The British Dam Society

Managing Risks for Dams and Reservoirs - Synopses

CONTENTS

A review of the applicability of the EA reservoir flood mapping specification for reservoir risk assessments

L YUSTE ZABALLOS, AtkinsRéalis
R RIBEIRO, AtkinsRéalis
J RIBEIRO CORREIA, formerly AtkinsRéalis

SYNOPSIS In 2021, the Environment Agency (EA) published new reservoir flood maps of all the statutory reservoirs in England. These maps are intended to be used for a range of purposes related to flood risk and planning. In parallel, the EA also undertook to assess the Average Societal Life Loss (ASLL) associated with a breach for each reservoir, although this information has not been made publicly available.

The new reservoir flood maps (and ASLL figures) developed by the EA were assessed following the guidance provided in the EA's Reservoir Flood Mapping (RFM) Specification (EA, 2019). This was a nationwide exercise and therefore some broad assumptions had to be adopted so the methodology could be applied to all the reservoirs.

This paper presents a review of the EA's RFM Specification and associated technical papers to understand where there is the potential for conservatism in the assumptions made when developing EA Breach hydrographs and ASLL figures. This will equip reservoir undertakers with an understanding of the applicability of the data for use in assessing the societal risk posed by a reservoir.

Risk Informed Decision Making for Dinas Dam

G P M MASON, Statkraft Energy Ltd
R P H WOOD, Statkraft Energy Ltd
H T STEHLE, Stillwater Associates Ltd
T R WANNER, Stillwater Associates Ltd

SYNOPSIS Dinas dam is located on the Afon Rheidol and forms part of the Rheidol Hydro Scheme owned and operated by Statkraft Energy Ltd (hereby known as the undertaker). It is a 27m-high concrete arch gravity dam that went into operation in 1962. The dam has several well documented historical issues, mainly associated with development of alkali-aggregate reaction (AAR) within sections of the dam, that was first identified during the 1980s and continued to develop for the next 30 years. The identification, monitoring and evaluation of the AAR was largely overseen by an All Reservoirs Panel Engineer (ARPE).

The aim of this paper is to provide a brief background on how the historic issues at Dinas dam have been managed to date from a risk perspective and to describe the methods and techniques used during a Quantitative Risk Assessment (QRA) workshop. The paper will also provide details of how the learnings from the workshop will assist with making risk-based decisions regarding Dinas dam, that will enable effective planning for future management / works to ensure the longevity of the dam. Lastly, the paper will discuss how this type of workshop can be used as a tool for information sharing and knowledge transfer.

Improving the quality of flood modelling studies for reservoir safety assessment

C WALLER, Environment Agency
T TOOGOOD, Environment Agency
T HUNT, Environment Agency
P WELTON, Environment Agency
D McKEOWN, Environment Agency

SYNOPSIS Flood modelling studies underpin decision making on reservoir spillway capacities and dam freeboard allowances. Flood modelling is a specialist subject with many methodological decisions and assumptions that can significantly affect outcomes. It is often undertaken by third party consultants on behalf of the reservoir operator.

This paper describes the work undertaken by the Environment Agency over the past two years to improve the quality of flood modelling studies undertaken for reservoirs owned and operated by the Environment Agency. This has included developing standardised modelling scopes, reporting templates, and quality assurance procedures. We have also sought to improve guidance and accessibility of tools for undertaking calculations. Within the Environment Agency, we have introduced training materials and led webinars on flood modelling for reservoir safety studies to improve understanding across modelling and engineering professions. Together, these are improving the quality assurance of our flood modelling studies. However, there have been challenges, including the difficulties of completion of work within MIOS deadlines, and tensions between the role of modelling technical assurer and the role of the panel engineer. We make recommendations for collaborative ways of working to overcome these challenges.

Developing a new hazard classification for Reservoir Safety in England and Wales

D SHAW, Ove Arup and Partners Ltd
C FRENCH, JBA Consulting
A MORGAN, Ove Arup and Partners Ltd

SYNOPSIS Following the major incident at Toddbrook Reservoir in August 2019 and a subsequent independent review, the Department for Environment, Food and Rural Affairs (Defra) and the Environment Agency (EA) have established the Reservoir Safety Reform Programme (RSRP). Workstream 1 of the RSRP is developing a new reservoir classification system that will underpin new legislation in England and Wales.

This paper presents the main elements of work completed to date which include reviews of international reservoir legislation and other UK high-risk industries, and development and testing of potential classification options. A new approach that uses a multi-criteria classification system is proposed and this will now be taken forwards for further refinement ahead of wider public consultation and drafting of new legislation.

Risk-based approach for safety review of tailings dams

S SAFAVIAN, SLR Consulting Limited (UK)
F van HEERDEN, SLR Consulting Australia Pty Ltd

SYNOPSIS The aim of this paper is to show, by way of a case study, how the risk-based approach to the safety review of dams can help dam owners prioritise upgrade options.

Risk-based assessment is a powerful tool to assess the safety of a dam by focusing on credible failure scenarios which will help identify risks, prioritise the required actions and eventually mitigate the risks in an efficient and cost-effective way. The main advantage of this method compared to the traditional standards-based assessment is the prioritisation of the risk mitigation options based on the risks associated with different failure modes.

This paper is based on a risk-based safety assessment that was carried out for an existing tailings dam, referred to herein as a Tailings Storage Facility (TSF). The objective of the study was to ensure that the risks to society are tolerable and to suggest several practicable risk mitigation options. As a result, the estimated risks for all loadings and failure modes were expressed as F-N plots representing the level of societal risk.

Although the risk profile of the TSF was determined to be in the risk-tolerable area, efficient risk mitigation options were evaluated which could reduce the risk significantly; however, due to the marginal initial risk of the project it was concluded that the project is satisfying ALARP at this stage of the construction.

Skavica Hydropower Project: Mitigation of seismicity and foundation conditions through dam geometry and grout curtain design

T WEBSTER, Mott MacDonald
T BLOWER, Mott MacDonald
J PAWSON, Mott MacDonald

SYNOPSIS Skavica HPP is a proposed 224MW hydropower scheme on the Black Drin in Albania that aims to improve the national power security of the country. Mott MacDonald was commissioned to develop a front-end engineering design (FEED) for the project.

This paper discusses how the site constraints impacted the design decisions taken with respect to the dam structure, its foundation, the grout curtain arrangement and associated works. The scheme will be located in a limestone gorge and the reservoir would be impounded by a 160m high trapezoidal RCC dam. The trapezoidal dam cross-section geometry was informed by preliminary rigid body stability analyses that indicated that the governing case for stability is sliding in the SEE seismic case. This is largely due to a combination of relatively low foundation strength parameters, along with large seismic accelerations.

The unusual dam geometry (driven by the global stability requirements) heavily influences the design of the grout curtain. A further complication was the karstification of the limestone which, whilst not thought to be highly developed, nevertheless has an impact on the proposed grout curtain and drainage arrangements. The lateral extent of the grout curtain is proposed to control seepage uplift pressures and exit gradients, to limit the flow of water bypassing the grout curtain laterally, and to promote abutment stability and integrity.

The development of reservoir safety management plans

A L WARREN, Mott MacDonald
M HEWITT, Mott MacDonald
P D DOWN, Mott MacDonald
D SCOPES, Mott MacDonald

SYNOPSIS The national reservoir safety review in 2021 indicated a need for high-risk statutory reservoirs to have in place a reservoir safety management plan (RSMP). The intent was that this plan should set out what surveillance, monitoring and maintenance is required at a reservoir and how it is to be operated, together with the frequency of each element, how it is to be delivered and by whom. Drawing on research for the Environment Agency, the paper discusses:

- The basic requirements of a RSMP in line with international practices and guidance
- How the scope of the RSMP for any given reservoir might be informed through legislation and site-specific studies
- The responsibilities of stakeholders in preparing and managing the plan
- How development of RSMP's might change the current provisions for reservoir record-keeping.

