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Risk Management R&D Programme

Understanding the lowering of beaches in front of coastal defence structures, Stage 2
Technical Note 5

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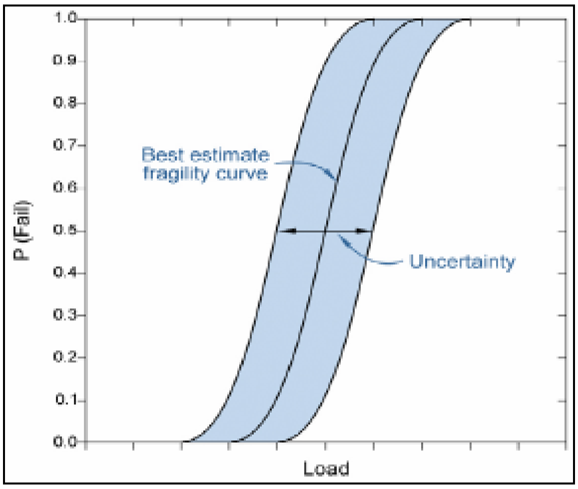
Understanding the lowering of beaches in front of coastal defence structures, Phase 2

Integrating scour research into reliability analysis of coastal structures



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Contents

1. Introduction

This joint Defra/EA Flood and Coastal Erosion Risk Management R&D project, "Understanding the Lowering of Beaches in Front of Coastal Defence Structures, Stage 2" (FD1927) is undertaking research into local, often short lived toe scour at coastal defences and reviewing methods of monitoring and mitigating scour. The research uptake will be aided by integrating the outputs of this research with ongoing work on asset management. This Technical Note describes how the results from FD1927 integrate with the programme of research already underway into the reliability analysis of coastal structures, particularly Establishing a Performance-based Asset Management System Phase 2 (PAMS2) which was funded by the Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Programme. PAMS Phase 1 (HR Wallingford, 2004) was a scoping study that provided the Environment Agency with a new vision for managing its flood defence assets. The overall aim is to manage flood risk as efficiently and effectively as possible by inspecting, maintaining, repairing and if necessary replacing flood defences in order to achieve the required performance and to reduce risk. Central to PAMS are two concepts that might be helped by receiving improved information from FD1927:

1. Fragility; and
2. Condition indexing.

Fragility has been defined as the probability of failure of a particular defence or system given a load condition (HR Wallingford, 2005a). Fragility can be expressed in the form of a uni-variate distribution when one loading variable is considered, in the form of fragility surface when two loading variables are considered or multidimensional fragility space when three or more loading variables are considered. Combined with descriptors of decay/deterioration, fragility functions enable future performance to be described. The concept of fragility curves has been expanded beyond what was in PAMS Phase 1 in "Performance and Reliability of Flood and Coastal Defences – Phase 1" which was Project FD2318 in the Risk Theme of the Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Programme. The new fragility curves will be used in PAMS Phase 2. FD2318 has explored ways to assess the performance and reliability of flood and coastal defences in order to make better assessments of risk. Further detailed work on the failure modes of coastal defences is being undertaken in Task 4 of the Floodsite project (www.floodsite.net).

Condition indexing uses visual indicators that relate directly to Performance Features (PFs) that may be specific to one function of a defence element (or one failure mode). Condition Indexing is being developed further in the TE2100 project.

This Technical Note assesses the needs of the reliability analysis methods for beach level and beach state indicators. It then illustrates how the results from this project can be used in the PAMS framework for reliability analysis. The outputs of the present project include an improved scour predictor for predicting beach lowering at the toe of coastal defence structures subject to wave activity. The project has also make recommendations about monitoring to pick up the likely variations in beach levels that can be observed at low tides (HR Wallingford, 2006a). Figure 1 shows the FD1927 project map, illustrating the link to the PAMS framework for reliability analysis.

The rest of this Technical Note describes briefly the central elements of the PAMS framework and indicates what information can be transferred from FD1927 to the PAMS framework – although the first interaction may be with another project.

