

Goronyo Reservoir – 2010 Incident - Emergency Spillway Breach

J R CORREIA, Atkins

SYNOPSIS Goronyo dam, in the north-west of Nigeria, impounds the River Rima. The resulting reservoir has a total storage capacity of 974Mm³.

The reservoir is impounded by the main and secondary dams (total length 7.1km) and a 5.3km long saddle dyke which also incorporates a 2km long emergency spillway near the middle. The embankments are homogenous and made of silty sandy fill materials with upstream bituminous linings. The emergency spillway is surfaced with dense bituminous concrete lining and the downstream toe is protected by a reno mattress.

In September 2010, following the prolonged operation of the emergency spillway, the structure breached leading to the uncontrolled release of 700Mm³ of water causing widespread damage downstream. The breach was repaired in 2012/13.

This paper describes the events that led up to the breach and discusses features of the works which are believed to have contributed to the breach of the structure. Proposed changes to reservoir operating rules to increase the safety and sustainability of the works are also discussed.

Best value planning of strategic water supply reservoirs in England

J J WELBANK, Welbank Water Consulting Ltd

SYNOPSIS Climate change, the ambition to leave more water in the environment and a call for increased resilience to water supply droughts mean that the need for reservoir storage is greater than ever. Does the change to 'best value' rather than 'least cost' planning provide an opportunity to promote reservoirs alongside other solutions and continued reductions in the demand for water? Will there be a new era of reservoir construction and enlargement in England?

Prompted by policy announcements from government and regulators, a major programme of strategic water resource development is under way to address these challenges. The paper provides an update on the programme and describes the main drivers for new water resources. It also outlines the process adopted to articulate 'best value' and summarises the reservoir projects that are being appraised.

Predictive empirical dam breach peak outflows - A global analysis and proposed updates

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ABSTRACT A comparative analysis, among different predictive breach models, is introduced using the most updated dam failure database provided by Hood et al (2019). The performance of each model is estimated using an appropriate statistical index by comparing the measured peak breach flow with the modelled peak breach flow. Having applied a regression analysis, a new formula is proposed, which exhibits a very good performance against the observed peak flow statistical sample. An alternative equation with 6-parameters is proposed which has a probabilistic background. Based on the analysis, three models (McDonald, Pierce et al.) and the proposed regression model exhibit good performance against observed data. A hypothetical breach assessment case study has been carried out for a typical UK Pennine dam and a discussion is presented on the high uncertainty of the predictive breach models. The paper concludes that simplified breach formulas should always be applied with caution due to limited number of previous dam failures which have been used to develop these predictive models. The limitations of the existing predictive models are discussed, and the foundation of a probabilistic breach analysis is proposed.

Towards a new procedure for estimating the probable maximum flood in the UK

D FAULKNER, JBA Consulting
S LONGFIELD, Environment Agency

SYNOPSIS Research funded by the Environment Agency has comprehensively reviewed methods for estimating the probable maximum precipitation (PMP) and probable maximum flood (PMF). The research has also updated cataloguing of observed extreme floods and rainstorms, finding several exceedances of current estimates of the probable maxima. A review of research and international practice has identified many opportunities for improving current estimation methods applied in the UK and the project has identified a recommended way ahead for development of new methods. In the interim, a restatement of the current method has been produced, along with an Excel software tool to assist practitioners with applying it.

This paper outlines the type of methods recommended for development and some of the challenges, including the desire to reconcile the concept of the probable maximum with a risk-based approach to reservoir safety management.

Carr Mill Reservoir – Innovative underwater isolations for valve and pipework replacement

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S RICHINGS, Edwards Diving Services Ltd.

N WALDING, Edwards Diving Services Ltd.

T BROWNRIGG, Canal & River Trust

D BROWN, Canal & River Trust

M WELSBY, Kier Construction

SYNOPSIS Innovative and remotely deployed methods for securing underwater isolations were developed and installed on two 24" (609mm) diameter inlets at the reservoir end of a 67m long, 1.2m span brick arch draw-off tunnel, 10m below TWL, enabling the valves and pipework to be replaced and refurbished.

Traditional design options would have normally included full dewatering of the reservoir (a slow process, involving a large fish rescue and affecting the public amenity benefit of the site) or a sheet piled temporary cofferdam structure for localised dewatering of the draw-off tunnel. These had many drawbacks and risks to carrying out the safety recommendations.

A bespoke hydraulic Remote Operated Vehicle (ROV) was designed and built to operate underwater and to fit the constraints of the draw-off tunnel to deploy double isolation to each scour valve inlet. The solution substantially reduced the requirement for diver intervention removing the need for any intrusive diver work in the tunnel and enabled the valve and pipework works to be carried out safely downstream in dry conditions. The solution contributed to the completion of the safety recommendations at significant cost, environmental and social impact benefits to the client and local community and significantly reduced risks to the dam and draw-off tunnel structure.

Birds Park Upper Remedial Works

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S TENNANT, GHD
D THOMSON, United Utilities PLC
M DIXON, United Utilities PLC

SYNOPSIS Birds Park Upper and Lower impounding reservoirs were constructed around 1850 as a water supply to Kendal, Cumbria. Both reservoirs were abandoned before 1980 due to water quality problems and the Lower reservoir was subsequently demolished. Birds Park Upper, with a storage capacity of approximately 13,600m³, was retained as it was felt that flooding problems in Kendal could be worsened without the attenuating effect of the reservoir.

