The modern dam engineer

Like many industries, the dam industry is influenced by both internal and external factors which can prompt change. IWPC & DC was interested in finding out if such elements have affected the engineer’s working life when inspecting dams. We asked members of the industry for their own thoughts about the role of the modern dam engineer: Has this changed in recent years? Are engineers faced with increased challenges? And will this role continue to evolve?

Craig Goff, Principal Dam Engineer, HR Wallingford, UK

While the role of dam engineer has definitely evolved, the fundamentals of the dam management, remain the same. Of course, we now have more advanced electronic instruments for monitoring, and thanks to this technology, huge volumes of data to analyse, compared to what was previously available to the dam engineer. So that’s definitely changed, but these are still no substitute for hands-on physical inspections, for engineers using their personal engineering judgement to assess a situation. Some external factors have forced changes. Extreme weather events will naturally lead to more frequent examples of severe flooding. In most cases, dams are already well built to withstand these eventualities, but the incident in South Yorkshire in England in 2007, when hundreds of people were forced to evacuate their homes out of flood flows from the spillway eroded a large hole in the downstream toe of the dam at Olby Reservoir near Doncaster. This event demonstrated for the first time that the public awareness that dams can pose a risk to the local community. And in 2010, change to legislation governing reservoir safety in the UK, the Reservoirs Act 1975 – moved the industry from a standards-based approach to more of a risk-based approach. This is a good example of this.

What has been the impact of retiring engineers and generational knowledge transfer?

There are many suggested causes for the predicted decrease in dam engineers in the UK, including perception in the industry that the required experience demanded is no longer achievable due to the type of project roles typically available to aspiring engineers in a more globalised environment. We have the opportunity to embrace exciting new technologies, to learn ever more about innovation in the fields of leakage detection, monitoring and quality control, detailed design and construction management, and advances in dam break analysis, we are perhaps simplifying legislation.

With more and more development downstream and advances in dam fissile analysis, we are seeing more reuse and repurposing of dams with regard to the consequences of failure and survival, spillway enlargement and enhancement works. Rationalisation of smaller treatments in larger works supplied from regional resources and ‘ring mains’ has led to many of the smaller dams being adapted and their use extended, which is increasing the required experience demanded is no longer achievable due to the type of project roles typically available to aspiring engineers in a more globalised environment. We have the opportunity to embrace exciting new technologies, to learn ever more about innovation in the fields of leakage detection, monitoring and quality control, detailed design and construction management, and advances in dam break analysis, we are perhaps simplifying legislation.

Craig Goff has been involved with the management of dams and reservoirs for over 15 years, working initially with Herne Grove Dam and Impaction Team, and today as Principal Dam Engineer at HR Wallingford. Craig is the lead author of the Environment Agency’s 2009 ‘Owners Guide to Reservoir Safety’, an active Supervising Panel Engineer working with all types of reservoir owner. Earlier this year, Craig became the lead author on a new Dam Safety Handbook produced for Welsh Water.

Andy Hughes, Director of Dam Engineering, Atkins

I have been formally examining reservoirs as a地方政府engineer wanting to consider how one integrates their liabilities and hence, in my opinion, we will see an increasing number of streams to downstream reservoirs in the future. Over the past 20 years I have been seeing a growing need for constant change and improvement to the role of the dam engineer in China. Specifically, the lifelong responsibility has focused on the function and safety of major dams. The dam engineer takes the responsibility of the project in its full lifetime cycle and will work through all phases of the development of a hydropower project from feasibility, financing, basic design, monitoring and quality control, detailed design, construction, operation and maintenance, and decommissioning.

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Yeu Jiqnun, Vice Chief Engineer, PowerChina Huadong

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Underground Powerhouse of the 4GW Jinping 2 hydropower plant in China.

Andy Hughes is responsible for the Africa business in Damms and Q2G’s hydropower business. His career experience includes being Resident Engineer on the Sydney Olympic Dam, a number of China projects and now he is currently overseeing a number of hydropower projects, including the development of a new hydro power plant at Ginninderry Reservoir in York and at a few dams in the Lake District, plus the rehabilitation of a hydro power plant and dam in Sri Lanka.

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Yeu Jiqnun is Vice Chief Engineer at PowerChina Huadong. PowerChina Huadong was established in 1984 as a joint venture between China and the United States, and later became a fully owned subsidiary of PowerChina Corporation, one of the largest construction contractors in the world.

