Structural health monitoring

A number of systems are available to aid in the inspection and monitoring of the critical components of hydropower and dam projects

References

https://www.usace.army.mil/Media/News/NewsSearch/Article/3276980/structural-health-monitoring-key-to-a-more-resilient-modern-infrastructure-netw/

ONE OF THE KEY factors to help ensure a more resilient and modern infrastructure network is to carry out regular monitoring and inspection of structures. Utilities and project owners need accurate and real-time information on the conditions of such critical infrastructure such as dams and levees.

As Crystal Maynard from the US Army Engineer Research and Development Center said in a recent blog, inspecting these critical components can be expensive, time consuming and dangerous. However, the cost of doing nothing is much greater – as an easily repairable glitch can grow much larger if left unchecked, causing a catastrophic failure that closes key navigation routes, severely snarls supply chains and inflicts millions of dollars in economic losses.

The US Army Corps of Engineers (USACE) is solving this challenge through a broad range of structural health monitoring (SHM) capabilities. It has developed sensors that serve as virtual eyes and ears, providing constant, real-time information on structural conditions. SHM can warn of impending failure and provide an estimate of the remaining life and reliability of an infrastructure component or system.

Leading this research is Dr. Brian Eick, a research civil engineer with the U.S. Army Engineer Research and Development Center's (ERDC) Construction Engineering Research Laboratory and the technical lead and program manager of ERDC's Structural Health Monitoring Program.

"[SHM] provides a clear line of sight from observation to deciding a plan of action," Eick said. "We use sensors on the infrastructure to continuously and in real-time collect information about the health of the infrastructure that can then be used to make decisions."

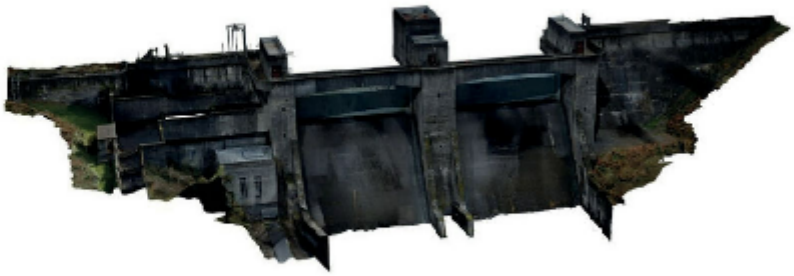
This effort paid large dividends in September 2009 when engineers monitoring sensor data at The Dalles Lock and Dam on the Columbia River noticed large and unusual shifts involving one of the lock's steel girders. Further investigation by a dive team discovered extensive cracking on the lower section of the gate. Authorities quickly initiated emergency repairs, preventing more significant damage that could have closed the lock for months or even years.

Today, Eick and his team are seeking new ways to make SHM faster, more dynamic, and as accurate as possible.

"It is very difficult to access some of these structures routinely and safely," Eick said. "So, we ask how do we put sensors on it or do we even need to put sensors on certain pieces to collect data? One of the latest things we have been doing in research and development is non-contact sensing, using cameras or lasers to obtain the same information you would otherwise need to put a sensor on the structure to collect."

Developing no-contact sensing capabilities negates the need to place sensors on structures, run cables and even the worry about the need for batteries, which

Right: **As part of the process of creating digital twins of Bluestone Dam in West Virginia, researchers have created 3D models of many of the corridors and inner workings of the facility. These models move from a photograph to the creation of the geometry and wireframe, and then finally to the final color model**
(USACE Courtesy Photo)



Left: **Voith Hydro is teaming up with Strucinspect, who operates the world's first Infrastructure Lifecycle Hub for digital infrastructure inspection and lifecycle management. Initial data is often collected via drones. Image shows a 3D model of a hydropower dam based on drone data**

is a challenge, particularly on those infrastructure components that are very remote.

There are many other areas of SHM under development, including new algorithms to process collected data, methods to remove environmental noise that may cloud this data, and approaches to interpret changing weather conditions that corrupt the data.

Looking ahead, SHM development will include the use of digital twins to help managers make decisions and ensure maintenance investments are optimized.