Following assessment in 2012 it was identified that the reservoir had an unacceptable risk for internal erosion and flooding with the reservoir overtopping in the 1:100 year flood. An operational solution was put in place to manage the risk but recognised that this was not sustainable in the long term and plans to discontinue the reservoir were put in place.

Early in December 2015 Storm Desmond caused significant flooding in Kendal and the EA were keen to retain this asset to mitigate the impacts and support their proposed Flood Risk Management Scheme. Following flood studies it was acknowledged that the attenuation potential of the reservoir was minimal and UU have since progressed works to reduce storage capacity to below 10MI.

This paper will look at the challenges of undertaking works at this constrained and environmentally sensitive site to reduce Top Water Level (TWL) ensuring no detriment to the flood risk downstream and reducing internal erosion and overtopping risks.

Dorisland Reservoir Embankment Stabilisation

D BELL, AECOM

S MARTIN, AECOM

SYNOPSIS Dorisland Reservoir is a 300 MI Category A reservoir with main and return embankments of total length 590 m and up to 13 m high. The reservoir is effectively a storage basin to collect drawoff flows from the six other impounding reservoirs within the upstream Woodburn reservoir complex, prior to passing into treatment and supply. Whilst modest in volume, the reservoir sits above the town of Carrickfergus, with approximately 725 properties in the inundation zone. The reservoir is likely to be the only one in Ireland to be located across the toe of extensive post-glacial landslips, on the lower slope of the Knockagh escarpment

In October 2016, during a routine site walkover by the reservoir manager, Northern Ireland Water (NI Water), the staff member observed a substantial wet spot at the toe of the Western return embankment. At the request of the reservoir manager, AECOM undertook a site inspection which not only confirmed the presence of the wet spot but also identified a significant crack / slippage of the downstream slope on the line of the wet spot. The textbook slip failure ultimately resulted in a visible tension crack over 20 m in length with a horizontal displacement of up to 400 mm.

This paper aims to take you on a journey through the project, from the initial discovery of the 'wet spot' to the implementation of remedial works, with further discussion on how the problem arose, the investigative works undertaken, the remedial options considered, the chosen design solution, the implementation of site works as well as highlighting some of the factors which influenced the construction.

Wallasea Island Dynamic Lagoons

J S YEOH, Jacobs

J E NORRIS, Jacobs

SYNOPSIS Jacobs was engaged in engineering works on Wallasea Island located at the junction of the Crouch and Roach estuaries in Essex to the Royal Society for Protection of Birds (RSPB) since 2010. This paper describes a unique feature of the overall scheme where a non-impounding large-raised reservoir under the Reservoirs Act 1975 has been constructed in supporting a landmark conservation and engineering project on a scale never before attempted in the UK and the largest of its type in Europe.

As Wallasea Island is located below the surrounding intertidal marshes this scheme relies on a regulated tidal exchange to control the inflow of water from the sea and leave the existing seawalls intact. Nearly 10km of new earth embankments were constructed to help store water, while being below high tide level, is artificially retained above natural ground to help create a large controllable 'microtidal wetland' which has a high ecological value and has achieved major flood alleviation benefits and distinctive climate change adaptation functions. At 670ha, Wallasea Island is the largest coastal wetland ever created in the UK and the scheme constitutes the largest regulated tidal exchange scheme in the UK. This remarkable project demonstrates how engineering and conservation can work together to create valuable wildlife habitat, flood defence, and help mitigate environmental and climate changes.

Foundation leakage from service reservoirs

ALAN J BROWN, Jacobs

ANDY P COURTNADGE, Jacobs

CIARA E GILL, Jacobs

SYNOPSIS A significant proportion of service reservoirs have no underdrainage or back of wall drains, presumably because the designer considered that the foundation was sufficiently permeable that any leakage would soak away into the foundation. In these situations drop tests are the only way to measure leakage from the reservoir.

The authors are aware of situations where this ongoing leakage has caused significant settlement of the service reservoirs, and loss of water into old coal workings is a case history of a service reservoir incident in CIRIA SP167.

The paper describes back analysis of drop tests carried out on an existing twin cell service reservoir, showing that the head difference between the test cell and cell remaining in use has a significant effect on water levels in the test cell. This is probably partly due to leaking inlet and outlet valves, but there appear to be other factors which cannot be fully quantified.

The authors conclude with suggested good practice in use of drop tests to assess leakage from existing service reservoirs, noting that this is only way to monitor vulnerability to possible foundation failure.

Remote Inspection of Reservoirs

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SYNOPSIS Periodic inspections are necessary to ensure ongoing safety of reservoirs, this can include both Section 10/Section 47 inspections or other regular visits by Undertakers. Historically these have been 'in-person' inspections where the Engineer visits the site. Recent technological developments mean that a level of remote inspection is possible.

