Abstract

In the EU, the asset value of dams and flood defence structures amounts to billions of Euro. These structures include, amongst others, concrete and embankment dams, tailing dams, flood banks, dikes, etc. Many large dams in Europe are located close to centres of population and industry and the consequences of catastrophic failure of one of these structures would be far worse than most other types of technological disaster. To manage and minimise risks effectively, it is necessary to be able to identify hazards and vulnerability in a consistent and reliable manner, to have good knowledge of structure behaviour in emergency situations, and to understand the potential consequences of failure in order to allow effective contingency planning for public safety. This has led to concerted long term research in Europe (including the CADAM, IMPACT, and FLOODsite projects) to reduce uncertainty in predicting extreme flood conditions and improve predictions of risk due to these structures. The specific objectives of the research described in this paper and the following sessions are to advance scientific knowledge and understanding, and develop predictive modelling tools and methods in a number of areas including: (1) breaching of embankments, (2) catastrophic inundation, (3) mechanisms of sediment movement and (4) embankment integrity assessment through the use of geophysical techniques.

What are CADAM, IMPACT and FLOODSITE?

The European Commission funds multiple, wide ranging programmes of research and development work aimed at improving the efficiency and quality of life in Europe. Research programmes are typically aimed at addressing European, rather than national issues. Research funding is normally to the extent of 50% for commercial organisations so as to encourage integration and support from industry, which in turn helps to ensure the value of the research. CADAM, IMPACT and FLOODsite are all projects funded by the Commission that address different aspects of flood risk management.

CADAM (Concerted action on dambreak modelling) was completed in 2000 and, amongst other results, provided prioritised recommendations for research in the field of dambreak analysis to improve the reliability of predictions. CADAM did not fund new research work, but provided a mechanism for researchers and practitioners to meet, exchange information and to some extent, co-ordinate existing national research work. The value of funding for CADAM was ~ €250K. IMPACT (Investigation of extreme flood processes and uncertainty) is a 3-year project under the EC 5th framework programme that finishes in November 2004. IMPACT addresses a number of the key issues that were highlighted by the
CADAM project. The value of work undertaken by IMPACT is ~€2.6M. FLOODsite (Integrated flood risk analysis and management methodologies) is a new project funded under the EC 6th framework programme integrating a wide range of work, undertaken by 36 different partners drawn from 13 countries. The value of work funded is ~€14M. The focus of work under FLOODsite is on flood risk management in general, whilst CADAM and IMPACT specifically address dambreak or extreme flood related issues. Nevertheless, there are aspects of research under the FLOODsite project that are of continuing interest to the dams industry.

The CADAM Concerted Action Project

Members of the CADAM project team comprised researchers and industrialists from across Europe who had an interest in the various aspects of dam-break modelling. The CADAM project team aimed to:

- exchange dam-break modelling information between participants: Universities <=> Research organisations <=> Industry
- promote the comparison of numerical dam-break models and modelling procedures with analytical, experimental and field data.
- promote the comparison and validation of software packages developed or used by the participants.
- define and promote co-operative research.

The project was funded as a concerted action by the European Commission, formally commenced in February 1998 and ran for a period of two years. The principal focus of the Concerted Action was a series of expert meetings and workshops, each of which considered a particular topic (e.g. breach formation, flood routing, risk analysis etc). The performance of various numerical models was assessed throughout by comparison under analytical and physical model tests cases and finally against real dam break data. Detailed information relating to the project may be found at www.hrwallingford.co.uk/projects/CADAM).

Findings and Recommendations

The final report from CADAM (available on the CADAM website) drew some 31 specific conclusions and identified a series of areas where further research and development was needed to improve the reliability and accuracy of dambreak analysis. A number of these priority areas form the basis for the IMPACT project research programme. These included:

Breach Formation Modelling:
Considerable uncertainty related to the modelling of breach formation processes was identified and the accuracy of existing breach models considered very limited. Research was recommended in a number of areas including:
1. Structure failure mechanisms
2. Breach formation mechanisms
3. Breach location

Debris and Sediments:
It was identified that the movement of debris and sediment can significantly affect flood water levels during a dambreak event and may also be the process through which
Flow modelling:

The following research areas relate to the performance of flow models and the accuracy of predicted results:

1. Performance of Flow Models
2. Modelling Flow Interaction with Valley Infrastructure
3. Valley Roughness
4. Modelling Flow in Urban Areas

Other research priorities were identified under the headings of database needs and risk / information management. These are not detailed here, but may be found in the CADAM final report.

