instability includes settlement due to soil disturbance or poor compaction and liquefaction.

Instabilities may occur as a result of hydraulic gradient or uplift forces which could have larger impacts at transitions due to internal (and therefore largely invisible) changes in permeability, poor compaction or poor soil properties. More visible scour at the toe of a structure can also cause slope instability.

These issues were not addressed by the research into transition reliability (Environment Agency, 2022c), as this mechanism is rare post construction in England and Wales. This is especially the case for landward slopes of levees since hydrographs are generally too short to elevate pore pressures sufficiently; and failures of waterward slopes tend to occur after floods due to rapid drawdown. In addition, instability of hard structures within a composite defence involving an earth embankment is related to the design of the composite structure rather than the transitions, and therefore this was not considered further in this research.

3.1.4 Hard structure instability

Hard structure (flood wall) instability is related to the collapse (due to undermining of support material), overturning or sliding of the structure. This can be caused by the increase of external erosion processes at a transition due to changes in geometry (scour at the toe), subsidence caused by different assets settlement or due to the increase of hydraulic impact forces caused by changes in geometry.

3.1.5 Crest degradation

The loss of crest elevation can cause the functional or hydraulic failure of the flood defence system. At transitions, rutting or a difference in crest elevations between a levee and flood wall can create preferential overflow paths. This, in turn, may exacerbate problems of external erosion of the rear face.

4 Summary of the research reports

4.1 Report 1 - Risk assessment and prioritisation

This report (‘Development of top-down methods for identifying and prioritising asset transitions based on risk’, Environment Agency, 2022a) explores how to prioritise flood defence transitions for inspection, and how performance data (from the ‘Quantifying the probability of failure at asset transitions’ report, Environment Agency, 2022c) can be used to refine risk assessments and reprioritise transitions for more detailed inspections or fixing.

4.1.1 Report 1: Definition of need

The scope of this report evolved during the course of the project. It was initially envisaged to focus on the definition and pilot testing of a new method to account for transitions within flood risk systems analyses. As the project progressed, it became apparent that quantifying the transition impacts in the ‘Quantifying the probability of failure at asset transitions’ report (Environment Agency, 2022c) (via fragility curves) would be compatible with existing agency prioritisation techniques and tools.

Instead, the need to define, develop and trial an automated preliminary method for identifying important transitions that should be prioritised for initial (Tier 1) field inspection was identified as important to support the roll-out of a transition inspection and evaluation process. This approach is described here as a ‘Tier 0’ prioritisation method. This work was identified as important following:

- the spatial analysis of transition locations and types, carried out as an additional piece of work under Stage 2 of the project (see section 2), identified 167,500 transitions between assets across England, of which 4,506 are transitions between embankments and hard structures, and 2,149 between embankments with a hard and a soft revetment
- discussions with the National Engineering and Innovation Panel (NEIP) and its concerns over the practicality of asset inspectors carrying out bespoke inspections at each of these locations
- the piloting exercise of the ‘Framework for onsite inspection and evaluation of asset transitions’ (Environment Agency, 2022b) guidance (that takes flood defence asset managers through the process of identifying whether asset transition elements should be considered for improvements)
- the development and piloting of the updated hrRELIABLE tool that accounts for transition characteristics in determining transition specific asset fragility curves

4.1.2 Report 1: Outputs

The report 1 range of outputs includes:

- an evaluation of 3 risk assessment methods potentially of use for prioritising transition elements where any increased likelihood of failure (resulting from its characterisation as a transition) would mean a significant increase in associated consequences
- a case study application of all 3 methods to the project’s second pilot study area – the Tidal Trent
- a recommended preliminary transition prioritisation process, including:
    - learning from the case study application
    - supplementary guidance (drawn from the outcomes of reliability modelling sensitivity testing carried out in ‘Quantifying the probability of failure at asset transitions’ report (Environment Agency, 2022c)) on screening out transitions

that either have physical characteristics or hydraulic loading conditions that make them less vulnerable to failure

4.2 Report 2 - Guidance for the inspection and evaluation of transitions

Asset inspection is an important part of the overall cycle of risk and performance-based asset management. Inspections should be targeted to need rather than being dictated by routine alone, and they allow interventions to be timed to pre-empt asset deterioration and possible failure.

