Dam Inspection Report

Craig Goch Dam

Prepared for

Welsh Water
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Nelson, Treharris
Mid Glamorgan CF46 6LY

By

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Disclaimer

This document has been prepared in good faith based on data collected by Abyss Solutions Pty. Ltd. during the inspection of Craig Goch Dam on January 23-24, 2019. The information contained herein, is to the best knowledge of Abyss Solutions Pty. Ltd. complete and accurate.

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Table of Contents

1 Document Details

1.1 Document History

Date	Version	Description
10.02.2019	1.1	First Draft
20.02.2019	1.2	Client Revision

Executive Summary

Traditional asset inspections through the use of divers and dewatering are highly disruptive, unsafe, costly and often deliver sub-optimal quality information. This creates a major disincentive for establishing accurate and complete asset records of older infrastructure, where information for effective asset management decision making is often lacking.

Abyss Solutions was hence engaged by Welsh Water to demonstrate an alternative approach to inspecting and documenting the condition of underwater assets that avoids these limitations. Abyss Solutions' underwater remotely operated vehicle (ROV) equipped with high-fidelity visual imaging systems was used to conduct a baseline survey of Craig Goch Dam.

The survey involved (1) deploying the ROV from the western bank of the dam, (2) locating and inspecting the key features of the dam and (3) processing the data offsite to produce a visual record of the inspection, the underwater configuration of the dam and a condition assessment.

The key findings of the inspection are summarised in the table below.

Table 1 - Outcomes of the high fidelity ROV inspection of Craig Goch Dam

Reservoir Element	A Priori Information	Inspection Findings
Dam Wall/Tower Interface	- Blockwork potentially articulated - Tower potentially displaced from dam wall	- Articulated blockwork between tower and wall confirmed - No separation between tower and wall
Tower Intake Trash Screen Grates	- Arrangement unknown - Condition unknown	- Grates consist of 5 verticla bars with cross member at mid-height - Grates heavily corroded with significant material loss - Minor obstruction (10%) of one grate of western tower wall
Tower Blockwork	- Condition unknown	- No major cracking of blockwork - Grout inplace with no instances of missing grout
Dam Wall Blockwork	- Condition unknown	- No major cracking of blockwork - Grout inplace with no instances of missing grout
Earthing/Lightning Cables	- Condition unknown	- Cables intact with no major deterioration - Termination devices at ends missing
Culvert Inlet	- 450mm (Dia.) pipe with 90 degree elbow becomes vertical and terminates with bellmouth - Pipe condition unknown - Unknown how pipe is supported within culvert	- A priori pipe configuration confirmed - Pipework found to be intact with no obstructions - Pipe found to be supported on 4 equally spaced I beams embedded within concrete culvert headwall
Scour Outlet	- Silt level over outlet unknown - Condition of outlet and headstock unknown - Operability of valve headstock unknown	- Scour outlet determined to be below silt level - Headstock found to be intact but heavily fouled with surface deterioration - Headstock likely inoperable
Coffer Dam Wall	- Configuration of coffer dam wall unknown - Condition unknown	- Concrete wall confirmed to have trapezoidal section - Wall found to be intact with no major cracking - Wall found to be protruding from silt - Section of wall above silt had dimensions of 15m (L) x 3m (W) x 3m (H)

1 Introduction

Welsh Water has indicated to Abyss Solutions that it lacks accurate and readily accessible documentation and condition information for a number of its older underwater assets. This information is critical for responsive, reliable and cost-effective asset management decision making. However, the limitations of traditional inspections, such as dewatering or divers, create a major disincentive for collecting this information. Dewatering is highly disruptive and costly while diver inspections can be dangerous, resource intensive and often deliver sub-optimal quality data.

Abyss Solutions was engaged by Welsh Water to demonstrate an alternative approach to collecting this information that avoids the limitations of traditional inspections. Abyss Solutions' underwater remotely operated vehicle (ROV) equipped with high-fidelity visual and acoustic imaging systems was used to conduct a baseline survey of Craig Goch Dam. The information collected was used to establish the configuration of the asset as well as the condition of its key features.

2 Asset Information

The general details of the dam are summarised below.

Table 2 - General details of Craig Goch Dam

Basic

Dam name - Craig Goch Dam
Location - SN 89689 70389
Location grid reference - 52°18'17.7"N 3°37'26.8"W
Year built - 1897

Capacity

Volumetric capacity - 7,569,878 m³
Contents - Raw water
Wall Dimensions - Length 156m, max. width 32m, height 37m
Water level - Max depth 32m

Construction

Type - Stone blockwork clad unreinforced concrete
Key features -
- *Outlet tower:* Octagonal 5m (W) x 24m (H) with 16 2.1m (H) x 0.6m (W) steel intake grates on 4 faces and 2 lightning & earthing cables
- *Scour outlet:* 900mm (Dia.) pipe beneath silt with valve headstock 6m above on dam wall
- *Culvert inlet:* 450mm (Dia.) pipe with 90 degree elbow and bellmouth termination supported on 4 I-beams embedded within the 5m diameter concrete culvert tunnel headwall blocked off with blockwork 10m in
- *Coffer dam wall:* Concrete wall with trapezoidal section protruding from silt 15m (L) x 3m (W) x 3m (H)

Access

Access road - National Cycle Route 81
Gates and fence - None
Parking - Parking at abutments of dam

3 Inspection Details

The inspection was conducted using Abyss Solutions' underwater remotely operated vehicle (ROV) equipped with high-fidelity imaging and sonar systems. The ROV was deployed from the western embankment of the dam. The ROV was navigated in a systematic pattern to locate the key features such as the outlet tower grates, culvert inlet, coffer dam wall and scour outlet valve headstock using the onboard sonar. Once a feature had been located a close visual inspection was undertaken with high-fidelity imagery collected.

Following data collection, the imagery was subject to Abyss Solutions' algorithmic enhancement pipeline. The enhancements improved both colour and detail representation whilst avoiding distortion of features within the imagery.

4 Inspection Findings

The general outcomes of the inspection are presented in Section 4.1 with examples of the high-fidelity imagery collected shown in Section 4.2. The overall condition of the surveyed portion of the dam is reported in Section 4.3. A detailed condition assessment of the key features of the dam is presented in Section 4.4.

4.1 Inspection Outcomes

The key outcomes of the inspections are summarised in Table 3.

Table 3 - Outcomes of the high fidelity ROV inspection of Craig Goch Dam

Reservoir Element	A Priori Information	Inspection Findings
Dam Wall/Tower Interface	- Blockwork potentially articulated - Tower potentially displaced from dam wall	- Articulated blockwork between tower and wall confirmed - No separation between tower and wall
Tower Intake Trash Screen Grates	- Arrangement unknown - Condition unknown	- Grates consist of 5 verticla bars with cross member at mid-height - Grates heavily corroded with significant material loss - Minor obstruction (10%) of one grate of western tower wall
Tower Blockwork	- Condition unknown	- No major cracking of blockwork - Grout inplace with no instances of missing grout
Dam Wall Blockwork	- Condition unknown	- No major cracking of blockwork - Grout inplace with no instances of missing grout
Earthing/Lightning Cables	- Condition unknown	- Cables intact with no major deterioration - Termination devices at ends missing
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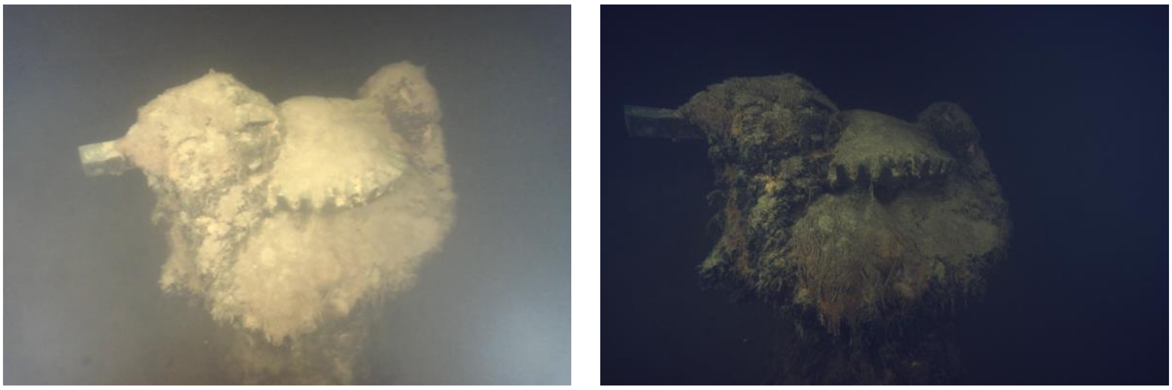
Coffer Dam Wall	- Configuration of coffer dam wall unknown - Condition unknown	- Concrete wall confirmed to have trapezoidal section - Wall found to be intact with no major cracking - Wall found to be protruding from silt - Section of wall above silt had dimensions of 15m (L) x 3m (W) x 3m (H)

