

Dams and Reservoirs

Local knowledge, global expertise



ARUP

Arup is a firm of designers, engineers and business consultants providing a diverse range of professional services to clients. The firm is the creative and inspirational force behind many of the world's most innovative and sustainable planning, building and infrastructure projects.

We believe that talented people and collaborative working relationships form the basis of successful project delivery. By sharing knowledge and expertise with colleagues across the globe, our local teams can draw upon a wide range of specialist skills. Through bringing together an unrivalled range of technical, design, creative and management expertise we create real value for our clients.

We are a wholly independent organisation owned in trust, giving us the freedom to work on some of the most challenging projects in the world. We have more than 10,000 staff working in 90 offices in more than 30 countries. Arup's multi-disciplinary approach means that any given project may involve people from any or all of the sectors or regions in which we operate. Our fundamental aim is to bring together the best professionals to meet our clients' needs.



Dams and Reservoirs



La Ferme Dam, Mauritius

Dams and reservoirs are crucial for the storage of water, whether it is for potable water supply, flood alleviation, hydro-electricity, or irrigation. The development of a new dam or reservoir, the final choice of site and design of the structure will depend not only on the topography but also on the geology, seismic activity and environmental impact.

Arup's holistic approach delivers dam and reservoir projects, on time and to budget. Seeking excellence in every aspect of our work and organisation provides the very best service to our clients. Our approach considers the social, technical, economic and environmental issues for a sustainable solution within the local, regional and national political context.

Our constantly evolving skills base reflects the diversity of both our clients and our staff. However complex the challenge, we have the expertise and the resources to resolve it.

Our objective is to help our clients meet their business needs by adding value through technical excellence, efficient management and personal service. To this end we are professionally committed to providing optimal solutions to all our clients in the water engineering sector.

Our services include the following:

- Planning and promotion of proposed developments
- Expert advice
- Feasibility and design
- Hydrology and water resources planning
- Remedial works and rehabilitation
- Construction supervision and project management
- Supervision and inspection of existing dams and reservoirs
- Hazard indexing and risk assessment
- Geotechnical appraisal
- Sustainability appraisal and environmental assessment
- Reservoir safety studies, seismic and dam break analysis
- Decommissioning of existing assets
- Hydropower assessment and implementation
- Technical research
- Computational fluid dynamics

Feasibility and Design

Arup has over 60 years experience of modern dam design. We have worked with clients at all stages of the design process. Our input into recent schemes has included:

- Desk studies and site selection
- Site investigation
- Optioneering and value engineering
- Hydrological analysis and water resources planning
- Feasibility and planning stage design
- Hydraulic analysis of control structures
- Geotechnical, structural and seismic analysis
- Consideration of environmental impact and sustainability
- Technical review and expert advice
- Contract management and site supervision

We have been involved with the design and construction of earth embankment dams; concrete gravity dams; concrete buttress dams; rockfill dams and a concrete arch dam. Design work has also been carried out on Roller Compacted Concrete (RCC) dams. Our input has ranged from small local schemes to large international projects and at all stages of the design process.

Arup has a strong capability in hydrological analysis of proposed and existing reservoirs and can provide specialist input on all aspects of the water cycle, including yield analysis and water resources planning. We carry out flood risk assessments of existing dams, working closely with our inspecting engineers to support their assessments of the structures. Such analyses have been carried out for individual reservoirs, cascades of multiple reservoirs, and portfolios of reservoir assets.

Our hydrologists have been involved in the selection and development of new reservoir sites; optimisation of both proposed and existing dams and detailing of control structures, including detailed hydraulic analysis, leading to scour protection and stilling basin design. Dam spillway hydraulics can often be highly complex, therefore we adopt a tiered approach to hydraulic analysis to ensure the level of assessment carried out is proportionate to the design implications. Where necessary, we can go into the highest level of detail, using physical modelling and computational fluid dynamics to drive the design.



Vistula Dam Study, Poland

Arup is undertaking a feasibility study for a possible second dam on Vistula River, located in the protected area of Natura 2000. Our scope of work includes concept design, multi-criteria analysis of several locations and solutions, Environmental Impact Assessment, a cost benefit analysis and dam breach analysis.



