The British Dam Society

# 20th BIENNIAL CONFERENCE

## *Smart Dams and Reservoirs*

## Synopses

**Session 1 Planning and investigatory techniques**

**Session 2 Working with our heritage**

**Session 3 New approaches to design**

**Session 4 Innovative approaches in during dam construction**

**Session 5 Sensing and monitoring techniques for the 21st century**

**Session 6 Emergency preparedness**

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## SESSION 1: PLANNING AND INVESTIGATORY TECHNIQUES

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M CAMBRIDGE

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**Recent Experiences in the Use of Geophysical Methods to Assess Seepage through Dam Embankments**
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**Comparison of shear-beam and dynamic finite-element modal analysis of earth dams**
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**Lo - Building dams on rock or soft soil – frequency-domain analysis of dynamic dam-foundation interaction**
E LO AND L PELECANOS

# The Environmental Permitting of a new mine waste facility in Devon

M CAMBRIDGE, Cantab Consulting Ltd

SYNOPSIS The EU Directive on the management of waste from the extractive industries (2006/21/EC) is focused on the categorisation of a mine waste facility (MWF) in terms of the risks posed, with the highest risk category being determined by either waste or facility characterisation thresholds. Extractive waste regulations in the UK address the safety and stability of mine waste but do not specifically consider characterisation. Separate guidelines for compliance with the Directive were therefore necessary and the Environment Agency was appointed as the Regulator for the Environmental Permitting of all mine waste facilities in England. The first new facility to be permitted in accordance both with existing regulations and with the 2010 Environmental Permitting Regulations was the Hemerdon MWF associated with the Drakelands Tungsten Mine in Devon. This facility comprises the stage-constructed 113m high embankment dam which will confine more than 8Mm³ of fine mine waste and process water.

This paper describes the engineering approval and permitting processes required during the design and construction of the preliminary stages of the mine waste facility. The paper summarises the approach taken by the Regulator, the Competent Person (an All Reservoirs Panel Engineer) and the Developer in meeting both technical and regulatory requirements and in resolving potential conflicts with existing HSE Regulations.

# Valve Tower internal 3D laser scans to survey and facilitate design

A PASKINS, Mott MacDonald Bentley
J R FOSTER, Mott MacDonald Bentley
S SHAH, Yorkshire Water Services

SYNOPSIS Confined Space Access into Yorkshire Waters large group of Valve Towers requires a professional on-site safety team of which are rope access trained with highly intricate procedures to get a casualty up and out of the deep reaches of these submerged structures.

The utilities company have tasked MMB with designing a safe system of access, egress and rescue for their personnel who enter these irregular spaces monthly, to guarantee the safety of their operatives across the vast number of reservoirs in Yorkshire.

For the more complex tower arrangements, along with a confined space entry survey, a 3D laser scan has been carried out to rapidly capture the cluttered structures, some of which are 60m deep containing 10 or more intermediate landings, to aid the designs by using the virtual point cloud. This output data can be tailored for all the major design software such as Revit, CAD 3D and Navisworks to create 2D drawings, isometrics, sections and elevations, 3D solid models, mesh and so on.

This paper will describe the project directives, challenges due to the nature of the environments, the technologies used to gather accurate information to provide a more reliable and detailed solution for the client along with the applications in Health and Safety and design.

# Recent Experiences in the Use of Geophysical Methods to Assess Seepage through Dam Embankments

A WALKER, Mott MacDonald
TM HEWITT, Mott MacDonald
AL WARREN, Mott MacDonald
MJ MCAREE, Mott MacDonald

SYNOPSIS This paper will cover the investigations undertaken at a number of embankment dams after concerns were raised regarding high leakage flows. Two geophysical survey methods, Controlled Source Audio-Frequency Domain Magnetics and temperature sensing, were utilised to investigate potential leakage paths through the embankments. The results of these investigations were used in the design of targeted geotechnical investigations to inform the need for remedial works.

The paper will present the case studies, describe the investigations, discuss the application constraints of the two survey methods and draw conclusions about their suitability and limitations.

# Embankment Seepage Investigation

R DAVY, Mott MacDonald
M J MCAREE, Mott MacDonald

SYNOPSIS Following an inspection under Section 10 of the Reservoirs Act 1975, Yorkshire Water Services Ltd appointed Mott MacDonald Bentley in 2012 to undertake an investigation to address the recommendations made at one of Yorkshire Water's reservoirs in Holmfirth Valley, in the interests of safety. Subsequent geotechnical investigation indicated groundwater within the clay core and downstream shoulder, suggesting potential seepage could be occurring.

The investigation at Digley has included conventional geotechnical investigation techniques and the use of innovative fibre-optic temperature sensing probes. A number of the investigation technologies have been adapted to allow for remote monitoring of the site and can lead to more cost effective long-term asset management and potential avoidance of expensive remedial measures.

# Island Barn Reservoir – Embankment Leakage remedial works

D M RETTURA, Atkins Ltd
M ALESSANDRINI, Atkins Ltd
L ABEYWICKRAMA, Costain
J GREEN, Thames Water
B PHILPOTT, Thames Water

SYNOPSIS Island Barn Reservoir is a non-impounding reservoir retained by an earthfill embankment that has a history of leakage. Thames Water has undertaken a Portfolio Risk Assessment identifying seepage at the reservoir as a priority remedial work activity. A Willowstick® geophysical leakage detection survey was undertaken at the reservoir and three areas of leakage were identified through the embankment and foundation. Atkins was commissioned, as part of the Eight2O alliance, to design the remedial works required to seal the leakages. As result an impermeable barrier made of steel sheet piles was assessed to be the optimal solution to form a contiguous cut-off wall to reduce the leakage.

This paper describes how the leak was identified and remedial works proposed and undertaken. In particular, the conclusion of the feasibility study played a crucial role for the development of the remedial works planning along with the site space restrictions and associated waste disposal requirements. This paper examines all the stages of the project's development, from site survey to the remedial works design and construction. This project demonstrates how remedial works can be carried out without affecting the integrity and stability of embankments whilst achieving sound results.

# Loch Thom: Ground Investigation and Preliminary Results from Jet Erosion Testing (JET)

L HAMILTON, Mott MacDonald
D ARMOUR, Mott MacDonald
T M HEWITT, Mott MacDonald
T JUDGE, Scottish Water

SYNOPSIS Loch Thom reservoir was formed in 1825 by the construction of an earth embankment approximately 20m high, making it one of the highest embankment dams in Scotland at that time. In 1875, to increase storage capacity, the Main Embankment dam was raised by approximately 2.4m and a second 10m high dam (Garvocks Embankment) was built across a saddle along with three other smaller embankments. A need to improve the installed drawdown capacity was identified following a statutory inspection in 2013. The dams have been described as having puddle clay cores, however, there are no surviving records and a contemporary account given at the ICE in 1843, by Robert Thom, who designed the original Main Embankment, states that "the bank was built in layers of puddle peat or alluvial earth alternating with gravel beaten together with wooden dumpers until completely mixed, on the principle that the whole embankment should be made water-tight." A ground investigation was undertaken at both dams to establish the internal composition of each dam using intrusive and geophysical methods. The vulnerability of each dam to internal erosion is currently being assessed to inform drawdown requirements, and includes Hole Erosion Tests (HET) and Jet Erosion Tests (JET). It is believed to be the first time such tests have been undertaken on soils from a UK dam. This paper describes the approach to the investigations, details of the fieldworks and testing undertaken and preliminary JET results.