4.2 High-fidelity imagery

A comparison of the imagery obtained using Abyss Solutions' imaging system and subject to post-processing with the ROV navigation camera imagery is presented in Figure 1. The latter represents the quality that can be achieved using standard underwater cameras and which is obtained by divers and standard ROVs. The high-fidelity imagery presents superior detail and colour information than that captured by the navigation camera, to enable improved condition assessment.



(a) (b)

Figure 1 Comparison of the imagery obtained using Abyss Solutions' imaging system and subject to post-processing (a) with the ROV navigation camera imagery (b) of the Craig Goch scour outlet valve headstock.

4.3 Reservoir Condition

The condition of the inspected portion of the dam and its key elements was established using the criteria in Table 4. Overall the dam was found to be in an **adequate** condition. Moderate to major deficiencies, including siltation of the scour outlet and inoperability of its headstock were noted. However, the majority of the dam elements remained functional as designed.

Table 4 - Condition grading criteria used in this report

1. Excellent - No defficiancies noted

2. Good - Minor deficiencies noted. Element functioning as designed.

3. Adequate - Moderate deficiencies noted. Element functioning as designed.

4. Poor - Major deficiencies noted. Element requires repair to continue functioning as designed.

5. Awful - Repair or preplacement required immediately. Item no longer functions as designed.

4.4 Condition of Reservoir Elements

Seven elements of the reservoir were inspected as part of the survey by Abyss Solutions. These included (a) the dam wall/tower interface, (b) dam wall and tower blockwork, (c) outlet tower trash screen grates, (d) earthing and lightning cables, (e) culvert inlet, (f) scour outlet and valve headstock and (g) coffer dam wall. The condition of each of the elements was established in accordance with the criteria in Table 4.

(a) Dam Wall/Tower Interface

The blockwork at the interface of the dam wall and outlet tower appears to be articulated. The dam wall and outlet tower blockwork appeared to be aligned together from surface to maximum depth. No obvious separation between the outlet tower and dam wall was detected. The interface was as such judged to be in good condition.

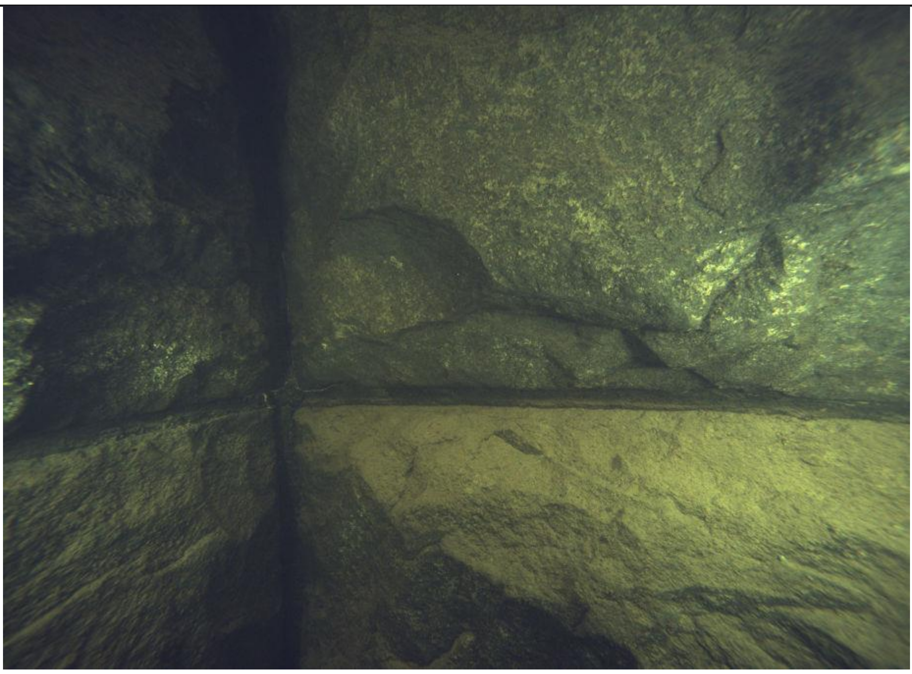


Figure 2 - Western interface of outlet tower and dam wall near surface level. No obvious separation between the outlet tower and dam wall was detected.

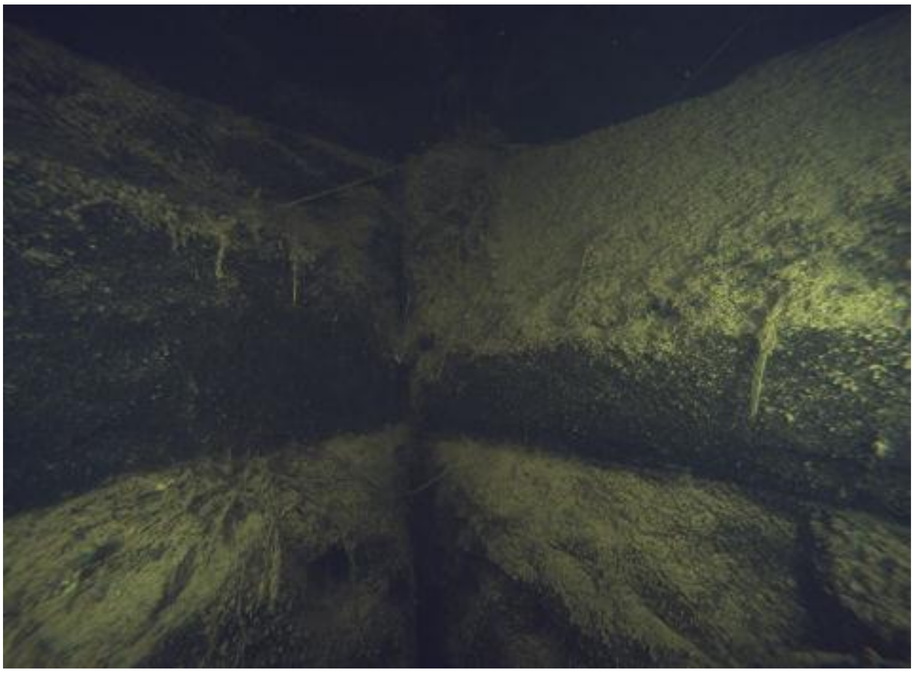


Figure 3 - Western interface of outlet tower and dam wall at maximum depth. No obvious separation between the outlet tower and dam wall was detected.