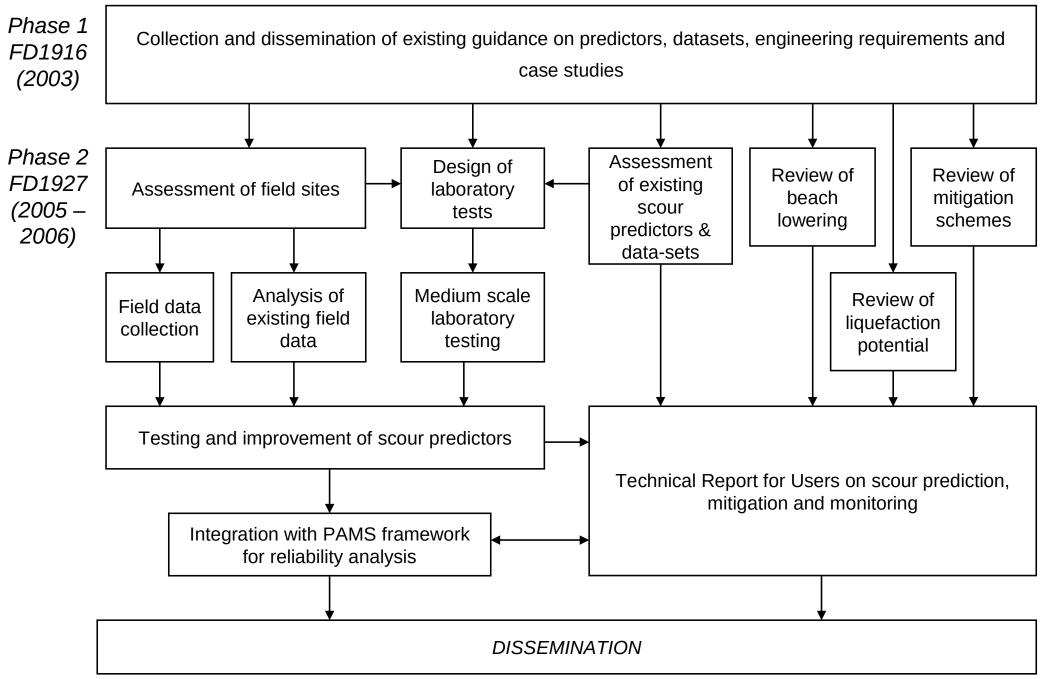

Figure 1 Project map showing where PAMS is integrated into the project.

2. PAMS Operational Framework

The PAMS operational framework developed in PAMS Phase 1 (HR Wallingford, 2004) is shown in Figure 2. The main elements cover the following issues (taken from HR Wallingford, 2004):

- "Inspection and condition assessment methodologies – To improve asset management decisions it will be important that PAMS includes an improved approach to condition assessment. This module of PAMS refers to the process by which data is collected and asset condition is assessed. It will also include recommendations on minimum information requirements, for example the features of an asset that should be collected as a matter of routine (crest level for example) and which should only be gathered if the collection costs can be justified in risk reduction terms.
- System analysis (Performance assessment) – To understand flood risk and the effectiveness of any intervention the decision maker must first have an understanding of how risk is generated and how it can be influenced (reduced). The general concepts of system analysis are currently being addressed outside of PAMS through projects such as RASP (Environment Agency, 2003) and the review of risk methods within flood and coastal defence (Environment Agency, 2002) [and now Floodsite]. However, PAMS will need to develop these methods to cover the issues relevant to asset managers. The systems analysis module of PAMS will involve the integration of source, pathway and receptor terms together with information on how these drivers of risk are modified through management intervention and/or asset deterioration as well as climate or social change. Therefore this module will include the analysis undertaken to provide an understanding of the performance of an asset (in its present, deteriorated or improved state) and the defence system in the context of risk and risk reduction.
- Decision approaches and option selection techniques – As with the system analysis a number of generic issues are currently being addressed – or are planned - outside of PAMS. However, significant effort will be required to develop the specific decision approaches within PAMS to reflect the interface with higher level plans and the broad spectrum of criteria to be considered in selecting the preferred maintenance or operational intervention. This module of PAMS will therefore cover the process of the decision-making and option selection.
- Common databases and data and information management – Allowing data to be stored and accessed for re-use will be a key feature of PAMS. Maximising the use and re-use of data will inform any of the modules outlined above. In particular, PAMS will specify the asset data to be recorded; including format, mandatory and optional parameters, histories, uncertainties etc and appropriate fields developed within NFCDD and the use of related databases on flood plain assets."