# CFD modelling for engineering solution optimisation on the Usk Reservoir

J MEHTA, Mott MacDonald
OJ CHESTERTON, Mott MacDonald
AL WARREN, Mott MacDonald

SYNOPSIS Dŵr Cymru Welsh Water, operators of Usk Reservoir, has had concerns with freeboard, spillway chute capacity and the performance of the spillway baffle blocks in the recent past. Physical modelling was carried out in 2014, with improvement works to address the findings from previous inspections and the physical model beginning in 2016. Mott MacDonald carried out a Computational Fluid Dynamics (CFD) model, employing its use for a number of aspects of the works.

This paper discusses the validation of the baseline CFD model against the physical model, confirming hydraulic performance such as the presence of cross-waves down the chute, and the bias of flow through different portions of the weir. The use of modelling outputs to ensure efficient wall raising to prevent out of channel flow was also employed.

The CFD model was used to predict stilling basin wash out to extend the dataset beyond what had already been modelled. The results were validated against the findings of the physical model and theoretical equations. The full data set was plotted to produce nomographs, detailing the unit flow entering the structure, end ramp height, washout point, flow depth and required wall height to contain flow. The nomographs were later employed as a design tool, along with the growing potential of CFD modelling outputs, to reassess the design without requiring further physical modelling.

# Investigating Scale Effects of a Hydraulic Physical Model with 3D CFD

C TORRES, School of Civil Engineering, University of Leeds, Leeds, UK
D BORMAN, School of Civil Engineering, University of Leeds, Leeds, UK
A SLEIGH, School of Civil Engineering, University of Leeds, Leeds, UK
D NEEVE, Arup, Leeds, UK

SYNOPSIS In the present study, the three-dimensional (3D) Computational Fluid Dynamics (CFD) Volume of Fluid (VOF) method is validated to reproduce hydraulic free surface flows over a labyrinth weir and a spillway for several flow rates using the open source toolbox OpenFOAM 3.0.1 and the commercial CFD package ANSYS Fluent 17.2. The CFD solvers are employed to simulate the 1:25 scale Froude number similarity physical model of the scheme, with validation conducted using experimental observations and measurements. It is found that both solvers are capable of accurately reproducing the velocities and depths measured in the physical model and are also able to capture complex flow features. The models are applied to simulate the prototype hydraulic flows so that scale effects from the physical model can be quantified. Results show the overall decrease in water depth and increase in velocity in the prototype can be up to 15% and 10%, respectively, for the lower flow rates, with scale effects reducing for larger flow rates. The prototype scale simulations also exhibit some variation in the labyrinth weir rating curve when compared to the scaled case; showing lower heads upstream of the crest for the same discharge. As theory would suggest, discrepancies in the rating curve at the two scales are more pronounced for low flow rates.

# Comparison of shear-beam and dynamic finite-element modal analysis of earth dams

E LO, University of Bath, UK.
L PELECANOS, University of Bath, UK.

SYNOPSIS This paper compares two well-established but different methods for frequency-domain analysis of earth dams. The first method is shear beam approach which is an analytical technique for estimating the natural modes and frequencies of vibration of earth dams. The second method is the dynamic finite-element modal analysis approach which is a numerical technique that can predict the actual dynamic response of earth dams. Although both methods attempt to predict the same physical mechanism, they usually yield completely different results. This paper aims at quantifying the "error" from shear-beam analysis, as compared to the more accurate finite-element analysis.

# Building dams on rock or soft soil – frequency-domain analysis of dynamic dam-foundation interaction

E LO, University of Bath, UK.
L PELECANOS, University of Bath, UK.

SYNOPSIS This paper is concerned with the design of new and the assessment of existing earth dams. It aims to understand the effect of a soft soil foundation for earth dams. The effects of a compliant foundation are more pronounced under dynamic events such as earthquakes. This study uses dynamic finite element analysis to investigate the dynamic response of earth dams during earthquakes. It is shown that the presence of a soft foundation layer increases the fundamental period of vibration of the dams and, depending on the properties of the dam and foundation, it may lead to amplification or de-amplification of the seismic accelerations. This is an important observation as design codes (e.g. EC8) need to consider the frequency content of the earthquake and the natural frequencies of the dam structure. Therefore this study may lead to a better seismic design of earth dams.

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## SESSION 2: WORKING WITH OUR HERITAGE

# Where To For Reservoirs?

C SCOTT, Stantec
A PALMIERI, World Bank (retired)

**SYNOPSIS** UK and global societal needs and demands are often changing the use of reservoirs from single purpose to multipurpose. These changes are affecting existing structures as well as others planned or under construction. In 2013 ICOLD recognised this and established a working group to investigate and prepare Bulletin 171 on Multipurpose Water Storage "Essential Elements and Emerging Trends" (ICOLD, 2016).

The Bulletin's scope was to provide a global view on the dynamics of Multipurpose Water Schemes (MPWS) by presenting "Essential Elements" and "Emerging Trends" for planning and managing such projects. It is based on 52 global case studies. The focus of the Bulletin is not on what should be done, but rather on what is being done, and how and by whom. "Essential Elements" represents a considered set of checklists for implementing Multipurpose Water Storage schemes. "Emerging trends" is a snapshot of the current "state of the art" of MPWS projects. This has been evolving significantly in recent decades and further evolution is expected as innovative approaches emerge in search of optimal sustainable solutions.

This paper presents a summary of Bulletin 171 and its findings with relevance to the UK. It discusses the Role of Water Storage, MPWS Projects, including economic and financial assessment, presents long term planning solutions, identifies institutional and procurement changes occurring, highlights MPWS problem-solving solutions and lastly summarises global "Essential Elements" and observed "Emerging Trends".

# The Ultimate Dam Revisited

A N THOMPSON, United Utilities
P J RIGBY, United Utilities

SYNOPSIS Professor Paul A Back, formerly of Sir Alexander Gibb & Partners, gave the first Binnie Lecture at the 1990 BDS Conference held in Nottingham (Back, 1990). The lecture was entitled “The Ultimate Dam” where he suggested ten desirable criteria for the ultimate dam.