Cheddar Reservoir Number 2, UK

Arup is providing advice on feasibility, planning and delivery of a new 6,000 Ml raw water storage reservoir at Cheddar, in Somerset, England. The new reservoir will be fed from Mendip spring sources close to the famous Cheddar Gorge show caves, and gravitate from there to the existing reservoir, located nearby.



Upper Thames Reservoir, UK

Arup provided project management skills and advice on the broad range of planning and consultation issues involved in Thames Water's proposal for a new reservoir. It would be the largest of its kind in Europe, with a base area of approximately 10 km².



Pickering Flood Alleviation Scheme, UK

Arup is undertaking detailed design of a large raised reservoir to operate as flood storage, attenuating the 25 year event at Pickering. The scheme is highly sensitive and public perception is paramount. The site borders an important SSSI and is bounded by a privately owned steam railway.



Lotsane Dam, Botswana

Arup has been engaged for the feasibility study, tender and construction supervision services for Lotsane Dam. Upon completion it will have a 30m high, 1,5km long earth/rockfill dam with an ungated 180m long spillway crest and an active storage of 42 million m³.



Foxwood Dam, South Africa

Arup is undertaking a detailed feasibility study for Foxwood Dam on the Koonap River in Adelaide. Our scope of work includes water resource assessments, environmental scoping, geotechnical investigations, dam design and agricultural assessments.



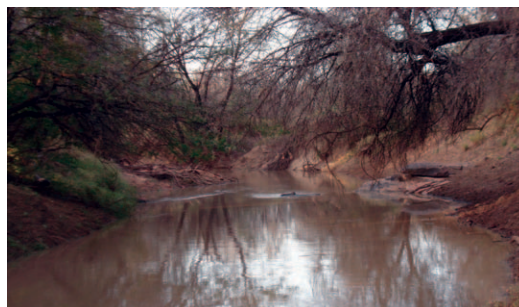
Murowa Dam, Zimbabwe

Arup provided full design and construction supervision of the mine water supply. The scheme comprised of water resource assessments to meet a high level of assurance of supply, an off river storage dam, a pumping station with an off take weir on the Runde River and steel and GRP pipelines.



Letsibogo Dam, Botswana

Arup was appointed in a Joint Venture for the detailed design and construction supervision of this 27m high rockfill dam and outlet works. This involved a detailed review of the hydrology, project optimisation and geotechnical assessment.



Lower Notwane Dam, Botswana

Arup undertook a pre-feasibility study to identify dam and off river storage sites on the Lower Notwane River and its tributaries. The river is one of the last non utilised major surface water resources in Botswana. Its catchment includes the capital Gaborone and other large conurbations as well as Gaborone dam and Bokaa dam.

Dam Safety Inspections

Regular inspection and supervision of existing dams is imperative in minimising risk and highlighting potential issues in a timely manner. This enables further studies or remedial works to be programmed before becoming critical to the safety of the structure. Arup has particular experience in:

- assessing the safety of existing dams
- undertaking risk assessments
- design and implementation of remedial measures
- dam break and inundation maps
- emergency planning
- expert witness
- construction supervision

We have undertaken a number of dam safety studies for portfolios of dams, which includes the Nurek Dam, the tallest dam in the world.

Arup also provide expert advice for emergency planning; risk reduction and have been called out to assist during incidents. A number of Arup staff and sub-consultants are licensed under the relevant statutes, for example to act as an All Reservoir Panel or Supervising Engineers under the United Kingdom (UK) Reservoirs Act 1975; or internationally, as Large Dams Panel Engineers. Arup staff have also acted as World Bank Dam Panel Experts on several international dam projects including the Rogun Dam project, which on completion will be 335m high.



Rogun Dam, Tajikistan

Arup is providing expert advice to the World Bank on dam engineering, dam safety and seismic engineering for the Rogun hydropower plant in Tajikistan, Central Asia. When completed, the 335m high Rogun Dam will be the tallest dam in the world. The Rogun hydropower plant will have a power generating capacity of 3,600MW.