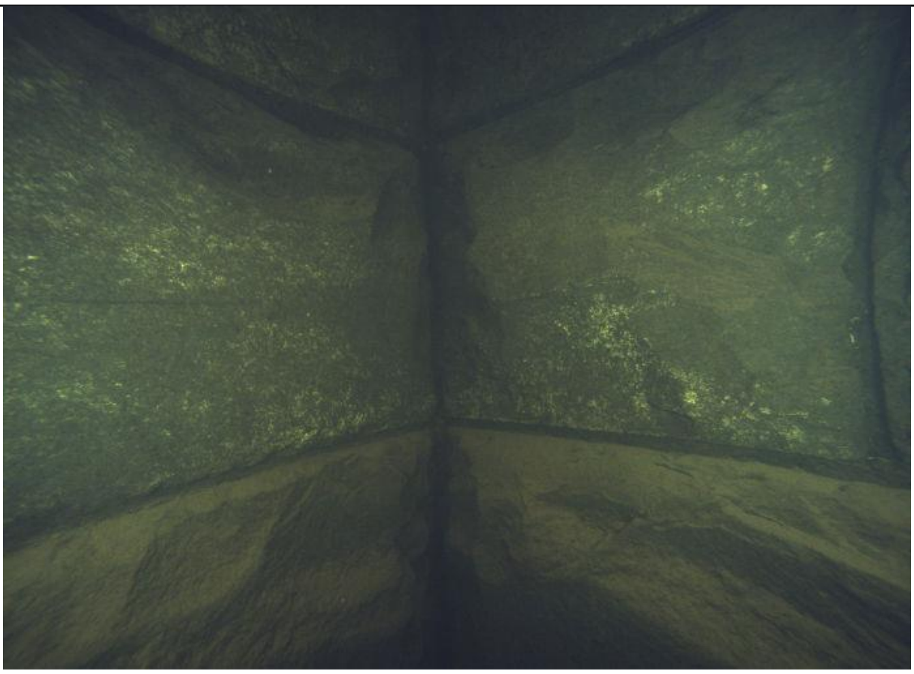


Figure 4 - Eastern interface of outlet tower and dam wall near surface level. No obvious separation between the outlet tower and dam wall was detected.

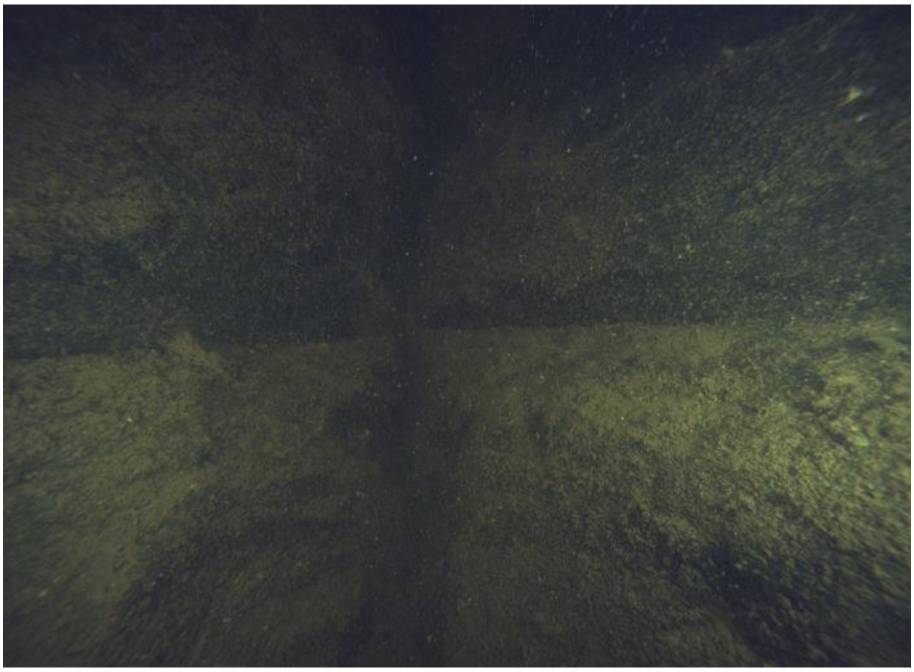


Figure 5 - Eastern interface of outlet tower and dam wall at maximum depth. No obvious separation between the outlet tower and dam wall was detected.

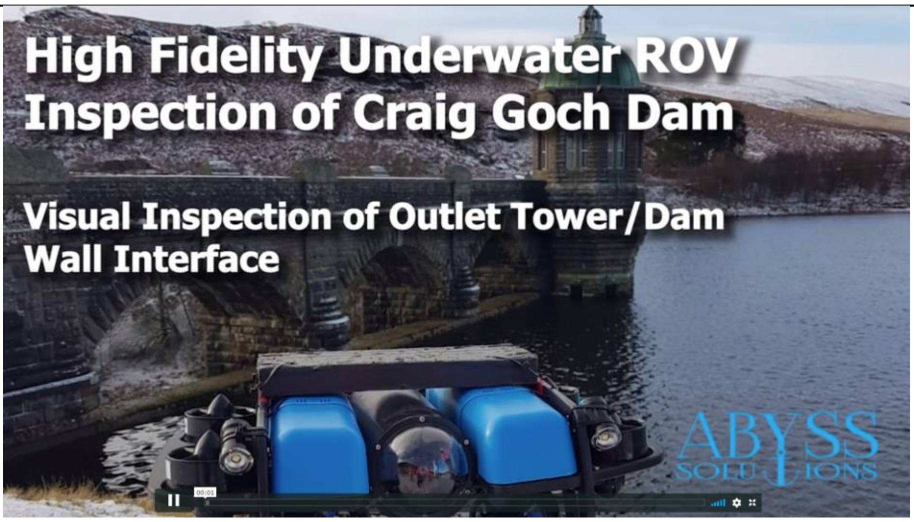


Figure 6 - Inspection video of outlet tower/dam wall interface (click here or on the image above to launch).

(b) Dam Wall and Tower Blockwork

The exterior of the unreinforced concrete dam wall was found to be clad in stone blockwork. Blockwork junctions appeared to be grouted. The outlet tower was constructed with an octagonal profile, with 5 of the walls on the upstream face of the dam. The outlet tower was observed to be constructed of grouted stone blockwork. Condition - The blockwork was found to be intact with no signs of major cracking observed. Grouting appeared to be in place with no instances of missing grout identified. Stone lintels above trash screen grate penetrations appeared intact. The blockwork appeared to be in good condition.

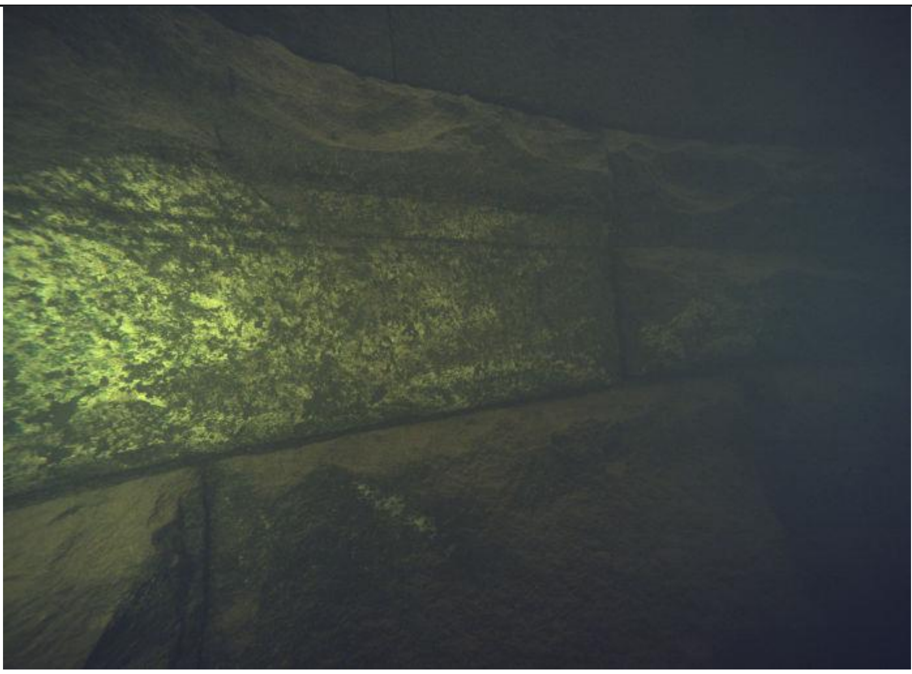


Figure 7 - Example of stone blockwork near surface level at the western end of dam wall. The blockwork was found to be intact with no signs of major cracking observed. Grouting appeared to be in place with no instances of missing grout identified.