The aim of this paper is to reflect on Back’s ultimate dam criteria, 28 years on, and discuss its relevance in today’s dam society. The criteria were originally intended by Back for the construction of a new dam but in the UK there are limited opportunities to apply the criteria to new dams. However it has basis for what should be aspired to by dam owners and undertakers for improving the safety of our existing structures as the custodians of our forever aging portfolio of assets. The following sections discuss each of the criteria for the Ultimate Dam and how this is being applied.

# The multiple uses of NRW reservoirs over the centuries

S MORRIS, Natural Resources Wales
A R DAVIES, Natural Resources Wales
M COOMBS, Arcadis Consulting (UK) Ltd

SYNOPSIS Natural Resources Wales (NRW) has had a significant increase in reservoir assets since 2014, due to a combination of the change in legislation within Wales requiring >10,000m³ reservoirs to be registered and the creation of NRW by the amalgamation of three separate bodies. The net result is that NRW is now the Undertaker for a significant variety of reservoirs, with multiple functionality, significantly varying in age and construction. The types of reservoirs include flood storage, water supply, National Nature Reserves (NNR), historic mining, public amenity and natural lakes that have been raised. Some of these provide multiple uses, or have changed use within their lifetime.

NRW is currently reviewing these reservoirs to determine the most beneficial use for each going forward. This paper presents examples of the reservoirs in question, the different functionalities they provide, or their change in use over several centuries.

# Killington Reservoir, a historic structure – spillway refurbishment in 2017

D H BROWN, Canal & River Trust
F HARTLEY, Canal & River Trust

SYNOPSIS

Killington Reservoir was built to supply the Lancaster Canal nearly 200 years ago. During its first century, it was beset by many challenges though little intervention has been needed since the introduction of reservoir safety legislation in 1930. The history of the dam and the refurbishment of its spillways are described below.

# Lower Bretton Dam: Ensuring function while protecting heritage

A OLAND, JBA Consulting
N FOVARGUE, Wakefield Council

SYNOPSIS The construction of Lower Bretton dam was completed in 1782 to form an amenity lake in the grounds of the Bretton Hall estate and impounds a reservoir which is the lower of a cascade of two. The River Dearne flows past the two reservoirs in a substantial channel on the left bank and all except extreme floods bypass the reservoirs and flow down a large, Grade II listed, masonry cascade routed down the left mitre of the lower dam. The right hand wall of the masonry cascade supports the toe of the dam embankment.

A Reservoirs Act Section 10 inspection in 2012 identified a number of measures to be taken in the interests of safety. The most important were related to substantial damage to the masonry cascade and concerns with the spillway flood discharge capacity. The Inspecting Engineer recommended emergency repairs to the cascade together with a new flood study and physical modelling to more accurately assess the hydraulic performance of the dam.

The paper describes the approach to the design and construction of the remedial works to this High-Risk reservoir. These included sympathetic modifications to the approaches to the main and auxiliary overflows to improve the discharge characteristics, reconstruction of the cascade wall, and repair of the masonry cascade. The paper also sets out the construction challenges faced during the abnormally wet winter of 2015-16.

# Modelling, investigation and analysis of masonry spillways

D REBOLLO, Mott MacDonald
J R FOSTER, Mott MacDonald
O J CHESTERTON, Mott MacDonald
J WILSON, Mott MacDonald

SYNOPSIS Recent incidents on masonry lined spillways involving removal of masonry blocks during floods and subsequent unravelling of the invert have shown that, despite sound construction and maintenance, there is a need to better understand the limits of masonry linings and determine methods to assess their ability to safely convey floods.

This paper describes the findings of six projects undertaken on behalf of Yorkshire Water to evaluate the ability of existing masonry spillways to safely convey their design flood. A combination of computational fluid dynamics (CFD) and on-site inspections, as well as destructive and non-destructive testing, was employed to evaluate the structures.

CFD was used to provide velocities and magnitudes close to the bed and around the masonry joints. From this, uplift pressures were calculated from known joint pressure and velocity relationships. The uplift pressures were then applied to selected masonry blocks on site using a pull-out test rig. In parallel, thorough site investigations and Ground Penetrating Radar (GPR) surveys were used to inform the assessments of the masonry.

The modelling, inspection, and testing regime outlined in this paper showed that the maximum potential for pull-out could be assessed with CFD and tested on-site. This methodology for evaluation and safety assessment of masonry spillways has improved knowledge and the confidence in the structures investigated, enabling capital savings to be delivered where previously it may not have been possible.

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## SESSION 3: NEW APPROACHES TO DESIGN

**Smart engineering makes smart dams**
R BRIDLE

**3D geological modelling to aid efficient remedial works design and planning**
P BENNETT, M EDMONDSON, P FAIR AND J RICHARDSON

**Vartry Lower Reservoir – The Planning and Design of Upgrade Works**
J K HOPKINS AND E FLEMING

**Fuse-plug Spillways**
J L HINKS AND C A GOFF

**Innovative automatic spillway gates to provide assurance of operation for dam safety**
P D TOWNSHEND

**Design and installation of new Rock Anchors to ensure the long term security of Seathwaite Tarn IR**
C D PARKS AND D E JONES

**Stanford Reservoir – Design and Construction of the Upgrade Works to Increase the Overflow Capacity**
T WANNER, J CORREIA, P FARNELL AND K JAROSZYNSKA-ETIENNE

**Dams for Small Hydropower in Scotland**
A SHEERMAN-CHASE, A VEITCH AND J L HINKS

**Developments in the design and construction of the Usk Reservoir spillway**
A L WARREN, E C ARCHIBALD AND N WALDING

# Smart engineering makes smart dams

R BRIDLE, Dam Safety Ltd

SYNOPSIS 'Smart' motorways make use of powerful modern digital monitoring and computing technology to apply '*A Theory of Traffic Flow on Long Crowded Roads'* (Lighthill and Whitham, 1955b) to reduce the speed of vehicles on the motorway, thereby increasing its capacity and relieving congestion.

In embankment dam engineering it is not possible to reduce the loads from earthquakes and floods that would cause instability or external or internal erosion. Smart engineers must therefore design or re-design, and if necessary remediate, dams using the 'theories' now available, and inspect and monitor smartly afterwards to confirm that the dam remains as designed. The paper discusses the theories available to design against instability and surface and internal erosion to an acceptable standard, and surveillance and monitoring to confirm that those standards are maintained in the long term.

# 3D geological modelling to aid efficient remedial works design and planning

P BENNETT, Mott MacDonald
M EDMONDSON, Mott MacDonald
P FAIR, Mott MacDonald
J RICHARDSON, United Utilities

SYNOPSIS Upper Chelburn is a 200 year old impounding reservoir with northern and southern earth-fill embankments. The works at Upper Chelburn form part of a targeted risk reduction strategy implemented by United Utilities (the client) termed 'Portfolio Risk Assessment' which when used in conjunction with their 'Toolbox' assessment highlights key risks to be addressed to reduce the probability of failure to an acceptable level.

