The British Dam Society

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

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

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

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

DINORWIG POWER STATION

Dinorwig Power Station is a closed loop pumped storage power station located in Llanberis, North Wales. The station was constructed in the 1970s and was first commissioned in 1982. The station operates by balancing water volumes between reservoirs Marchlyn Mawr (upper reservoir) and Llyn Peris (lower reservoir). A schematic of the power station is shown in Figure 1. Since commissioning, the high pressure waterway system has not been fully drained down.

While underwater ROV inspections have been carried out periodically (MMT Services, 2021), clear close-up views of the concrete manifold and penstock liners had not been viewed since construction. Replacement of two of the main inlet valves (MIVs) required the system to be drained down for the first time in over 40 years (Stantec, 2021), creating a window in which to investigate the condition of the concrete liner with various techniques, with a view to verifying the remaining design life.

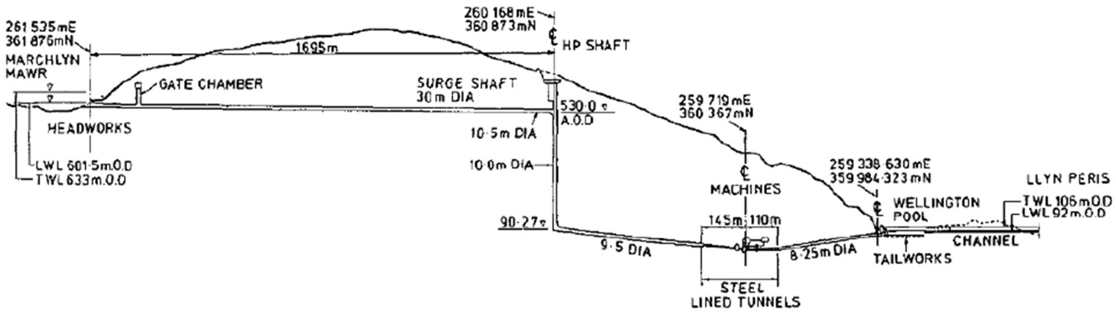

Figure 1. Dinorwig waterways layout (CEGB, 1980)

2023 System Drawdown

The high pressure hydraulic system was drawn down over approximately 12 days in May 2023. Following the drain down a series of condition assessment works were carried out including a photographic survey, concrete core extraction, concrete testing and analysis and in-situ stress testing. The works were carried out to provide parameters for geo-mechanical modelling, to identify any new or existing defects for repair or monitoring, and to provide a detailed condition assessment to outline the remaining design life for the structure.

Photographic Survey Requirements

The photographic survey was commissioned with the aim of creating both a photographic and vectored database of the high pressure shaft, manifold and penstocks to visually assess the current condition of the concrete liner and to create a baseline of data in which future surveys can be compared against to monitor for change.

PHOTOGRAPHIC SURVEYS

CCI was engaged by Engie to undertake the surveys of the insides of the shafts and tunnels at Dinorwig. It was agreed that AssetScan, a computer vision AI developed by CCI, would also be used to undertake an analysis of the position of cracks, spalling concrete, and past patch repairs for all surveyed surfaces.

Shaft Survey

This data collection survey focussed on the vertical shaft and was undertaken in May 2023. This made use of a specialist vehicle developed for the capture of photographic imagery in shafts and tunnels. In summary, the vehicle consists of a control platform and a camera platform incorporating a high gain radio system. This is shown in Figure 2.

The control platform used is a robotic control platform which uses large diameter, high power drone thrusters in a vector configuration to enable both rotational and translation control within the cross section of the shaft. Additionally the vehicle has a number of instruments that can be used in GPS denied environments: four laser scanners which can be used to determine the position within the cross section of the shaft, as well as magnetometers and gyros which were used to monitor approximate bearing and keep rotational speeds to a minimum, and keep the vehicle pointed in a single known direction.