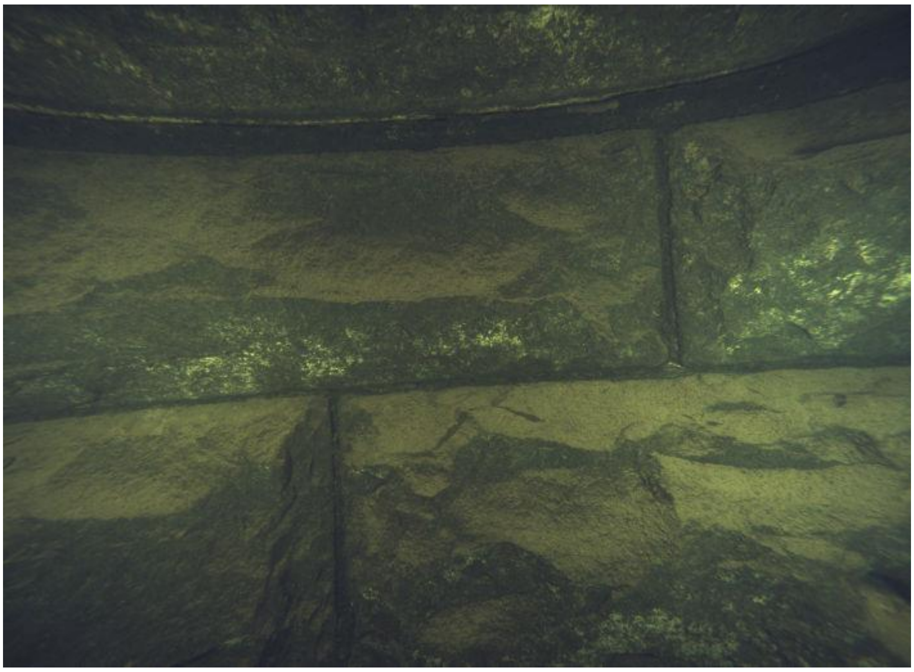


Figure 8 - Example of stone blockwork near surface level at the western end of the outlet tower. The blockwork was found to be intact with no signs of major cracking observed. Grouting appeared to be in place with no instances of missing grout identified.

Figure 9 - Example of stone blockwork at maximum depth near the centre of the dam wall. The blockwork was found to be intact with no signs of major cracking observed. Grouting appeared to be in place with no instances of missing grout identified.

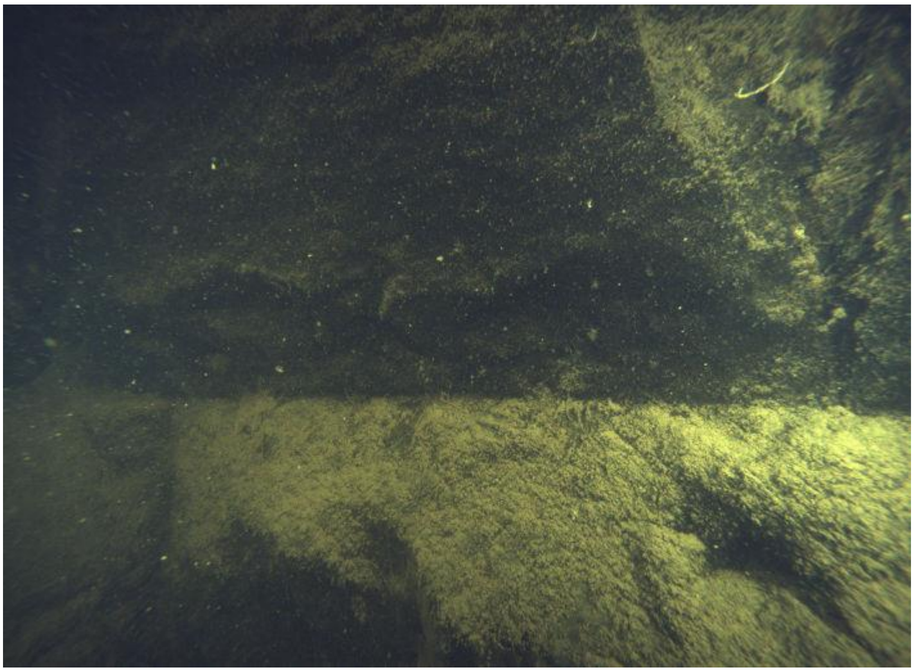


Figure 10 - Example of stone blockwork at maximum depth at the eastern end of the outlet tower. The blockwork was found to be intact with no signs of major cracking observed. Grouting appeared to be in place with no instances of missing grout identified.

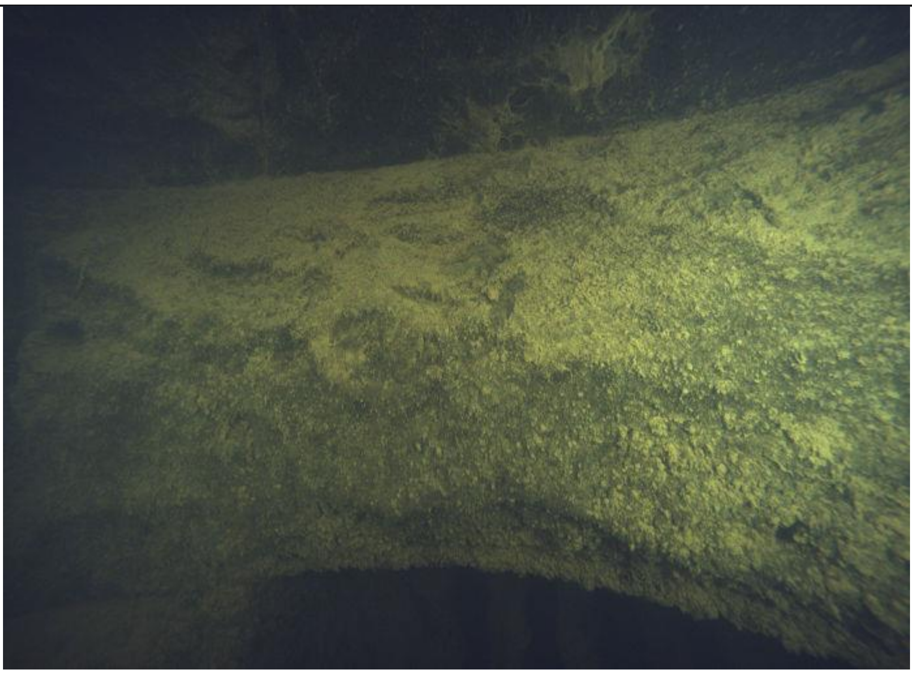


Figure 11 - Example of stone lintel captured at 8m depth on eastern wall of outlet tower. The lintels appear intact and free of major cracking.