Large Dam Safety Inspections, Zimbabwe

Arup was appointed by the World Bank to provide technical assistance to the Zimbabwe National Water Authority (ZINWA). Our scope includes the inspection of 25 large dams, a review of the legislative and institutional framework with respect to dam safety and the provision of recommendations for dam modernisation.



Expert Advice and Emergency Planning, UK

Arup has provided reservoir experts to undertake training and advice to Local Resilience Forums. The training included legislation; types of dam; and appurtenant works and incident management.

Dams and Reservoirs



La Ferme Dam, Mauritius

Arup carried out a performance and condition assessment on an existing dam, and developed a dam safety training programme which was delivered to the local client.



Confidential Chile Project

Arup was commissioned by an insurance client to undertake damage assessment and reporting on causes of damage to a hydroelectric dam, appurtenant works and power station, following the Chilean earthquake in February 2010.



Gorpley Dam Monitoring, UK

Arup designed a tailored survey methodology to ensure that any significant movement would be detected at Gorpley Dam. A combination of Terrestrial Laser Scanning (TLS) and contact theodolite survey was used to develop an accurate baseline and in detecting any movement between surveys.



La Mesa Dam, Philippines

Arup carried out a peer review including: safety evaluation and hazard categorisation; condition and performance assessment; hydraulic studies; structural and geotechnical assessment; seismic hazard assessment; sedimentation study and recommendations for rehabilitation works.



Statutory Inspections, UK

Arup provide Panel Engineers for Section 10 and Section 12 Statutory Inspections under the UK Reservoirs Act 1975. Our clients include the Environment Agency; Water Utilities; Councils; as well as numerous private individuals. We also have staff who are qualified internationally as Large Dams Panel Engineers.



Nutclough Reservoir, UK

In July 2012, Arup actioned an emergency call out of an All Reservoirs Panel Engineer following heavy rain and flooding in the Hebden Bridge area. Arup undertook an immediate site visit to assess the state of dam, reporting back to the client on remedial measures to be taken, both in the short and medium term.

Rehabilitation

Inspection of existing dams world-wide frequently reveals the need for remedial works. Most of the works are required because of the gradual deterioration of the dams and their associated structures/equipment, combined with the imposition of stricter requirements for flood, seismic and dam break analyses.

Rehabilitation works include:

- raising of earth embankments and concrete dams
- upgrading of draw-off towers and tunnels
- provision of new, enlarged spillways and intakes
- provision of emergency drawdown facilities
- strengthening works
- leakage reduction measures
- installation of instrumentation
- performance monitoring
- water quality monitoring / water treatment
- spillway modification

Arup make extensive use of advanced hydrological techniques, including both numerical and physical hydraulic modelling. This enables us to accurately route floods through the reservoirs and existing spillway structures. Increasingly these investigations are now supplemented by seismic and dam break analyses, which often did not form part of the original design for the existing dams.

We have been responsible for the design and specification of remedial, improvement, abandonment and discontinuance works at many existing dams and service reservoirs.



Lake Mead Intake, Hoover Dam, USA

Arup is leading the engineering design of a vital new intake tunnel at the lake, to safeguard future water quality and supply amid declining lake levels caused by drought. Arup's scope includes tunnel and shaft design, geotechnical engineering, hydraulics design and intake structure design.



Windleden Reservoir, UK

Arup provided a Qualified Civil Engineer under the Reservoirs Act 1975, to supervise the design and construction of a new spillway. The study included a hydraulic model test of the original masonry spillway and the design of a new reinforced concrete spillway.



La Ferme Dam, Mauritius

Arup is undertaking the detailed design for the rehabilitation and raising of a composite concrete/masonry gravity dam and earthfill embankment dam. We are also involved in the preparation of tender documentation and construction supervision.

Dams and Reservoirs



Mill Beck Reservoir, UK

A disused railway embankment in Market Weighton, was deemed to act as a large raised reservoir under the Reservoirs Act 1975. Arup provided reservoir safety advice, feasibility of options to pass the Probable Maximum Flood (PMF), outline design, consultation, environmental impact & detailed design.