Extensive ground modelling has been successfully applied to inform the design of permeation grouting; new spillway; sheet-piling and wave-bund. This has added-value throughout the design and further, by engaging the construction team, client, and subcontractor throughout the delivery of the works. The modelling has enabled both the grouting and sheet piling solutions to be highly targeted, reducing both programme and cost whilst also allowing for the effective design and management of temporary works design for a large historical landslip present on the site.

As a portion of the works requires a third party to be satisfied as to the quality of the recorded output, constant tracking of the developing solution throughout the works has allowed for greater client, construction team, and subcontractor engagement, as well as greater overall confidence in the output provided. Ultimately the contract records have been used to achieve sign-off of the works as a whole, to satisfy a client commitment to OFWAT.

# Vartry Lower Reservoir – The Planning and Design of Upgrade Works

J K HOPKINS, Black & Veatch
E FLEMING, Dublin City Council

SYNOPSIS Vartry Lower Reservoir, located in the Wicklow Mountains to the south of Dublin, was constructed in the 1860s. The associated water treatment works provides treated water to South Dublin and the Wicklow area. As part of a major upgrade to the water supply system the reservoir works are to be upgraded and the existing water treatment works replaced.

This paper explains the background, reasons for the need for the upgrade to the reservoir, including spillway improvements, and replacement/ refurbishment of the drawoff pipework. It discusses how these proposals have been integrated with the water treatment works replacement and how flexibilities in operational capabilities will be improved. This includes retention of a temporary siphon for permanent beneficial use, including providing an alternative future supply to the water treatment works to allow maintenance and inspection, and re-use of an existing hydro-turbine using winter spillage instead of it becoming redundant once the new water treatment works is operational.

# Fuse-plug Spillways

J L HINKS HR Wallingford Ltd
C A GOFF HR Wallingford Ltd

SYNOPSIS There are fuse-plug spillways at many large dams around the world. These may be designed to trigger in floods with return periods of, say, 10,000 years but may also trigger in much smaller floods if these are combined with failure of one or more of the main spillway gates to open. The annual probability of the latter combination may be much higher than that of experiencing a flood with a return period exceeding, say, 10,000 years.

Earthfill bunds, of conventional appearance, sitting on non-erodible foundations (whether rock or concrete) are examples of such fuse-plugs and typically have sloping clay cores resting against erodible downstream shoulders.

Tipping gates in steel or concrete have become popular in the last thirty years and there are several examples in the north-west of England. Various types of rubber dams are also used to hold water until they deflate when overtopped by a critical depth of water.

# Innovative automatic spillway gates to provide assurance of operation for dam safety

PD TOWNSHEND, Amanziflow Projects (Pty) Ltd, Johannesburg

SYNOPSIS Conventional hydro-mechanical spillway gates are mainly operated by electro-mechanical mechanisms usually connected to sophisticated control systems. Since the inception of the Tainter or radial gates in the early 1900s there have been numerous incidents of gate failures, some with catastrophic consequences to lives and property.

Electro-mechanically operated gates are therefore a major risk to dam safety. This risk is increased in developing countries where the remoteness of the dams, lack of maintenance, operator unreliability, uncertainty of power supply and backup systems all add to the risk of gate failure and therefore to dam safety.

However, an innovative self-actuating automatic gate has been developed in South Africa to eliminate the problems associated with electro-mechanical gates. These gates open and close automatically in response to water levels only. They are therefore not reliant on any external mechanisms, or operators, to operate the gates. They can therefore be used with confidence and assurance for dam safety.

This paper presents this type of automatic gate, explains its operation and refers to existing working installations in Southern Africa.

# Design and installation of new Rock Anchors to ensure the long term security of Seathwaite Tarn IR

C D PARKS, United Utilities
D E JONES, United Utilities

SYNOPSIS Seathwaite Tarn IR is situated 5km west of Coniston, Cumbria. The dam is of unusual hybrid construction; part curved concrete gravity and part earth/rock fill with concrete cut-off wall. A concrete cut-off extends into the bedrock under the entire length of the dam. The dam was constructed in stages between 1906 and 1907 and has suffered a history of leakage and modifications.

A post tensioned system comprising 35 single-bar rock anchors with a single layer of corrosion protection were designed and installed in 1974 to improve the stability of the gravity section of the dam. The anchors have been subject to “lift checks”, with stress adjusted by “shimming” where appropriate, at approximately 10 yearly intervals. The anchor design is out of current code requirements, but their performance has generally been satisfactory; however, they have suffered from under-head corrosion. The extent of the corrosion could not be assessed and its effects have prevented performance testing. United Utilities took the decision to replace the anchors in order to maintain the long term security of the dam.

# Stanford Reservoir – Design and Construction of the Upgrade Works to Increase the Overflow Capacity

T WANNER, Atkins Ltd
J CORREIA, Atkins Ltd
P FARNELL, Severn Trent Water
K JAROSZYNSKA-ETIENNE, North Midlands Construction

SYNOPSIS Stanford reservoir, with a capacity of 1.5Mm³, is impounded by a 10m high, 265m long embankment constructed in 1928 for water supply purposes. The main overflow consists of a 76.6m long side weir discharging into a concrete spillway channel. The full length of the crest of the dam and downstream slope are protected by cellular concrete blocks to allow overtopping during an extreme flood event.

Historic model testing determined that the main spillway could only accommodate the 1 in 100 year flood event before the dam was overtopped. The upgrade works to increase the main overflow capacity to safely pass the design flood were recently completed. This paper describes the design and construction stages of the spillway works, which consisted of the lowering of the invert and the widening of the channel from 6.1m to 11.5m to achieve a discharge capacity of 80m³/s. This solution was chosen in order to retain various existing upstream weir structures, penstock gates and the right side spillway wall. The development of the detailed design also took the contractor's construction staging into consideration and the requirement for the spillway to be able to 'operate' during a flood at all times during construction.

# Dams for Small Hydropower in Scotland

A SHEERMAN-CHASE, Independent Consultant
A VEITCH, Hydroplan Operations Ltd
J L HINKS, HR Wallingford Ltd

SYNOPSIS Over recent years government incentives have led to the development of numerous small hydropower schemes in the Scottish Highlands of which four are described in this paper. The dams are all "smart dams" in that they have sophisticated control systems and are operated remotely.