The IMPACT Project

The IMPACT project addresses the assessment and reduction of risks from extreme flooding caused by natural events or the failure of dams and flood defence structures. The work programme is divided into five main areas, addressing issues raised by the CADAM project. Research into the various process areas is undertaken by groups within the overall project team. Some work areas interact, but all areas are drawn together through an assessment of modelling uncertainty and a demonstration of modelling capabilities through an overall case study application. The IMPACT project provides support for the dam industry in a number of ways, including:

- Provision of state of the art summaries for capabilities in breach formation modelling, dambreak prediction (flood routing, sediment movement etc)
- Clarification of the uncertainty within existing and new predictive modelling tools (along with implications for end user applications)
- Demonstration of capabilities for impact assessment (in support of risk management and emergency planning)
- Guidance on future and related research work supporting dambreak assessment, risk analysis and emergency planning

The core of this paper provides an introduction to the work being undertaken in each of the IMPACT work packages (WPs). Each of these programmes is also detailed under a separate paper in this workshop and more detailed information on all research may be found via the project website at www.impact-project.net. The WPs comprise:

WP2: Breach formation
WP3: Flood propagation
WP4: Sediment movement
WP5: Uncertainty analysis
WP6: Geophysics and data collection
WP2: Breach Formation

**Overview of breach work programme aims and objectives**

Existing breach models have significant limitations (Morris & Hassan, 2002). A fundamental problem for improving breach models is a lack of reliable case study data through which failure processes may be understood and model performance assessed. The approach taken under IMPACT was to undertake a programme of field and lab work to collate reliable data. Five field tests were undertaken during 2002 and 2003 using embankments 4-6m high. A series of 22 laboratory tests were undertaken during the same period, the majority at a scale of 1:10 to the field tests. Data collected included detailed photographic records, breach growth rates, flow, water levels etc. In addition, soil parameters such as grading, cohesion, water content, density etc. were taken. Both field and lab data were then used within a programme of numerical modelling to assess existing model performance and to allow development of improved model performance.

**Current position of research**

All field and laboratory modelling work has now been completed. The tests undertaken comprised:

- **Field Test #1** 6m homogeneous, cohesive embankment. 
  \(D_{50} \approx 0.01\text{mm}, <15\%\text{ sand, }<25\%\text{ clay} \); overtopping.
- **Field Test #2** 5m homogeneous non-cohesive embankment \((D_{50} \approx 5\text{ mm}, <5\%\text{ fines})\); overtopping.
- **Field Test #3** 6m composite embankment (rockfill with moraine core); overtopping.
- **Field Test #4** 6m composite embankment (rockfill with moraine core); piping.
- **Field Test #5** 4m homogeneous embankment (moraine); piping.
- **Lab Series #1** This series of 9 tests was based around Field Test #2 at a scale of 1:10. The test material was non-cohesive with variation in material grading, embankment geometry and breach location (side breach).
- **Lab Series #2** This series of 8 tests was based around Field Test #1 at a scale of 1:10. The test material was cohesive, with two different materials used, along with different embankment geometry, compaction effort and moisture content.
- **Lab Series #3** This series of 5 tests was based around the initiation of pipe formation for Field Test #5. Test data was used to develop reliable failure mechanisms for the field tests. Tests were also undertaken on 1m\(^3\) samples of embankment taken from flood defences in the UK.

In conjunction with the field and laboratory tests and data collection an extensive programme of numerical model testing has been undertaken. Some core objectives of this component of work included:

- Identification of more reliable modelling approaches for simulating breach formation
- Assessment of the level of uncertainty of current breach modelling techniques
- Incorporation of knowledge gained from the field and laboratory tests into existing modelling tools
Modelling was undertaken by members of the IMPACT Team plus additional organisations internationally. Modelling was first undertaken without access to the field or lab data, and subsequently with access. In this way the performance of models and modellers may be assessed objectively – which more closely matches the conditions under which modellers are typically asked to predict embankment failure.