Geomembranes in new pumped storage schemes

G VASCHETTI, Carpi Tech
V VERDEL, Carpi Tech
A JACKSON, Carpi Tech

SYNOPSIS Construction of pumped storage schemes is increasing to balance electricity networks and to maximise the energy coming from wind and solar sources. The reservoirs of such schemes must be lined with durable watertight facings to prevent water loss, ensure structural safety, and minimise maintenance, involving outage and heavy revenue losses. Geomembranes have been used in pumped storage schemes since the 1990s to restore watertightness of dams forming the reservoirs, and since the middle of the 2010s geomembrane were considered for new pumped storage reservoirs, substituting concrete or bituminous concrete facings. The advantages of geomembranes are numerous, the most important ones being the capability to resist settlement; differential displacement; joint openings; their maintenance-free durability and their repairability, also underwater. Several pumped storage scheme reservoirs have or will have a watertight flexible geomembrane facing, with different site-specific anchorage systems to maintain stability under varying hydraulic and wind loads. The paper presents design concepts, advantages, available systems, and related installation aspects of exposed flexible geomembranes through case histories recently completed or ongoing: Kokhav in Israel and Pinnapuram in India, with geomembranes anchored in trenches, and Abdelmoumen in Morocco, where a lacquered geomembrane was adopted to enhance durability in an environment with high UV radiation.

St Blazey Flood Storage Reservoir: A Case Study on the Importance of a Holistic Approach to Reservoir Risk Assessment

R RIBEIRO, AtkinsRéalis
D HARKER, Environment Agency

SYNOPSIS The St Blazey Flood Storage Reservoir was situated to the north of the town of St Blazey, Cornwall and was impounded by Highway Dam, which crossed the Treffry Canal. The right side of the reservoir was also contained by a sandy railway embankment supported by a masonry wall. Following a Section 10 inspection and failure of a section of the masonry wall retaining the railway embankment, an Inspecting Engineer recommended that the risk posed by the presence of the reservoir be assessed.

AtkinsRéalis undertook a qualitative risk assessment considering the existing arrangement and options to upgrade or discontinue the reservoir, and also performed a high-level strategic review to enable the owner (the Environment Agency) to assess the best solution for the local population. As a result of the assessment, the project team determined that the reservoir presented an unacceptable risk to life and should be discontinued through the removal of Highway Dam.

This paper discusses the methodology used to determine discontinuance as the preferred solution, focusing on how a holistic view on risk versus benefit was adopted, supported by flood modelling to quantitively assess the benefits provided by the reservoir. Furthermore, the paper discusses how consideration of the societal benefit created by the presence of a reservoir is critical in assessing the tolerability of the risk to life, rather than limiting consideration to the likelihood and consequences of failure alone.

Buckshole Reservoir: Use of Physical Modelling to Optimise a Risk-based Solution

H T STEHLE, Stillwater Associates
J P HOLLAND, Stillwater Associates
M WEARING, CRM Rainwater Drainage Consultancy Ltd

SYNOPSIS A risk-based assessment has been undertaken to determine proportionate reservoir safety improvement works at the 11m-high embankment dam retaining the Category A Buckshole Reservoir in Hastings, East Sussex. The study addressed a recommendation made in the interests of safety following a statutory Section 10 inspection in June 2016 that related to the service spillway channel not being of sufficient capacity to accommodate the design flood.

In addition to providing a brief summary of the risk-based approach, this paper will focus on a laboratory-based hydraulic physical model study which was commissioned to inform the detailed design of the proposed new 4m-wide, 90m-long spillway channel and stilling basin. The model study helped to overcome the hydraulic challenges posed by the complex plan alignment of the new channel which broadly followed the right mitre of the embankment. The various components of the new channel, including flow deflectors positioned at various locations along the length of the channel and a bespoke stilling basin at the downstream end, were optimised during the model study.

In the case of Buckshole Reservoir, although the risk-based approach justified adopting a solution that would not strictly meet the standards-based approach for a Category A reservoir, the physical model study was instrumental in identifying modifications to the design to ensure that the spillway channel would safely contain extreme flood flows almost equivalent to the routed Safety Check Flood outflow.

The new spillway channel, completed in November 2022, has significantly reduced the risk of out of channel flow and any resulting damage / breach of this Category A reservoir.

Risk Assessments for Reservoir Safety – The Value of a Risk-Based Approach

J P HOLLAND, Stillwater Associates
H T STEHLE, Stillwater Associates
H KULA, Stillwater Associates

SYNOPSIS The Institution of Civil Engineers 'Floods and Reservoir Safety', 4th edition (ICE, 2015) states: *'The risk-based approach using appropriate tools and methods seeks to provide an approach that allows an owner and their advisors to better understand and evaluate reservoir safety risks in a structured way. This then allows for risk-based decisions to be made to reduce risks to people, the environment and the economy but still maintain an important reference to accepted best practice.'*

There is an increasing use in the industry of a risk-based approach to assess reservoir safety. This paper considers four case studies with Undertakers each faced with different threats to their reservoirs, looking at why and how the approach has been applied, aiming for pragmatism in each case whilst maintaining best practice.

An initial screening assessment allows an early view on whether or not the outcome of a risk-based approach is likely to be different to the outcome of a standards-based approach, and therefore whether or not the risk assessment would be of value. Close involvement with the reservoir owner in each case helps to ensure a pragmatic approach to identifying and assessing specific threats, associated probabilities of failure and realistic viable options for improvement works. This involvement has also been found to be critical to ensuring 'buy-in' from the reservoir owner in terms of the assessment outcomes and next steps once options for improvement works have been identified.

Ground Investigation through London's raised reservoirs with a summary of ground investigation risks and recommendations, citing techniques used at two sites.

H E FISHER, AtkinsRéalis

SYNOPSIS Thames Water operates and maintains thirty raw water reservoirs across London and the Thames Valley, supplying water services to nine million customers. Most of these reservoirs are retained by a perimeter embankment with a puddle clay core that extends down into the underlying London Clay Formation bedrock. These reservoirs were built with selected material placed downstream of the core to act as a filter, but with no drainage system to monitor; therefore non-intrusive geophysical surveys are regularly carried out by Thames Water to identify areas of excess leakage or seepage, with remediation works being carried out afterwards.

Ground investigation through puddle clay cores is notoriously challenging with a number of key risks; this paper uses two projects as case studies to provide a summary of the ground conditions and associated risks which may be expected at the various reservoir sites around the capital. This paper also summarises the various techniques used for investigating the dams to mitigate these risks and support the construction and remediation of the structures, with a particular focus on the requirements of British Standards and best practice, and the practicality of using these techniques in the field.

Different approaches to assessing and improving stability of dam structures

R N T TEIXEIRA, Mott MacDonald Bentley (MMB)
S R GOLDS, Mott MacDonald Bentley (MMB)
P R CHOUDHURY, Mott MacDonald Bentley (MMB)

SYNOPSIS Mott MacDonald Bentley (MMB) was commissioned by Dŵr Cymru Welsh Water (DCWW) to undertake dam stability works which have flexed through various approaches and different analytical tools to reduce risks and to extend the lives of existing assets. This paper covers the following projects.

Llandegfedd: a stability analysis of a combined overflow and draw-off tower, access bridge and piers under seismic conditions. The tower is a 35m tall concentric twin cylindrical reinforced concrete shell. The bridge is a 90m long reinforced concrete structure with 4No. unreinforced concrete piers with history of alkali-silica reaction.

Rosebush is a concrete arch-gravity dam. MMB undertook stability analysis, employing a 3D Finite Element model under static, thermo-mechanical and seismic loading. The seismic response was computed using fully dynamic analysis with UK-specific accelerograms generated by a tool developed in-house.