As a result of the Covid pandemic, contracted overseas inspections of reservoirs in Hong Kong by UK Panel Engineers have not been possible over the past two years due to restrictions preventing travel. In order to maintain the programme of inspections and ensure safety of the reservoirs, Engineers from Arup and Binnies have used remote techniques to inspect a large number of sites over this period. The techniques adopted have included Headcam livestream and recorded video, standard and 3D photographic surveys, and drones. The techniques were found to be adequate but the lack of fine close-up detail, tactile investigation and overview/perspective presented challenges. The support and experience of local staff, both from the client and consultant, were invaluable.

Afon Wydden Upstream Flood Storage Reservoir Spillway Improvements

R J TERRELL, Binnies

A R DAVIES, Natural Resources Wales

SYNOPSIS Afon Wydden Upstream Flood Storage Reservoir a 29,000 cubic meter flood storage reservoir impounded by a 4.4 meter high embankment dam near Llandudno in North Wales adjacent to the A470 trunk road. As a result of an assessment it was found the stone in the existing reno mattress spillway was of an inadequate size to prevent it moving during overtopping events.

This paper looks at the innovative way in reusing the existing reno mattress and replacing the stone, reusing the removed stone elsewhere in the project. A new training wall is required, and this is built out of woodcrete blocks which is an Insulated Concrete Formwork (ICF) construction using cement impregnated recycled wood chip block. Using this block has multiple benefits including Health and Safety benefits as well as reducing the quantity of Concrete required. Making improvements to the inlet and outlet channel while reducing the embedded carbon and reusing existing materials and using Concrete Canvas to line the channel. Other works include betterment to an environmental pond whilst ensuring the pond does not affect the upstream toe of the embankment and a new wider layby for safer parking of NRW operational vehicles

Design of dual-purpose dams – incorporating flood storage dams into new-build infrastructure – the A120 Little Hadham Bypass and Flood Alleviation Scheme

P M DICKENS, Arup
M COOPER, Arup

SYNOPSIS The village of Little Hadham, Hertfordshire, UK has suffered many years of traffic congestion and air pollution at a junction in the centre of the village, marring the lives of residents and disrupting travel through the region. Meanwhile the village has been flooded by the River Ash and its tributaries on numerous occasions, including most recently in 1998, 1999, 2000, 2001, 2009 and 2014.

Hertfordshire County Council and the Environment Agency have jointly promoted a combined highway bypass and flood alleviation reservoir scheme, designed to both reduce the impact of flooding and improve traffic flow on the A120 by bypassing the village of Little Hadham. The scheme incorporates two flood storage dams into the highway alignment, where the highway is to be constructed on embankments across the Albury Tributary and the River Ash valleys. These combined highway and flood alleviation embankments have been designed as Category A reservoirs, at 7m and 11m high respectively, to attenuate flood waters in upstream agricultural land, and limit flood risk to downstream residents. Both dams carry the A120 bypass on their crests and feature reinforced concrete spillways with flow control culverts, highway bridges as well as deep seepage cut-offs into the underlying chalk.

This paper will describe the unique challenges and opportunities faced during the design of a combined flood storage reservoir and highway scheme for two different owner-maintainers.

Installation of emergency drawdown system for Dam Safety Management at Cogra Moss IR, Cumbria

M L DIXON – United Utilities

C D PARKS – United Utilities

SYNOPSIS Cogra Moss IR is a small Impounding Reservoir situated in the north west of Cumbria some 7 miles to the east of Workington. The embankment is a typical Pennine type with a puddle clay core 87m in length and with a maximum height of 8.7m. The dam has a capacity of 295ML.

Following a Section 10 inspection by Dr A K Hughes on 12th November 2015, two items were identified In the Interests of Safety to be completed by 31st December 2018, namely:

- The draw-off tunnel be grouted up whilst providing some drainage
- Facilities are installed which are capable of drawing down the reservoir by at least 1 metre a day at top water level assuming no inflow down to a level of 5 metres below top water level.

The paper describes the planning, design and installation of a new siphon system over the left hand crest of the embankment. The siphon is designed to give the required drawdown capacity and is operated by an innovative trailer mounted portable generator and vacuum system to be brought to the site in the event of an emergency. The paper also describes the grouting works required for the tunnel and remedial works to the original overflow to ensure long term stability.

Given the complications of the operation and use of the reservoir there was a delay to the start of the project necessitating a further 'S10' inspection, which was carried out on 21st December 2018 extending the completion deadline until 30th June 2019.

The Victorian approach to the Sustainability of British Dams

P J RIGBY, United Utilities

A N THOMPSON, United Utilities

J A CLIFFORD, United Utilities

SYNOPSIS There has been much talk in recent times about the need to adopt a sustainable approach in every area of our lives. So what is behind this drive to be sustainable? According to the United Nations (2019) there is estimated to be over 10 billion people living on the planet by 2100 with the consequent increase in demand for energy and resources. The need to be sustainable will not be a choice but a necessity.

The population explosion within the UK commenced during the 19th century at the start of the industrial revolution. Modern Britain was “invented” sometime between 1830 and 1900 coinciding with the height of the dam building period driven by industrialisation and the need for a sustainable water supply. However, with this increasing demand for resources the Victorians are often cited to be one of the most sustainable generations in UK history driven by necessity to reduce, reuse and recycle. Studying the Victorian period may provoke new ways of thinking about contemporary issues including the problem of environmental degradation and climate change.

This paper will look at two examples of recent remedial works and compare to original Victorian construction practices to evaluate whether we are being more or less sustainable in our current approach to construction.