Analysis of the modelling results highlighted some interesting facts and features. Some of these are listed below. All are explained in more detail in the associated paper on breach formation (Hassan et al).

- The laboratory tests highlighted the effect that variation in soil parameters / embankment condition could have on the breach formation process. For example, varying compaction effort and / or changing moisture content, particularly for cohesive materials, could change the erodibility and hence rate and nature of breach growth by an order of magnitude. It was noticeable that very few breach models included these parameters and hence would struggle to reproduce the true embankment behaviour.

- Whilst some models appeared to predict the flood hydrograph reasonably well for some test conditions, all models either over or under predicted the breach growth rate and dimensions. This suggests that prediction of the basic physical growth processes in conjunction with flow calculation is not undertaken accurately. An observation that supports this is the fact that most models predict a critical flow point within the body of the embankment and hence a flow area based upon breach body width. However, both field and laboratory tests often show the growth of curved flow control sections which move upstream out of the breach body and the flow erodes material from the upstream slope.

- Variation in embankment geometry such as slope from 1:3 to 1:2 or 1:4 appears to have little impact on the breach growth process. However, variation in breach location from the centre of an embankment to the side, where lateral growth is restricted in one direction, does have a noticeable effect. This should be taken into consideration when using data to validate models such as from the Teton failure, which was a breach event adjacent to an abutment. It is also relevant in the case of planning breach growth through a landslide generated embankment. Initiating failure adjacent to an abutment will limit the rate of breach growth and hence the rate of flooding downstream.

- An average accuracy of perhaps ±50% may be attributed to many models (broadly considering timing, peak discharge etc). Models simulating aspects of embankment soil behaviour (e.g. slope stability, failure etc.) appeared to show better performance with an indicative accuracy reaching perhaps ±20%.
Future Direction of Research

At the time of writing, analysis of the field, laboratory and numerical modelling data is still to be completed, along with the consideration of scale effects between field and laboratory data. A further area of work investigating factors affecting breach location in long fluvial flood defence embankments is also underway. Results and conclusions from a breach review workshop held at Wallingford in April 2004 will be made available. Research work will continue in this area beyond the completion of the IMPACT project through work packages in the FLOODsite project. It is anticipated, however, that the emphasis of analysis under FLOODsite will shift from breach formation (IMPACT) to breach initiation, so helping to enhance our overall ability to predict and ultimately prevent breach formation occurring.

WP 3: Flood Propagation

Overview and objectives

The objective of this area of work is to improve our understanding of the dynamics of a catastrophic (extreme) flood and to improve our propagation modelling capability. Four partners are involved in this area, namely the Université Catholique de Louvain (Belgium), CEMAGREF (France), CESI (formerly ENEL) and the University of Zaragoza (Spain). The scope is broadly divided into two areas; urban flooding and flood propagation in natural topographies. General objectives of the work package are to:

- identify dam-break flow behaviour in complex valleys, around infrastructure and in urban areas (i.e. gain insight into flood flow characteristics)
- collect flood propagation and urban flooding data from scaled laboratory experiments that can be used for development and validation of mathematical models
- adapt and develop modelling techniques for the specific features of high intensity floods, like those induced by the failure of man made structures
- perform mathematical model validation and benchmarking, compare different modelling techniques and identify best approaches including the assessment of accuracy
- develop guidelines and appropriate strategies concerning modelling techniques for the reliable prediction of flood effects
- identify, select and document a real flood event affecting an urban area to be used as a case study where modelling techniques and lessons learned can be applied and tested

Current position

To achieve these goals a combination of desk work, laboratory experiments, field work and computer modelling has been undertaken.

The mathematical description of extreme flood flows has been tackled on the basis of the non-linear shallow water equations. Issues like non-linear convective transport, the formation of travelling waves (bores and hydraulic jumps), the forcing due to bottom and bank reaction forces (as included in the source terms of the equations of motion) and wetting and drying problems are key issues in devising the appropriate computer model.