Upper Carno: refurbishment and strengthening of this double-leaf masonry structure needed to ensure both static and seismic stability. An innovative technique was employed adding fibre-reinforced concrete to the inner leaf of the masonry wall, coupled with dowels ensuring composite behaviour.

Llyn Egnant: stability analysis of a concrete gravity dam considering the effects of ice and seismic loading concluding that the above ground dam section did not meet modern design standards with further works being required to stabilise the dam.

Pond-y-Gwaith: a peat dam faced by dry stone walls upstream and downstream. Ground investigation was undertaken despite difficult access and sensitive environmental constraints. Analysis using Slope/W; rigid block analysis for overturning and sliding; and finite element structural analysis.

Novel geophysical ground imaging technology for the automated long-term monitoring of reservoir dams

S BUTLER, Canal & River Trust
O SPINOLA-RICHARDS, Mott MacDonald
T WEBSTER, Mott MacDonald
P B WILKINSON, British Geological Survey
P MELDRUM, British Geological Survey
J BOYD, British Geological Survey
O KURAS, British Geological Survey
H HARRISON, British Geological Survey
A WHITE, British Geological Survey
R SWIFT, British Geological Survey
J NGUI, British Geological Survey
M CIMPOIASU, British Geological Survey
J CHAMBERS, British Geological Survey

SYNOPSIS This paper covers the use of a novel geophysical investigation technique, PRIME, undertaken at two Canal and River Trust reservoirs, Slaithwaite and March Haigh. Due to concerns over seepage the Trust commissioned the surveys to try and establish the cause of the potential seepage pathways. This paper will give an overview of the 4D imagery, its methodology, and the results of which have been interpreted with the use of each of the reservoirs' known geological settings, available ground data and construction information. As with all geophysical techniques, it does have its limitations, however these surveys have provided an insight into the suitability of this technique for identifying seepages within embankment dams through long term monitoring and how it can be further developed for use across the Trust's assets.

Upper Carno: A case study of multidisciplinary remedial works to an embankment dam

J SWETMAN, Mott MacDonald Bentley
M McAREE, Mott MacDonald Bentley
B COTTER, Dŵr Cymru Welsh Water
R WILLIAMS, Stantec

SYNOPSIS Upper Carno is a 14m high embankment dam in south Wales. Items of remedial work had been identified by Dŵr Cymru Welsh Water (DCWW). Investigations undertaken by Mott MacDonald Bentley (MMB) to inform the remedial works highlighted risks, and a subsequent Section 10 inspection resulted in eight measures in the interest of safety concerning the spillway condition and capacity, embankment stability, and drawdown condition and capacity. The resultant suite of remedial works required careful management of interfaces between the various workstreams throughout design and construction, to reduce the risk of failure to acceptable levels and to improve the working life of an aging asset.

This paper outlines the arc of the project and highlights the importance of developing the permanent works, temporary works and dam safety construction risk management together, given their entwined relationship throughout the whole of the project.

Looking into reservoir geophysics – emerging technologies

J E HAMLYN, TerraDat
C L BIRD, TerraDat
M J COOPER, Arup
R J COTTRELL, Arup
M HAYWARD, Fairhurst

SYNOPSIS As the UK reservoir stock continues to age, further deterioration of these assets should be expected. In particular, leakage and erosion through embankment dams present a significant risk to public safety. Traditional risk management relies on surveillance, and where leaks have been detected this is often supplemented by monitoring of leakage rates and turbidity. However, these techniques are limited to leaks which emerge through the downstream face of the embankment dam. Understanding and monitoring the conditions within the embankment structure are therefore often limited; however, new innovative geophysical techniques are now available that enable medium to long-term monitoring of subsurface flows.

Here we present results from long-term geophysical monitoring of Oakenholt embankment dam, where subsidence and settlement had been identified as possible symptoms of potential internal erosion. An Electrical Resistivity Tomography (ERT) survey mapped the internal structure and surrounding geology of the dam and found a localised zone of potential moisture ingress. Subsequently, a geophysical monitoring system was installed along the embankment for continuous monitoring of the electrical potential field, which changes in direct response to subsurface ground water flow. Water seeping through the dam was identified in relation to the corresponding reservoir level at which it is initiated. The data provided evidence that the seepage is not currently developing further. This study demonstrates that geophysical monitoring is an effective tool for engineers and reservoir Undertakers.

Lessons for dam safety in the UK from the landslide-generated waves incident in the Apporo dam reservoir, Japan

M HEIDARZADEH, University of Bath
V HELLER, University of Nottingham
T ZHAO, Brunel University London
C GOFF, HR Wallingford

SYNOPSIS We report and analyse the damage caused by landslide-generated waves in the Apporo reservoir (Japan) and take lessons for dam safety in the UK. The incident occurred in September 2018 following an M6.6 earthquake and typhoon Jebi. Apporo dam is a trapezoidal Cemented Sand and Gravel dam with a height of 47.2m. The simultaneous occurrence of the earthquake and the typhoon triggered thousands of landslides. Through field surveys, we identified several landslides on the banks of the reservoir at a close distance to the dam, causing a runup height of 5.3m at the shore. Visible damage, confirmed by site engineers, indicated that the waves damaged the reservoir bank revetments. Here, we model the landslide using Plaxis 3D, replicate the landslide-generated waves applying empirical equations, and discuss the lessons for dam safety in the UK. Using GIS data on elevation, rainfall, and seismicity, we identified the UK regions most susceptible to landslides. Region 3, the highest risk area, contains 252 large reservoirs, indicating the need to include landslide-generated wave risks in assessments of potential failure modes. We discuss prediction capabilities that can be applied for hazard and risk assessment of UK reservoirs regarding landslide-generated waves and propose a four-step methodology for such assessments.

Megget Reservoir: Investigation into potential internal erosion in an asphaltic concrete core rockfill dam

C RESTORICK-VYSE, AtkinsRéalis
S SHAHRIARI, AtkinsRéalis
M BOOTH, AtkinsRéalis
M W HUGHES, AtkinsRéalis

SYNOPSIS Megget Reservoir is an impounding reservoir in the Megget valley of the Scottish Borders, which is used to supply water to Edinburgh and the Lothians. The dam retaining the reservoir is a 56m high asphaltic core rockfill dam constructed in 1982, believed to be the only one of its type in the UK.

In 2021, an inspection under Section 47 of the Reservoirs (Scotland) Act 2011 observed dark fine silty deposits within the drainage gallery, which had historically gone unreported. There were concerns that, due to the unknown nature and origin of the deposits, the erosion of material could increase risks to dam safety. AtkinsRéalis carried out an investigation into the source of the material, including a series of advanced soil characterisation tests, alongside a separate comprehensive study into the monitoring data at the reservoir. The outputs were used to determine the likely nature and origin of the material, as well as qualitatively assessing the risks to dam safety due to the erosion and recommending a future monitoring regime to mitigate the associated risks.

Understanding the flood risk benefit of small reservoirs and recommendations for maintenance

P WEST, Binnies
D BULLOCK, Binnies
M COOMBS, Binnies
R RAINBOW, Teignbridge District Council
J SHIMELL, Teignbridge District Council
R NEWTON, Environment Agency (EA)

SYNOPSIS Coombe Valley Dam is a 4,500m^3 flood storage reservoir located in Teignmouth, Devon, constructed in the 1980s as compensation for development and subsequently transferred to Teignbridge District Council (TDC). As it is outside of the Reservoirs Act 1975 (HMG, 1075) (the Act), it has not had the stringent maintenance regime required for registered reservoirs that would complement its design function. However, responsibility remained under the Health & Safety at Work Act 1974 (HSWA) (HMG, 1974)and under Rylands v Fletcher 1868 (see in Howarth, 2002). Dam information had no assurance of accuracy, and the flood protection and standard were unknown.