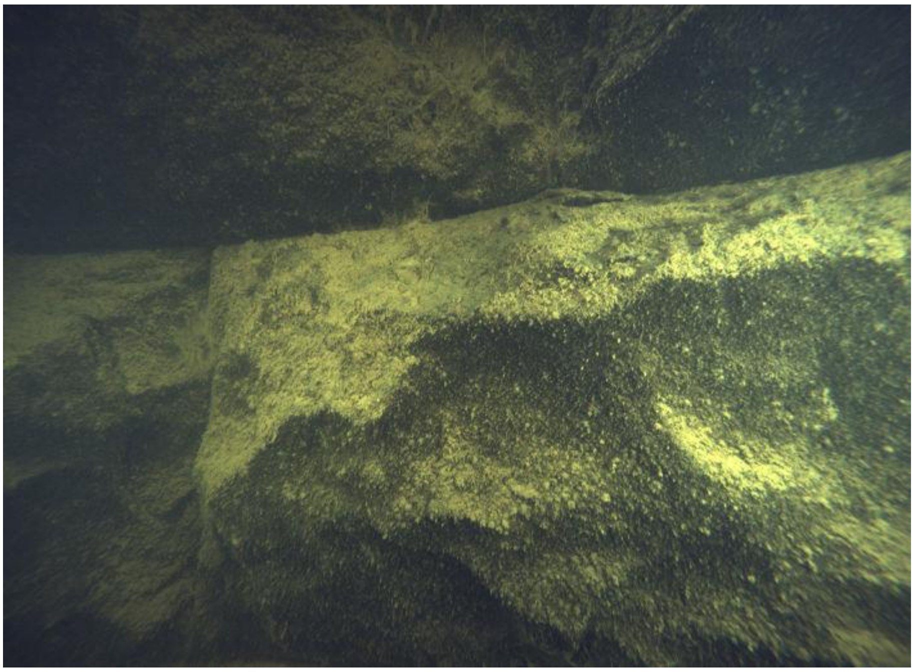


Figure 12 - Example of stone blockwork captured on western wall of outlet tower. The blocks appear intact and free of major cracking.

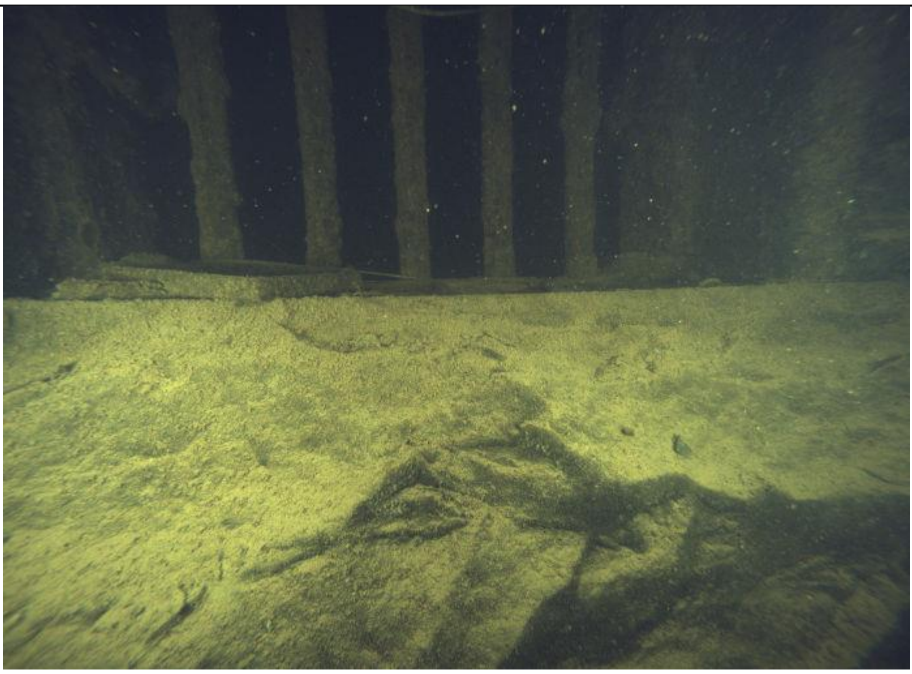


Figure 13 - Example of stone sill captured at 5m depth on south western wall of outlet tower. The sill blocks appear intact and free of major cracking.

Figure 14 - Example of stone blockwork at corners captured at 5m depth on south eastern wall of outlet tower. The blocks and grouting appear intact and free of major cracking.

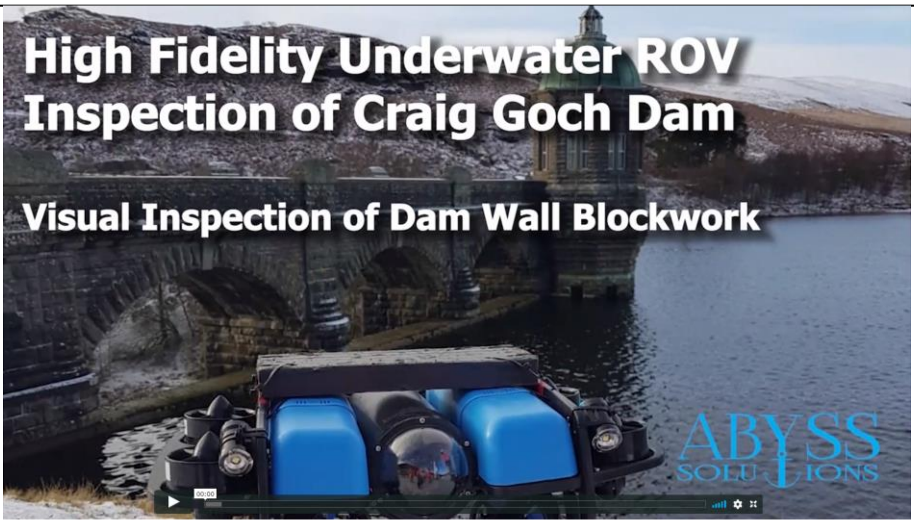


Figure 15 - Inspection video of dam wall blockwork (click here or on the image above to launch).

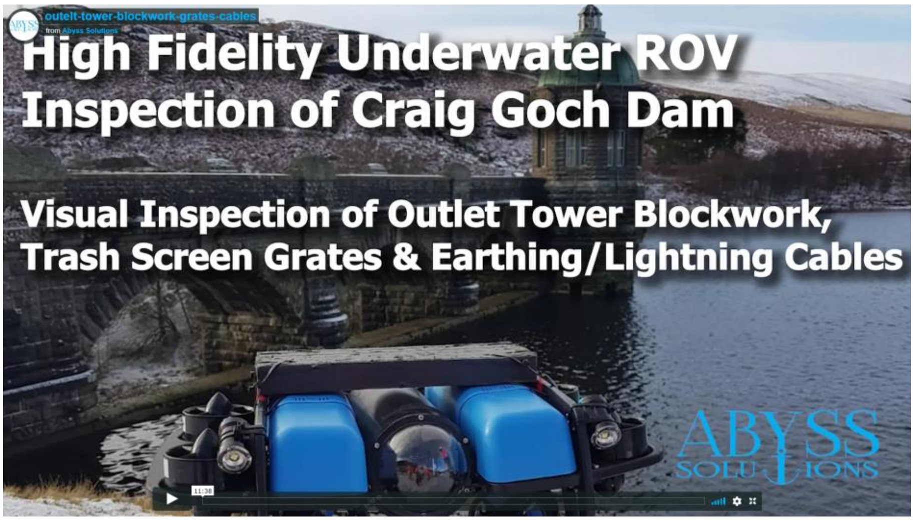


Figure 16 - Inspection video of outlet tower blockwork (click here or on the image above to launch).

(c) Outlet Tower Trash Screen Grates

Four rectangular trash screen grates were observed on each of the western, south western, south eastern and eastern walls of the outlet tower. The grates had dimensions of 2.1m(H) x 0.6m(W). The grates consisted of 5 vertical bars with a single cross member at mid-height. The grates were observed to be heavily corroded with significant material loss. Nevertheless, the grates and bars remained in place. The surrounding blockwork appeared intact. material obstructing 10% of the grate at 8m depth on the western wall was observed. The grates are judged to be in poor condition as major deficiencies have been noted. These elements will require repair to continue to operate as designed.

Figure 17 - Trash screen grate at 1m depth on the western wall of the outlet tower. The grate is heavily corroded with significant material loss.

Figure 18 - 3D model of trash screen grate at 1m depth on the western wall of the outlet tower (click here or on the figure above to launch.