As regards modelling of flood propagation in a city, several strategies have been investigated. A simple one-dimensional model of a city with the streets modelled as water channels has proven effective despite its simplicity. Limitations concern model applicability at wide junctions such as squares etc. Also important two-dimensional features of the flow are often lost, as happens with wave reflections and expansions around building corners. Another technique referred to as bottom elevation, represents buildings and obstacles to flow as abrupt
elevations of the bed function within a two-dimensional model. This is easy to set up but the numerical method must be robust enough to accommodate this sort of singular source term forcing. Another simple technique analysed entailed increasing the roughness coefficient of the area where buildings or obstructions were located. Finally, the highest level of detail can be attained, at least in theory, by careful two-dimensional meshing of the streets and other city areas prone to flooding.

The aim of the experimental work was to provide an insight into understanding key flow features and to provide data under controlled, reproducible conditions that can be used for computational model validation and improvement. Two types of laboratory experiment at a scaled down geometry have been conducted for urban flooding; one devoted to the study of the flow structure around a single building (front impingement and reflection, refraction etc.) and the other to overall flood-city interaction in which a model city in a scaled down (1:100) valley was subjected to a simulated flood event. The data obtained have been used to set up two benchmark sessions against which computer models have been tested, firstly in a blind phase and then followed by the release of experimental data to allow for model tuning.

A case study based upon a real life flooding event, including inundation of urban areas, has been documented to enable modelling and validation of model results. Modelling of the catastrophic flooding of the small Spanish town of Sumacárcel after failure of the Tous Dam is currently underway and results will be presented at the project final meeting to be held in Zaragoza in November 2004.

![Figure 2: Aerial view of the river reach from Tous Dam to Sumacárcel town about one week after the flood (left); and digital model of the town used for simulations (right).](image)

**Results and future trends**

Preliminary conclusions from the research can be summarised as follows:

- Catastrophic (high intensity) flooding entails several phenomena that pose difficulties to accurate mathematical modelling. These include highly convective flows, formation of abrupt fronts, wetting and drying of extensive areas and abrupt bathymetries. All these effects are difficult to describe mathematically.
- The most complex mathematical framework currently feasible, based upon the shallow water equations, performs well overall if appropriate integration techniques are used. General trends of the flood as well as some of its details (water depth and velocity evolution at certain locations) can be predicted to within twenty per cent accuracy in most cases.

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Tous Dam

Sumacárcel
when the flood characteristics (inflow hydrograph and timing etc …) and bathymetry data are well known.

- However important details of the flood may be completely lost when strong deviations from the model equations appear (strong vertical accelerations, high curvature of the streamlines etc…), when the spatial resolution is not enough to precisely describe the geometry or when the flood characteristics are not well known.

  Spatial resolution is likely to be a problem when urban areas are to be treated at the same time as propagation of the flood down a natural valley or open terrain.

As a general conclusion it can be said that careful validation initiatives like the ones represented by the Impact project, in particular involving real life data, are still needed to assess the accuracy and uncertainty of present day models and hopefully improve our modelling capabilities.

**WP4: Sediment Movement**

**Overview of WP4 work-programme aims and objectives**

The “Sediment movement” IMPACT work package explores the field of dam-break induced geomorphic flows. In a number of ancient and recent catastrophes, floods from dam or dike failures have induced severe soil movements in various forms. Other natural hazards also induce such phenomena: glacial-lake outburst floods and landslides resulting in an impulse wave in the dam reservoir or in the formation of natural dams subject to major failure risk. In some cases, the volume of entrained material can reach the same order of magnitude (up to millions of cubic meters) as the initial volume of water released from the failed dam.

The main goal of work package is to gain a more complete understanding of geomorphic flows and their consequences on the dam-break wave. Dam-break induced geomorphic flows generate intense erosion and solid transport, resulting in dramatic and rapid evolution of the valley geometry. In counterpart, this change in geometry strongly affects the wave behaviour and thus the arrival time and the maximum water level, which are the main characteristics to evaluate for risk assessment and alert organisation.

**Near-field and far-field behaviour**

Depending on the distance to the broken dam and on the time elapsed since the dam break, two types of behaviour may be described and have to be understood and modelled.