The position of Chief Engineer is a highly respected and influential role in China. Chief Engineers are typically involved in all aspects of a project from planning to construction, and their decisions can have a significant impact on the outcome of a project.

Yeu Jiqnun is the Vice Chief Engineer at PowerChina Huadong, an experienced and respected engineer in the hydropower industry who has been involved in many significant projects in China.

China has a long history of hydropower development, and the country has been at the forefront of innovation in this sector. Yeu Jiqnun's experience and expertise in the field of hydropower engineering is valuable in ensuring the successful development and operation of hydropower projects in China and around the world.

In his role as Chief Engineer, Yeu Jiqnun is responsible for overseeing the entire project, from planning and design to construction and operation. He is also involved in the development of new technologies and methods, and he works closely with other engineers and stakeholders to ensure the project meets its goals and objectives.

Over the years, the role of the Chief Engineer has evolved, and Yeu Jiqnun's role is highly respected and influential in the industry. His experience and expertise in hydropower engineering are valuable in ensuring the successful development and operation of projects, and he continues to play a crucial role in advancing the field.

With a strong background in hydropower engineering and a proven track record of success, Yeu Jiqnun is well-positioned to lead the way in the development of innovative and sustainable hydropower projects in China and beyond.
Dam inspection | Special feature

Over the past 20 years, there has been enormous innovation and development in information, construction equipment and materials such as the application of the roller-compacted concrete dam characterized with lower cost content, less rapid and faster construction. With new technology and continuous development, a dam engineer will certainly continue to be an important evolving role.

Marius Jonker, Specialist Dams Engineer, Entura, Australia

Although dam safety has always been a critical goal for the dam engineer, modern dam safety programmes really came into effect in the 1970s, particularly after the catastrophic failure of Teton Dam in 1976 in the US state of Idaho. In the 70s and 80s the role of the dam safety engineer evolved as countries enacted dam safety legislation and developed regulations and procedures for conducting dam safety inspections. Since then, we’ve seen further development in dam safety management and ongoing change to the role and qualifications of the dam engineer undertaking safety and surveillance activities. These changes mainly relate to the following factors:

■ **Enhancement in dam engineering technology:** In the last 20 years, dramatic measures to ensure the safety of dams have improved, such as those for external erosion protection, and corrosion protection in ground anchors. Modern materials and technology have enabled faster and more economical construction, such as the use of roller-compacted concrete and high-technology construction plant.

■ **Methods for analysing dams:** Methods for analysing dams have also become more sophisticated with increased computing power and more advanced analysis software, in particular finite element model and stress analysis for seismic loading. It is no longer acceptable for a dam safety engineer to rely only on visual inspection and monitoring data.

■ **Modern dam engineers need to understand the underlying design philosophy and keep up with the latest construction practices and their impact on dam behaviour.** We also need to maintain an enhanced understanding of the performance of dams and appurtenance structures under various load conditions.

■ **Better understanding of failure modes and risk:** Modern dam safety risk assessments have become standard practices over the past two decades as we’ve increased our understanding of risk. Risk assessment now defines the dam surveillance scopes and programmes. In particular, the last 20 years have seen significant developments in analysis of failure modes and effects. Failure modes analysis, although initially used in risk assessments and the design of new dams and dam upgrades, is now the foundation of a risk-based dam safety and surveillance programme.

■ **When assessing failure modes, the dam engineer needs to work alongside geologists and construction engineers to understand the impact of construction and to identify features that are not readily visible through visual inspection but could affect the safety of a dam, such as the foundation conditions that contributed to the spillway erosion at Oroville Dam in the US in 2016.**

■ **Improved monitoring technology:** The modern dam engineer has access to contemporary geotechnical and structural monitoring instruments, which are useful for interpreting the behaviour of a dam. In recent years, electric instruments and automated data acquisition systems have enabled real-time monitoring of dams and base continuous time history records for the dam engineer to evaluate. However, the collection, organization, interpretation and presentation of such data can be a time-consuming challenge for dam owners and dam engineers. Often such data is stored in multiple locations and formats, or different types and models of instruments are used with varying methods of collecting data. Also, the software used to collect and process the data may not be compatible.