Little spend, large gain. The importance of targeted and proportionate effort analysing failure mechanisms when applying RARS

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S SHAKESPEARE, Welsh Water

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SYNOPSIS This paper presents the assessment of a specific failure mechanism that provided a high-risk rating for a concrete Ambursen-type dam, after the initial assessment using Risk Assessment for Reservoir Safety (RARS). The event tree analysed related to the dam's potential collapse initiated at the toe by hydraulic pressure, following a burst of the scour pipe, filling up the dam void. A more detailed hydraulic assessment of the pipework system and a better understanding of the dam structure enabled the design team to revise the event tree with greater confidence. As a result, the risk value was reduced to as low as reasonably practicable (ALARP), eliminating the need to undertake costly further investigations and likely engineering works. The study was overseen by an All Reservoirs Panel Engineer (ARPE), providing reassurance over the approach and outcomes.

This example shows that a targeted, detailed analysis of specific failure mechanisms, identified by a high-level screening exercise, is a cost-effective way of prioritising dam risk assessments. The tiered approach in RARS was applied here to first provide an overview of the risks and then, using a modest investment, further investigate key failure mechanisms and the dam's structural and mechanical elements. The study led to substantial savings and the reduction of pressure on the reservoir owner's emergency and maintenance plans.

Rhodeswood Reservoir – A combined approach to the investigation and remediation of an ageing asset

J A CLIFFORD, United Utilities

C D PARKS, United Utilities

I SCHOLEFIELD, United Utilities

A HUGHES, Dams and Reservoirs Ltd

SYNOPSIS Rhodeswood Reservoir is the third of five reservoirs within the Longdendale valley cascade. Standing 22.6m high, it has a central puddle clay core and a unique profile as a result of the complex geology and history of landslips within the valley. Limited historic drawings and ground investigation data suggest a steep interface between the core and rock, described as ‘shaken ground’, at the northern (right hand) abutment. This has resulted in a branched puddle trench and upstream blanket wrapping around the northern upstream abutment area. United Utilities undertake a planned programme of studies that assess the risks posed to its dam asset base for flooding, internal erosion and seismic loadings. This identified a potential intolerable risk of scour at the abutment/core interface, which was supported by a history of seepage within this area.

This paper details recent combined investigation and grouting remedial works, targeting the interface between the core and heavily broken rock abutment. Through collaborative working and a flexible programme of works, confirmation of ground conditions and subsequent development of a detailed ground model was achieved. This identified zones of high permeability within the rock abutment but also loss of fines and flush water at the core to foundation interface. A grouting solution using ascending stage and Tube-a-Manchette techniques, to target the core to foundation interface, was adapted for the conditions encountered. Additional challenges included inclined grouting around the reservoir siphon pipe which was situated within the grout zone and the containment of grout and flush water on the crest due to the sensitive nature of the surrounding environment.

Determining the condition of a Masonry Dam with the use of UAVs and machine learning

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J CRAMMAN, CC Informatics

A TALIANA, Dwr Cymru Welsh Water

SYNOPSIS Masonry dams often rely on the facing stone to achieve stability and therefore it must be maintained to ensure it remains in-situ. It is challenging to carry out detailed assessments of masonry faced dams from ground level or with traditional optical techniques. The most successful existing technique requires rope access operatives scaling the dam and collecting information, which requires secondary processing to return useful information and allow the scoping and pricing of maintenance. Dwr Cymru Welsh Water (DCWW) and CC Informatics (CCI) agreed on a jointly funded research programme to investigate the feasibility of undertaking both high detail UAV surveys and mortar condition classification using machine learning techniques. This resulted in the production of Statistical, 2D, and 3D outputs for use by DCWW to undertake repointing quantity estimation and to identify areas of deterioration.

Cowlyd reservoir scour valve refurbishment: A story over 7 years

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L SHAW, Stillwater Associates (previously of RWE Generation UK Plc)

SYNOPSIS Cowlyd Reservoir is in the Snowdonia National Park in North Wales. A Measure in the Interest of Safety was recommended in 2014 associated with the provision of a secondary means of emergency draw down. This paper details the process followed to satisfy the measure and the challenges faced when doing so.

The paper concludes that when undertaking necessary works in environmentally protected, difficult to access upland environments, the durations required, and costs involved in satisfying the measure can be significantly greater than first envisaged. An appreciation of these difficulties and continued communication between interested parties is necessary.

Cwm Clydach – investigation of an ownerless and historic masonry dam

A WARREN, Mott MacDonald Ltd
J HOWARD, JBA Consulting Ltd
S MORRIS, Natural Resources Wales

SYNOPSIS The Cwm Clydach Reservoir once served ironworks associated with Neath Abbey in South Wales. The dam comprises a 10m high masonry dam with a hearting of earth fill. The reservoir has only been registered under the Reservoirs Act 1975 in modern times and Natural Resources Wales manage the site as the dam body is ownerless. The paper describes the dam and the series of investigations carried out to examine its construction characteristics. This culminated in an extensive programme of geophysical surveys and intrusive investigations to inform a stability review and measures to promote the safety of the dam. The dam is a Scheduled Ancient Monument under Welsh legislation which poses constraints on the nature of safety interventions at the site. The paper explains the challenges involved in carrying out the investigations and balancing reservoir safety and heritage interests.