This paper presents the hydrological study and hydraulic modelling employed to understand the dam's standard of protection and assess flood risk benefit provided by simulating a hypothetical dam removal scenario. Details of the model validation are presented to demonstrate how evidence from a recent storm was used to give confidence to the study with otherwise limited data. Assessment of the model outputs is discussed to estimate the number of properties benefiting from the reservoir.

Recommendations were made to allow TDC to operate the reservoir within the spirit of the Act. The paper provides management guidance to similar asset owners with limited experience as reservoir Undertakers (Owners and operators as defined under the Act).

Lessons Learnt from the First Inspections of Reservoirs (with capacities of 10,000m^3 - 25,000m^3) in Wales

J NICOLLE-GAUGHAN, Dŵr Cymru Welsh Water
S TUDOR, Dŵr Cymru Welsh Water
M CRAVEN, Dŵr Cymru Welsh Water

SYNOPSIS This paper outlines the process and challenges Dŵr Cymru Welsh Water (DCWW) has faced working with our regulator Natural Resources Wales (NRW) to carry out the first inspections of 52 reservoirs with capacities of between 10,000m^3 and 25,000m^3. These reservoirs included a small number of impounding and non-impounding assets but the majority are service reservoirs (SRVs) and raw water tanks (RWTs).

Bruton Flood Storage Reservoir – Adopting a risk based approach to assessing spillway adequacy

A P COURTNADGE, Jacobs

SYNOPSIS Bruton Flood Storage Reservoir was originally built in the 1980s and was subsequently raised by 2m in 2009 and upgraded with a 50m long precast stepped-block spillway. The dam is now 14m high. A 10m high railway embankment crosses the downstream valley approximately 100m downstream of the dam, and in extreme floods, or if the underpass became blocked, tailwater could back up almost to the dam crest.

The 2009 design relies on this tailwater to protect the downstream face during extreme floods when the flank embankments overspill. The validity of this approach was reviewed in the recent Section 10 inspection with hydraulic modelling to assess various issues including the effect of the railway embankment breaching on tailwater levels, the time it takes for tailwater to establish, the increased scour risk at the location of the hydraulic jump and the effect of flow concentration due to mitres above the tailwater. The study found that the spillway did not comply with engineering standards and a risk-based approach was used to assess if the cost of upgrading the dam would be proportionate following ALARP principles.

This paper outlines the approach taken and the benefits of using a risk-based approach.

A Pragmatic Approach for Mitigating Siltation Clearing in Confined Spaces and Culverts in Flood Storage Reservoirs

S YEOH, Jacobs
S GARATTINI, Jacobs

SYNOPSIS Siltation can pose a significant challenge in flood storage reservoirs, particularly within confined spaces such as culverts. As part of the Lincolnshire and Northamptonshire (L&N) Reservoirs Remedial Works programme, Jacobs and the Environment Agency implemented a novel solution to help manage the risk associated with clearing sediment build-up in the control structures and culverts at Rase North and Rase South flood storage reservoirs.

The flood control structures here, comprising typical culverts crossing the main embankment, suffer from significant build-up of siltation, likely due to changes caused by development and climate change. The Environment Agency (as reservoir Undertaker) is facing ever-increasing challenges and costs due to increased frequency of silt clearance, exacerbated by confined space working conditions. Conventional silt traps and sediment excluders are impractical due to their substantial footprint, and are cost prohibitive.

To address these issues, 'in-channel chambers' were designed and installed in the river channel upstream of the control structures to help catch incoming sediment. The design approach, part of a trial initiative, aims to improve maintenance practices and mitigate health and safety risks by minimising the need for confined space entry during silt clearance. The unique construction of these chambers within the river channel and bed helps mitigate adverse impacts on the environment, morphology and hydraulics of the river channel.

This paper presents a practical solution applicable to similar reservoirs in environmentally sensitive areas facing siltation problems, that require regular maintenance and lack space to implement other conventional solutions to intercept and contain sediment inflow.

Design and Construction of an Open Stone Asphalt Spillway for Wychall Flood Storage Reservoir

J G PENMAN, Mott MacDonald
S A HAYWOOD, Environment Agency
A L WILDEE, Mott Macdonald
N A HENDERSON, Environment Agency
R C SMITH, Hesselberg Hydro (UK) Ltd

SYNOPSIS Wychall Flood Storage Reservoir is a Category A flood storage reservoir on the River Rea in the Kings Norton area of Birmingham. A section 10 inspection in 2020 identified shortcomings in the existing spillway provision and recommended measures in the interests of safety. A subsequent flood study identified that the spillway needed to be lengthened and reinforced to withstand overflowing velocities of up to 7.3m/s. The reservoir is located within a local nature reserve and great importance was placed on maintaining biodiversity and minimising the visual impact of any alterations. Opportunities to reduce the carbon footprint of the project was also a priority. Possible options for reinforcing the spillway were a cast in-situ cellular reinforced concrete system, precast concrete blocks, or open stone asphalt (OSA). Following a review of options, OSA was selected as the preferred solution for reinforcement of the spillway. The paper will describe the design, construction and future maintenance of the spillway. It will also discuss the practicalities and benefits of using OSA instead of more conventional reinforcement systems.

The client was the Environment Agency, the designer was Mott MacDonald, the contractor was Jackson Civil Engineering and Hesselberg Hydro (UK) Ltd were a sub-contractor who installed the OSA.

Draycote Reservoir – Drawdown Enhancement

A WALKER, Mott MacDonald
J CAMPBELL, Mott MacDonald
I M HOPE, Severn Trent Water
D McKUNE, Severn Trent Water

SYNOPSIS Permanent siphons are increasingly being fitted to increase the discharge capacity at reservoirs to ensure that the precautionary drawdown provision to mitigate the risk posed by the reservoir satisfies recent guidance. Routine 'wet' testing of reservoir drawdown systems is fundamental to providing confidence that they can be relied upon in emergency situations.

This paper summarises the optioneering, design and construction of the three, 1200mm diameter vacuum-primed siphon system installed at Draycote Reservoir in 2023 to enhance the existing drawdown capacity and testing functionality. The paper will discuss the arrangement and functionality of the drawdown enhancement works, including for routine 'wet' testing; the risk of pollution, including of invasive, non-native species, and flooding during testing and emergency operation; and constraints imposed by the water resources and amenity functions of the reservoir and site.

Multiple Types of Spillway Installation/Refurbishment in Wales (Ten years of experience)

M COOMBS, Binnies UK
S MORRIS, Natural Resources Wales
A DAVIES, Natural Resources Wales
J PARKINSON, Natural Resources Wales
P ISAAC, Natural Resources Wales

SYNOPSIS Over the last decade Natural Resources Wales (NRW) has undertaken design and construction of a number of new spillways (and drawdown facilities) as well as refurbishment of numerous existing structures. This has included works at several new and existing flood storage reservoirs, but also a large number of historic reservoirs brought within the Reservoirs Act 1975 by the changes in registration capacity implemented within Wales from 2016.

With a portfolio of newly registered reservoirs, a full programme of investigation works, studies and evaluations was undertaken to determine the risks associated with the different dam structures and subsequent mitigation works required. The range of spillways has included conventional concrete spillways, Armorloc, Armorflex, Dycel, Grasscrete, Reno mattress/gabion, overtopping crest design and a labyrinth weir.

This paper will discuss the design and construction of these different spillway types and their relative merits for the specific locations; design factors affecting the choice of spillways; and issues and difficulties encountered (and overcome) during construction. It also considers the lessons learnt during the process, subsequent operational performance and a commentary on the appropriateness of selecting and implementing various spillway types for a range of sites.