■ **Some technological advances do hold promise for streamlining the collection and storage of data, such as the application of the roller-compacted concrete dam characterized with lower cost content, less rapid and faster construction.** Improved monitoring technology: The modern dam engineer has access to contemporary geotechnical and structural monitoring instruments, which are useful for interpreting the behaviour of a dam. In recent years, electric instruments and automated data acquisition systems have enabled real-time monitoring of dams and base continuous time history records for the dam engineer to evaluate. However, the collection, organization, interpretation and presentation of such data can be a time-consuming challenge for dam owners and dam engineers. Often such data is stored in multiple locations and formats, or different types and models of instruments are used with varying methods of collecting data. Also, the software used to collect and process the data may not be compatible.

■ **Environmental factors:** For dam engineers, consideration of environmental factors is nothing new. However, the potential for changes in weather patterns, and the consequences of these changes, are increasingly important concerns for the modern dam engineer, as well as the complex changes in the size and frequency of rare flood events when evaluating the required spillway capacity, or investigating the adverse impact on embankment dams during long periods of low rainfall, which could lead to erosion and cracking of the material.

■ **Economic factors:** Some large dams are now more economic to build than to keep in disrepair or inadequately monitored. However, the limited budgets of public and private sector dam owners can constrain their ability to fund comprehensive surveillance and maintenance and dam remediation works. This places increasing pressure on the modern dam safety engineer, who should recommend a prioritized programme of risk-reduction work within the context of the owner’s financial constraints, to ensure that risks are adequately managed.

■ **Community awareness:** Dam engineers are increasingly required to consider the safety of dams in the context of the community’s cultural and heritage interests. Community awareness of the safety of a dam, or of planned works to improve safety, continues to increase. With the advent of social media, public awareness is now much more continuous and global. This is a challenge for modern dam engineers, who are not often trained in community engagement.

■ **Safety:** Over the last few years, workplaces and health and safety requirements have had a significant impact on dam-engineering practice. Although new responsibilities, the regulatory requirements to ensure safe construction, operation, maintenance and decommissioning have increased, requiring modern dam engineers to be aware of legal requirements and safety standards beyond their core skills.

■ **Generational change:** Ten to twenty years ago many dam engineering organisations experienced the ‘bathtub’ effect in the age distribution of their workforce, with a general shortage in the 10–20-year experience bracket. As the workforce ages, engineers with 20+ years experience are moving towards retirement, taking with them the knowledge of the generation who designed and constructed the dams that are now more than 50 years old and may still retain original technology. The modern dam engineer therefore faces a dual challenge: not only to stay up to date with the latest technology, but also to maintain an understanding of older equipment and instruments.

With twenty-five years of experience in dam engineering and related fields, Marius Jonker, is very familiar with the evolution of dam projects, including dam safety in large-scale water storage, and dam safety systems and sub-systems. As well as the dam safety projects including dam safety portfolio management, facility reviews, individual dam and portfolio risk assessments, safety inspections, flow monitoring, surveillance, operation, maintenance, and dam safety emergency planning.

Rebecca Knott, Tim Logan and Dan Forster, Dam Safety Intelligence, New Zealand.

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Dam inspection | Special feature

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Dam inspection | Special feature

Rachel Pether, Project Director for Dams and Reservoirs, Black & Veatch, UK

The recent rainfall events across the UK have brought about many changes, but not, in my opinion, significantly changed the role of Dam Inspectors.

What has become more apparent is a general shift from relying entirely on an individual All Reservoir Panel Engineer’s (APPE) judgment, to a more presentational basis. For example, clear documentation of observations and issues, as taken from the site, has become an expected practice.

However in general, the system of periodic inspections and safety review by the ARPE has remained largely unaltered. Despite certain external factors have definitely influenced the role of dam engineers. Climate change and increasing rainfall events are one such fact, in that it has become more important in relation to what happens in the vicinity of the dam. With Alaska Veatch having undergone a change in ownership, it is now clear that risk could be greater of sliding and instability of slopes which were not really such a great concern in the past. This also led to greater vigilance associated with flooding and debris and sediment, in many reservoirs worldwide.

Anchors Schlesinger, President of the International Commission on Large Dams

I think the role of the dam-safety engineer has changed considerably in relation to the monitoring equipment we use today. Engineers have to handle complex and big data from different modules, such as automated and remote monitoring, which is obtained at regular intervals and sent directly to a computer. Ultimately the development of such equipment had led to the development of new technologies which will have a significant impact on the inspection process.

In the past the dam engineers had to read scientific reports, with the data being sent to a platform where it could be interpreted by a person or a computer. The dam inspection today is a completely different process.