The camera platform allows the mounting of seven SLR cameras – six in a circumferential orientation and one mounted axially. The cameras have been set to trigger using a common timer, which in combination with the target winch speed resulted in high resolution images being captured every 0.3m of depth. The camera head also incorporated high power LED lighting sufficient to illuminate surfaces some distance from the cameras.

The vehicle was powered by two lead acid batteries which were enclosed in sealed and reinforced housings. This was undertaken to minimise the risk of electrical fires caused by high electrical loads from the control platform.

The vehicle was lowered on a winched steel cable. Despite using anti-twist cable, the use of both a low resistance bearing at the mounting location and the powered control platform was necessary to keep the vehicle stable on descent. Each descent took approximately one hour.

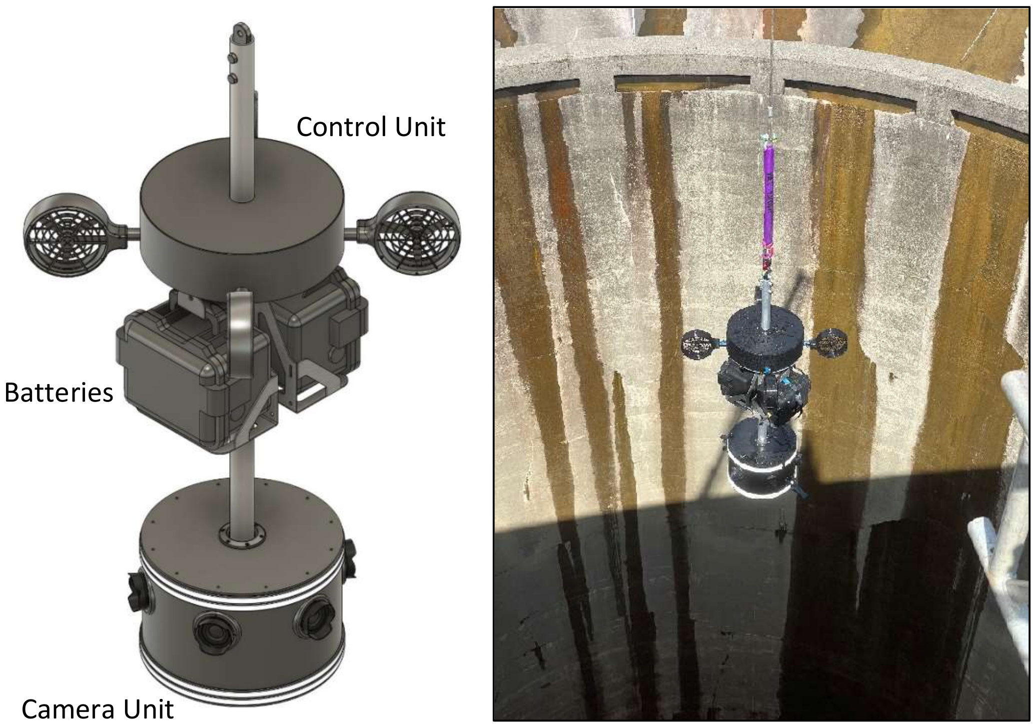

Figure 2. Shaft Inspection Vehicle – design render (left) and implementation (right)

Tunnel Survey

The second data collection mission focussed on the tunnels between the shaft and the main inlet valves, inclusive of the 10m diameter tunnel and the 3m diameter unit penstocks. This required that the same camera platform was deployed using an alternative wheeled vehicle, shown in Figure 3 and Figure 4.

Initially it was planned to make entry into the tunnels via a 600mm diameter manhole. As such, a vehicle was designed using metallic truss and light weight scaffold poles. This included bespoke manufactured wheel fittings and a roped mast deployment to ensure that the vehicle could be constructed internally within the tunnel without needing a larger access portal.

The vehicle mast was used to deploy the camera platform inclusive of lighting. The triggering of the cameras was undertaken using a magnetic sensor on the wheels of the vehicle, such that the images were captured at 0.3m intervals.

Managing Risks for Dams and Reservoirs

The vehicle was light enough to mobilise manually, and to preserve weight and construction complexity no motorised platform was deployed. Steering was undertaken with the use of bespoke manufactured fittings.