The present research into scour can assist in 2 main ways:

1. By updating the fragility curve for seawalls to include the improved scour predictor developed within FD1927;
2. By importing knowledge gained from FD1927 on beach level variability and using it to improve the system of condition assessment or condition indexing;

The concepts of the fragility curve and of condition indexing are considered in more detail in the following sections.

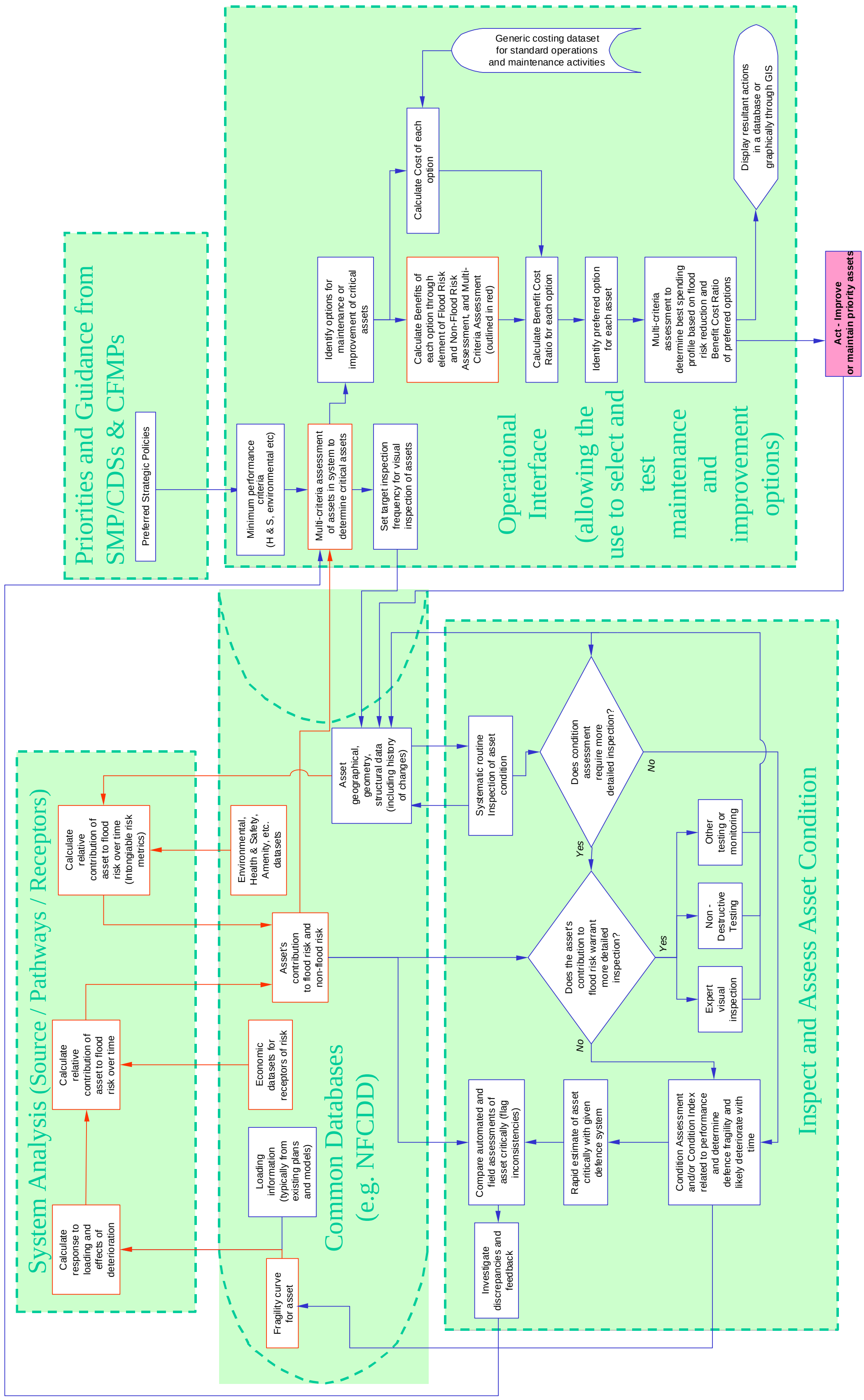

Figure 2 PAMS Operational Framework (from HR Wallingford, 2004)

3. Fragility Curves

The concept of fragility is described in detail in HR Wallingford (2005a) from which the following text is derived. The concept of fragility in flood and coastal erosion risk management represents the link between the likelihood of defence response (pathway) and different loading conditions (source). A shortage of knowledge about how defences fail and variations in the characteristics of defences result in a range of defence responses and associated likelihood. The concept of fragility tries to capture the probability of a range of defence responses to a given load. A typical fragility curve is shown in Figure 3. Where the probability of failure is a function of two loads, a fragility surface may be formed.