In the near field, rapid and intense erosion accompanies the development of the dam-break wave. The flow exhibits strong free surface features: wave breaking occurs at the centre (near the location of the dam), and a nearly vertical wall of water and debris overruns the sediment bed at the wave forefront, resulting in an intense transient debris flow. However, at the front of the dam-break wave, the debris flow is surprisingly not so different as a uniform one. An important part of the work program was thus devoted to the characterisation of the debris flow in uniform conditions.

Behind the debris-flow front, the behaviour seems completely different: inertial effects and bulking of the sediments may play a significant role. Surprisingly, such a difficult feature appears to be suitably modelled by a two-layer model based on the shallow-water assumptions and methods. The work package included experiments, modelling and validation of this near-field behaviour.
In the far field, the solid transport remains intense but the dynamic role of the sediments decreases. On the other hand dramatic geomorphic changes occur in the valley due to sediment de-bulking, bank erosion and debris deposition. Experiments, modelling and validation of the far-field behaviour composed the last part of the work package.

**Current position of research**

It appears that one of the most promising approaches of the near-field modelling is a three-layer description (Fig. 3). Three zones are defined: the upper layer \((h_w)\) is clear water while the lower layers are composed of a mixture of water and sediments, the upper part of this mixture \((h_s)\) being in movement.

In the frame of shallow-water approach, it is possible to express the continuity of both the sediments and the mixture and also the momentum conservation with the additional assumption that the pressure distribution is hydrostatic in the moving layers, which implies that no vertical movement is taken into consideration:

![Figure 3. Assumptions for mathematical description of near-field flow](image)

Comparisons and validation were carried out from experimental data on idealised dam-break: typically, horizontal beds composed of cohesionless sediments saturated with water extending on both sides of an idealised "dam", with various sediment and water depths.

For the far field, special attention was paid to the modelling of the bank behaviour. The bank failure mechanism was observed and modelled, taking into account the specific performance of eroded / deposed material in emerged / submerged conditions.

The far-field experiments consisted in a dam-break flow in an initially prismatic valley made of erodible material, evidencing the bank erosion, the transport of the so-deposited material, and the genera widening of the valley.

**Results and future direction of work**

Experimental results, obtained at the University of Louvain (Belgium) were proposed as a benchmark to various partners: University of Louvain (Belgium), University of Trento, Cemagref (France) and Technical University of Lisbon (Portugal). Fig. 4 presents a comparison between experimental observation and the model presented above.

![Figure 4. Comparison between experiments and numerical results, 1 s after the dam break](image)
It appears that some characters of the movement are well modelled, such as the jump at the water surface, the scouring at the dam location, the moving layer thickness. The modelled front is ahead but this advance appears constant, which implies that the front celerity is correctly estimated.

Also for the far-field behaviour and the valley widening, the models at this stage can produce valuable results to compare with experimental data from idealised situations.

But it is suspected – and this is general conclusion for the “Sediment movement” work package – that we are far from a completely integrated model able to accurately simulate a complex real case. A tentative answer to this could probably be given from the results of real-case benchmark regarding the Lake Ha!Ha! dike break occurred in Quebec in July 1996. The first results of this benchmark will be available after the last IMPACT meeting to be held in Zaragoza, Spain, in November 2004.

WP 5: Uncertainty Analysis

The objective of this work package was to try and identify the uncertainty associated with the various components of the flood prediction process; namely uncertainty in breach formation, flood routing and sediment transport models. In addition, to demonstrate the effect that uncertainty has on the overall flood prediction process through application to a real or virtual case study and to consider the implications of uncertainty in specific flood conditions (such as water level, time of flood arrival etc.) for end users of the information (such as emergency planners). The scope of work under IMPACT does not allow for an investigation of uncertainty in the impact of flooding or in the assessment and management of flood risk.

The challenge of assessing overall modelling uncertainty is complicated by the need to assess uncertainty within two or more models, to somehow transfer a measure of uncertainty between these models and to develop a system that allows for the different complexities of the various models. Two basic approaches were adopted, namely sensitivity analysis and Monte Carlo analysis. However, whilst a breach formation model may be able to run hundreds or thousands of simulations within a period of hours, it is unrealistic to assume that a complex 2D flood propagation model can undertake a similar process without undertaking weeks or months of analysis. A compromise solution was adopted for IMPACT that combines sensitivity analysis, Monte Carlo simulation and expert judgement. Whilst this approach may provide an estimate of uncertainty which contains a degree of subjectivity (expert judgement) it also provides a mechanism that is achieved relatively simply and provides a quick indication of potential uncertainty.