Today’s engineers have to handle much more data, sometimes obtained at increasingly more regular intervals, and the need to have to handle large and complex data sets means they have to have a good understanding of the data, handling equipment, remote sensing, computer and surveillance etc. Things have also changed in this respect, especially with high quality, it was difficult to follow up any development of new technologies and new opportunities to use the traditional and tested methods.

I do think that accountability in the role increased more over the years. Certainly there is a greater public awareness of risks, and this is something that both dam owners and engineers need to respond to. The modern dam engineer is increasingly going to be in a position to design, develop and implement new technology and ensure that it is properly installed and calibrated so that it can answer the question of the dam safety engineer.

The challenge is how to ensure that all this data is presented in an intuitive way to a wide audience – so gone are the days of needing the encyclopaedic memory. This is a real bonus for technical teams working on issues – it can be less helpful if it’s in the public domain and incorrect information is spreading exponentially during incidents. A key task for dam safety engineers is to ensure that all the information about a dam to be presented in an intuitive way that instruments cannot – at least not yet.

Improvements in technology have led to health and safety improvements by eliminating the need to access confined spaces to measure gauges or seepage. Gas detectors allow us to understand the environment we are entering or working in, without the need for deformation monitoring, bat surveying for reservoirs and canal surveys, drone inspections of portable and mobile ladders – and significantly improved standards for health and safety in the workplace and legislative requirements on all activities in a workplace involving dam inspection. This has led to release of funds to replace unsatisfactory access systems altogether.

Rebecca Knott, General Manager/Principal Engineer, Tim Logan, Principal Dam Safety Analyst, and Dan Forrester, Principal Dam Safety Engineer with Dam Safety Intelligence in New Zealand – a disbanded group of dam engineers, scientists and geologists focused on the safe management of dams and other water infrastructure, based in Wellington, New Zealand. They have 100+ years of dam experience between them. damsafe.co.nz

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Anchors Schlesinger is the President of the International Commission on Large Dams and of the International Commission on Large Dams in China. He was a professor of engineering and water resources at the University of Hong Kong and was involved in the design of many hydro-electric power projects around the world such as on hydraulic engineering and management. In 1997 he was named full professor and became Director of the Chair of Hydraulic Construction in the Civil Engineering Department of the Swiss Federal Institute of Technology in Zurich. Former chairman of the Swiss Committee of Dam Safety and of the Swiss Committee on Flood Protection, he formerly served as vice-president of ICOLD and was elected president in 1995.

Piano key weir at Black Eak Reservoir in Scotland, a world first – Courtesy of Black & Veatch

Anchors Schlesinger, President of the International Commission on Large Dams

I do not think that generational knowledge transfer is a problem as more often than not young engineers work with a more experienced engineer to ensure continuity. One advantage that younger engineers do have is that they are much more knowledgeable about how to handle ‘big data’. They’re not afraid of it and don’t see it as a problem. This is one positive way the role of the modern dam engineer has evolved.

However, in some developing countries perhaps engineers can feel a little flooded by the volume of data. They need to have the ability to be able to sort this data to get good information from it. For example, in Switzerland every year a dam engineer responsible for the dam has to present reports on how the dam is behaving based on the readings done by the dam’s inspectors. Switzerland has recently collaborated with China to carry out training for this in the framework of Swiss-Chinese cooperation in the domain of hydropower (The dam inspection programme).

China has so many dams with many measurements but sometimes not always data available. It is important to develop an assessment report to monitor dam behaviour. The involved Swiss experts on dam safety have shown them how it is done in Switzerland and shared their experience and expertise. These procedures are very important to ensure that engineers are not overburdened by data.

Needless to say, the role of the modern dam engineer has embraced a greater variety of competencies. Those who carry out monitoring activities will be also able to be the first to analyse the data.
Craig Scott, Africa/Europe Dam and Hydropower sector leader, MWH, now part of Stantec

I don’t think the role of the dam engineer has changed significantly over the last 80 years or so. Many owner organisations still prioritise dam safety, and the fundamentals of dam safety have not really changed. Innovation in dams after dam entities, and the private development of many dam structures has led to more internal owners dam safety work. I have seen a move away from very formalised BPA type inspection processes to more reliance on individual and more experienced dam safety experts.