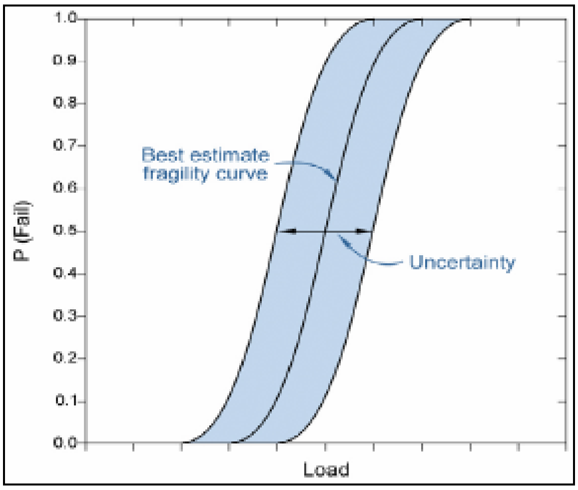

Figure 3 Generic fragility curve

A failure curve or surface can be defined for each failure mode in a fault tree, provided sufficient information is available. Altering a fragility curve, or surface, will alter the relative importance of the failure model it represents in the fault tree.

The generic sources of uncertainty are of two types: natural variability and knowledge uncertainty. The latter includes the following categories:

- Statistical model uncertainty. A distribution function represents the best fit to a dataset, and therefore does not capture all of the data within the statistical model. The quality of the fragility depends on the quality of the underlying statistical models.
- Process model uncertainty. Process models that quantify failure processes are limited in their representation of reality. Model uncertainties can be quantified and incorporated in fragility. An increasing quality in process based model reduces these uncertainties.
- Decision uncertainty. This is the strength of belief in the decision made and of its robustness. This type of uncertainty is part of the overall decision process informed by fragility and other performance measures and targets.

3.1 INPUT FROM FD1927

PAMS fragility curve for vertical seawalls contains a toe scour term (scour = 0.5Hs). This can be replaced by the improved scour predictor, based on an empirical fit to the best data available. This will reduce the process model uncertainty. In addition the details of scour predictor have been supplied to Task 4 of the Floodsite project to assist in their description of the failure modes for seawalls.

4. Condition Indexing

Condition Indexing is the process of assessing the likely performance of a defence asset through observation of Performance Features and subsequent calculations based on the findings (HR Wallingford, 2005b). No detailed measurement of asset geometry is required and the inspection process should not require a qualified engineer. In this respect the process fits into Option C "Non-expert inspection and condition assessment with periodic expert inspection and condition assessment" identified during the PAMS Phase 1 scoping study (HR Wallingford, 2004).

The proposed process of Condition Indexing and its use within an overall asset management system is shown in Figure 4 (from HR Wallingford, 2005b). Steps 1 to 3 form the revised method of visual inspection described in HR Wallingford (2005b), whilst Steps 4 to 6 show the asset management actions that would make use of the visual inspection results. Failure modes and the Performance Features (PFs) that apply to them are predefined by asset type. Further failure modes and PFs can be added to the method and will require alteration to the contribution weightings that link PFs to failure modes or failure modes to the asset.