At the time of writing, the approach had been tested using the HR Breach model only. The steps undertaken included:

- Sensitivity analysis of the model to a range of model parameters (implicit within this is expert judgement on selection of appropriate and realistic ranges for parameter variation)
- Prioritisation of the modelling parameters to identify those with the greatest effect on modelling results
- Selection of the top three parameters for Monte Carlo analysis (implicit within this is the selection of a probability distribution function for each parameter, again based upon judgement)
- Analysis of results from 1000 model runs; selection of upper, mid and lower scenarios leading to a comparison between the base run (best estimate of model with chosen
modelling parameters) and the uncertainty analysis upper, mid and lower estimates.

Table 1 shows analysis of results from 44 model runs to assess model sensitivity to various modelling parameters. This analysis considers only peak discharge. Figure 5 then shows the distribution of model results from the Monte Carlo analysis (based on peak discharge) and specific flood hydrographs representing base, upper, mid and lower scenarios.

Table 1: Sensitivity of the peak outflow to the different input parameters

<table>
<thead>
<tr>
<th>Input Parameter</th>
<th>Input Parameter Range</th>
<th>Output Parameter variation analysis</th>
<th>% Var. from the Mean</th>
<th>% Var. from the base</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sediment transport eq.</td>
<td>-</td>
<td>Min 50 Max 236 Mean 110 Base 131</td>
<td>-57.4 100.4 157.7  -61.0 86.4 142.1</td>
<td></td>
</tr>
<tr>
<td>Sediment flow factor</td>
<td>0.5-3.0</td>
<td>Min 51 Max 190 Mean 122 Base 131</td>
<td>-53.8 64.8 98.2   -53.4 45.3 98.7</td>
<td></td>
</tr>
<tr>
<td>Angle of friction</td>
<td>25-45</td>
<td>Min 57 Max 166 Mean 122 Base 131</td>
<td>-44.8 35.9 60.6  -43.6 26.4 75.0</td>
<td></td>
</tr>
<tr>
<td>Breach width to depth ratio</td>
<td>0.5-2.5</td>
<td>Min 43 Max 116 Mean 55 Base 131</td>
<td>-46.7 24.3 71.5  -62.3 -11.6 72.8</td>
<td></td>
</tr>
<tr>
<td>E/B</td>
<td>1.5-1.9</td>
<td>Min 1.15 Max 1.93 Mean 1.80 Base 1.31</td>
<td>-25.1 20.5 48.7  -12.1 4.7 58.5</td>
<td></td>
</tr>
<tr>
<td>density (KH/m3)</td>
<td>19-23</td>
<td>Min 57 Max 127 Mean 104 Base 131</td>
<td>-55.4 21.7 57.1  -43.0 -5.2 51.8</td>
<td></td>
</tr>
<tr>
<td>Manning</td>
<td>0.003-0.045</td>
<td>Min 1.15 Max 1.46 Mean 1.32 Base 1.31</td>
<td>-12.7 10.1 22.7 -11.6 11.1 23.0</td>
<td></td>
</tr>
<tr>
<td>BFL (mm)</td>
<td>3-6</td>
<td>Min 124 Max 151 Mean 130 Base 131</td>
<td>-8.7 9.6 19.5  -5.2 15.3 30.5</td>
<td></td>
</tr>
<tr>
<td>Cohesion (KH/m2)</td>
<td>0-13</td>
<td>Min 120 Max 132 Mean 126 Base 131</td>
<td>-4.7 4.4 9.1  -8.2 3.5 8.3</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5: Probability distribution of peak outflow and selected upper, mid and lower scenarios.

These results start to give an indication of the uncertainty within the overall flood prediction process. Certainly for breach peak discharge, the suggested realistic range (in this case) is at least ~±30% for peak discharge. However, it is interesting to note that the base run, which represents the experts best judgement in this case, is within 10% of the observed peak discharge. It remains to be seen within the IMPACT project how this band of uncertainty translates through a flood propagation model to uncertainty within the prediction of flood water levels lower in the valley. Whilst attenuation of the flood hydrograph along the valley will tend to reduce the band of uncertainty in water level prediction, the addition of uncertainty within the flood propagation model itself will tend to increase the uncertainty in water level prediction.