The development of national standards or legislation has been the biggest driver of change. I have seen owners enhance their own dam safety legislation, enhanced environmental legislation, and become party to global environmental treaties. Each has developed its own unique approach to grappling with technical, environmental and social aspects of dam related infrastructure. Structures for irrigation, water supply, and flood protection are increasing with a lesser influence of hydropower related dams. The recent draft ICOLD bulletin on increasing with a lesser influence of hydropower safety, and the fundamentals of dam safety have

Mano Dam and hydropower project on the border of Sierra Leone and Liberia is a major project which is currently under consideration, but with significant environmental constraints that are being evaluated to determine if the project is environmentally and socially viable.

Sharon Tapia and Erik Malvick, California Division of Safety of Dams, US

As a result of the Lake Oroville spillways incident in February 2017, dam safety regulations in California were strengthened. The State Legislators and Governor to require flood inundation maps and Emergency Action Plans for all dams and the California Division of Safety of Dams (CFS) modernised its personnel, staff, and systems for dam related hazards classification. Additionally, the Governor ordered comprehensive re-evaluations of dam approach spillways and floodways, to bolster dam safety across the State.

Significant regulatory advances and increases in funding often occur following major incidents or systematic changes. It makes the role of the modern dam engineer so crucial, to assist dam owners in fulfilling their legal responsibilities whilst avoiding any harm and ensuring the safety of downstream residents.

California’s Dam Safety Programme began in 1929 and has grown to become the largest and most comprehensive program of its kind in the world. California’s Dam Safety Programme includes oversight of dam safety at more than 1,250 dams statewide ranging in height from six feet to 770 feet tall and storing up to 3.5 million acre feet of water.

In California, more than 70% of the dams are directly related to the standards of practice and design loading conditions have been revised to ensure that the system of practice is consistent with current standards of practice. To date, these lessons learned related to physical factors have emerged from the California Division of Safety of Dams (CFS) as follows:

1. Physical inspections are not sufficient to identify risk and manage safety.
2. Comprehensive reviews of the original design and construction information do not support current standards of practice.
3. Owners must recognize that meeting regulatory requirements is an insufficient standard for managing the public and owner’s risk.

Regular visual inspections and maintenance activities performed on dams and their appurtenant structures are necessary for long-term performance of the dam and its appurtenant structures are needed, ensuring the safe performance of the system and avoiding the risk posed by the dam and its structures on public safety.

Covenants are now having a major role in dam safety. The role of the dam engineer today is much more than a dam inspector. It is a role that contributes all the way to the dam and its upstream, and proposes solutions to the challenges faced by many dam owners. Dam owners rely on their engineers to consider future demands, like climate change, environmental factors, or public expectations, that are placed on the operation of reservoirs, dams, and their appurtenant structures. With the regulatory impact that the Lake Oroville spillways incident is now having on the dam safety industry, the role of the dam engineer has never been more critical.

The consequences of dam failure can be serious and whilst this has not fundamentally changed, the public acceptance of risk I believe has reduced as the benefits of dam has become more normalised and sometimes forgotten. This issues affects many industries. Related industries such as insurance for cover of owners and advisors has changed and tightened leading to greater costs, and also a greater reliance on expertise as a form of mitigation to ensure dam safety compliance.

Photo of the primary spillway at Oroville Dam on September 22, 2017, under construction as part of the recovery project in response to the February 2017 incidents (photo courtesy of California Department of Water Resources).

Large reservoirs in the US are covered by national safety legislation which dates back to the 1930s. While one can lose their lives because of dam failure in the UK since then, we cannot be complacent. The mandatory periodic safety inspections by specialist engineers has been a cornerstone to the effectiveness of the legislation. There is no doubt that the role of the dam inspection engineer in promoting dam safety has changed over the years and will continue to evolve. For example, the amount of background information available today to the inspecting engineer has greatly increased over time. Where once the only available information might have been construction drawings, the inspecting engineer may have to also review various studies, reports, investigation data and monitoring statistics to inform their deliberations. The emergence of numerical engineering tools addressing the like of flood and seismic risk or quantitative risk assessments has promoted a consistent approach, however it has also introduced the scope for engineering judgement. It can be challenging to decide between these gaps, the reasons are complicated but in making decisions which effect dam safety.