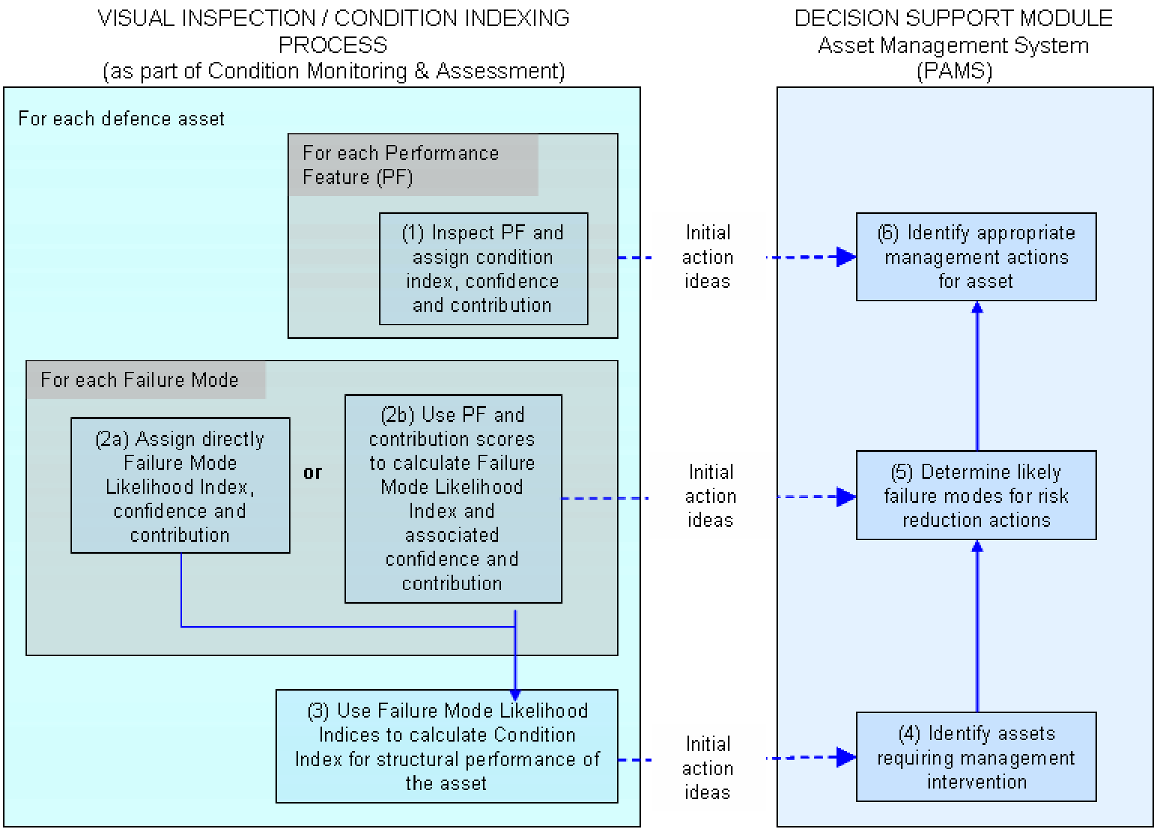

Figure 4 Outline of condition indexing process and links to asset management system

Step (1) is the on-site visual assessment of condition, confidence and contribution for the Performance Features (PFs). Prior to undertaking this process an inspector should review historical data on the assets to be inspected. This will determine the asset type and therefore the set of Failure Modes and PFs to be inspected in relation to a particular asset. There are two important outcomes from this step, the PF Condition Index and Confidence. The method of obtaining a condition index is outlined below.

Each PF will be inspected and assigned an index in accordance with guidance provided in the form of tabular descriptions and/or simple flowcharts. The definition of the PFs that relate to specific Failure Modes is critical to the Condition Indexing process. There are a number of factors to take into account in their definition:

- From an operational viewpoint there is a limit to the number of PFs that can be inspected without increasing the inspection duration beyond practical constraints.
- Each PF should be related, directly or indirectly, to at least one failure mode either through performance models, or in their absence by expert judgment.
- There must be enough PFs to evaluate individual Failure Mode Likelihood Indices
- PFs must be unambiguous in terms of their definitions and supporting information.
- All PFs must be visually inspectable without the need for detailed measurement.
- All PFs must be able to be given a Condition Index in discrete steps ranging from 'Insignificant – no negative impact on desired performance' to 'significant – major negative impact on performance'.
- A PF will relate to an individual defence element, to a group of defence elements or to a defence asset as a whole.

Table 1 shows examples of PFs for the four main structure types encountered in the TE2100 area (from HR Wallingford, 2005b). It includes toe scouring / undermining for gravity walls, sheet piles walls and revetments. An example of the guidance provided for assessing the condition index for the toe scour/erosion performance feature of a gravity wall is given in Figure 5 (HR Wallingford, 2005b).