4.2.1 Definition of need

Assets are typically identified and recorded in databases, but to date these databases rarely separately identify transitions between flood defence assets or the multiple transitions that may arise in composite assets. This problem is further compounded by additional transitions between flood defence and non-flood defence assets.

The normal defence asset inspection and evaluation process in England and Wales is tiered. The default tier is routine visual inspection, the procedures for which are well embedded in the Environment Agency using the Condition Assessment Manual (CAM) (Environment Agency, 2012). This is followed, if needed, by other tiers of activities which seek more detailed information than is routinely collected. Typically, a second tier of non-intrusive investigations is carried out by an appropriate expert. This may be followed by a third tier of intrusive investigations into the make-up of the asset, and/or specialist advanced analysis. Both second and third tier investigations require additional investment and need to be justified in terms of risk reduction benefit.

Previous research (see Bown and others, 2014) has identified that these well-established methods do not explicitly highlight issues at transitions, particularly where the transition is at the end of a long linear asset, which itself might be in good condition.

4.2.2 Report 2: Outputs summary

The report 2 range of outputs includes:

- a guide to the inspection and evaluation of transitions
- an accompanying set of decision support flowcharts that were incorporated within the prototype AIMS app
- an accompanying set of inspection field visit proformas; those directly related to the flowcharts were also largely incorporated in the prototype AIMS app
- recommendations for changes to the Condition Assessment Manual (CAM) and the associated Weightings guidance
- recommendations for changes to the T98 inspections training to cover transition specific inspection needs

- recommendations for improvements to the AIMS app to more fully reflect the final flowcharts and proformas

4.2.3 Inspection and evaluation guide

The inspection and evaluation guidance sets out a process that uses available data, field inspection and engineering judgement to determine whether a transition is weaker than the neighbouring defences and causes unacceptable flood risk.

The envisaged users of the guidance are the teams responsible for inspecting assets, evaluating asset condition, and identifying the need for asset improvement. The method of assessment will depend on the type of transition and on the failure mechanisms/modes being considered.

4.3 Report 3 - Reliability analysis (performance assessment) of flood defence transitions

The report sets out how to quantify the failure risk of a transition using fragility curves, including how information collected during inspection (Environment Agency, 2022b) can be used.

4.3.1 Report 3: Definition of need

Quantified assessment and prioritisation techniques require failure probability to be quantified. Fragility curves describe failure probabilities relative to a driving variable (in flood risk this is often water level, or overtopping rate).

This work sets out how transition specific fragility curves can be created.

4.3.2 Report 3: Outputs

The report 3 range of outputs includes:

- technical research report on the representation of the reliability (performance) of embankment assets that include transitions
- reporting (combined within the research report) on a parameter sensitivity testing exercise to:
    - explore the sensitivity of the annual failure probability to a number of parameters (for example, geometry, soils) using a generic hydraulic loading condition
    - evaluate the impact of a range of plausible hydraulic loading conditions on the outcomes
- technical research report on a computational fluid dynamic (CFD) study looking at amplifications in sheer stress and velocities at transitions between walls and embankments

- updated hrRELIABLE tool for transition assets and a supporting user guidance document

4.4 Report 4 – Fixing transitions - Design and management guide

This report sets out the consideration for designing remediation and fixes to existing flood defence transition features.

4.4.1 Report 4: Definition of need

In order to reduce the vulnerability of transitions, where the condition of those assets has been identified as potentially weakening the performance of the overall flood defence asset, guidance is needed on the design of improvements. The guide is therefore intended for the design of improvements to existing transitions, to ensure the transition is no longer the weakest point.

The envisaged users of the design guide are the teams responsible for designing flood defence improvements, in particular senior engineers, in any flood defence asset management organisation. In the specific context of the Environment Agency, this would be the catchment engineers, the Asset Performance teams, the Operational field teams and potentially their consultants.