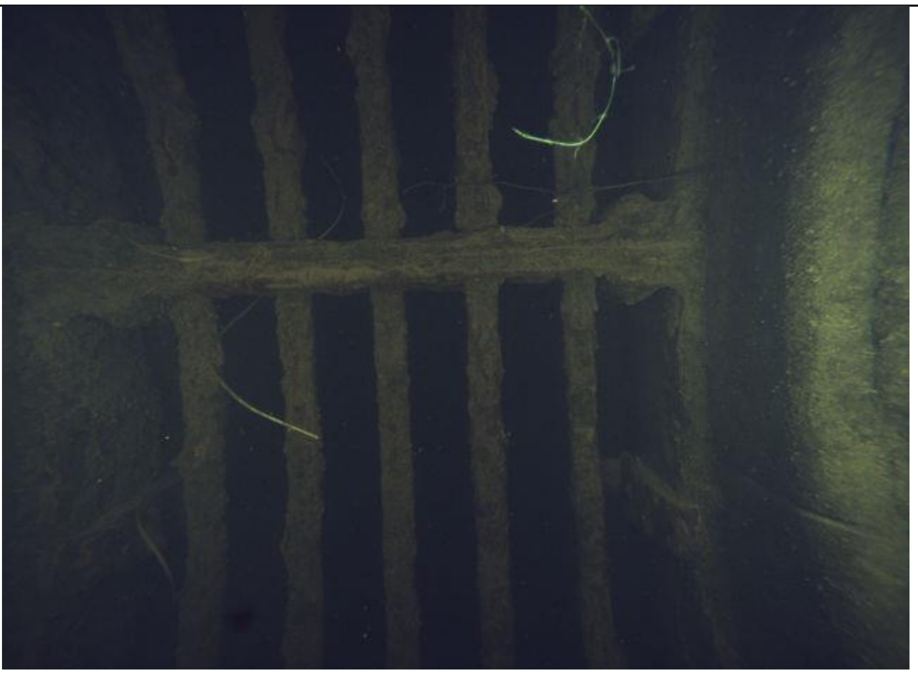


Figure 19 - Trash screen grate at 5m depth on the western wall of the outlet tower. The grate is heavily corroded with significant material loss.

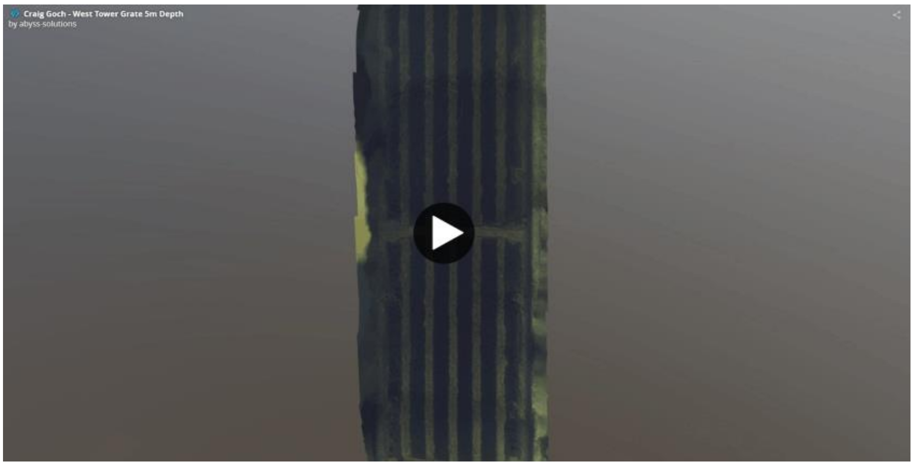


Figure 20 - 3D model of trash screen grate at 5m depth on the western wall of the outlet tower ([click here]() or on the figure above to launch).

Figure 21 - Trash screen grate at 8m depth on the western wall of the outlet tower. The grate is heavily corroded with significant material loss. Material obstructing 10% of the grate was observed.

Figure 22 - 3D model of trash screen grate at 1m depth on the western wall of the outlet tower (click here or on the figure above to launch).

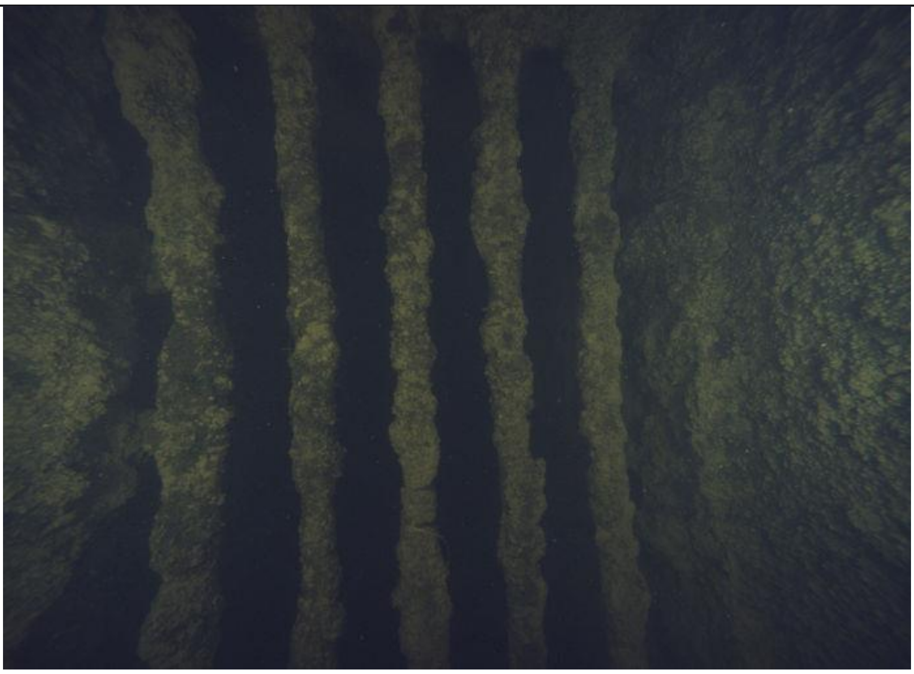


Figure 23 - Trash screen grate at 10m depth on the western wall of the outlet tower. The grate is heavily corroded with significant material loss.

Figure 24 - Trash screen grate at 1m depth on the south western wall of the outlet tower. The grate is heavily corroded with significant material loss.

Figure 25 - Trash screen grate at 5m depth on the south western of the outlet tower. The grate is heavily corroded with significant material loss.

Figure 26 - Trash screen grate at 10m depth on the south western of the outlet tower. The grate is heavily corroded with significant material loss.

Figure 27 - Trash screen grate at 1m depth on the south eastern wall of the outlet tower. The grate is heavily corroded with significant material loss.

Figure 28 - Trash screen grate at 5m depth on the south eastern of the outlet tower. The grate is heavily corroded with significant material loss.

Figure 29 - Trash screen grate at 8m depth on the south eastern of the outlet tower. The grate is heavily corroded with significant material loss.

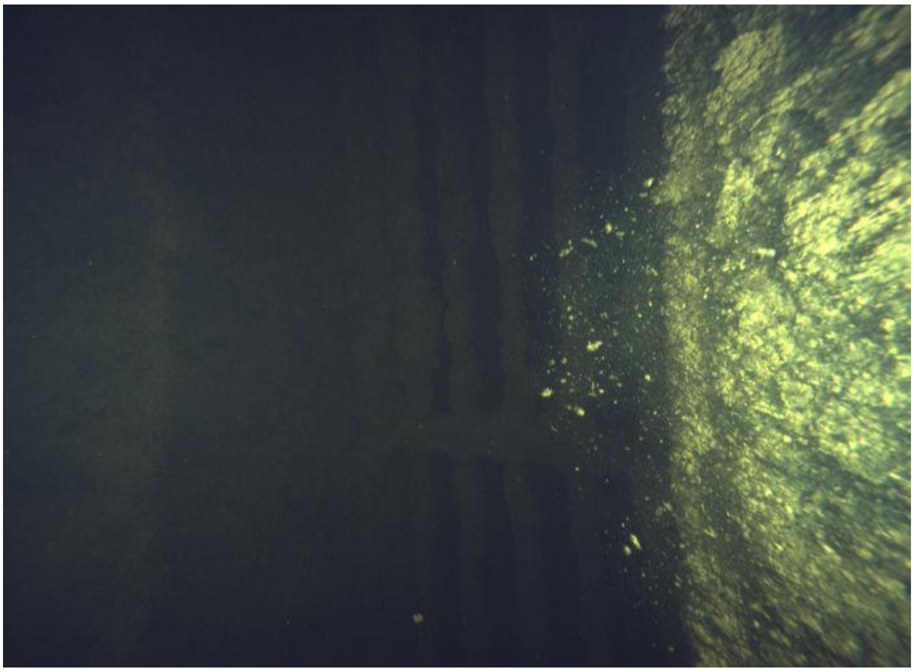


Figure 30 - Trash screen grate at 10m depth on the south eastern of the outlet tower. The grate is heavily corroded with significant material loss.