Challenges in inspecting and assessing performance legacy bellmouth drop shaft and siphon spillways

D CROOK, Arup
V K MARTIN, Arup

SYNOPSIS The majority of impounding reservoirs have overflows comprising a spillway discharging into an open channel that leads to a receiving watercourse downstream. During the 20th Century, alternatives were developed including bellmouth drop shafts and siphons. These can introduce efficiencies but can be difficult to analyse. This was recognised at design stage and model testing was typically undertaken to develop the head/ discharge curve. Over time, many of the model test reports have been lost, including the caveats about the limits of the studies. The duty to independently assess all aspects of a dam has been emphasised by the Safety Review Report that was issued following the Toddbrook incident. This can present difficulties in not just confirming the head/ discharge curve but also the physical inspection of the structures. This paper looks at examples, problems encountered and ways forward.

Re-establishing and Improving Scour Capacity at Daer Reservoir

R McHUGH, Mott MacDonald
M HEWITT, Mott MacDonald
K MURRAY, Scottish Water

SYNOPSIS Daer Reservoir was formed in the 1950s by the construction of a 43m high, 790m long earthfill embankment dam with a concrete corewall.

During the winter of 2021/22 monitoring showed that the water levels in the vertical drains on the downstream side of the corewall were significantly higher than previously recorded and there was increased wetness from the downstream face. A review of the monitoring data found that drainage flows increased significantly once the reservoir was within 2m of the full supply level. Attempts to lower the reservoir using the scour (bottom outlet) pipe found it to be restricted by debris from the valve house that had collapsed in 2005. Following works in 2022 to clear rubble from within the scour pipe, it was found that the 24" needle valve which controls the scour discharge was in poor condition and uneconomical to refurbish.

While the scour was being cleared, a notch was cut in the spillweir to aid control of the reservoir level. During this time, a 24" diameter washout off the supply main was used to control the reservoir level. Due to this frequent operation, the washout valve became damaged. Repair of the valve would have required shutdown of flow to the works.

This paper will briefly outline the investigations and cause of the wet areas and the difficulties and measures taken to control reservoir levels, and the works undertaken to re-establish and improve drawdown capacity. These include replacing (upsizing) the scour needle valve, installing permanent penstock gates within the notch formed in the spillweir, and replacement of the 24" diameter washout off the supply main without interrupting flow to the works.

Improving the emergency drawdown reliability at Llyn Brenig reservoir – Part II

G CARRUTHERS, Mott MacDonald Bentley
M MCAREE, Mott MacDonald Bentley
S SHAKESPEARE, Dŵr Cymru Welsh Water

SYNOPSIS This paper builds on the paper published and presented by Tudor and Morgan (2018) at the 20th BDS Biennial Conference in Swansea for the design of improvements of emergency drawdown reliability at Llyn Brenig.

Dŵr Cymru Welsh Water (DCWW) appointed Mott MacDonald Bentley (MMB) to install and commission the upgraded scour facilities, including the extensive temporary works required to enable construction to take place, and replacement of the "Goliath" crane mounted to the top of the valve tower located circa 300m from the reservoir's shoreline.

Management of water levels and isolations were required to enable gate replacement whilst maintaining a desirable volume of stored water. Draining the reservoir was not feasible due to the operational requirement to maintain flows to the River Dee for abstraction purposes. Issues arising during construction and performance of the enhanced system following commissioning and handover are also covered in the paper.

Managing risks associated with the infilling of the adit at Tunstall Reservoir

B AGUILAR, Stantec
N ASHCROFT, Stantec
I CARTER, Stantec

SYNOPSIS Significant leakage was observed on the left flank of Tunstall Dam upon first filling of the reservoir. A concrete-filled cut-off wall was extended into the abutment in 1879, which significantly reduced the flow but did not resolve the problem. In a further attempt to manage leakage, the adit and shaft that had been used to form the cut-off wall was repurposed and extended with additional drifts cut into the hillside to capture and transfer leakage flow.

Several measures in the interests of Safety (MIOS) arose out of a Section 10 inspection in 2021, one of which recommended "*fill the tunnel (i.e. adit) whilst providing some drainage"* in response to a concern about its structural integrity and the potential risk to the embankment dam and spillway in the event of a collapse. The remedy comprised filling the adit passing beneath the dam and appurtenant works with expanding geopolymer introduced via a series of injection holes drilled from the surface. Due to the depth, there was a significant risk that the drillholes would miss their target and that drilling might damage the existing 18-inch diameter cast iron pipe conveying leakage flows beyond the dam structure.

This paper describes how risks were managed and mitigated, the key aspects of the investigations and design process, and the works that took place to satisfy this MIOS measure.

Valve Tower GRP Lining - Llyn y Fan Fach Refurbishment

A HANDLEY, Arup.
C WALTERS, Dŵr Cymru Welsh Water
L FERGUS, Arup
S FISHER, Morgan Sindall

SYNOPSIS A Section 10 inspection on Llyn y Fan Fach dam led to MITIOS, one of which was to arrest the structural cracking and eliminate leakage into the draw-off shaft. This paper covers the investigation that was done into the causes of cracking, including finite element modelling; the different options that were looked in to, such as decommissioning, demolition and rebuild, less intrusive repairs and structural lining, and why the chosen solution was lining the tower with a structural FRP liner and its design. The paper then looks at the construction, including procurement, delivery, installation and how it functions in place.

Holistic photographic surveys and AI defect identification of the shaft and tunnels at Dinorwig Power Station

R COOMBS, CC Informatics
A PRITCHETT, Engie
J CRAMMAN, CC Informatics

SYNOPSIS In 2023, the high pressure shaft and tunnels at the Dinorwig hydro pumped storage scheme were fully drawn down for the first time since operations started on site. This presented owner/operator Engie with an opportunity to collect data about the condition of the concrete in the 10m diameter, 476m deep shaft, and several kilometres of large diameter tunnels feeding the power station.

Engie engaged CC Informatics to undertake the surveys. The project required the development of an imaging platform which could be attached to either an automated shaft inspection robot, or to a trolley within the tunnels. The project collected approximately 38,000 high resolution photographs, totalling almost 1 TB of data. These were subject to interrogation by CCI's patent pending AI, AssetScan, to look for cracks, surface loss, and previous patch repairs. The photographic and AI data was then presented to Engie and their engineers in large 2D drawing formats and databases.

The data was used to: compare and validate information from historical underwater remotely operated vehicle (ROV) data; create a baseline database of information to allow potential future change detection; and verify concrete core strength data. In the future the technology may be used to identify defects under internal pressure, identify feature dimensions other than area (width and length of defect), and assess permeability of the concrete liner.

Adapting earthworks design for adverse weather conditions

J MEHTA, Mott MacDonald
W J S SHEEHY, AECOM (formerly Mott MacDonald)
D LOEB, Mott MacDonald
S ZALMAY, Mott MacDonald
J R FOSTER, Mott MacDonald

SYNOPSIS Undertaking earthworks in winter and wet weather is generally avoided due to construction difficulties and potential quality implications. However, with changing climate and programme related challenges, it may not always be possible to avoid this.

Barrowford reservoir has had a long history of seepage and stability issues and due to the constrained nature of the site, the preferred solution was agreed to reduce the top water level and to regrade the slope within the existing site boundary to improve the factors of safety. The north embankment showed signs of accelerated settlement when compared with the other embankments and signs of internal erosion having been noted in the history of the site. A filter blanket was designed for the north embankment to prevent migration of the fine material.

Delays in construction meant that winter working was required in order to maintain regulatory compliance. This paper summarises how the works was investigated and designed to improve slope stability and reduce risk of internal erosion at Barrowford Reservoir and how the design was revised part-way through construction in consultation with the Construction Engineer, Undertaker and Contractor to allow winter working to be undertaken and quality was maintained by adopting a method specification with performance testing of the earthworks.