The paper describes the control systems and the choices made to optimise the schemes. It reviews construction problems encountered, including those attributable to working in a harsh environment, and experience gained from operating the completed schemes.

| Scheme | Dam | Height m | Head m | Turbine Type | Generator kW |
|---|---|---|---|---|---|
| Ardtornish | Teàrnait | 5.7 | 58.8 | Overshot Francis | 699 |
| | Rannoch | 13.6 | 68.0 | Undershot Francis | 1499 |
| Ederline | Socach | 4.7 | 214.5 | Twin Jet Pelton | 1900 |
| Beinn Eun | Wyvis | 5.6 | 102.5 | Undershot Francis | 1400 |

# Developments in the design and construction of the Usk Reservoir spillway

A L WARREN, Mott MacDonald
E C ARCHIBALD, Jacobs (formerly Mott MacDonald)
N WALDING, Dŵr Cymru Welsh Water

SYNOPSIS Usk Reservoir in South Wales is a large water supply reservoir formed by a 31m high earth embankment dam with a clay core wall and a concrete cut-off wall through the foundation. The spillway comprises a free overflow weir, leading to a concrete chute and stilling basin. In 2014, approximately 60 years after construction, leakage was noted adjacent to the spillway chute. The mass concrete forming the chute and stilling basin had cracked and required refurbishment.

This paper contrasts the original design approach and construction of the spillway with the adopted solution developed through modern investigation, analysis, design and construction techniques. It describes how a combination of modern and traditional methods of investigation, analysis and design were used throughout the feasibility and detailed design phases of the project to arrive at the final design solution. A suite of geophysical surveys was used to investigate the condition of the structure and to understand the mechanisms of deterioration. This informed the risk and value considerations in developing the design approach. Computational fluid dynamics were used to refine the design solution and to improve the performance of the stilling basin. The project showcases how modern technology - unavailable to the original designers - can be applied to extend the operational life of existing assets and improve their technical performance in a cost-effective manner.

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## SESSION 4: INNOVATIVE APPROACHES IN DURING DAM CONSTRUCTION

**Safeguarding Critical Infrastructure against Landslip Risk on a large dam in Albania**
T BLOWER AND S DAVIDSON

**Building Two Dams in the 'Smart Era'**
D NEEVE, S THOMPSON, D WEST, D COOKE AND P KELHAM

**Trebeddrod – A case study on the construction of a small spillway at a constrained site**
M COOPER, P KELHAM AND R GROSFILS

**First underwater installation of a geomembrane system in a UK dam - Llyn Teifi spillway**
G VASCHETTI, R COLCOMBE AND G LILLIU

**Palo Redondo - smart CFRD design and construction**
M WAMZER JEISS, A L WARREN, S A SOLERA AND H MALDONADO

**A risk-based approach for assessing a flood discharge for the design of river diversion structures**
R MALIZDERSKYI

**Intelligent rollers for embankment dam construction**
B C DOOLEY AND R J ROBSON

# Safeguarding critical infrastructure against landslip risk on a large dam in Albania

T BLOWER, Mott MacDonald
S DAVIDSON, Mott MacDonald

SYNOPSIS The 80m high, 960m long Banja Dam located on the Devoll River in central Albania has a clay core and gravel shoulders. It is founded mainly on Eocene flysch bedrock, which comprises a repetitive sequence of thin beds of mudstone, siltstone and sandstone, with variable dip. Where the beds dip out of the natural topography, slopes are prone to instability.

The Banja Hydropower Project had been started originally in the 1980's but funding difficulties and political upheaval halted construction in the 1990's. At that time, there were also significant technical challenges, with landslips affecting the powerhouse excavation and the headrace tunnel, and with concerns over the stability of the whole hillside above the left abutment.


Figure 1. Location of Banja Dam

When construction started again in 2013, there was concern that these historical landslips would be re-activated, and that critical parts of the project would once again be affected by the threat of slope instability. However, during construction the site supervision team took measures to manage these risks and to allow the works to proceed to a successful conclusion. The key components of these measures were regular monitoring of key stability indicators and the construction of a large stabilising berm.

# Building Two Dams in the 'Smart Era'

D NEEVE, Arup
S THOMSON, Arup
D WEST, Galliford Try Black and Vetch
D COOKE, Arup
P KELHAM, Arup

SYNOPSIS Technology, construction plant and on-site testing have advanced, enabling the construction of two separate dams to a higher standard and tolerance than would have been imagined at the start of the last century.

Flood protection at the Eller Beck Dam has technology at its centre with active river control via a fully automated penstock that uses live data to restrict flows entering the town. The dam is a significant addition to the landscape with a crest length of 623m, a 35m wide labyrinth weir and 150m long reinforced concrete spillway.

Construction works for both the Eller Beck Dam and the smaller Waller Hill Dam utilised drones for project planning, 3D models for the earthworks and construction plant controlled by GPS. Vibrating wire piezometers were used to control fill rates above very soft clays at Eller Beck and computer controlled grouting used for the cut-off at Waller Hill Dam. However, technology is not always infallible, for example seismic refraction interpretation led to a smaller area of shallow rock head being anticipated than was actually present, requiring modifications to the design during construction. The project is also assisting in Computational Fluid Dynamic (CFD) modelling advances by being the subject of a PhD thesis.

Along with highlighting where technology has been used (both successfully and unsuccessfully), this paper also shares lessons learnt during the construction of the two dams, including dealing with springs; bedrock grouting; embankment fill selection and conditioning; and construction of reinforced concrete structures within the body of the dams and spillways.

# Trebeddrod – A case study on the construction of a small spillway at a constrained site

M COOPER, Arup
P KELHAM, Arup
R GROSFILS, Arup

SYNOPSIS Following recent re-categorisation of Trebeddrod Reservoir to a Category A dam a new spillway was required to safely pass the Probable Maximum Flood (PMF) outflow of 28.7m³/s. The small and constrained nature of the site, along with the limited access and working space governed many aspects of the design and construction of the spillway.

The works at Trebeddrod were planned and designed with a degree of flexibility to enable the contractor to use his experience to develop the most suitable construction methods for the constrained conditions. At the design stage a continued role for the designer was agreed. The resulting collaborative approach to the works enabled various aspects of the design to be further developed and modified during the works, to suit the contractor's favoured approach to construction.

This paper presents some examples of how the design and contracting teams worked together, and adopted some innovative approaches during construction, to successfully complete the new spillway.

# First underwater installation of a geomembrane system in a UK dam: Llyn Teifi spillway

G VASCHETTI, Carpi Tech
R COLCOMBE, Kaymac Marine & Civil Engineering Ltd
G LILLIU, Carpi Tech

SYNOPSIS Llyn Teifi reservoir, owned by Dŵr Cymru Welsh Water and used for water supply, is formed by a series of small embankment dams. One of these has a concrete gravity section acting as overflow, with adjoining draw-off tower and wing walls. The concrete of the spillway was in poor condition and leaking; in the interests of safety, to improve water tightness and stability, the designer MWH selected a geomembrane system that could be installed without dewatering or lowering the reservoir water level due to water resource constraints. The system lines the upstream face of the spillway, the joint with the southern wing wall, and part of the draw-off tower. A drainage system behind the geomembrane allows the water tightness to be monitored. The challenges were difficult boundary conditions, uneven surfaces, difficult geometry involving multiple changes in inclination in restricted areas, complicated drainage discharge and poor underwater visibility. Waterproofing works started on October 26th, 2016 and were completed on December 1st, 2016, after completion of downstream concrete works to increase the spillway's stability.