Table 1 Performance Features for the TE 2100 area

Embankments	Gravity Walls	Sheet Piled Walls	Revetments
Visible deformation of cross-section (e.g. slumping, heave, local translation)	Obvious deformations of structure &/or surroundings relevant to failure mode	Obvious deformations of structure &/or surroundings relevant to failure mode	Obvious deformations of structure &/or surroundings relevant to failure mode
Animal burrowing / infestation	Toe scouring / undermining	Toe scouring / undermining	Toe scouring / undermining
Foreign objects in the crest or rear slope	Condition of the wall material	Condition of the wall material	Condition of the revetment material
Cracking &/or fissuring	State of the joints	State of the joints	State of the joints
Third party damage (cattle, vehicles etc)	Third party interference with load or resistance	Third party interference with load or resistance	Third party interference with load or resistance
Direct evidence of seepage or piping	Animal infestation in ground around structure	Animal infestation in ground around structure	Animal infestation in ground around structure
Revetment condition	Seepage through, behind or in front of structure	Seepage through, behind or in front of structure	Seepage through, behind or in front of structure
Vegetation condition	Presence of foreign objects	Presence of foreign objects	Presence of foreign objects
Erosion of cross section			

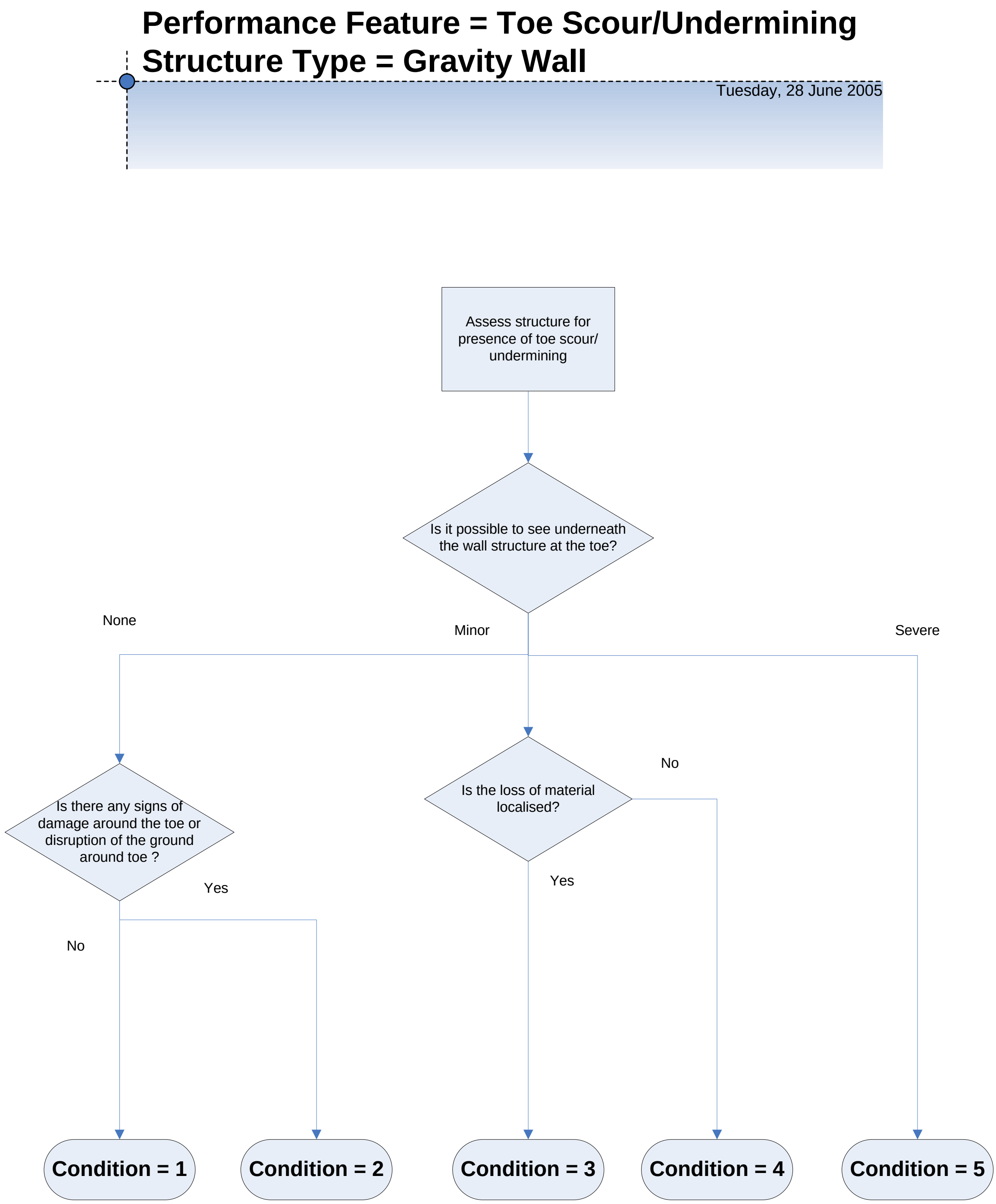

Figure 5 Flow chart for toe scour/undermining performance feature for a gravity wall.

4.1 INPUT FROM FD1927

The condition indexing system developed for TE2100 includes toe scour/undermining as a performance feature for gravity walls, sheet pile walls and revetments. HR Wallingford (2006a) looked at the changes in the mean and standard deviation of the measured beach levels at the toe of a coastal defences. In particular it noted that beach levels were on average lowest and the standard deviation in the beach levels were highest in spring (February to April) for the

Lincolnshire beach profiles analysed. This type of analysis could be repeated for any stretch of coast in order to inform the timing of condition indexing surveys. Clearly a survey between February and April is more likely to provide observations under the wall structure at the toe than a survey in September or October, when beach levels are relatively high and the standard deviation in levels is relatively low. Moreover, the differences in the average and the standard deviation of the beach level caused by altering the number of surveys per year was demonstrated (HR Wallingford, 2006a, Figures 29 and 30).

A local analysis of beach levels could be used to influence both the timing and the frequency of condition indexing surveys. There may be a need to consider the scouring or undermining of mitigation measures as well as of walls themselves, when dealing with the coastal zone.

5. Other linkages between FD1927 and reliability analysis