Threipmuir and Harlow Reservoirs, UK

Arup was commissioned to support modification works to two reservoirs in a sensitive natural environment. This provided increased flood attenuation and storage capacity as part of the Water of Leith Flood Prevention Scheme.



Ulley Reservoir, UK

In June 2007, one of the spillways at Ulley reservoir failed. Arup managed the emergency works to stabilise the dam and carried out investigations to determine the extent of rehabilitation works. We undertook detailed design and construction supervision of a new spillway, rehabilitation of dam core, rip rap and draw-off pipework.



Trebeddrod Reservoir, UK

Arup provided detailed design to increase the spillway capacity at this Category A reservoir. We developed the preferred engineering option, undertaking all necessary investigations and environmental surveys for the works. Flood reduction benefits were conserved through use of multi-stage overflow weirs.



Bransholme Surface Water Lagoon, UK

Arup undertook a review of surface water flooding and developed options for increasing capacity of an existing surface water reservoir; addressing recommendations made in the interests of safety under the UK Reservoirs Act 1975. We prepared outline designs, tender documentation and undertook construction supervision.



Washburn Valley, UK

Arup undertook detailed design, hydrology, risk and value management, management of the planning application, tender process and construction supervision for three major reservoir safety schemes in the Washburn Valley. Works included raising of the crest levels, reconstruction of spillway bridges and increasing spillway capacity.

Hydropower

A robust and thorough assessment of technical, environmental, and economic issues is essential to the successful delivery of hydropower projects. Arup provides clients with an integrated package of skills that address often complex and detailed design issues, including:

- strategic site evaluation and site selection, engineering and environmental feasibility assessment, project management, hydropower resource assessment, economic analysis and access feasibility
- design & assessment planning, project management, environmental impact assessment (including all specialist skills e.g. sustainability, ecology, fisheries, archaeology, landscape, noise, etc), turbine selection, control system design, grid connection, consents and licensing, flood risk assessment, access design and geotechnics
- project implementation including project management, procurement, ecological management planning and monitoring, habitat creation and technical advice to financial institutions



Tsitsa Falls hydropower, South Africa

Arup reviewed a potential scheme for generating upto 100MW of hydropower. The scheme included large Roller Compacted Concrete (RCC) dams and hard rock tunnels. Our scope included water resource assessments, engineering concept development, energy generation, capital cost estimating and economic modelling.



Zengamina mini Hydropower, Zambia

Arup provided site engineering and management for the 700kW hydro electric scheme. The project acts as an independent self sustaining community minigrig/utility for an impoverished area with significant pressure of population increase, relying mostly on subsistence farming.



Mini Hydropower, Armenia

Arup is reviewing five mini hydropower projects, which are currently at different stages of development in Armenia. We are assessing whether the projects have been executed in compliance with technical and engineering international best practice. The five schemes selected for this project will have installed capacities in the range 1.4MW to 3MW.



Botterkloof and Kruisvallei Mini Hydro, South Africa

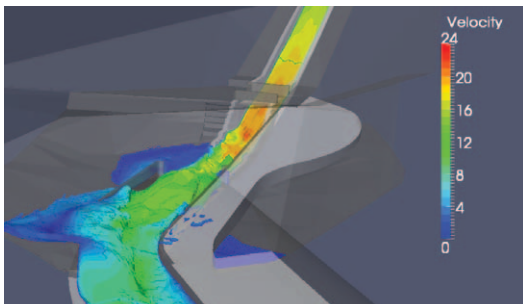
Arup was appointed by Rand Merchant Bank and the Development Bank of Southern Africa to undertake due diligence reviews of two separate 4MW mini hydro schemes on the As river in South Africa. The schemes are promoted by two separate developers.

Computational Fluid Dynamics

Computational Fluid Dynamics (CFD) software packages provide a means of mathematically modelling complex flows within and around physical objects and scenes. These packages can be used where traditional hydraulic engineering cannot represent the complexity of the flows. Arup has tested CFD approaches against physical modelling on a number of schemes and can confidently represent the complex geometries, optimising the design more readily.