Alternatives to the old inspection and safety information used in coming to conclusions

Changes in legislation which stipulate minimum reporting requirements

Increasing the availability of data and guidelines documents to consider

The need to set out the conditions of the inspection and safety information used in coming to conclusions

Typical CFD modelling application for a spillway.
Some aspects of the reporting are relatively new. For example, inspection reports would once normally confine discussion to matters of the intrinsic safety condition or the physical condition of structures. However, these days they also typically cover matters which could affect the responsiveness of the owner to deal with an incident, the health and safety implications of reservoir operations and environmental considerations. Reporting is undoubtedly more holistic now than ever before.

Advances in digital technology and modelling capability also continue to change what dam owners can expect from an inspection report and related research. Aerial imagery is now widely available and can provide insight to the structural and seepage performance of dam embankments. The tools available in determining seepage paths have matured and their application can save considerable costs in scoping targeted remedial works. The application of computational fluid dynamics (CFD) software can greatly improve the efficiency of developing optimal remedial or improvement works, which has led to a reduction in the number of physical models used in the industry. Figure 2 shows an application of CFD in dam safety studies.

Another factor to consider is the decline in dam building across Europe in recent years, which has had an impact on the number of qualified inspecting engineers. In the UK, a survey was recently conducted to project the possible decline over the coming decades. Figure 3 shows the results of the survey.

The increasing demands on inspecting engineers and their decreasing number mean that urgent succession planning is needed to keep our dams safe. Individual organisations and the British Dam Society are working to help engineers gain the experience they need.

Jianping Zhou, Chief Engineer, PowerChina

Dam cascades along rivers in both developed nations and some developing nations, play a crucial role in flood control, power generation, irrigation, water supply, shipping, leisure and tourism. Meanwhile, the safety of these dams and their cascaded reservoirs have become a focus of social attention due to the increasing uncertainties caused by extreme climate conditions, floods, earthquakes, geological disasters and deteriorating materials and structural performance.

Dam engineers play an indispensable role in guaranteeing dam safety. They are needed in areas such as river development planning, dam design, construction and safety management. The dams should fulfil all expected functions with good economic feasibility, convenient condition for construction and operation and maintenance, environmental friendliness, and sustainability, while the safety is guaranteed. Dam safety is a concern for the whole life cycle of the dam, not just in-service period.

The dam is the most important structure in the water or hydropower project. The feasibility of the complex often depends on the reliability and economic feasibility of the dam. However, dams are not standardized structures. Their design and construction schemes have to take into consideration of the complicated engineering environment and carry out extensive and in-depth investigations and researches in multiple sectors, disciplines and fields on the issues such as meteorology, hydrology, topography, geology, natural construction materials, river sediments, and ecological environment to realize the functions such as water retaining, water discharge, flood control, power generation, water supply, navigation and ecological environment protection. Dam engineers should identify and analyse the risks, assess the dam work condition and the potential threats, and determine the corresponding technical schemes and countermeasures, applying their professional knowledge and engineering experience and modern engineering technology and computing analysis technology.

In dam safety management, the work of dam engineers helps to nip the potential risks in the bud. Dam safety management requires professional dam engineers to make analysis and comparisons of the monitored data, assess the dam operation status and trends, and improve warning and precautionary indicators. As the service period of dams become longer, there are more factors to be taken into consideration, such as the ageing and deteriorating of dam materials and structures, sedimentation of reservoir, change of dam functions, and alteration of operating conditions. All these require the dam engineers to conduct dam safety analysis and assessment, which should be regularized and carried out on a long-term basis to guarantee the sustainable and safe operation of the dam and the realisation of the dam’s multiple purposes.

Another important work of dam engineers is to pass on the experience, updated knowledge and skills of dam design, construction and management, dam safety management, and risk management to the younger generation of engineers, and therefore to train qualified successors and ensure the hundreds of thousands of dams be kept in controllable and satisfactory conditions.

As more and more dams are built on the river and their service period is extended, dam engineers need to pay increasing attention to material properties degradation, ageing, extreme weather conditions, as well as the unanticipated flood, earthquake, geological disasters, and coupling effects of such factors which can result in damage, lowering reliability and thus threaten the safety of the river basin. So, looking to the future, the dam engineers’ role is indispensable in dam safety management.

Countries such as the UK and Norway have clearly benefitted from independent and rigorous periodic safety inspections of dams. It is an approach that should be considered and adopted by other countries to make sure that dams continue to be constructed, operated and maintained in a safe manner.

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Jinping-1 Project on Yalong River China is the highest arch dam in the world at 305m.