A sustainable approach to spillway refurbishment for Talybont Reservoir

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T WEBSTER, Mott MacDonald Ltd
D REBOLLO, Mott MacDonald Ltd
B COTTER, Dŵr Cymru Welsh Water

SYNOPSIS Talybont Reservoir is located in the Brecon Beacons, South Wales, and formed by a 30m high embankment dam. The reservoir is served by an 80m long side overflow weir which discharges into a masonry/concrete lined tumble bay and masonry-lined spillway chute. The masonry lining of the chute had deteriorated, partly on account of aggressive water chemistry conditions. Options were evaluated for remediation of the chute to ensure that it will withstand the design flood conditions. A series of geophysical investigations, coring and pull-out testing of masonry blocks informed the preferred approach. An alternative solution was favoured over the more common approach of relining in reinforced concrete. Pressure pointing and grouting of the chute was undertaken with pattern doweling of the masonry blocks to the formation concrete. This maintained the original appearance of the chute in an area of great natural beauty and provided considerable cost and carbon savings compared with the more traditional solution.

Reflections on the national review of reservoir safety

A L WARREN, Mott MacDonald Ltd

SYNOPSIS The UK government's independent review of reservoir safety was published in March 2021. The recommendations of the report will drive and shape change in reservoir safety processes and management for many years to come. The paper examines some of the key recommendations and considers the challenges, practicalities and likely impacts of the proposed changes for the various parties to national reservoir safety management. The delivery of the changes, which will require considerable coordination between the regulator and the various bodies representing the reservoir industry, is discussed. The paper also explores alternative strategies considered during the preparation of the review which could offer benefits to the industry.

Washland flood detention reservoirs - Developing a consistent approach for assessing reservoir safety aspects

ANDY P COURTNADGE, Jacobs

ALAN J BROWN, Jacobs

SYNOPSIS Around 40% of the Environment Agency's portfolio of 217 flood detention reservoirs are offline washland reservoirs located in low lying floodplains, often with no formal overflow spillway. Such washlands are widespread in Yorkshire, East Anglia and the Somerset levels, many being legacy structures formed for land drainage etc rather than designed as formal flood attenuation reservoirs. In the absence of guidance, there is currently some inconsistency in how Inspecting Engineer's treat these reservoirs, e.g. when to apply reservoir safety standards versus flood risk management standards, defining top water level and selecting an appropriate catchment area for extreme flood estimation.

Jacobs have developed a consistent approach for Tier 1 risk assessments in accordance with the Guide to Risk Assessment for Reservoir Safety (RARS) and propose the approach may also be useful as a general basis for Section 10 inspections. The paper defines typical characteristics of a washland reservoir and suggests approaches for

- defining top water level; and
- scenarios to consider when assessing adequacy of overflow.

RARS – A Client’s Perspective

N C BENNETT, Canal & River Trust

J FOSTER, Mott MacDonald

M HEWITT, Mott MacDonald

SYNOPSIS Over the past three years, the Trust have undertaken a comprehensive programme of RARS Tier 2 assessments for its 71 regulated reservoirs, in line with the EA Guide to risk assessment for reservoir safety management (RARS). The Trust have worked with the consultant Mott MacDonald to develop detailed workbooks which take the RARS process beyond assessment, allowing scoping to be completed quickly and easily to compare the relative proportionality of different risk reduction options. The level of granularity given by the tools has enabled the Trust to prioritise investigation works and allocate funding for capital projects, with over £40M of additional spend planned over the upcoming investment period to reduce risk.

The tool will be ingrained in the Trust’s business planning and project development processes going forward to ensure a continuous cycle of improvement and targeted risk management in an illustrative way. This proactive approach is in line with the recommendations of the recent Balmforth Independent Reservoir Safety Review, which stated that reservoir owners should manage the safety of reservoirs by ensuring the risks that they pose are managed to be as low as is reasonably practicable (ALARP).

This paper will detail the development of the workbook tools and scoping methods used by the Trust. It will discuss some of the findings and trends of the assessments and will comment on the perceived limitations of the current RARS process and the learning from the assessments.

Grass cover – improving establishment and resilience to deal with increasing stresses

M W HUGHES, Atkins
D HOLLAND, Salix

SYNOPSIS Maintaining healthy grass cover is necessary for safeguarding the resilience of embankment dams and is critical if the dam is designed to overflow.

Grass will tolerate stresses ranging from drought to saturated ground if: the type of grass is appropriately selected and is sufficiently diverse; care is given to proper establishment; and sufficient attention is given to maintenance all year round. The use of standard 'grass only' mixes, taken directly from guidance, is likely to lead to disappointment if it is unsuited to the local site conditions and not measured against a sufficiently robust specification.

This paper reviews a number of current industry publications and specifications for grass seeded and turfed areas and provides recommendations for more easily enforceable definitions of what acceptable grass cover is.

The paper also questions the standardised approach of specifying grass only seed mixes, and whether more diverse seed mixes including a small percentage of appropriately selected herbs or legumes may instead be beneficial and whether selection should be based on observations of existing grass diversity in the embankment and adjacent areas.