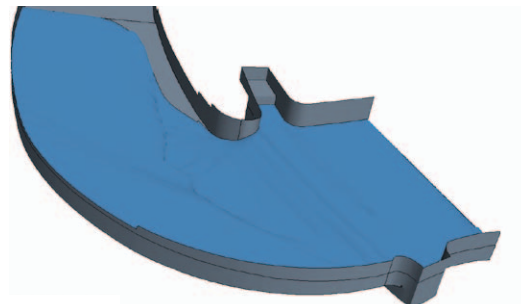
We make extensive use of physical hydraulic modelling for complex 3D flow problems such as: reservoir spillway design; assessment of potential structural failure mechanisms; water quality modelling and flow circulation. This aids the development of detailed design solutions.

Arup is leading the research and use of Terrestrial Laser Scanning (TLS), which augments our in-house capability. TLS data acquisition techniques have the potential to provide CFD models with data that is of sufficient high quality to not be a significant source of error in flow prediction; thereby ensuring channels and structures are no longer under-represented in CFD models.



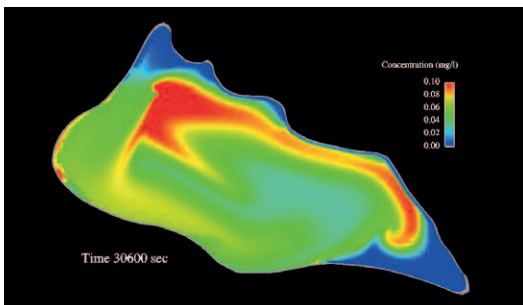
Carno Reservoir, UK

Arup carried out a CFD study to assess the hydraulic capacity of the spillway and the impact of a proposed road crossing under various flood event scenarios. The modelling provided the flow properties of the spillway, the stilling basin, the culvert channel and part of the downstream natural channel under 100 year event and PMF.



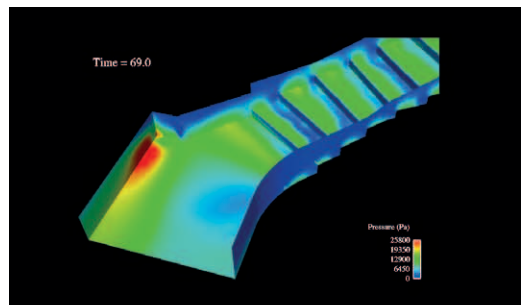
Ulley Reservoir, UK

Arup used Terrestrial Laser Scanning (TLS) and the site monitor software to capture any movement during the emergency situation that resulted in the 2007 floods. The TLS survey was used to construct a wireframe model of the spillway, which was transferred into CFD software and allowed 3D analysis of flows down the spillway.



Reservoir Circulation, UK

CFD modelling techniques were used to predict and modify water circulation patterns within a reservoir, in order to react to water quality issues in the river channel.



Boltby Reservoir, UK

CFD study of the spillway at Boltby, following an extreme flood event in June 2005, which resulted in severe damage of the spillway channel and stilling basin.

Hazard Indexing and Risk Assessment

The reliance on ageing dam structures and their associated apertunance works results in increased maintenance; remedial works; major civils works and possible damage and failure during extreme events. The assessment of the risk a dam structure poses to the downstream population and the likelihood of failure of that structure is imperative in the management of our dams. Within the UK in recent years, there have been incidents with ageing masonry spillways; undersized spillways due to changing hydrological conditions and issues with the fabric of historic embankment dams.

Arup has been involved in developing systems of hazard indexing and risk assessment for dams to assist in the programming of maintenance works, surveillance schemes and emergency plans. Our analysis incorporates not only details of the dam, but also information on the operational reliability of gates and hoists, for example, and reviews of instrumentation data. We have capability in undertaking risk assessments on dam structures worldwide, including specialist seismic assessments.



QRA of Embankment Dams

The study assessed and categorised risk across nearly 100 dams owned by the client. This provided an overview of risk across the portfolio and identified the highest risk dams, ranked using alternative criteria such as level of risk, consequences, annual probability of failure and management of the risk.