Prominent failure mechanisms for vertical seawalls include:

- Undermining by toe scour (covered in Section 3.1)
- Structural failure due to wash out of fill following joint failure

The letter could be expanded to include structural failure due to wash out of fill following scour. Cases have been noted where there was no obvious sign of damage before collapse occurred due to the loss of fill, caused (it is believed) by scour. This is difficult to detect as there may be no visible outward signs of damage until failure occurs. The use of non-destructive testing to assess the presence of significant voids within a structure is one option to identify those that are at risk of failure. An alternative method for identifying structures that may have lost fill material when beach levels dropped below the structure toe is outlined below.

Techniques developed within FD1927 (HR Wallingford, 2006a) can be used to identify whether the beach level is likely to drop below the level where washout under the structure can begin (assuming that level is known). The simplest way of doing this is to combine the extrapolation of a long-term trend in beach levels (which will be a linear trend possibly with a sinusoidal seasonal variation) with a Gaussian distribution of beach levels about this trend. The data from this can be obtained from a long-term data-set of beach levels (extending over 10 years or more). It may also be possible to combine this with predictions from the toe scour equation (HR Wallingford, 2006b) although some, as yet unproven, assumption about the joint probability of low beach levels and deep scour events would need to be made.

If a structure has voids caused by a loss of fill due to scour, it will have an increased risk of failure and could be worth investigating in more detail – possibly using non-destructive testing. Therefore the trigger for a more detailed asset inspection (shown in the 'Inspect and Asses Asset Condition' box in Figure 2) could be the extrapolation of beach level data, rather than the result of a non-expert inspection.

6. Conclusions

The work performed in the Defra/EA Flood and Coastal Erosion Risk Management project, FD1927 "Understanding the lowering of beaches in front of coastal defence structures" (particularly that summarised in HR Wallingford, 2006a, 2006b) will assist in the development of the PAMS framework for reliability analysis in two main ways:

1. The derivation of an improved scour predictor will inform the future development of fault trees and fragility curves for coastal structures which are known to be sensitive to scour;
2. The analysis of beach levels in front of coastal structures will inform work on deterioration as it indicates when and how often condition assessment should occur. Moreover, extrapolation of beach level data could be used to trigger a more detailed form of condition assessment, rather than waiting for scour to be observed or failure to occur.

7. References

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