Eick said digital twins – which are digital replicas of physical assets, processes, people, places, systems and devices – will streamline data processing and analysis required for operation and maintenance and provide a centralized platform for modeling scenarios that will better prepare and inform decision makers.

"Where I see USACE going soon is this notion like digital twins, where we have no contact sensing," Eick said. "This is where we are focusing a lot of our efforts – how do we collect data without ever touching the structure?

"This is taking many different forms right now, such as cameras on robotic platforms, lasers, cameras and even UAVs."

Digital twins

Back in 2021, details were announced of a five-year collaboration project between Pacific Northwest National Laboratory (PNNL) and Oak Ridge National Laboratory (ORNL), sponsored by the US Department of Energy's Water Power Technologies Office, to create the Digital Twins for Hydropower framework. Over the course of the project, PNNL and ORNL are expected to develop a virtual, open-access platform that creates a digital representation of hydroelectric plants using virtual and real-time data and feedback to optimize operations.

The platform will serve as a place for the hydropower industry to evaluate and replace mechanical components, accelerate technology development, and improve hydropower operations and performance. These improvements reduce service downtime and shutdowns, which interfere with delivering electricity to the grid.

"The goal here is for hydropower to remain an efficient, affordable resource to own and operate, and to address the ever increasing demand of providing grid resiliency," said Osman Ahmed, a PNNL mechanical engineer and advisor leading the Digital Twins project.

Digital Twins uses next-generation technologies, including artificial intelligence, machine learning, and virtual reality to simulate hydropower generation, transmission, and distribution systems. The simulations can predict plant performance under various types of market demand and complexities.

"If you have the digital twin, it can help you to decide what kind of investment is needed before you spend money," Ahmed said. "Maybe you kick the virtual tire and take it for a virtual test drive. It's a big area of opportunity."

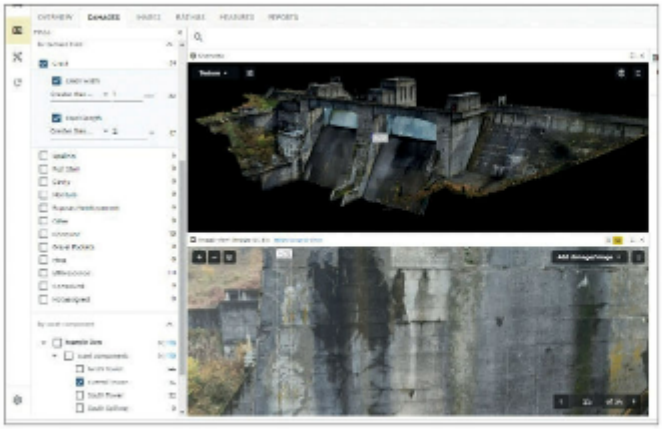
In the first year of the project, PNNL designed an open platform framework of a Digital Twin needed to modernize the hydropower fleet. The PNNL team engaged with owners, operators, utility companies, and technology providers in the hydropower industry to get their feedback and incorporate the elements and components that should be included in the platform. For example, industry stakeholders are weighing in on what elements in the platform would help a hydroelectric dam perform more efficiently, flexibly, and affordably.

"What we're hearing is that the industry needs a multifaceted design that accounts for operations, predictions of failure, how to avoid downtime, and scenario planning with the different complexities," Ahmed said. "If you create a good Digital Twin, they can all learn from each other."

ORNL will use its capabilities in modeling and simulation to develop the prototype of the platform to demonstrate to the hydropower industry how it works. The platform is expected to be built next year and should be customizable for users within the next three to four years. Users will be able to pick and choose à la carte mechanical components to add to or change their plant.

In the long-term, the platform is expected to create a library of hydropower plants across the US fleet so that users can adapt their plant based on others they've seen work effectively.

Below: **Strucinspect's Infrastructure Lifecycle Hub**



Above: **HR Wallingford has a suite of tools to help manage dams safely**

Infrastructure engineering software company currently Bentley offers services for digital twins. Back in November last year, the company announced at the Year in Infrastructure Conference, the release of Bentley Infrastructure Cloud, its combination of enterprise systems that span the end-to-end lifecycle and value chain of the world's infrastructure. Powered by the iTwin Platform and Bentley's infrastructure schemas and integrating with Bentley's engineering applications, Bentley Infrastructure Cloud will enable better creation, delivery, and ongoing operation of better infrastructure, through complete and evergreen digital twins.