Wloclawek Dam Breach Modelling, Poland

Arup is undertaking a dam break analysis on the proposed new dam across the Vistula river as well as the existing Wloclawek dam. The analysis will consider breach scenarios, following Modes of Dam Failure research and define the inundation envelope of the downstream flood wave.



Emergency Drawdown Study, UK

Arup undertook a regional drawdown study on our clients' portfolio of reservoirs, in accordance with the UK Department for Environment, Food and Rural Affairs (DEFRA) Draft Engineering Guide to Emergency Planning for UK reservoirs.



Resilient Cities, UK

In order to assess Sheffield's resilience to the effects of climate change, Arup developed a toolkit which helped identify systems that would be affected and what the key interdependencies are. We are now working with the Council, stakeholders and communities to implement the action plan.

Technical Research

Arup has extensive knowledge and experience in the design, construction and performance of dams of various types and the associated fields. This enabled the firm to carry out research contracts for various bodies in the United Kingdom. Our clients have included: CIRIA; BRE; Scottish and Southern Energy Plc; DEFRA and private water companies.

Our research has covered a wide range of dam and reservoir specific issues, including: Small Embankment Reservoirs (CIRIA); Field Testing Techniques for Embankment Dams (BRE); Reinforced Grass Spillways (CIRIA); Stepped Block Spillways (CIRIA); Concrete and Masonry Dams (CIRIA); Valves and Pipework (CIRIA); Performance of blockwork and slabbing protection (with HR Wallingford); Modelling techniques using CFD (private); Application of CFD to hydraulic structures (private).



Terrestrial Lidar for CFD Modelling of Reservoir Spillways

Arup developed a methodology by which scenes, objects and structures could be measured using TLS, represented in a spatial model for stable CFD modelling. A series of repeatable stages are then created which allows future projects to be conducted in an efficient and consistent way.



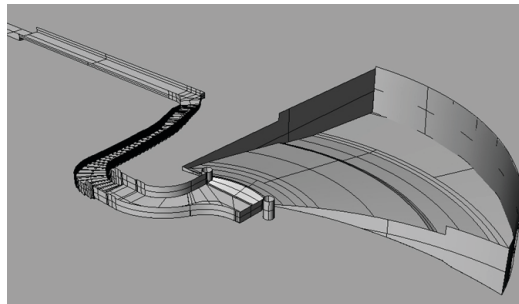
Scoping Study on Modes of Dam Failure and Measuring and Monitoring Techniques, UK

Arup carried out a study on the modes of dam failure for earth embankments in the United Kingdom. The scoping study focused on two areas: modes of failure of dams and failure of monitoring techniques; and monitoring and measuring methods for embankment dams.



International Hydropower Association Sustainability Protocol

Arup facilitated two phases of consultation and development on the International Hydropower Association's 'Sustainability Protocol', for the IHA's Hydropower Sustainability Assessment Forum.



Application of CFD Modelling to Hydraulic Structures

Arup analysed two spillways, highlighting the objectives and reasoning behind the application of CFD to aid the design. The case studies showed CFD can increase confidence in the design decisions made and aid understanding of the physics of the structure at full scale.

Sustainability Appraisal and Environmental Assessment

Hydropower, dams and reservoirs, developed and managed sustainably can provide national, regional, and local benefits, and have the potential to play an important role in enabling communities to meet sustainable development objectives. Sustainability impacts may arise at any stage of a project lifecycle, including the construction, commissioning and operation of a dam as well as the decommissioning stage. Planning and funding decisions need to be informed by sustainability criteria which achieve a balance between economic, social and environmental values.

Sustainability is a key component of our dams and reservoirs project work. In 2009, Arup facilitated two phases of consultation and development on the International Hydropower Association's 'Sustainability Protocol' for the IHA's Hydropower Sustainability Assessment Forum. The protocol sets out a process to assess, and improve, the contribution to sustainable development that a hydropower project could offer.