Soil-Structure Interaction Analysis and Design of the Boston Barrier

M DEANE, Mott MacDonald

M SCHAFFER, Mott MacDonald

SYNOPSIS The Boston Barrier Tidal Flood Defence Scheme is a £100M project to reduce the risk of tidal flooding in Boston, Lincolnshire. At the core of the scheme is a gate which spans the river and can be closed against high tidal flood events, protecting the town. This gate and the equipment to lift it are accommodated by a large 'barrier structure', formed primarily of around 6,000m³ of reinforced concrete.

The need for the barrier has only increased given the expected impacts of climate change, with major sea level rise as well as higher fluvial flows expected over the design life of the structure.

This structure is founded directly onto the clay bed of the river and is subject to numerous load cases which combine long-term and highly transient loads. Its unusual shape, loading and compressible foundation resulted in complex soil-structure interaction, which needed appropriate modelling to determine structural stress distribution to be used for design.

Such soil-structure interfaces are common within UK embankment dams and can pose a significant threat to such dams if not fully understood. Increasingly powerful tools are available to help understand this interaction and need to be implemented appropriately to reduce the hazard posed.

This paper will summarise the design requirements and explore the load cases, data collection, analysis process and findings of the soil-structure and structural Finite Element Analysis (FEA) modelling.

Towards a Systems Analysis of Flood Storage Reservoirs in a Changing Climate

S GARATTINI, Jacobs

S YEOH, Jacobs

D COBBY, Jacobs

E BUSH, Jacobs

Arup- Jacobs and the Environment Agency (EA) are delivering the Ox-Cam River Nene Storage study in the UK to better understand the impacts of climate change and future development on flood risk, and to understand the role of flood storage in future flood risk management. The study has focused on 19 existing Flood Storage Reservoirs (FSRs) and 12 potential future locations for FSRs in the nearly 2,000 km² River Nene catchment between Daventry and Peterborough. The study analysed a large and diverse number of FSRs, collating reports and expert knowledge gained through site visits on their history, current status and potential future.

A holistic review of the individual assets was undertaken encompassing asset condition, whole-life cost and flood performance. The findings will help the EA move towards a better understanding of the benefits offered by the FSRs, both individually and as part of a catchment-wide flood management system. A system-wide understanding of the existing FSRs would be beneficial prior to analysis and design of new assets, unless time-limited opportunities for new assets arise. This system understanding should not be limited to future flood performance and costs, but also further enable collaborative working between flood risk management and water resources sectors that could be an important aspect of climate resilience.

The paper illustrates:

- Progress on a staged approach towards a future system of FSRs
- The need to transition analysis from individual assets to a system analysis incorporating flooding and water resource management
- How early consideration of climate and future pressures can shape the development of a future system of FSRs.

Future Proofing Old Dam Protection Gates Using Modern Techniques

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SYNOPSIS The average age of a dam in the United Kingdom is over one hundred years, hence large parts of the existing fleet of dam protection gates has grown into middle and old age. The gates and related hydro mechanical works need to be considered as part of any dam assessment and subsequent refurbishment.

The tools available to hydro engineers today to determine the suitability of gates for continued service range from conventional dimensional surveys through 3D laser scanning and onto assessing the structures to modern codes (EUROCODE and DIN19704) finite element analysis with the measured corrosion, analysis of structural failures, modelling of the operating equipment and reliability analysis.

This paper reviews the technology available and issues in applying it to gate assessment.

As an illustration of the application of such techniques, the work performed by KGAL Consulting Engineers on

Two power stations are presented, Ardnacrusha Power Station constructed in 1929 and Ffestiniog Power Station first commissioned in 1963 as the UK's first major pumped storage power facility.

Design and Construction of Wastewater Treatment Lagoons at Hollym, Myers Lane, East Yorkshire

J GOWER, Stantec

D HERNON, Ward & Burke

B MARSHALL, Yorkshire Water

M HILL, Stantec

SYNOPSIS In early 2020, Ward and Burke were appointed by Yorkshire Water to undertake the design and construction of a new wastewater treatment facility at Hollym, East Yorkshire. The chosen solution required construction of two treatment lagoons, each with 75,000m³ storage capacity and above existing ground level. As the structures would be registered under the Reservoirs Act 1975, a Construction Engineer was appointed to oversee the design and construction phases.

This paper will provide a summary of the works undertaken with an overview of the design and construction, including earthworks design and testing requirements.

Calverley Flood Storage Reservoir: sustainably delivering flood protection for social benefit

A D BULL, Mott MacDonald
E HALE, Mott MacDonald
C ALLMAN, Mott MacDonald

SYNOPSIS The 2015 Boxing Day floods damaged more than 3000 homes and businesses in the Leeds area. Phase 1 of the Leeds Flood Alleviation Scheme, was under construction at the time and was inundated by high water levels.

Subsequent analysis indicated the rarity of the flood as it exceeded a 0.5% Annual Exceedance Probability (AEP), and Leeds City Council set its sights on an expanded scheme which would protect the residents of Leeds from an equivalent event.

The scheme has sought to use a catchment-based approach of hard and soft engineering – increasing the length of flood walls through the city centre to the 1% AEP flood level, providing an online flood storage reservoir (FSR) at Calverley, 13km upstream of the city to enhance the standard of protection to 0.5% AEP, and working with landowners to implement natural flood management solutions across the wider Upper Aire catchment to increase scheme resilience allowing for climate change.