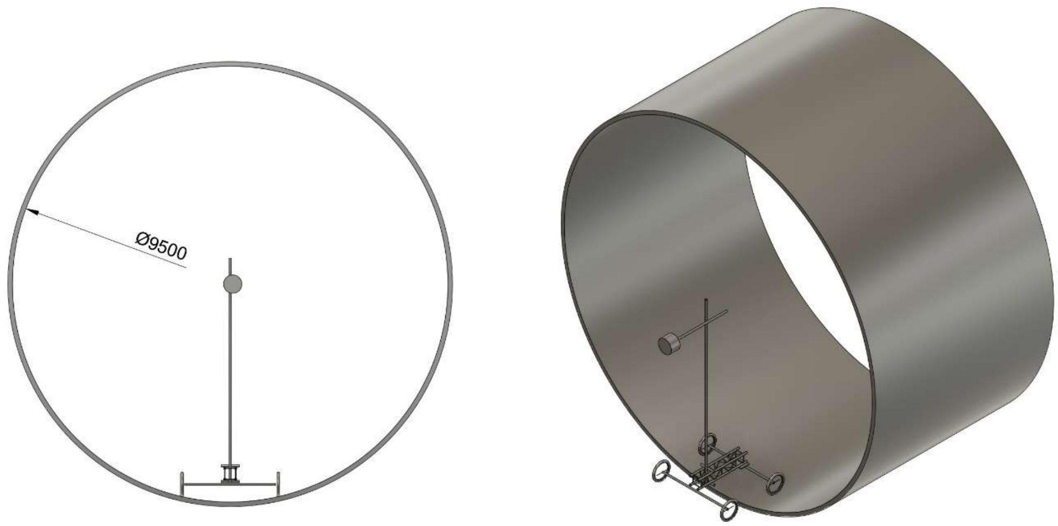

Figure 3. Tunnel Inspection Vehicle design for c.10m diameter configuration

INTERPRETATION

The data collection missions captured approximately 38,000 images, totalling almost 1TB of data. In its captured format, this data would be difficult to use.

The photographic data was post-processed using two sequential methods. The first was to orthorectify each image to ‘flatten’ the surface captured, thereby allowing stitching of an orthomosaic. The second was to process the images using the AssetScan AI to automatically identify defects of interest.

Figure 4. Tunnel Inspection Vehicle, implementation in c.4m diameter configuration

Image Remapping

The remapping of the images was undertaken using a set of calibration images captured of a flat grid. This, in combination with the known radius of the shaft/tunnel, was used to generate a warping profile which was used to stretch each image. The warping was undertaken using a subroutine available in the OpenCV image processing library (Bradski, 2000). An example of this is shown in Figure 5.

Once each image was flattened, a process was used to determine the radial position of each image in comparison with the neighbouring cameras. This allowed the construction of dense image 'rings' of the entire circumference of the shaft and tunnel at each position as an orthomosaic. The edges of each image were feathered to ensure a smooth transition between each image. The native resolution of the images was approximately 1mm/pixel. Following this, a central band of the image, representing 300mm, was extracted and stacked against the preceding and following 'rings' to form a large orthomosaic of the entire shaft and tunnel. An example of this is shown in Figure 6.

This allowed the production of 13 Tagged Image Format (tif) files, totalling more than 25GB of processed photography data. The results were projected onto 11 large A0 printing templates for use by Engie and their engineers.