Hydrological Risk Management for Proposed Mentarang Induk Hydroelectric Project in Indonesia

M HUSSAIN, Stantec
C BARRY, Stantec
A R RONEY, PT KHN (Indonesia)

SYNOPSIS Stantec has been engaged by PT Kayan Hydropower Nusantara, Indonesia to review the catchment hydrology and hydropower operation for the proposed Mentarang Induk Hydroelectric Project (MIHEP) in North Kalimantan, Indonesia. The project includes a 230m high concrete faced rockfill dam, gated spillways structure, 1375MW surface powerhouse and a reservoir (226km^2). This project is planned to displace fossil fuels sourced electricity in Indonesia.

Stantec re-established a rainfall-runoff model for the Mentarang catchment to generate long-term flows. The performance of the model was significantly improved due to a longer period of observed flow record supporting the updated model calibration. This provided a better understanding of the flows at Mentarang dam site. Stantec also conducted a climate change assessment using three widely recommended Global Circulation Models (GCMs) from the Coupled Model Intercomparison Project Phase 6 (CMIP6). The assessment suggests that under a mean ensemble of the three selected climate models, there would be 10% to 15% increase in future flows compared with the baseline period of 1990-2014. Reservoir operation was established incorporating the reservoir control rules and latest flows generated. The projected increase in future flows indicates improved power output for MIHEP. However, these findings should be considered with the caveat that GCMs have high uncertainty in projecting future precipitation and river flows.

PMP - Maximum Precipitation, Probably

J D MOLYNEUX, Binnies UK ltd
R FRASER, Binnies UK Ltd
A ZEQIRLLARI, Binnies UK Ltd

SYNOPSIS Climate change poses significant challenges to the accurate estimation of probable maximum precipitation (PMP), a crucial parameter used in the design and assessment of flood control infrastructure. This paper investigates the potential implications of climate change on current predictions of PMP and its derived parameter, probable maximum flood (PMF). Case studies from Scotland, Wales and England highlight real-world examples of the challenges posed by climate change and the importance of incorporating climate change considerations in PMP and PMF estimations.

Numerical simulation and assessment of a clay embankment dam experiencing climate-induced deformation

A S ZWIERS, Stantec UK
I ANTONOPOULOS, Stantec, New Zealand
M HILL, Stantec UK
C SMITH, Thames Water Ltd

SYNOPSIS Thames Water's Reservoir Safety Group noted movement in the south-eastern slope of the Stoke Newington (East) Reservoir embankment, deemed to be excessive for the relative size of the embankment and showing a marginal increase in settlement rate over time. By modelling the climatic conditions as a boundary condition within a Finite Element and Finite Difference Analysis model and simulating the periods for which measurement is available, the mechanism of deformation within the embankment could be identified. PLAXIS was found to be useful for setting up boundary conditions to simulate the fluid-mechanical conditions within the embankment, but the software does not accurately translate this behaviour into representative stress and strains. FLAC was used as an alternative to model these conditions using the saturation profile from PLAXIS as a starting point. The deformation predicted by FLAC shows a good correlation with the monitoring results available, allowing the asset owner to forecast the strains to be developed in the embankment in the future and to set up inclinometer trigger levels for monitoring the asset. With this information in hand, together with the knowledge that climatic boundary conditions are due to worsen with global warming, a solution was later developed to mitigate the risk of embankment instability.

The use of vibrating wire piezometers to measure matrix suction in dams

R MONROY, Klohn Crippen Berger

SYNOPSIS A knowledge of pore water pressures in embankment dams and in mining dams is essential to monitor performance. In many instances, this knowledge forms part of a critical risk control to prevent a high consequence event, such as global instability and release of containment. Yet the field measurement of pore water pressures can be difficult. This is particularly the case when unsaturated conditions prevail for long periods. Vibrating wire piezometers are used in many instances to monitor negative pore water pressures in dams, both in the foundation and in the fill; yet these instruments, which can measure small sub-atmospheric pressures, have not been designed to operate in an environment of sub- atmospheric pressures indefinitely. This paper touches on two topics that are of interest to the dam engineer: (i) the effect of degree of saturation and matrix suction on liquefaction potential, and (ii) the measurement of matrix suction in the field using vibrating wire piezometers.

Leakage Remediation Works at the Hampton Distributing Reservoir

S QI, AtkinsRéalis
J R CORREIA, formerly AtkinsRéalis
P MARSDEN, Keller
C SMITH, Thames Water

SYNOPSIS Hampton Distributing Reservoir is a non-impounding reservoir built in 1900s and located in Hampton, southwest London. The reservoir, formed by a typical puddle clay core embankment, has a total perimeter of 800m and a storage capacity of 32,000m^3.

An increase in embankment settlement was detected, starting from 2011, based on annual crest levelling surveys, which was then followed up with a non-intrusive geophysical survey in 2020. This identified a distinct leakage path at the foundation level of the reservoir embankment. In order to mitigate the risk of seepage-induced instability such as internal erosion, leakage remedial measures were proposed to arrest the leakage.

Limited working space and difficult access were some of the main constraints for the remedial works. Following an optioneering/feasibility study, permeation grouting using Tube-a-Manchette (TaM) was identified as the most practical remedial solution. Grouting works were carried out on both sides of the clay core to target flow paths and create a low permeability zone reducing the leakage/seepage through the dam.

This paper presents the key aspects of the project, from the initial investigative works to construction, covering also the optioneering and design of the grouting works. Challenges and lessons learnt from the project are also highlighted.

Case studies from permanently installed siphon works

J TOULSON, Mott MacDonald Bentley
J WALKER, Mott MacDonald Bentley
D NODDLE, Mott MacDonald Bentley
P BELL, Mott MacDonald Bentley

SYNOPSIS Adequate draw down of reservoirs by gravity means only may not always be feasible. Siphons may be seen to be a suitable option and efficient means of drawing off the upper portion of a reservoir volume. This paper looks to cover case studies of schemes completed in recent years.

Based upon multiple examples of physical projects undertaken, this paper will look into the constraints, planning and decision-making involved leading up to and executing improvement works, along with the temporary works, permanent works and commissioning of permanently installed siphons. The intention of this paper is that the learning taken from these works may be of use to others in the industry.

All works were undertaken on statutory reservoirs and as such had been planned and undertaken with the supervision of an All Reservoirs Panel Engineer.

Mott MacDonald Bentley (MMB) planned and undertook works at the following:

- Warland Reservoir
- Warley Moor Reservoir
- Lower Barden reservoir
- West Hallington reservoir

Leakage Remediation at a Small Heritage Reservoir

P D DOWN, Mott MacDonald

SYNOPSIS Abbeydale Industrial Hamlet, on the outskirts of Sheffield, is a former steel-working site along the River Sheaf and has become a museum open to the public. The site, including the reservoir and dam, is designated a Scheduled Monument and the forge works are Grade I listed. Several other buildings within the site are Grade II* listed. It has a history thought to go back to 1685, with the present-day site reported to date from the early 18th century. To provide power for the machinery, a small reservoir was constructed and filled with water abstracted from the River Sheaf. The reservoir was enlarged as the site developed although remains below 25,000m^3 capacity, and thus is not registered under the Reservoirs Act 1975 (as amended).

There has been a history of leakage from the reservoir. In November 2022, the most recent leakages and damage to structures were investigated with the aim of developing suitable remedial measures. At the end of May 2023, significant leakage from the reservoir into one of the Listed buildings occurred resulting in emergency action being taken. This paper details the issues encountered, works previously performed, recent investigations and the development of remedial works to provide a longer-term solution.