Figure 31 - Trash screen grate at 1m depth on the eastern wall of the outlet tower. The grate is heavily corroded with significant material loss.

Figure 32 - Trash screen grate at 5m depth on the eastern wall of the outlet tower. The grate is heavily corroded with significant material loss.

Figure 33 - Trash screen grate at 8m depth on the eastern wall of the outlet tower. The grate is heavily corroded with significant material loss.

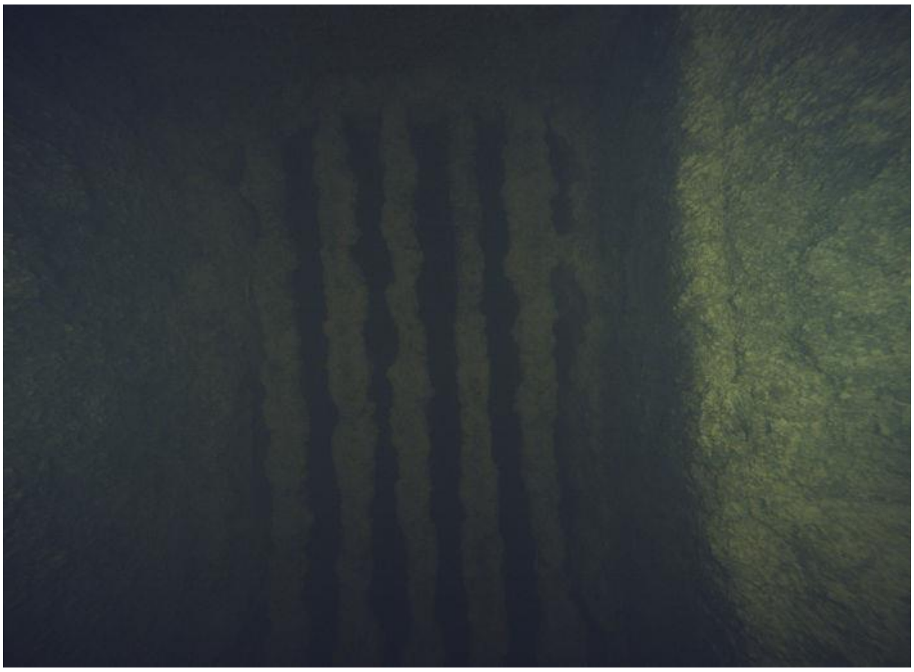


Figure 34 - Trash screen grate at 10m depth on the eastern wall of the outlet tower. The grate is heavily corroded with significant material loss.

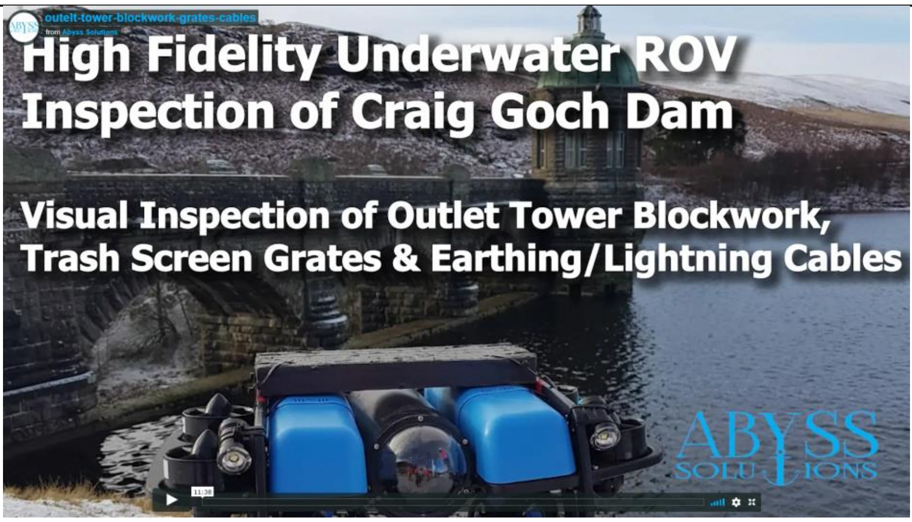


Figure 35 - Inspection video of outlet tower trash screen grates (click here or on the image above to launch).

(d) Earthing and Lightning Cables

The earthing cable was found to track down the south western wall of the outlet tower unsecured to approximately 8m. The cable was found to be unterminated with the termination device likely missing. Similarly, the lightning cable was found to track along the southern wall of the outlet tower unsecured to 8m. The cable was again found to be unterminated with the termination device likely missing. Both cables appeared intact with no obvious deterioration. However, termination devices at the ends of the cables appeared to be missing.

Moderate deficiencies have been identified which include the missing terminators. These elements will require repair to continue to function as designed. The cables are judged to be in adequate condition.

Figure 36 - Earthing cable at 5m depth. The cable appears intact.

Figure 37 - Base of earthing cable at 8m depth. The cable termination device appears to be missing.

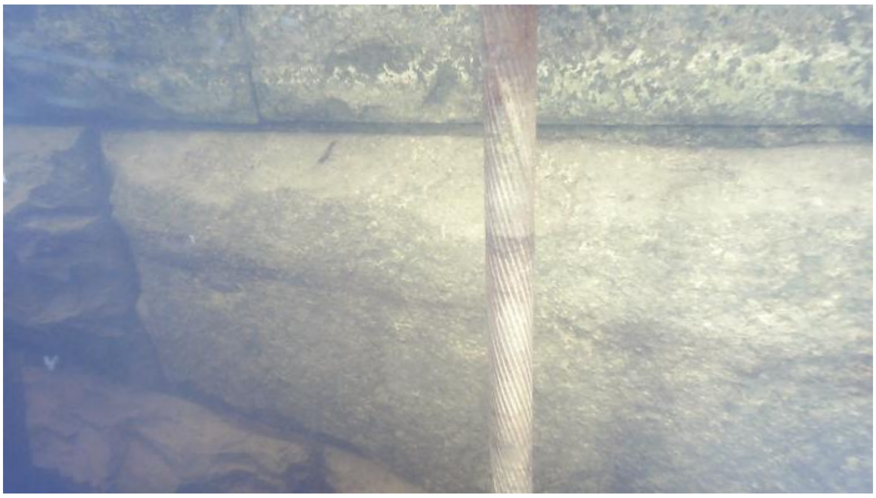


Figure 38 - Lightning cable at 5m depth. The cable appears intact.