Bentley Infrastructure Cloud encompasses ProjectWise, for project delivery; SYNCHRO, for construction; and AssetWise, for asset operations. These enterprise systems now leverage digital twin technologies, powered by iTwin, to open up data contained in engineering files through automated and intrinsic mapping to Bentley's infrastructure schemas. By advancing these enterprise systems to become fundamentally data-centric without disrupting file-based workflows, Bentley Infrastructure Cloud provides user organizations with significant opportunities to improve collaboration, productivity, and quality.

Bentley's infrastructure schemas are both open and extensible, and now link to reality modeling and IoT devices, and incorporate carbon calculation and subsurface data. The rich data representation of Bentley's infrastructure schemas serves well the export of Industry Foundation Classes. The ability to share data seamlessly and to enrich it throughout the lifecycle helps engineering firms and owner-operators create and derive more value from their engineering data.

The potential for a unifying, cloud-based solution across the lifecycle of infrastructure engineering arises from the institutionalized limitations of fragmented information flows that have impeded connections, feedback, analytics, reuse, and knowledge transfer. Bentley Infrastructure Cloud comprises a data-centric, always on, always current, always accessible federated environment that persists and relates engineering data throughout the span of design, construction, and operations. Information mobility and semantic continuity across traditional boundaries through Bentley Infrastructure Cloud will help accelerate, among other advancements, modular design and design for constructability, and performance-based design.

Bentley's Senior Vice President of Enterprise Systems Ken Adamson said: "Bentley Infrastructure Cloud stands for our commitment to connect everyone and everything in the infrastructure engineering value chain and extended project ecosystems. Infrastructure professionals deserve an evergreen digital twin environment for data that they can trust and act upon. I believe Bentley Systems is uniquely positioned to fulfill this requirement by virtue of the combined comprehensiveness of our ProjectWise, SYNCHRO, and AssetWise enterprise systems, our software's intrinsic engineering fidelity, and our commitment to openness – including our unique resolve to semantically integrate the full range of relevant engineering file formats. The iTwin Platform, in becoming the robust foundation for unifying all of our software development, has been proven equal to this challenge."

Bentley Systems also unveiled major enhancements to ProjectWise to extend its scope from work-in-progress engineering to full digital delivery. By supplementing each project's sequential file-based workflows with data-centric information mobility and analytics across all projects: rough new project portfolio and program management capabilities, ProjectWise users can now apply analytics at the level of engineering fidelity across all projects, learn from and reuse rich project data, and retain knowledge to enhance the quality and efficiency of future projects; and through new digital twin capabilities, ProjectWise users can undertake interdisciplinary design reviews and advanced design validation to improve the effectiveness and quality of their designs, and also increase the richness of their digital deliverables for construction and operations, to position their businesses for transformational digital services beyond handover.

Powered by iTwin, ProjectWise leverages iTwin Capture to integrate reality modeling data, increasingly the norm, to capture and monitor the digital context of designs, geospatially coordinated with engineering data. It also leverages Bentley's infrastructure schemas to semantically align design file data across multiple disciplines for comprehensive design reviews, and across all projects to understand dependencies, and to reuse datasets, including for machine learning to develop proprietary analytics, while also leveraging iTwin Experience to offer immersive visibility into project digital twins, assuring quality and improving performance.

Lori Hufford, vice president, engineering collaboration for Bentley Systems, commented: "Engineering firms today face unprecedented challenges to deliver more and better projects despite scarcer talent, a retiring workforce, and loss of institutional knowledge. By leveraging the iTwin Platform, we are now able to advance ProjectWise beyond engineering work-in-progress for one project at a time, to be used across all projects to maximize insights, learnings, and reuse, and for machine learning. ProjectWise users already have a wealth of project experience incorporated in their ProjectWise archives. Now as part of Bentley Infrastructure Cloud, ProjectWise can drive a necessary

step-change in the efficiency, effectiveness, and transformation of engineering firms."