The 2020 national seismic hazard maps for the United Kingdom

I MOSCA, British Geological Survey
S SARGEANT, British Geological Survey
B BAPTIE, British Geological Survey
R M W MUSSON, University of Edinburgh
T PHARAOH, British Geological Survey

SYNOPSIS The 2020 seismic hazard maps for the United Kingdom (UK) update the previous national maps published in 2007 and are intended for use with the National Annex for the revised edition of Eurocode 8. The 2020 national seismic hazard model uses an up-to-date earthquake catalogue for the British Isles, for which the completeness periods have been reassessed. It also uses a modified version of the 2007 source model and incorporates some advances in ground motion modelling since 2007, including host-to-target adjustments for the ground motion models selected in the logic tree. For the first time, the national maps for the UK are provided for not only peak ground acceleration but also spectral acceleration at 0.2s and 1.0s for 5% damping on rock and the return periods of 95, 475, 1100, and 2475 years. The maps confirm that seismic hazard is generally low in the UK and is slightly higher in North Wales, the England-Wales border region, and western Scotland. We disseminate the updated seismic hazard maps via a dedicated webpage, downloadable data, models and outputs, interactive mapping tools, linkages with professional bodies and industry, as well as public seminars, webcasts, and attendance in scientific conferences.

Developing an Understanding of the Reservoir Safety Risks of Non-Statutory Reservoirs

G HITCHINS, Severn Trent Water
A MORGAN, Arup

SYNOPSIS In 2022, Severn Trent Water (STW) appointed Arup to carry out a project to appraise the reservoir safety risks posed by 71 reservoir sites with capacities identified in the range 10,000 to 25,000m³ above natural ground level. Following the Flood and Water Management Act 2010, which amended the Reservoirs Act 1975 (the Act), it was anticipated that these reservoirs would likely be brought into the Act when the threshold is amended to 10,000m^3; this would increase the number of statutory reservoirs within STW's portfolio. By investigating and studying each reservoir, the project helped STW to understand the potential increase in financial risk which could occur because of additional regulation. This considered both operational requirements and capital works, to ensure the potential statutory reservoir safety risks posed by the reservoirs are minimised and managed in good time.

The paper explains the methodology that was applied to carry out the assessment, together with the key themes discovered, including common reservoir safety risks and recommended mitigation actions, as well as an exploration of the challenges and opportunities of the process. In conclusion, the recommendations made in relation to reservoir safety risks of the non-statutory reservoirs, how STW used the outputs to feed into their asset management planning process and the next steps that STW is taking to manage the risks identified are all described.

Overflow and outlet screens

J BENN, JBA Consulting
J HOWARD, JBA Consulting
C DALE, JBA Consulting

SYNOPSIS Overflow/outlet screens are often fitted to reservoirs to prevent human exposure to hazards, to catch large debris, or to prevent fish and mammals being washed downstream.

Whatever its primary purpose, a screen will collect debris and block temporarily. This blockage can lead to an increase in reservoir water level and could alter the stage-discharge relationship of the overflow or outlet. Furthermore, blocked screens will reduce the available freeboard and overflow capacity. Their impact must therefore be considered in reservoir flood studies and the design of outlet structures. This is particularly important for flood storage reservoirs (FSRs) that operate infrequently and rely on maintaining the design stage-discharge relationship to achieve the required flood attenuation.

Case studies are presented concerning two FSRs fitted with self-activating flow-control devices on their outlets that failed to operate as anticipated on first filling. In both cases the unexpected operation was attributed to downstream screens fitted to mitigate perceived hazards. A third case study concerns the impact of a 'fish' screen placed in the overflow spillway of an amenity lake.

This paper summarises research on the impact of screen size on fish and mammal passage, and on debris movement, in particular the relationship between debris volume and bar spacing. It looks at some alternative screen design and management measures to reduce the impact on reservoir water level and overflow capacity.

River Roding Flood Storage Reservoir – CFD modelling and optimisation of a double baffle outlet to manage risk of tailwater

T M DUTTON, Jacobs
J PLANT, Jacobs
A P COURTNADGE, Jacobs

The River Roding flood storage reservoir design has recently been completed and construction commenced in Spring 2024. The new 1.4Mm^3 flood detention reservoir will be retained by a 7m high and 570m long homogeneous earth embankment with a passive, 'double baffle' flow control structure. This structure will comprise six reinforced concrete bays each with a crump weir and double baffle arrangement. This will be the third double baffle flow control structure to be constructed in the UK, following Banbury and Chapelton reservoirs.

The double baffle structure is an alternative to more conventional vortex flow control devices, all of which are sensitive to downstream tailwater conditions; in this case due to a downstream road embankment. Double baffle structures are better suited for higher pass-forward flows and are less vulnerable to debris blockages than vortex devices.

Computational Fluid Dynamics (CFD) was first used to validate the modelling approach, based on the Banbury physical scale modelling to reduce the risk of the control structure not performing as designed. Following this an iterative approach between CFD and fluvial analysis was used to scale the design to achieve the optimum depth discharge characteristics. Due to the importance of tailwater depth, CFD simulations were run comparing how various upstream and downstream water depths affected the performance of the control structure.

A novel aspect is provision of a low flow bay with incorporation of a fish pass. Future adaptation has been incorporated into the design though the use of various bay widths and incorporating an additional spare bay.

Risk assessment of existing flood detention (storage) reservoirs

A BROWN, Jacobs
A COURTNADGE, Jacobs
M PANZERI, HR Wallingford Ltd.
C GOFF, HR Wallingford Ltd.
M ATYEO, HR Wallingford Ltd.
M COOMBS, Binnies UK Limited.
A DAVIS, Binnies UK Limited.

SYNOPSIS The Environment Agency is carrying out a portfolio risk assessment of their portfolio of around 200 large flood detention reservoirs (FDRs), to inform their reservoir safety management and operation.

The 'Guide to risk assessment for reservoir safety management' (RARS) was published in 2013 and provides a methodology for risk assessing existing reservoirs in the United Kingdom. It was intended primarily for reservoirs which are normally full, where indicators of poor condition can be observed. It was therefore necessary to extend RARS to cover FDRs, and this paper describes the key elements of the extension to the RARS Tier 1 methodology. It is anticipated similar extensions could be applicable to FDRs owned and operated by other agencies. The next step is to extend RARS for Tier 2 and 3.

Washland flood detention reservoirs are in effect partially bunded reservoirs, so some aspects of the approaches adopted here will also be applicable to non-impounding reservoirs.

Design of Dam Safety Measures for three Dams in Zambia

P M DICKENS, Arup
V K MARTIN, Arup

SYNOPSIS Arup was commissioned by the United Nations Office for Project Services (UNOPS) in 2022 to design measures for improvements to the safety of three dams in Zambia. The three dams were all homogeneous earthfill dams, but with differing geometries and spillway forms. All three dams share the common problems of inadequate flood capacity, lack of freeboard, scour damage and irregular dam construction with excessive seepage in places, but they differ in the hazard they pose to the downstream population.

The paper will describe the assessment of the downstream hazard posed by each dam, the identification of the proposed solutions and optimisation of the resulting designs.

Control of reservoir water levels during construction when existing scour facilities are not available

G CARRUTHERS, Mott MacDonald Bentley
M McAREE, Mott MacDonald Bentley

SYNOPSIS Whilst working on existing scour and draw-off systems it is not unusual to have to install temporary works in order to maintain specified drawdown levels, supply to water treatment works and compensation flows to the downstream watercourse. This paper investigates the many ways of achieving the required controls and reviews the potential costs and pitfalls associated with each of the identified options from schemes that Mott MacDonald Bentley (MMB) has undertaken.

Based upon multiple examples of projects undertaken, the paper presents temporary pumping, siphons and associated priming and control, learnings realised and solutions implemented to resolve commissioning issues. All works were undertaken on statutory impounding reservoirs and as such have been planned and undertaken with the supervision of an All Reservoirs Panel Engineer.