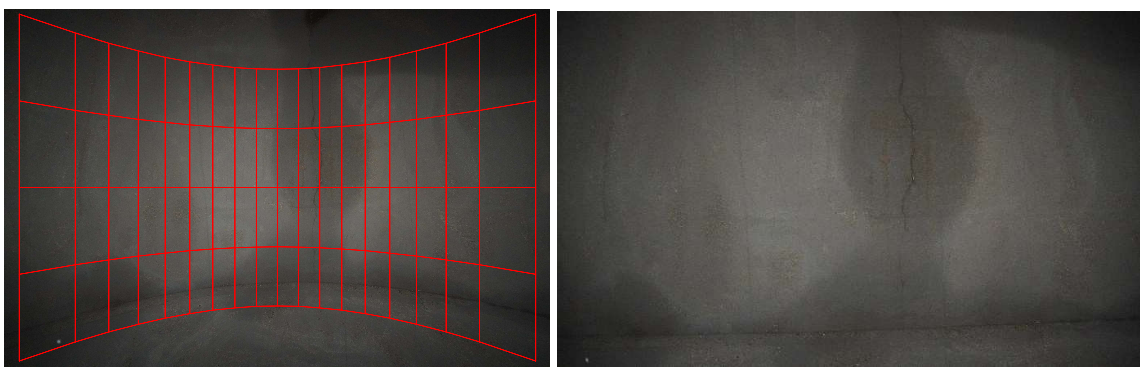

Figure 5. Image Remapping – (left) orthorectification warping mask (right) approximate orthorectified image