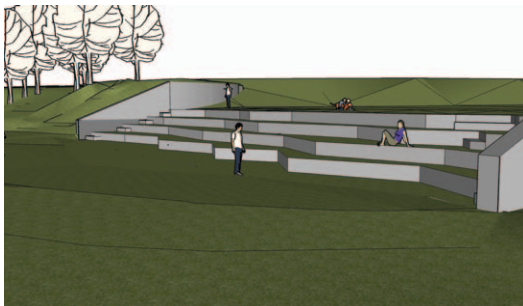
Vistula Dam, Poland

Arup is undertaking an environmental impact assessment (EIA) for the proposed Vistula Dam. The upstream dam was constructed in 1970 and is located in the protected area of Natura 2000. This is an extremely environmentally sensitive project, as the existing reservoir contains large amounts of potentially harmful sediments.



Havant Thicket, UK

Arup managed ecological issues during planning for a new 19million m³ reservoir, particularly the loss of over 15 hectares of semi-natural woodland habitat and rare species. The mitigation strategy was devised to improve forestry biodiversity as a result of habitat creation and the protection of the existing forest edge.



Mill Beck Balancing Reservoir, UK

Arup delivered the detailed design of a new spillway. The site is in the heart of the local town and required a socially inclusive and flexible design approach, along with consideration of environmental constraints to deliver optimum hydraulic performance, whilst enhancing the aesthetics of the downstream space and local environment.



Cheddar Reservoir Number 2, UK

Arup are producing a high level master plan setting out how the scheme will be delivered. This will map out the recommended strategy and will cover all aspects of the scheme including consultation, environmental surveys and studies, planning, land purchase, design, construction and operational issues.

Geotechnical Appraisal and Seismic Analysis

Arup's geotechnical engineers and engineering geologists provide specialist design, advisory and management services and also provide the UK representative to the ICOLD seismic technical committee.

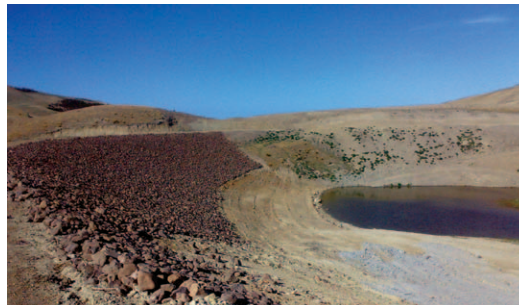
Arup has expertise in a wide portfolio of specialist skill areas, such as geology, seismology, and risk analysis and we have used these skills successfully on an extensive portfolio of projects. We can provide a wide range of detailed analytical skills, access to resources and to the full spectrum of geo-hazard, seismic hazard, seismic risk and earthquake engineering skills.

We have been involved with a number of projects in the United Kingdom, the United States, Greece, New Zealand, Southern Africa, Turkey, the Philippines and Indonesia, to assess the safety of dams and reservoirs under seismic loading. This has involved investigations into the behaviour of both embankment dams and concrete gravity dams using pseudostatic, deformation and dynamic analyses.



Evinos Dam, Greece

The 124m high earthfill dam was perceived to have certain deficiencies in the design by the EU. Arup made recommendations for changes to the hydrology and flood assessment, the spillway tunnel, the seismic aspects, risk assessment and natural slope stability and the slope protection.



Haldon Dam, New Zealand

Arup is acting as expert witness for Haldon Dam. Our scope covers dam safety, geotechnical and seismic appraisal of the existing dam. The dam structure is 20m high and retains 250,000m³ of water.



La Mesa, Philippines

The La Mesa Dam is a 30m high earth fill embankment which was constructed over 80 years ago to form a reservoir. It is part of the strategic water distribution network for a large portion of Metro Manila. Arup carried out a peer review of a seismic and structural assessment of La Mesa Dam, intake structures and reservoir.



Confidential Project, Chile

Arup was appointed to carry out investigations on a HEP dam project in Chile, following the 2010 earthquake. We reviewed the project design documentation, undertook site inspection of the principal areas of damage, and conducted an analysis to determine whether the damage was earthquake related.

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