4.4.2 Report 4: Outputs

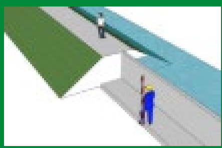
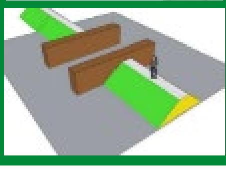
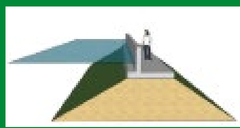
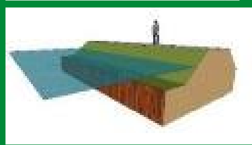
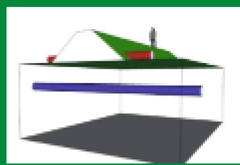
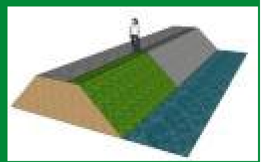
The final scope for this report was to provide guidance on the importance of transitions and their main performance parameters, the assessment and prioritisation of transitions, and basic rule of thumb/engineering judgement type guidance on retrofitting works to address the problems where transitions are considered to pose an increased risk compared to the wider defence.

The developed guide focuses on the improvement of transitions. In many instances, the improvement methods and design approaches are strongly linked, and very similar to those for regular flood defence embankments and structures. The transition design guide does not provide a step-by-step process with detailed instructions for addressing transition impacts. Instead, it focuses on the principles (how transitions can influence performance), highlights the issues with managing transitions, and presents methods for addressing the impacts. The design methods are typically not discussed in detail, because these are often very similar to methods for design and management of flood defences in general. The intention throughout is that the guide is used alongside the existing guidance and standards, notably the International Levee Handbook (CIRIA (2013).

The envisaged use of the transitions design guide starts from the outcome of the Tier 2/3 assessment/evaluation stage (see section 4.2) or equivalent, having identified a transition impact causing a weak link. Understanding the transition impacts is therefore essential for not only identifying weaknesses but also for remediating them. The guide also assumes that the transition has been prioritised for improvement, through assessments such as those explored in the ‘Development of top-down methods for identifying and prioritising asset transitions based on risk’ (Environment Agency, 2022a) report and the ‘Quantifying the probability of failure at asset transitions’ (Environment Agency, 2022c) report.

Table 1 shows, for each transition impact, the failure mechanisms that it can trigger. Those shown in Table 1 are directly initiated mechanisms, but these can typically then trigger other failure mechanisms (these secondary effects are not shown in this table). Green cells concern a reduction in strength, orange cells an increase in loading. Table 1 also shows the transition types to which each transition impact is most likely to apply. Note that this table may not be exhaustive.

Table 1: Transition impacts and failure modes for each transition type

Transition Impact	Longitudinal  	Cross-sectional  	Crossing infrastructure 	Revetments 
		1) **Geometry**		
a. Shorter seepage paths	SP		SP	
b. Steeper slope angles	GI, SE			
c. Irregular geometry causing turbulence	SE	SE	SE	SE
		2) Difference in behaviour of materials		
a. Hydraulic separation along hard/soft interfaces	SP	SP	SP	
b. Impeded root formation and shading	SE	SE		SE
c. Gaps in filter structure			BW	BW
		3) **Impediments to construction and maintenance**		

a. Poor compaction	GI, SP, CH		GI, SP, SE,CH	CH
b. Poor maintenance due to poor access and visibility	SE	SE	SE	SE
4) Preferential traffic paths causing deterioration				
a. Surface (vehicles, pedestrians, animals)	CH, SE	SE	SE	SE, CH
b. Animal burrows	CH		CH	CH

Key:

- GI: Global instability
- SP: Seepage and piping
- BW: Backfill washout
- CH: Crest height degradation
- SE: Surface erosion

For each of the identified transition impacts, the design guide describes and illustrates the physical process, the relation with failure mechanisms, principles for design, improvement/ management methods, design approach and examples.

5 References

BOWN, C., CHATTERTON, J. AND PURCELL, A., 2014. Asset performance tools – asset inspection guidance. Report – SC110008/R2. Bristol: Environment Agency.