Bentley also announced the availability of new asset-specific solutions, powered by iTwin, that leverage iTwin Experience, iTwin Capture, and iTwin IoT to deliver real-time asset health monitoring. One of these is AssetWise Dam Monitoring solution, which is purpose-built for engineering firms to offer digital services to dam operators who are modernizing their dam safety programs to reduce risk and address growing regulatory requirements. The upcoming solution will provide unified access to sensor data and will be able to be deployed without the need for specialized technicians. Users can incorporate sensor data in any digital twin for a contextual view of real-time data and associated metrics.

Above: **DAMSAT harnesses the power of satellite technology**

Fibre optic sensing

From older structures to builds in progress, real-time, active monitoring of environmental conditions and structural health is critical to the long-term safety and operation of dams, which distinct features and safety needs depending on the locations where they are built.

High-speed distributed fiber optic sensing can deliver fast, accurate and dependable structural health measurements by employing multiple optical measurement technologies using a single instrument.

A Luna Innovations structural health monitoring installation of fiber optic sensors and interrogators helps to monitor the Lake Rockwell Spillway around the clock for cracks and bowing of the walls. Covering more than 800 acres, Lake Rockwell is one of the three reservoirs that supplies over 300,000 people in Akron, Ohio with drinking water.

The monitoring system instrumentation is composed of optical interrogators, long-gage strain sensors to better measure strain over the large area between buttresses, accelerometers, temperature sensors, and tilt meters for other crucial measurements. The system continuously monitors the integrity and behavior of the spillway for possible failure or other possible damage.

Fiber Optic Sensing is also being used to monitor other important infrastructure. Luna Innovations was recently awarded a contract with PT Freeport Indonesia, an affiliate of Freeport-McMoRan, to provide an early-warning monitoring system for the West and East levees between the Otomona and Aikwa rivers in West Papua, Indonesia.

"Our fiber sensing solutions are helping Freeport manage and mitigate risks by providing decision-ready information across very long linear assets," said Scott Graeff, President and CEO of Luna. "The information we are able to deliver not only provides current conditions but also dynamic changes that have or are occurring, resulting in tremendous insight into the health of Freeport's levees and an overall increase in safety. Infrastructure monitoring applications like this are growing rapidly around the world, and Luna is well positioned to add significant value to customers that need robust, cost effective twenty-four seven monitoring of critical assets."

The monitoring of the two levees will be done using a fiber optic-based distributed sensing system. A range of up to 50km on both levees will be monitored for early warning signs of potential issues that could lead to a failure of the levee structure. The system can instantly identify cable breaks and temperature "hot spots" along the length of the fiber. The continuous monitoring of levees for changing conditions allows PT Freeport Indonesia the ability to run targeted inspections to determine if and what remedial action is necessary to prevent major failures.

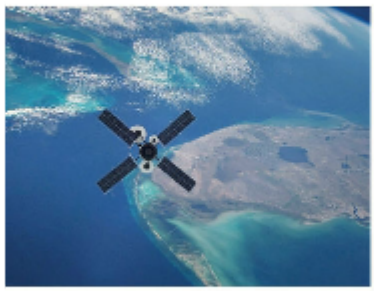
In addition to levee monitoring, Luna's distributed sensing technology has been used by PT Freeport Indonesia to monitor the slurry pipelines used in their mining operations since 2014.

Digital assessment

In March, Voith Hydro announced it is teaming up with Austrian corporate start-up Strucinspect for digital assessment and tracking of hydropower projects, with the first pilot project being carried out at the Clunie hydropower plant in Scotland.

Strucinspect operates the world's first Infrastructure Lifecycle Hub for digital infrastructure inspection and lifecycle management. The web-based collaboration platform is the core of the company's portfolio and combines technologies and functions to maintain bridges, tunnels, and dams in a safe, sustainable, and resource-saving manner. Based on that Strucinspect supports customers in transforming their existing infrastructure inspection and management into a fully digitalized process. Configurable technology building blocks allow for individual business solutions enabling effective maintenance decisions.

Below: **When it comes to dam safety, HR Wallingford says that research, data insights and dam engineering expertise need to be harnessed to help monitor assets with confidence**



Above: **Space technology can be used to solve on-the-ground problems**

While the solution is already applied in the transportation infrastructure sector the potential for hydropower dams is now on the rise.