The paper outlines precedents and design of the geomembrane system, addresses difficulties and measures adopted to overcome them, gives some installation details, and information on performance of geomembrane systems installed underwater on upstream faces, cracks and failing joints.

# Palo Redondo: smart CFRD design and construction

M WAMZER JEISS, Mott MacDonald
A L WARREN, Mott MacDonald
S A SOLERA, Mott MacDonald
H MALDONADO, Ripconciv Peru SAC

SYNOPSIS The Palo Redondo CFRD (Concrete Face Rockfill Dam) and associated works form part of the Chavimochic Irrigation Project in Peru that will provide irrigation of about 50,000Ha of new lands and improve the irrigation system of another 20,000Ha. The 97m high dam will create storage for approximately 400Mm³ of water within a normally dry valley and regulate water transferred to the reservoir by canal.

The dam is founded on sedimentary rocks on the right abutment and igneous rocks on the left abutment, and is founded on alluvium across the valley centre. The dam crest length is 840m and the embankment body contains over 9 Mm³ of alluvial gravel materials.

This paper explains how modern design techniques were employed to appraise the design challenges. It will also explain how instrumentation deployed during construction was used to inform the final design of the dam and the construction methodology. New construction techniques were used which reduced the health and safety risks to the workforce and improved fill placement productivity.

# A risk-based approach for assessing a flood discharge for the design of river diversion structures

R MALIZDERSKYI, Duglas Alliance Ltd

SYNOPSIS The paper describes a risk-based approach for determining an appropriate flood discharge value for the design of river diversion concrete structures and cofferdams erected for a dam construction period. This approach is based on the experience of Sendje HPP project implementation ongoing in Equatorial Guinea. The foundation pit of Sendje gravity dam was flooded due to an upper cofferdam overflow in October 2015, when the river flow increased from 660m³/s up to 2300m³/s in half an hour. The design flood of 1656m³/s was considerably exceeded. In addition to cofferdam damage and other material and equipment losses, that flood led to a delay in the construction works due to the need for a flood probability analysis; revision of the river diversion scheme design; repairs to the cofferdam and numerous meetings with the Client to discuss the incident. As a result, an attempt was made to develop a risk-based approach for determining the design discharge for river diversion works.

# Intelligent rollers for embankment dam construction

B C DOOLEY, Mott MacDonald Bentley
R J ROBSON, Mott MacDonald Bentley

SYNOPSIS In February 2017 slope stability improvement works commenced at Riding Wood Reservoir, near Holmfirth, with approximately 35,000T of material placed on the downstream face. Throughout the works, Nuclear Density Testing (NET) was carried out to confirm that adequate compaction had been achieved, with testing carried out at discrete locations across each compacted layer.

In-situ testing can introduce delays, preventing the placement of subsequent layers until testing results for previous layers are reviewed. At Riding Wood a trial was conducted using intelligent rollers, allowing the machine driver to monitor compaction in real-time. The rollers were fitted with accelerometers to monitor the force applied through the vibrating drum and produce Intelligent Compaction Values (ICVs). Through calibration with NDT, the rollers were set to achieve a pre-selected ICV, corresponding to the required in-situ density. This paper presents MMB's experience of using intelligent rollers and explores the benefits and limitations of this technology.

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## SESSION 5: SENSING AND MONITORING TECHNIQUES FOR THE 21ST CENTURY

**Space Technologies for Dam Monitoring**
R CIFRES, G COOKSLEY AND C DIXON

**Remote Monitoring – Opportunities and Challenges of Innovation**
P RIGBY AND A N THOMPSON

**Barriers to the Adoption of Remote Monitoring of Dams and Reservoirs**
D SHAW, D TRAM AND T WILLIAMSON

**Smart Construction Monitoring of Dams with UAVS - Neckartal Dam Water Project Phase 1**
G L COETTZEE

**The automation of data collection at Clywedog Dam**
D A BRUGGEMANN, I HOPE, J HIGHFIELD AND N SLATER

**Reservoir Safety System (RSS) V2.0 - A Digital Approach to Reservoir Surveillance & Monitoring**
K MURRAY, L MASON, A WALKER AND M HEWITT

**Dam Safety Monitoring at Komani dam Albania**
E QOSJA

**The use of Thermal Imaging Cameras for everyday Site Inspections**
R J ROBSON

**Smart membranes and pipe monitoring networks - waterproofing and real-time leak detection systems**
J CROWTHER, D A MAWSON, A CATALDO AND E DE BENEDETTO

# Space Technologies for Dam Monitoring

R CIFRES, Telespazio VEGA UK Ltd
G COOKSLEY, Telespazio VEGA UK Ltd
C DIXON, Telespazio VEGA UK Ltd

SYNOPSIS The current trend of adoption of new technologies for automation of dam monitoring presents a challenge when it comes to accurately monitor absolute 3D movements of a dam. Traditionally plumb lines and manual surveying techniques are often the methods of choice. Plumb lines actually measure tilt, from which displacement can be derived, and surveying campaigns being carried out manually cannot be automated, and hence the number of readings over time is scarce.

There are many technologies trying to fill the gap, such as robotised total stations, Ground Based Synthetic Aperture Radar (GB-SAR), and so on, which rely on expensive and delicate equipment to be installed on site and subject to harsh conditions and vandalism. The problem is even worse when it comes to monitoring slopes, abutments and landslides. The inaccessibility of some sites makes the task a huge challenge.

Satellite technologies can provide tools to accurately monitor movements without the need of expensive equipment on the ground as, in this case, the critical equipment is space-borne. Global Navigation Satellite Systems (GNSS) and Interferometric Synthetic Aperture Radar (InSAR) are two different approaches to the problem that can complement each other to provide a robust and complete solution.

# Remote Monitoring – Opportunities and Challenges of Innovation

P J RIGBY, United Utilities PLC
A N THOMPSON, United Utilities PLC

SYNOPSIS A dam is at its most vulnerable to failure at first filling and during the first years of its life. Failures also occur as a consequence of design and construction issues. Given the aging stock of dams within the UK probably the most likely failure modes for these assets are associated with operation of the dam and lack of maintenance. This paper reviews the impact of regular long-term monitoring of dams.