CIRIA, 2013. The International Levee Handbook. C731. London: CIRIA.

ENVIRONMENT AGENCY, 2012. Condition Assessment Manual. Managing flood risk. Bristol: Environment Agency.

ENVIRONMENT AGENCY, 2022a. Development of top-down methods for identifying and prioritising asset transitions based on risk. FRS17181. Bristol: Environment Agency.

ENVIRONMENT AGENCY, 2022b. Framework for onsite inspection and evaluation of asset transitions. FRS17181. Bristol: Environment Agency.

ENVIRONMENT AGENCY, 2022c. Quantifying the probability of failure at asset transitions. FRS17181. Bristol: Environment Agency.

ENVIRONMENT AGENCY, 2022d. Design and management guide for fixing transitions. FRS17181. Bristol: Environment Agency.

HEWLETT, H., BOORMAN, L. AND BRAMLEY, M., 1987. Design of reinforced grass waterways. CIRIA Report 116. London: CIRIA.

HR WALLINGFORD, 2014. Improved generic fragility curves for use in flood risk analysis. Wallingford: HR Wallingford. Report MCS0941-RT002-R05.

HR WALLINGFORD, 2019. Transitions for flood defences - CFD study, MCR5953-RT004-R01-00. July 2019.

ICOLD, 2016a. Internal erosion of existing dams, levees and dikes and their foundations. Bulletin 164. Volume 1: Internal erosion processes and engineering assessment. Paris: ICOLD.

ICOLD, 2016b. Internal erosion of existing dams, levees and dikes and their foundations. Bulletin 164. Volume 2: case histories, investigations, testing, remediation and surveillance. Paris: ICOLD.

MORRIS, M., BENAHMED, N., PHILIPPE, P., ROYET, P., TOURMENT, R., CAN DEN HAM, G., CAN BEEK, V., 2012. WP3: Reliability of Urban flood defences – D3.1 Guidance on improved performance of urban flood defences. Report number WP03-01-12-11FloodProBE (www.floodprobe.eu). [Accessed 16/11/22].

SIMM, J., GOULDBY, B., SAYERS, P., FLIKWEERT, J., WERSCHING, S. AND BRAMLEY, B., 2008. Representing fragility of flood and coastal defences: getting into the detail. Proc. Eur. Conf. on Flood Risk Management: Research into Practice (FLOODrisk 2008). London: Taylor & Francis, 621-631.

SIMM, J. AND TARRANT, O., 2018. Development of fragility curves to describe the performance of UK levee systems. Proceedings ICOLD 26th Congress, Vienna.

TOURMENT, R., ROYET, P., MORRIS, M., 2015. Comprehensive report on Action 3.1.2: Structure transitions. Report number WP03-01-12-10. 1 FloodProBE (www.floodprobe.eu).

VAN BERGEIJK, V.M., 2018. The effects of transitions on wave overtopping flow and dike cover.

VERHEIJ, H., HOFFMANS, G. AND VAN DER MEER, J., 2013. Evaluation and Model Development Grass Erosion Test at the Rhine dike (release 1). Delft: Deltares.

VERHEIJ, H., HOFFMANS, G., VAN DER MEER, J. AND VAN HOVEN, A., 2015. Evaluation and Model Development Grass Erosion Test at the Rhine dike (release 4). Delft: Deltares.

VROUWENVELDER, A.C.W.M., STEENBERGEN, H.M.G.M. AND SLIJKHUIS, K.A.H., 2001. Theoretical manual of PC-Ring, Part A: descriptions of failure modes (in Dutch), Nr. 98-CON-R1430, Delft.

WHITEHEAD, E. AND NICKERSONS OF ROTHWELL, 1976. A guide to the use of grass in hydraulic engineering practice. CIRIA Technical Note 71. London: CIRIA.

Acronyms

AIMS – Asset Information and Maintenance System

CAM – Condition Assessment Manual

CFD – Computational fluid dynamics

FCRM – Flood and coastal risk management

NaFRA – National Flood Risk Assessment

NEIP – National Engineering Innovation Panel

RMA – Risk management authorities

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