**Future Direction of Work**

During the summer of 2004 further analysis will be undertaken to link propagation of breach and flood routing uncertainty, leading to an overall prediction of uncertainty within the estimation of flood water levels lower in the valley.
**WP6: Geophysical Investigation**

This 2-year module of work was added to the IMPACT project through a programme to encourage wider research participation with Eastern European countries. The work comprises two components; (1) review and field testing of different geophysical investigation techniques and (2) collation of historic records of breach formation.

The objective of the geophysical work is to develop an approach for the ‘rapid’ integrity assessment of linear flood defence embankments. This aims to address the need for techniques that offer more information than visual assessment, but are significantly quicker (and cheaper) than detailed site investigation work. Research is being undertaken through a series of field trial applications in the Czech Republic at sites where embankments have already been repaired and at sites where overtopping and potential breach is known to be a high risk.

The objective of collecting breach data is to create a database of events that includes as much information as possible relating to the failure mechanisms, local conditions, embankment material and local surface materials. Analysis may then be undertaken to identify any correlation between failure mode, location and embankment material, surface geology etc.

**Geophysics and Data Collection**

Geophysical methods may be used in several variants, most commonly in the surface variant (measurement is performed directly on the earth surface), in the underground variant (in the drills, adits, cellars, etc.) and in the variant of remote monitoring from aeroplanes, satellites, etc. (so-called remote sensing).

During a survey for either hydrogeological, engineering-geological, or geotechnical purposes, it is necessary to select an appropriate combination of these approaches and methodology for the field works. Likewise, it is necessary to understand the relationship between measured physical properties of rocks and parameters that have to be measured or indirectly determined. From the principle point of view, geophysical methods are considered to be indirect methods, because they substitute direct field works such as drilling, excavation etc. Thus, they may significantly save both time and money in comparison and/or combination with direct methods. The main contribution of geophysical methods consists, therefore, in getting higher quality, more extensive and more reliable background information for further survey works. During their application, it is necessary to remain flexible in selecting the most appropriate methods for the site, by working in stages the most effective approach, both scientifically and financially, may be developed.

The key to success in utilising results of geophysical methods is in attaining close cooperation of geophysicists with specialists in hydrogeology and engineering geology. The aim of geophysical testing measurements within the IMPACT project is to investigate and confirm the possibility of using these non-destructive methods in assessing the description and state of existing flood defence dikes. In particular, the rapid assessment of long lengths of flood defence embankment. Geophysical measurements have been conducted on a number of pilot sites within the IMPACT study utilising the following geophysical methods:

- **geoelectric methods**
  - resistivity profiling (RP), self potential method (SP), multielectrode method (MEM), electromagnetic frequency method (EFM)
- **seismic methods**
  - shallow seismic method (SSM), seismic tomography (ST), multi-channel analysis of seismic waves (MASW)
- microgravimetric methods
- GPR methods
- geomagnetic survey, gamma-ray spectrometric survey

**Current position of research**

Geophysical tests and the monitoring of dikes have demonstrated the possibility of developing and subsequent application of specific geophysical technology that could be utilised for a “rapid integrity assessment” approach. The proposed approach is based upon the use of modified apparatus GEM-2. To finalise this approach it is necessary to collect verification data within the defined catchment, and to verify performance by supplementary methods (multi-electrode method ARS-200, method of spontaneous resistance polarisation – SRP, etc.). If successful, the new geophysical monitoring system should help catchment management and organisation through:

- **quick testing measurement** – its purpose is to provide a basic description of dike materials and structures and to delimit quasi-homogeneous blocks and potentially hazardous segments. Repeated quick testing measurement data will be stored in the database, allowing us to analyse long-term changes of the dike condition.
- **diagnostic measurement** for a detailed description of problematic and disturbed dike segments – it serves for optimal repair planning
- **monitoring measurement** of changes of geotechnical parameters – it serves for repair quality control and for observation of earth structures ageing processes, etc.