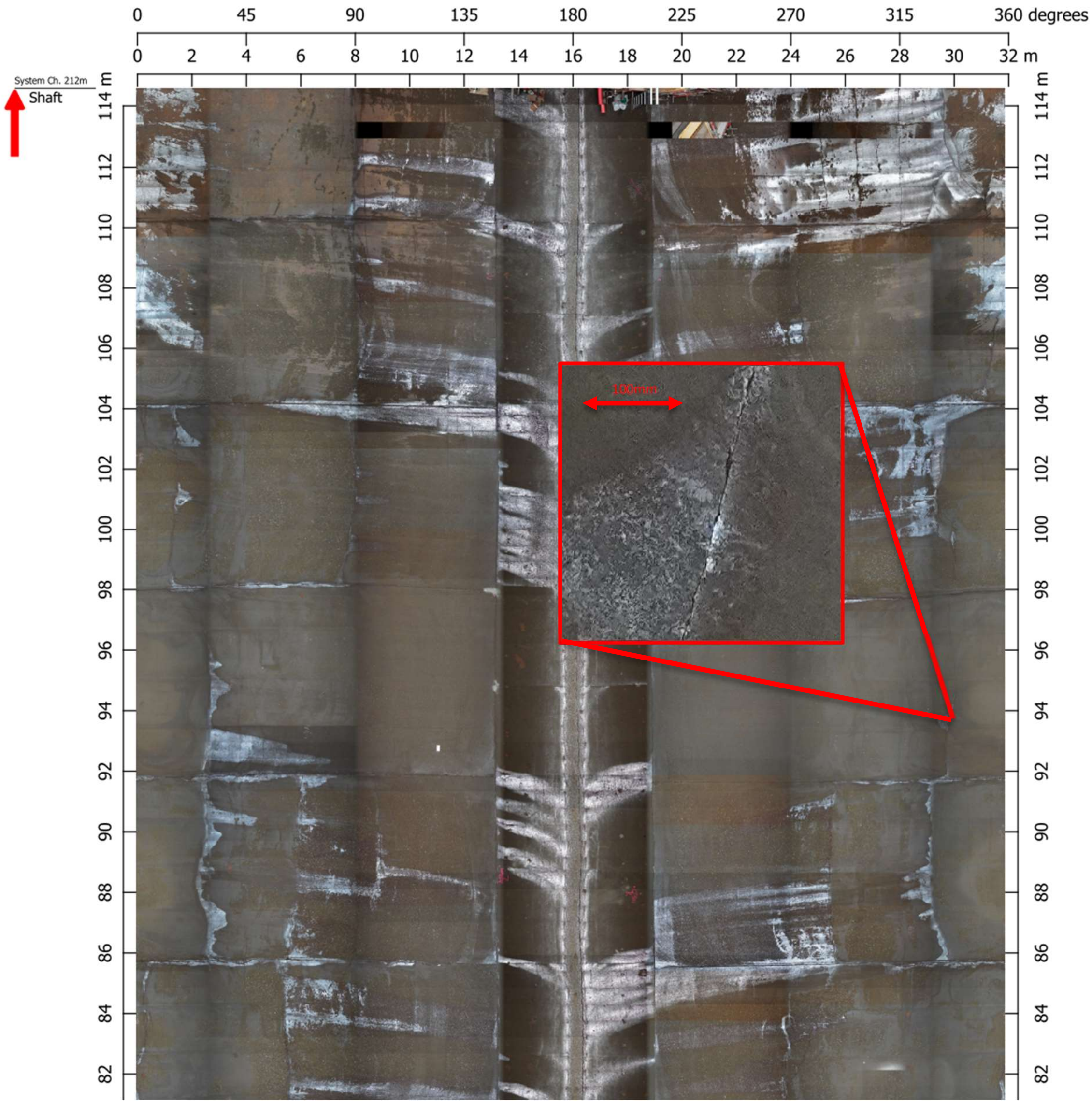

Figure 6. Composited orthomosaic – example outputs for c.10m diameter tunnel

AssetScan AI

The images were also subject to interpretation by AI. The scale of the surveyed surfaces was so large as to make it difficult to manually review the captured dataset. The primary purpose of the AI was to draw the attention of engineers to positions of defects. Three types of feature were specifically identified in the images: cracks, surface loss, and previous patch repairs. Further to this, two other types of feature were identified: formwork joints and formwork joints that were visibly compromised and potentially cracked.

Following previous work undertaken with AssetScan (Coombs, 2022), an existing off-the-shelf concrete AssetScan model was applied to the image datasets. It became clear that the high wetness of the concrete surfaces in the shaft would preclude use of this particular model since defects would appear quite differently. As such, a 'wet' concrete AI model was used for the shaft, and a 'dry' concrete AI model was used in the tunnels.

Following a detailed review at individual pixel resolution, the AI data was simplified into vector geometry and summarised on both drawings and tables. This could then be used by engineers to determine the location of surface indications that warranted attention throughout the entire length of the surveyed structure. This was mapped against chainage and orientation within the tunnel portal. An example of the simplified data is shown in Figure 7.