Traditionally monitoring of the dams constructed pre-1970s has been carried out by manual inspections, but with the increase in technology and the drive to have centralised integrated control systems asset owners are looking at options to monitor dams remotely, often with the view of reducing the frequency of visual inspections.

This paper explores the opportunities and limitations of remote monitoring instrumentation, citing examples of its use or proposed usage. It reviews the benefits, challenges and risks to dams from this type of monitoring and reflects on its use as part of the overall monitoring and surveillance regime for a dam.

# Barriers to the Adoption of Remote Monitoring of Dams and Reservoirs

D SHAW, Arup
D TRAM, Arup
T WILLIAMSON, Arup

SYNOPSIS Monitoring and surveillance of dams and reservoirs in the UK relies on regular site visits. These assets are often in remote locations and access can be challenging. Remote monitoring can offer a number of benefits. However the use of technology is not common across the industry. A study was undertaken to understand current use of remote monitoring systems and to determine barriers to their adoption. Questionnaires were completed by eight asset owners on their existing use and knowledge of technology and their aspirations for remote monitoring.

The majority of respondents would like to see more monitoring at their sites. Advantages cited included reduced confined space access; information on assets when inaccessible due to adverse weather; real-time monitoring; alarm systems; and ability to prioritise staff based on asset performance. However, there are a number of perceived barriers including physical site constraints; vandalism; commitment to funding; a need to change attitudes amongst owners and engineers who may be sceptical of the benefits; and a lack of capability to manage the data effectively. The respondents' needs varied significantly, which suggests monitoring has to be tailored to the individual companies based on their business drivers, and types and locations of assets.

# Smart Construction Monitoring of Dams With UAVS - Neckartal Dam Water Project Phase 1

G L COETZEE, Knight Piésold Consulting

SYNOPSIS The continual development of computational hardware and software makes unmanned aerial vehicles (UAVs) the future of dam construction world-wide. UAVs (also known as drones), may be used for photographic surveys to develop accurate three-dimensional models that can be used for smart construction progress monitoring of large scale projects. The technology was originally used for conceptual projects but has proven to be a reliable substitute for conventional topographic surveys. The Neckartal Water Project Phase 1 (NWPP1) (the construction of the largest dam in Namibia) is one of the first projects in the SADC region to apply this technology. Accurate surveys, project monitoring, material quantity measurements, Building Information Modelling (BIM) integration and the sharing of insights around the construction site were achieved with the aid of a UAV. The UAV assisted the engineers in developing, monitoring and quantifying construction activities. This paper shares the methods applied and results obtained at the NWPP1 in utilizing photographic surveys to develop three-dimensional topographic models, together with the integration of BIM.

# The automation of data collection at Clywedog Dam, Wales

D A BRUGGEMANN, Atkins Ltd
I HOPE, Severn Trent Water
J HIGHFIELD, Severn Trent Water
N SLATER, ITM Monitoring Ltd

SYNOPSIS Clywedog Dam is a 72m high buttress dam incorporating a saddle dam (Bwlch y Gle Dam) on the rim of the reservoir. The reservoir has a critical role in the regulation of the River Severn. Construction of the dam was completed in 1967 and recently a 50-year review was carried out. The review included an analysis of the monitoring data collected over the years. The behaviour of the main dam is monitored using a range of techniques and instruments. Monitoring of the Bwlch Gle saddle dam includes standpipe piezometers. Generally, the dam performance data is collected manually except for the piezometer data from Bwlch y Gle dam where piezometric levels are collected using a recently installed automated data logging system.

One of the recommendations in 50-year review was to automate the collection of performance data. This approach coincides with a company strategy to increase digitisation across all parts of the business.

The paper will describe the current manual data collection procedures and the proposals for automation of the data collection process. The impact of automated data collection on reservoir monitoring and surveillance procedures will be discussed as well as the benefits and pitfalls that may be associated with reliance on automated data collection systems.

# Reservoir Safety System (RSS) V2.0: A Digital Approach to Reservoir Surveillance & Monitoring

K MURRAY, Scottish Water
L MASON, Scottish Water
A WALKER, Mott MacDonald
M HEWITT, Mott MacDonald

SYNOPSIS Using bespoke software, developed and tested by Scottish Water and Mott McDonald, new approaches to the recording, validation, analysis and reporting of dam performance surveillance and monitoring (S&M) field data have been developed. The paper describes the challenges that were identified with the current system and the opportunities and benefits of a new digital approach.

# Dam safety monitoring of Komani dam – Albania

E QOSJA, Korporata Elektroenergjitike Shqiptare (KESH)

**SYNOPSIS** Power production in Albania relies on renewable energy such as hydropower, which produces almost 79% of the generating capacity in the country. This energy is generated by three hydropower plants; Fierza HPP, Komani HPP and Vau i Dejës HPP, which are installed on the Drin River cascade, the largest one in the Balkan region. In terms of height, importance and risk of failure, ICOLD has categorized them as 1st class dams.

Albanian Power Corporation (KESH), as the public owner of the dams, has paid special attention to dam safety by investing periodically in monitoring equipment and studies. In addition to in-built dam instrumentation, meteorological monitoring is also considered to be a necessary safety precaution. Hence a hydro-meteorological station network has recently been set up that will provide an early indication of the amount of rainfall and runoff entering the lakes.

The purpose of this paper is to present the methods that have been applied to discover the origin and direction of movement of water leakage in the dam toe at Koman HPP, even though it does not constitutes a threat to the dam's safety. To monitor this leakage KESH has conducted many studies and research. Over the last few years studies have been carried out based on geophysical methods to understand the water movement, including inspection of the concrete face using an ROV; tracer testing and diving. In addition to these studies, attention has been focused on the automatic data collection from the system of piezometers and inclinometers. This will enable the operator to receive the dam monitoring data in real time in order to provide improved operation of the dam and prompt intervention in the event of an incident.

# The use of Thermal Imaging Cameras for everyday Site Inspections

R J ROBSON, Mott MacDonald

SYNOPSIS This paper describes the use of basic thermal imaging cameras during routine visits and site inspections on a variety of reservoir projects to detect and trace leakage and also for quality control during construction.

The cost of electronic equipment is constantly reducing, whilst at the same time the sophistication of these devices is increasing, making what was once an expensive specialist piece of equipment affordable for everyday use.

This paper outlines the type of thermal imaging cameras available, presents a brief review of the technology behind them and provides examples of situations where they can be used to gain extra insight into reservoir investigations and design issues.

# Smart membranes and pipe monitoring networks; waterproofing and real-time leak detection systems

J CROWTHER, Sensor UK
D A MAWSON, Mott MacDonald Bentley
A CATALDO, Salento University
E DE BENEDETTO, Monitech

SYNOPSIS Sensor UK developed electronic geomembrane leak location monitoring systems for use on hazardous waste storage sites in the 1980s. The technology has been developed and adopted by industries to provide reliable and accurate geomembrane leak detection, designed to contain or protect assets.