"The idea is simple and at the same time ingenious," commented Voith Hydro CTO Dr. Norbert Riedel. "While it has been very complicated to literally keep an eye on your infrastructure, the digital assessment and tracking of civil conditions is now not only made easier but also safer."

The joint pilot project is now being performed in Scotland at the 72-year-old Clunie station, which is operated by SSE Renewables.

"We are excited about the new opportunities this technology brings and happy with the two companies we have on board for its implementation," said Stephen Crooks, Renewables (Civil) Engineer at SSE. "With this approach, we have all data managed centrally and generate measurable business value out of it."

"Currently, inspections of the civil infrastructure at Clunie take place physically," explained Albrecht Karlusch, Managing Director at Strucinspect. "However, problems might occur in case damages are not spotted during such manual inspections. And this is exactly where the benefits of our digital inspection technology comes into play."

The initial data can for example get collected by drones, underwater devices, or smartphones. This data is transfered to the Infrastructure Lifecycle Hub, where it is analyzed by Artificial Intelligence (AI) and a 3D model is created. Technologies such as Building Information Modeling (BIM) integration or Augmented Reality (AR) can be used as well. In future, digital inspections will be performed in shorter intervals with less manual effort. Even the smallest changes will be identified by the AI-assisted damage detection.

Data driven tools

When it comes to dam safety, HR Wallingford says that harnessing research, data insights and the power of dam engineering expertise will help owners and operators monitor their assets with confidence. To help with this the company has produced a suite of tools and software that includes the DAMSAT monitoring toolbox, and the agent-based Life Safety Model (LSM).

Earth observation scientists are now able to apply space technology to on-the-ground problems, while the diminishing cost of launching satellites has led to a huge increase in launches by private operators and transformed the amount, quality and variety of data available. HR Wallingford says that space technology and earth observation techniques have revolutionised the way the company works. One result has been the pioneering DAMSAT system that monitors tailings and water dams by harnessing the power of satellite technology, working alongside in-situ sensors and numerical modelling.

The system works by detecting changes to a dam's normal behaviour patterns to warn of dangerous movement and leakage. The data is displayed on a user-friendly interface that generates safety alerts and is made up of a number of modules to best suit the particular dam, and the users' needs. It can also be integrated with existing monitoring equipment.

After its development, DAMSAT was tested at hard-to-reach tailings and water dams in Peru. During the study, the system identified leakage incidents at the dams and provided information that helped the authorities to analyse minor movement incidents.

The Life Safety Model

Used worldwide, LSM informs and improves emergency plans for both dams and floods. Planning for catastrophes in advance identifies where risks are the highest, and helps to reduce the number of fatalities. The modelling used in LSM represents the behaviour and interactions with flood water of individual people, vehicles and buildings to provide a simulation of the possible risks of injury and loss of life, and evacuation times.

Even issuing a warning a few minutes before a dam breaks can save a significant number of lives. In fact, when the Brumadinho tailings dam disaster was modelled using LSM, it showed that with just 15 minutes' warning the death toll could have been reduced from 270 to zero.

Recently, dam owners in Canada have used the tool to check and implement safety upgrades to large dams, as well as develop emergency plans. In Malaysia, the LSM been used to calculate evacuation times, and the results are being used in improved emergency planning exercises.

HR Wallingford says that its products can also be used to support one another. For instance, the outputs from LSM can be integrated into DAMSAT's 'consequence modelling' module, alongside HR Wallingford's predictive breach models, EMBREA and EMBREA-MUD.

And with computing power and modelling techniques improving all the time, the future looks bright for data driven, automated techniques. One area that has great potential to benefit is breach modelling. The HR Breach was the original 1D predictive dam break model, and development is underway for the next generation of 3D models, using computational fluid dynamics to generate more realistic breach flood spreading estimations.

These developments are important. With an ageing population of assets, combined with the effects of climate change, HR Wallingford says the industry will to need to harness the power of technology and innovative thinking to create a world where we live and work sustainably with water. ●

Below: **The Life Safety Model improves emergency planning for dams**