This paper provides an overview of the scheme delivery from business case challenges up to commencement of detailed design. Delivered through a programme of overlapping investigation, design and planning activities, evolving hydrological modelling and resolution of environmental and physical constraints.

The Calverley FSR has faced many challenges in its development. Through a collaborative design and build approach, the obstacles were overcome, and construction began in July 2021 – delivering on the project mandate to deliver safely and sustainably a scheme that protects the public, businesses, infrastructure and the environment and promotes growth.

Non Statutory Reservoirs – A Journey of Discovery

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R THORP, National Trust (volunteer)

J BENN, National Trust (volunteer)

SYNOPSIS The National Trust owns some 200 reservoirs, of which 47 are Statutory Large Raised Reservoirs; of the remainder circa 40 are thought to have volumes in the range 10,000 m³ to 25,000 m³. The reservoirs were mostly built in the 18th, 19th or 20th centuries, when construction methods were both varied and evolving. They have therefore never been fully assessed against modern dam engineering standards. The National Trust has endeavoured to identify and manage all its non-statutory reservoirs with a view to understanding the risk they pose, assessing investment requirements, their significance within the landscape and developing appropriate management and monitoring practices to ensure dam safety.

With the likely change in threshold for registration with the regulator on the horizon the Trust has reviewed its non-statutory reservoir assessments and collected a number of common challenges and themes which appear regularly across its portfolio. These range from working within complex heritage designations, tree and vegetation management, through to better understanding of the resilience of reservoirs in small catchments. This paper aims to share some of this knowledge and raise some questions about potential future regulation and management of reservoirs.

Intelligent Satellite Dam Monitoring

M Coombs, Binnies
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SYNOPSIS The dam industry in the UK is in changing, interesting and challenging times. The incident at Toddbrook Reservoir in 2019 has led to the drafting of new guidance for Undertakers (Dam owners and operators), Reservoir Engineers and others, as well as the potential for legislation change. This will shape future UK dam industry requirements and is challenging the way we undertake reservoir safety.

Developing technology of the 21st century can assist us in managing our historic assets going forward, whilst complementing our existing data sets, processes and activities. The Intelligent Dam Monitoring System (iDMS) harnesses the power of satellite technology to proactively manage reservoir safety and address these challenges. It enables dam owners to understand their assets, improve risk management, deliver strategic objectives and realise operational and commercial benefits, bringing long term resilience to dam safety strategy.

By establishing a detailed understanding of the basal rhythm of the dam the system can provide early detection of anomalous change. It will allow for a better-informed analysis of risk across a portfolio of assets and will allow owners to demonstrate a duty of care by avoiding potentially catastrophic incidents through long-term planning and proactive risk management.

The system is currently being piloted by the Canal and River Trust at two of their reservoirs. This paper will outline the practical implementation and operation of the system, some of the findings and ongoing developments, which include tailoring the system to the CRTs own individual requirements.

Toddbrook Reservoir: spillway replacement design for a public space

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M HEWITT, Mott Macdonald

T GREENWOOD, Canal and River Trust

A LOBBAN, Canal and River Trust

In August 2019 the auxiliary spillway at Toddbrook reservoir overflowed and failed, resulting in a major incident to save the dam. This paper discusses the key influences and considerations behind the design of the replacement spillway system.

The reservoir is situated on the outskirts of the town of Whaley Bridge in an area of historic mining and is now surrounded by development and parkland that is highly valued by the local community. This imposed constraints on where the spillway could be located and required careful design to address the matters raised during public consultation. The shape and form of the spillweir and the stilling basin were particularly influenced by this, including provision for access and inspection as per Part A of the Balmforth recommendations.

The form, design detailing and sequencing of construction, including how to manage the risk arising from extreme flood events during construction, was developed in conjunction with the contractor. The need to build sustainably has also influenced the design, including consideration of alternative solutions to resist flotation of the overflow weir and tumblebay, as well as incorporating temporary works structures into the permanent solution. Construction is planned to commence in the first half of 2022.

Advancing the state of practice in seismic dam assessment – A case study for Toddbrook Reservoir

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J GO, Arup
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M ARRIGONI, Arup
J HOWELL, Arup
A PETERS, Arup
B GHOSH, Mott MacDonald
M HEWITT, Mott MacDonald

SYNOPSIS Following the 2019 incident on the auxiliary spillway at Toddbrook Reservoir the stability of the embankment dam was assessed. One of the findings was to assess the seismic performance of the embankment, including stress deformation analysis to estimate likely displacements.

In collaboration with the Canal & River Trust and the All Reservoir Panel Engineer, a seismic assessment has been developed taking a staged approach. We concluded that the traditional approach was inappropriate, and a more advanced set of studies were undertaken. The main assessment steps were:

- A probabilistic seismic hazard assessment (PSHA) to define the site-specific seismic criteria.
- Initial assessment of stability and liquefaction assessments using traditional methods to identify key areas of concern.
- A ground investigation including standard boreholes and more advanced multi-channel analysis of surface waves (MASW) and downhole testing to help characterize the dynamic properties of the dam.
- To simulate liquefaction in the embankment fill, the advanced soil constitutive model PM4Sand was implemented in FLAC numerical analyses.