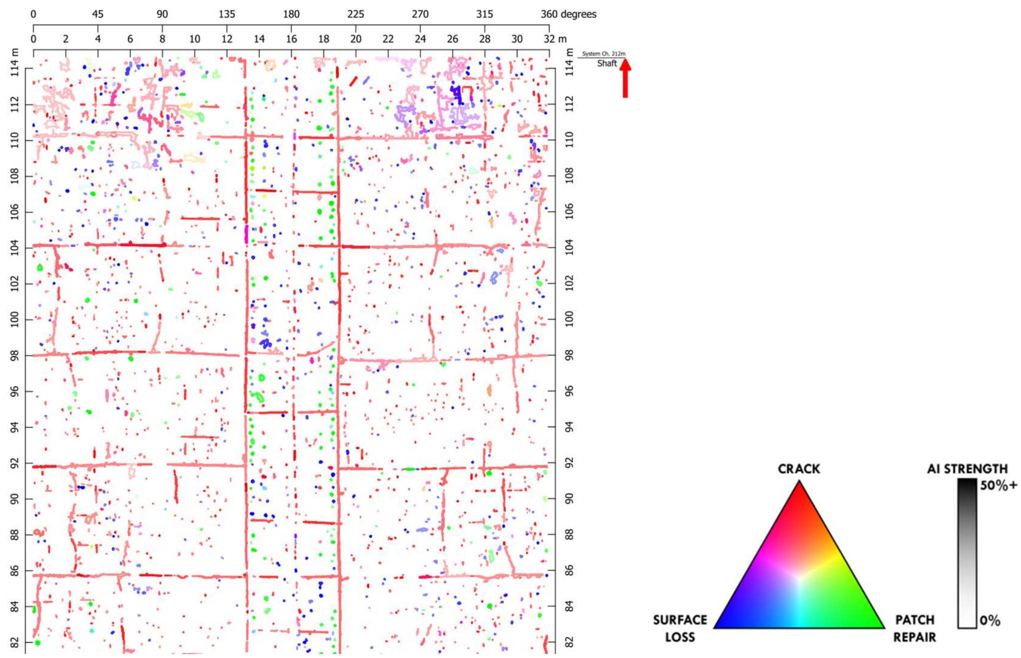

Figure 7. Composited AI data – tunnel example

EVALUATION OF DATA

In application at Dinorwig

There are examples of hydromechanical elements of the power station that have been surveyed in 3D to 1mm accuracy, such as within the spiral casings of the turbines, which provides engineers the facility of a virtual reality 'walk through' the structure and manually spot defects or measure components. For a structure as large as the high-pressure waterway system, however, AI analysis reduced the chance of missing any potential defects which may not have been picked up in manual visual checking.

As expected, the quality of the imagery captured as part of this project was much better than previous efforts with ROVs. The ROV surveys produced lesser quality imagery due to the presence of suspended solids and poor transmission of light. The ROV surveys were also difficult to interpret in terms of quality measurements for any identified defects, as well determining their size and position.

The outputs of this survey were useful in that they allowed:

- A snapshot in time of the high-pressure waterway system. The outputs of this survey may continue to be useful into the future if the survey is carried out again in following drawdowns, to allow detection of possible deterioration to allow extrapolation of deterioration which could inform future maintenance or timelines for refurbishment. As such, the survey not only provides information presently but is an investment for future monitoring and surveillance.

Managing Risks for Dams and Reservoirs

- Quantification of groundwater seepage, using photographic imagery, which give a general overview of concrete permeability as an input into "Factor of Safety" verification (Stantec, 2023).
- Preliminary video footage of the high-pressure shaft liner, which confirmed that there were no immediate concerns with regards to potentially loose concrete. This assisted with assessment of risk regarding personnel entering the manifold (First Hydro, 2022).

In general application

Holistic photographic surveys of tunnels and shafts are useful in that they capture not only the defects of interest, but also the relative size, position, and context of said defects. This means that engineers can quickly identify areas of interest on drawings and maps, and then rapidly find them during site reconnaissance. Additionally, it allows the development of surveillance targets on repeat inspections. The images generated by this project are approximately 1mm/pixel. This means that hairline cracks may not be visible in the images. Despite this, such a high resolution capture of a structure could act as a baseline for comparative assessment for larger defects.

The orthomosaics generated by a holistic photographic survey are difficult to manually review due to both their size and extent. Some of the high resolution TIFs generated for the shaft were in excess of 10GB, for example. On standard office equipment these can be challenging to view. Further to this, the image extent and resolution makes manual inspection of all defects an excessively time consuming activity. By extension, such an exercise would also be prohibitively costly for a large structure such as Dinorwig.

AssetScan demonstrates that this problem can be overcome with the use of computer vision. An AI model with sufficient complexity and trained on a suitably large dataset is able to interpret these datasets and return outputs which are easier to review manually. The AI results could then be used to draw the attention of an engineer to potential defects. In combination with high resolution orthomosaics, this would then allow engineers to assess the current condition of large structures.

Additionally, since the holistic photographic data capture method used is repeatable, and since the AI is able to locate most defects, this process could be repeated as part of an automated change detection assessment. For example, should a second survey be captured, then this data could be parsed by the AssetScan AI. The results from both surveys could then be compared directly. It is a trivial task to locate where the AI geometry has significantly changed between surveys, where each photographic survey has been taken relative to some known position. This could therefore be used to automatically point engineers to defects which are changing, or to defects which have developed since the previous survey.

REFERENCES

Bradski G (2000). The OpenCV Library. *Dr. Dobb's Journal of Software Tools,* **25**(11) pp. 122-125.

Coombs R, Williams R, Cramman J and Taliana A (2022). Determining the condition of a Masonry Dam with the aid of UAVs and machine learning. In *Dams and Reservoirs in a Climate of Change – Proceedings of the 21st British Dam Society Conference* (Thompson A and Pepper A (Eds.)). British Dam Society, London, UK. pp 249-260