**Results and conclusions so far**

The IMPACT monitoring and tests show that with expert application of geophysical methods we can better describe the real state of a dike. We expect that a proposed combination of geophysical methods would supplement other surveys and activities performed during maintenance (analysis of aerial and satellite photographs, inspection walks). We anticipate proposing a convenient methodology for embankment integrity assessment.

**Future direction of work**

At the present time, we are striving to prepare a programme of work for the year 2005 and 2006. This programme should cover regular monitoring of dikes in the catchment of Odra or Morava river, and the creation of a database with data measured by modified GEM-2 equipment. In problematic sections (changes of homogeneity of dikes) basic data should be complemented with data obtained by the more precise measurements performed by detail geo-electrical method ARS-200. Assessment of this database will enable us to determine the effectiveness and success of this methodology based on the fast preliminary measurement by GEM-2. This methodology should (together with other supplementary and more precise methods) serve to provide a fast and inexpensive check on flood defence embankments, allowing specific changes in their state with time to be identified (i.e. systematic monitoring of dikes by modified GEM-2 should be used for evaluation of weak places in the dikes, where failure could occur in case of overspill). In future, this fast and non-destructive geophysical method could make operation of water-management bodies within the catchment more effective, and assure early prevention of dike failure. Regular measurements of the dike state could enable estimation of risk of the dike failure, under the various hydrological conditions and plan early and effective repairs of embankments in selected sections. This method can be used for dikes up to about 10 m high of any length.
Where from here?

The IMPACT project has made significant advances in science in a number of areas but work is still to be implemented during the summer of 2004 in order to pull together and demonstrate this new knowledge. The Tous Dam failure (Spain) and Lake Ha! Ha! failure (Canada) will be used as case studies to demonstrate modelling capabilities in breach, propagation, sediment movement and uncertainty analysis. Final reporting of this work will be made through a 4th and final project workshop to be held in Zaragoza, Spain on 4-5 November 2004. Information will also be posted via the project website (www.impact-project.net).

The nature of the work undertaken and the type of funding from the EC (50%) means that much of the research work has also been integrated with existing national or organisation research projects. Within the UK, the research is meshed within a wider national programme of work funded by the government. Consequently, uptake of knowledge occurs through these links and, where appropriate, continuation of the research.

The concept and potential value of integrating research programmes, both nationally and internationally, is now being recognised. Effective integration of work avoids duplication of research effort and allows ideas and concepts from a wider range of sources to be considered. Building on best practice and experience from around the world has to be a more beneficial for all partners than remaining isolated in approach!

Within the last few years, real integration of research programmes can be seen nationally and internationally. This has probably been prompted by the growing use of the Internet as a means of disseminating information. For example, within the UK there are three major programmes of work for which full integration is being attempted. These programmes will run during the coming 3-5 years and comprise:

- Environment Agency / Defra national flood defence programme (applied research in field of flood risk management) [See www.defra.gov.uk/environ/fcd/default.htm]
- EPSRC / EA / Defra Flood Risk Management Research Consortium (FRMRC) programme (academic research programme) [See www.floodrisk.org.uk]
- EC FLOODsite Project (processes through to implementation for flood risk management) [See www.floodsite.net]

The FLOODsite Project

The FLOODsite project addresses a wide range of issues dealing with flood risk management. The research programme structure is shown by Figure 6 and covers activities from research into specific processes, through flood risk management, integration of tools, pilot site application and development, training, dissemination and networking. FLOODsite is the European Commission project addressing flood risk management.

The scope of FLOODsite is such that it is not possible to detail the programme here. However, it should be noted that issues of direct relevance to the dams industry such as breach initiation, flood inundation, integrated modelling and decision support tools, emergency planning tools, vulnerability, social and economic impacts are included within the programme of work. The European Commission has also recognised the value of integrating research from around the world. Under FP6, research projects may include partners from outside of the EC – such as the United States. Such a change in approach has not yet been widely recognised by European researchers, and uptake of funds to date has been limited. Opportunities exist here!

For more information on European research initiatives see the Cordis website at
www.cordis.lu. For detailed information regarding the FLOODsite project, see www.floodsite.net

Figure 6 Structure of the FLOODsite project

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