The studies have gone through extensive review and checking to ensure the risks for all stakeholders are kept ALARP for this important facility.

Remedial works to ornamental ponds within a historic park

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SYNOPSIS Prior Park is an historic landscaped garden funded in the 18th century by Ralph Allen, and designed by the poet Alexander Pope and 'Capability' Brown. The gardens include a Palladian Bridge and three man-made lakes. Following decades of decline, the National Trust was gifted the park in 1994, and has since set to restoring the park to its former glory.

This paper focusses on the restoration of the lakes, and describes how spillway capacities of embankments were increased and embankments repaired and strengthened without impacting upon the vision of the park set by the original architects. The engineering works included reinforcement of grass turf with geotextile, using stilling basins hidden in chambers below the embankments, and restoration of a cascade feature to one of the dams.

Loch Thom Reservoir: Drawdown Enhancement

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T M HEWITT, Mott MacDonald Ltd
R MCHUGH, Mott MacDonald Ltd

SYNOPSIS – At the statutory inspection completed in 2013, a number of safety recommendations were made for Loch Thom Reservoir which included undertaking a flood study to check for overtopping and a study to check the rate at which the reservoir can be drawn down.

It was determined from the CIRIA drawdown guidance that Loch Thom did not meet these requirements and that additional draw down facilities were required. The preferred option to improve drawdown was to install 3 x 1100mm siphons through the main dam and discharge into the spillway channel.

The siphons were commissioned in June 2021 with all works completed by September 2021.

Use of Operational Reservoir Assets for Additional Flood Protection

J R FOSTER, Mott MacDonald

J JEPPS, Thomas Mackay Ltd

Synopsis The routing and attenuation effect of an operational impounding reservoir inherently provides a degree of flood protection to downstream communities. A project was initiated by the Environment Agency to investigate the practicalities of providing additional flood storage at a set of 6 reservoirs, some of which operate in cascade, on a valley upstream of two communities which are regularly affected by flooding, and was particularly affected during December 2015 when two significant flood events occurred.

The feasibility project undertaken in partnership with the reservoirs' owner, a water utility, considered physical options of being able to provide storage prior to a flood event. The project considered the following as part of its methodology:-

- Engineering solutions to manage drawdown
- Drawdown trials
- Hydrology assessment
- Impact on operations
- Overall benefits

This paper summarises the process and findings of the above methodology and provides comment on the success or otherwise of this study and how it could be implemented elsewhere.

Hydraulic Study of the Taff Fawr Reservoir Cascade

P DICKENS, Arup

V STOYANOVA, Arup

SYNOPSIS Arup was commissioned by Dŵr Cymru Welsh Water (DCWW) to study the hydraulic performance of Beacons, Cantref and Llwyn-on Reservoirs. All 3 reservoirs are Category A large-raised reservoirs under the Reservoirs Act 1975. The flood studies were required following recommendations of the Inspecting Engineers.

The flood studies required the detailed assessment of the hydraulic performance of a range of overflows including masonry side channel service spillway, two sets of multiple barrel air regulated siphons and an auxiliary blockwork spillway. In the process of the study the as constructed structures were found to differ from the original physical model studies, as a result detailed numerical and CFD analysis was performed. All 3 reservoirs were found to have inadequate flood discharge capacity. Following the study, options were considered for flood discharge capacity improvements along with steps for further development. This paper will focus on the reservoir flood study.

Extending the life of reservoir assets – upstream pitching repairs at Selsset Reservoir

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M RHODES, Stantec

M CIARALDI, Northumbrian Water Group (NWG)

I CARTER, Stantec

SYNOPSIS Selsset Reservoir is the upper of two reservoirs in the Lune cascade of County Durham. Since its commission in 1960 the dam has suffered repeated pitching damage over its sixty-year life, with significant storm damage recorded as early as 1962.

Repeated interventions required at Selsset have cost the asset owner NWG significant time and expense, including a major scheme to cover the upper two thirds of the pitching face with a thick layer of heavy riprap in 1989. Since the last recorded intervention in 1994, further damage in subsequent years resulted in NWG seeking a solution that would prevent further intervention and prolong the life of the dam.

This paper aims to summarise a concept assessment regarding whole life cost, recognition of modern health and safety standards and temporary works measures to determine and deliver a robust solution to the repeated pitching damage.

Stabilisation of a service reservoir embankment suffering from seasonal downslope movements

D Y K CHAN, Mott MacDonald

T BLOWER, Mott MacDonald

J C GREEN, Thames Water

SYNOPSIS This paper presents the case history of a 15m-high embankment supporting a Victorian-era service reservoir on London Clay. The south slope of the reservoir was remediated some 10 years ago at which time the east slope appeared relatively stable. More recently, the east slope recorded accelerating seasonal downslope creep movements, culminating in localised slippage, which was deemed an unacceptable risk to the reservoir structure. The paper describes how the slopes, monitored over a period of 30 years, were analysed to understand the mechanisms of slope movement and thus to produce a geotechnical design to stabilise the embankment slopes. Climate change is expected to exacerbate seasonal wetting and drying cycles in clay embankments, necessitating more such schemes in the future.