MMB planned and undertook the following works:

- Level control – Pant Yr Eos Reservoir
- Level control - Upper Carno Reservoir
- Compensation and augmented river flows - Usk Reservoir
- Compensation flows – Gouthwaite Reservoir
- Level control – Cwmtillery Reservoir
- Additional drawdown capacity – Castell Nos Reservoir

This paper summarises the methodology behind each of the installations, reviews the scale of costs for purchase, hire and maintenance, strengths and weaknesses for each of the installations and lessons learned for future projects.

Springwell Service Reservoir, managing and effectively mitigating ground risks in design and construction.

M EDMONDSON, Mott MacDonald Bentley
J TAYLOR, Mott MacDonald Bentley

SYNOPSIS Northumbrian Water Group appointed Mott MacDonald Bentley to design and construct a new 43ML service reservoir in Springwell, Gateshead to increase network capacity and resilience. The structure is 100m by 75m by 9m deep adopting a semi-precast concrete solution. It is founded largely on competent incompressible sandstone however, the southernmost third will encroach over significantly more compressible weathered rock. This presents a risk of early and long-term differential settlement that could impact reservoir structural integrity and potential safety if not adequately managed in design and construction.

Concept and Definition design by WSP involved extensive intrusive ground investigation work. Modern 3D digital geotechnical design tools (Leapfrog Works and Settle 3) have allowed designers to fully predict both immediate and future settlements of the structure. Initial assessments, based on first interpretation of borehole data, were beyond tolerable limits for practical and sustainable design of the structure requiring either alternative foundation solutions or ground improvement. To mitigate this risk a simple surcharging solution comprising temporary construction of an 8m high monitored surcharge bund, formed from site won materials, represented the most cost effective and sustainable solution.

Discussed are the geotechnical design processes and outputs through key design and construction phases: development of a representative 3D ground model; iterative 3D settlement analyses in collaboration with structural designers; design, implementation and monitoring of surcharging; back analysis of surcharge monitoring data to establish representative ground stiffness parameters for structural design; and validation of assumptions during construction.

Recent underwater geomembranes solutions for dams and canals

G L VASCHETTI, Carpi Tech
V VERDEL, Carpi Tech

SYNOPSIS Underwater geomembrane technologies to stop or minimise leakage and grant safe and efficient operation started being adopted on dams in 1997, and have since been used to repair the full face of the dams, specific leaking areas, or failing joints. In the 2010s the combined expertise in waterproofing dams underwater and canals in the dry led to the development of a patented geomembrane system for underwater repair of canals in flowing water. Sibelonmat® is a watertight, factory prefabricated mattress formed by two geomembranes which are interconnected to form a void space, deployed underwater on site, to line the entire cross section of the canal or parts of it, and joined underwater to the adjacent mattresses by heavy duty watertight zips. The mattresses are then filled with cementitious grout to permanently ballast the bottom geomembrane that provides watertightness, while the top geomembrane confines the grout. This paper presents the state-of-the-art technologies in still water and in flowing water through two recent underwater projects: Studena, a 55m high buttress dam in Bulgaria, and the Kembs embankment, part of the Grand Canal d'Alsace navigation waterway in France.

The role of the Construction Engineer and Panel of Specialists in the modern contracting world

J D MOLYNEUX, Binnies UK Ltd
J WELBANK, Welbank Water Consulting Ltd

SYNOPSIS The Reservoirs Act requires that for any new reservoir or alteration to enlarge an existing reservoir, a Construction Engineer is employed to design and supervise the construction or alteration. Procurement procedures have moved on from when the Reservoirs Act was written. Is there a need to rethink the role of the Construction Engineer for the modern contracting arena?

The Coxon report (Coxon, 1986), produced after the failure of Carsington dam in 1984, recommends that a panel of specialists reviews and comments on the design and construction of any major new dam. Expert panels are common on international projects and in some water companies, but there is less recent experience of panels for new dams in UK. We propose possible organisational arrangements for panels of specialists appointed for the new reservoirs that are proposed in England over the next 20 years.

The Effect of Pretreatment of Organic Matter on the Outcomes of Dispersion Tests

R DAVY, University of Sheffield, Stantec
E BOWMAN, University of Sheffield

SYNOPSIS Internal erosion in clayey soils is associated to the identification of dispersion as this can be a major contributing factor in piping failure of earth embankment dams. For dams constructed without filters and of poor construction, it is critical to understand the nature of dispersive soils so they can be treated or appropriate remedial measures applied. This paper describes tests carried out using the Double Hydrometer Test, a type of physical dispersion test, on a representative core sample from a Pennine-type dam in Yorkshire. The determined potential for dispersion is compared for the soil tested with pretreatment using hydrogen peroxide to remove organic matter and without pretreatment. As well as highlighting the importance of pretreatment in determining the potential for dispersion, the results demonstrate that the amount of soil used in the hydrometer test should be carefully considered to avoid both hindered settling (using too much soil) at one extreme and poor hydrometer response (using too little soil) at the other.

Managing risk at Victoria Service Reservoir

A L WARREN, Mott MacDonald
C A GOFF, HR Wallingford
J RIPPON, Bristol Water

SYNOPSIS Victoria Reservoir is a reinforced concrete service reservoir located in the heart of Bristol. Constructed in 1914, it is one of the oldest reservoirs of its type in the UK. It was constructed on the site of an earlier open service reservoir. During the second world war, the reservoir was damaged and repaired on account of bombs being dropped on it during the Bristol Blitz. In more recent decades, a series of investigations and repairs have been carried out to assess and maintain its structural condition and operational performance. This paper will describe and discuss the various challenges faced by the operator in managing the safety and operational risks associated with a very old reinforced concrete service reservoir.

Case studies from challenging pipes and valves works

G CORNELIUS, Mott MacDonald Bentley
M McAREE, Mott MacDonald Bentley

SYNOPSIS With current UK dam stock ageing and infrastructure meeting or surpassing its intended asset life, critical maintenance and replacement of key pipework and valves becomes necessary. The design and construction of historic assets may not have considered aspects such as ease of operation, maintenance and replacement. This paper provides case studies of recent works completed with particularly challenging environments, from projects in Wales.

Based upon multiple examples of physical projects undertaken, this paper will look into the constraints, planning, decision making involved leading up to and executing improvement works, along with the temporary works, permanent works and commissioning. The intention of this paper is to share the learnings taken from these works, which may be of use to others in the industry.

The client for the schemes presented was Dŵr Cymru Welsh Water (DCWW), and the Principal Designer and Principal Contractor was Mott MacDonald Bentley (MMB) and Edwards Diving Services (EDS) as the diving contractor.

A Field Monitoring Data-Driven approach to Dams and Reservoirs: Risk Reduction Through Predictive Maintenance

D FORNELLI, Geotechnical Observations Limited

SYNOPSIS The challenges associated with reliable assessment of the conditions of geotechnical and structural elements of ageing dams and reservoirs are becoming more complex and critical, due to the combined effects of Climate Change and the need for optimised and sustainable maintenance (and construction) solutions. The paper focuses on how a quantitative understanding of the current behaviour of dams and reservoirs via field monitoring can help overcome such significant challenges. The paper presents a general approach to the monitoring of geotechnical and structural elements; it also discusses the use of specific technologies for the monitoring of some fundamental parameters of interest for dams and reservoirs. The use of field monitoring data for risk reduction and maintenance optimisation purposes revolves around meaningful and trustable field data (and metadata) as well as the robustness and durability of the monitoring system as a whole. The paper discusses the importance of high-quality field instrumentation, high-quality installation and high-quality data analysis, alongside the importance of the role and involvement of a Monitoring Specialist. Finally, the paper discusses the potential of using Digital Twins to help the interpretation of the field monitoring data and provide an assessment of the assets via numerical models (e.g. finite elements models, finite differences models, etc.) which, via Artificial Intelligence tools, can enhance predictions on the basis of field monitoring data.