The technology came to the UK water industry during concern for failing assets and unreliable coating systems, crucial to potable water supply. Various levels of protection have been developed from simple loose-laid impermeable membranes to real-time notification systems and remote operating of the membrane interrogation software.

A DWI Regulation 31 Approved geomembrane, designed for use in contact with potable water utilising the technology, identifies and locates leaks. The system has been installed above service reservoirs for various water authorities in the UK and Canada but is also suited to lining impounding reservoirs, tanks and lakes as well as chemical-free water treatment facilities.

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## SESSION 6: EMERGENCY PREPAREDNESS

**Improvements in Reservoir Flood Map as part of the Environment Agency's Flood Map Project**
M DEANE, P D DOWN AND D SANTORO

**Fatality and Loss Models: Modern hydraulic modelling techniques warrant a better approach**
R COOMBS

**Fixed and Variable Roughness Regimes for Rapid Inundation Modelling**
M CRAMMAN AND R COOMBS

**Learning from reservoir incidents – a summary of the causes and management of incidents in the UK**
A L WARREN AND B PATTEN

**Improving the emergency drawdown reliability at Llyn Brenig reservoir**
S TUDOR AND A MORGAN

**Guide to Drawdown Capacity for Reservoir Safety and Emergency Planning – Feedback**
A P COURTNADGE, S GLEDHILL, I SCHOLEFIELD AND J GOSDEN

# Improvements in Reservoir Flood Map as part of the Environment Agency's Flood Map Project

M DEANE, Mott MacDonald, Cambridge, UK
P D DOWN, Mott MacDonald, Leeds, UK
D SANTORO, Mott MacDonald, Cambridge, UK

SYNOPSIS Since 2015 the Environment Agency has commissioned a series of tasks under the Reservoir Flood Mapping (RFM) Project, culminating in the provision of new dam-break flood maps for all statutory reservoirs in England. The final task comprises hydraulic modelling and the creation of the new maps. This work commenced in Summer 2017.

The maps are intended to be used for the purposes of both emergency planning and risk designation. Their specification has been tailored for these purposes. Maps are produced for both "dry day" and "wet day" failure scenarios, the latter considering a fluvial flood event coincident with the dam-break.

The paper will explore the details of the modelling specification, process undertaken and maps produced, particularly where they deviate from the 2009 National Reservoir Inundation Map (NRIM) Project.

# Fatality and Loss Models: Modern hydraulic modelling techniques warrant a better approach

R COOMBS, CCH

SYNOPSIS While the technology and methods generally employed to determine the hydraulics of dam failures have advanced significantly over the last decade, a fatality model developed in 2004 for the *Interim Guide* is still commonly adopted. This was developed at a time when 2D Shallow Water Equation based hydrodynamic modelling techniques were only occasionally implemented. Since then this has become the industry standard approach for dam failure inundation studies.

Multiple hydrodynamic assessments of a UK reservoir have been undertaken for this paper in order to demonstrate the sensitivity of the fatality model to various hydrodynamic modelling techniques. The basis for a new disaggregated, coupled building damage and stochastic fatality model is broadly set out alongside an argument for the publication of new guidelines following the shift in industry focus to 2D modelling methods.

# Fixed and Variable Roughness Regimes for Rapid Inundation Modelling

M CRAMMAN, CCH
R COOMBS, CCH

SYNOPSIS 2D Hydraulic modelling has improved dramatically in recent years as software and hardware allow for larger, more detailed models to be constructed and run within workable timescales. The information required to construct complex models (such as LiDAR, land parcels data, etc.) is now readily available. Although detailed terrain information is generally used in these assessments, reservoir failure inundation modelling is normally carried out using a fixed roughness (n = 0.100) across the entire model domain. The study presented investigates the ramifications of various choices for modelling roughness within a 2D domain. A domain for a UK reservoir has been modelled using MIKE21 for five scenarios for which roughness is the only variable. This clearly demonstrates the differences in modelled velocities, and therefore depth-velocity product (the metric often adopted when determining the consequences of a reservoir failure).

# Learning from reservoir incidents – a summary of the causes and management of incidents in the UK

A L WARREN, Mott MacDonald
B PATTEN, Environment Agency

SYNOPSIS A system of post-incident reporting has been administered by the Environment Agency since 2007. Mandatory reporting of incidents at large raised reservoirs in England became a legal requirement in 2013. This paper summarises the Environment Agency's experience to date with voluntary and mandatory reporting. It explains how post-incident reporting has helped inform opinion on reservoir safety management and guide related research requirements. It discusses how the capturing of evidence on how incidents can inform research and best practice and how devolution may have an impact on the national provisions for capturing information on incidents.

# Improving the emergency drawdown reliability at Llyn Brenig reservoir

S TUDOR, Dŵr Cymru Welsh Water
A MORGAN, Arup

SYNOPSIS Llyn Brenig is one of Dŵr Cymru Welsh Water's (DCWW) largest reservoirs by volume, retained by a 50m high rockfill dam. Consequently, it has one of the largest emergency drawdown capacities of DCWW's portfolio of dams. However, whilst the theoretical capacity meets the capped basic recommended standard (Environment Agency, 2017), the forty years old drawdown facilities can be unreliable; unsafe to operate; time consuming to initiate flows and capable of causing downstream flooding.

The scour facility is in an arrangement that is unusual within the DCWW portfolio; it consists of large gates that discharge into the base of a tower into which the overflow also discharges, and then into a combined scour and overflow culvert. The upstream bulkhead gate is operated by a gantry crane situated at the top of the outlet tower. The crane is unreliable. The operation to lift the bulkhead gate and associated emergency roller gate is labour intensive and considered unsafe by DCWW.

This paper describes the work that has been done to improve the reliability and operability of the scour facility in order to address 'recommendations in the interest of safety' that were made following an inspection made under Section 10(2) of the Reservoirs Act 1975 (HMSO, 1975) in 2015. This has involved changing the way in which the scour system is operated, replacement of three large gates and investigations using Computational Fluid Dynamics (CFD).

# Guide to Drawdown Capacity for Reservoir Safety and Emergency Planning – Feedback

A P COURTNADGE, Jacobs
S GLEDHILL, United Utilities
I SCHOLEFIELD, United Utilities
J GOSDEN, Jacobs

SYNOPSIS In August 2017 the Environment Agency published guidance for assessing the adequacy of drawdown capacity at UK reservoirs. This paper gives an overview of the guidance and reviews its uptake within the industry and feedback from a sample of Undertakers. The paper then reviews the initial results from 212 reservoirs provided by four different Undertakers in order to gauge the implications that the guidance may have on the industry as a whole.