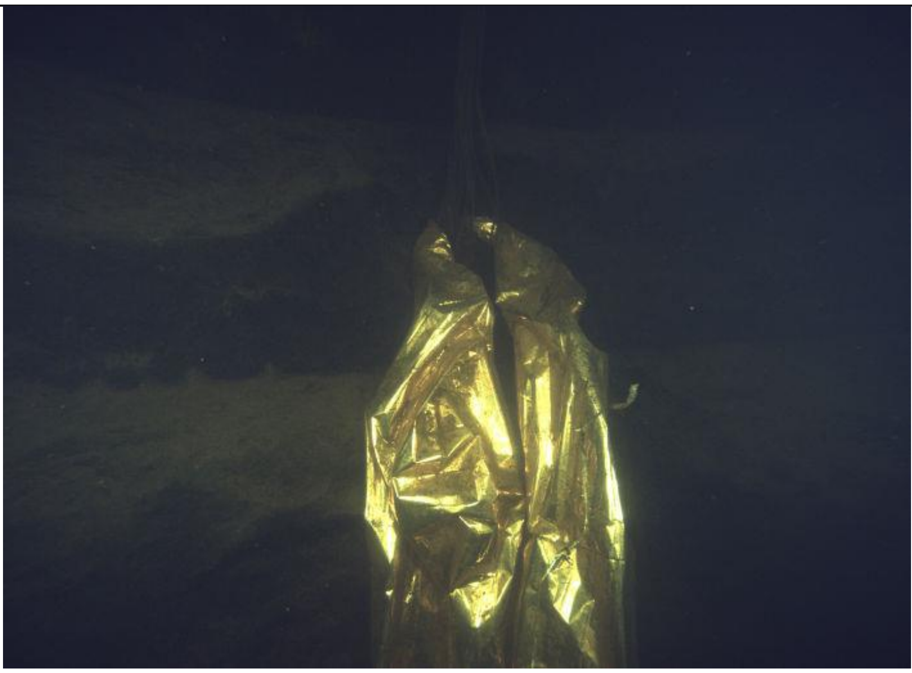


Figure 39 - Base of lightning cable at 8m depth. The cable termination device appears to be missing. A balloon appears to be caught on the end of the cable.

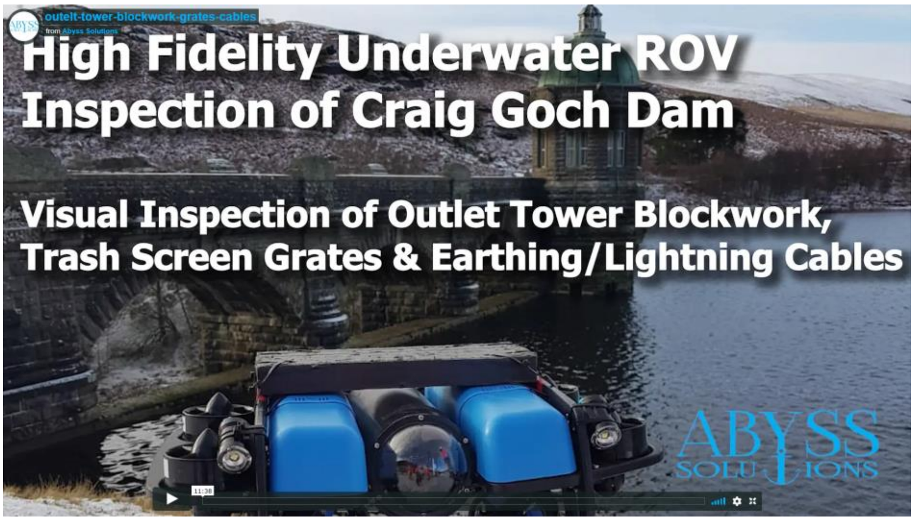


Figure 40 - Inspection video of outlet tower earthing and lightning cables (click here or on the image above to launch).

(e) Culvert Inlet

The culvert inlet was found to consist of an inlet pipe with a 90-degree elbow that becomes vertical and terminates with a bellmouth. The horizontal portion of the pipe is supported on a set of I-beams. The I-beams span across the width of the surrounding culvert headwall with their ends embedded within the concrete. The headwall was then situated at the end of a rectangular cutting into the foundation rock as expected.

The culvert inlet pipework, supports and bellmouth were found to be intact and covered in heavy fouling. Surface deterioration of the pipework is likely. The bellmouth appeared to be free of obstructions. The I-beam supports appeared to be intact and heavily fouled. The culvert headwall and I-beam interface appeared intact and free of major spalling. Overall the condition of the culvert inlet is judged to be adequate.

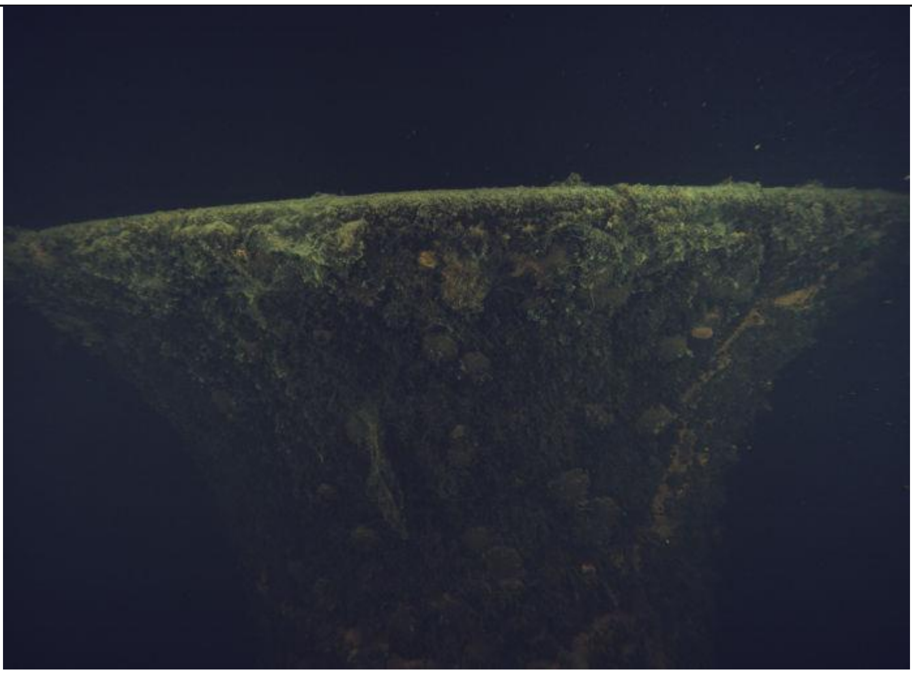


Figure 41 - Bellmouth at the end of the inlet pipe. The bellmouth appeared intact and free of obstructions.

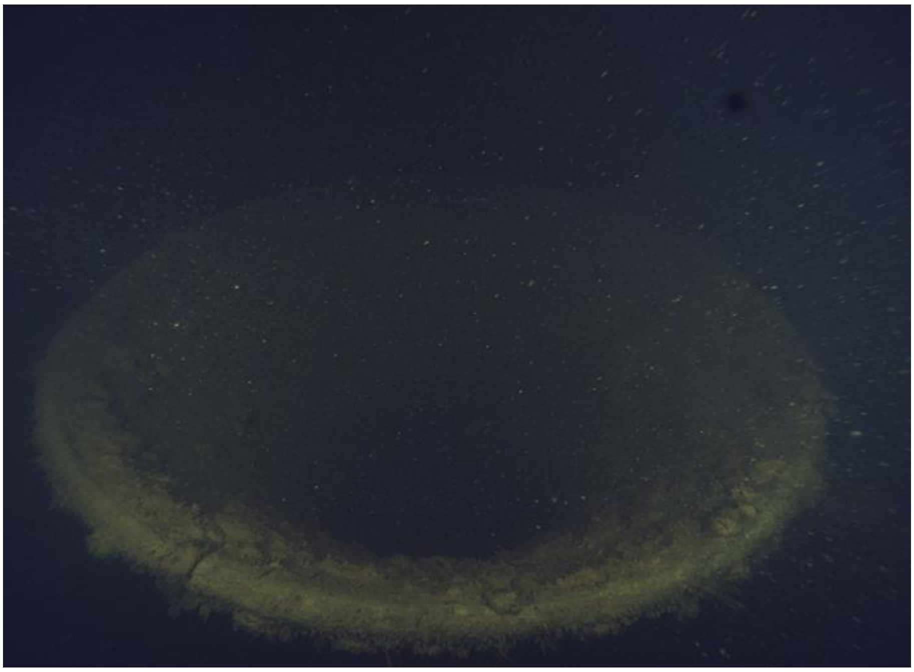


Figure 42 - Top of bellmouth at the end of the inlet pipe. The bellmouth appeared intact and free of obstructions.

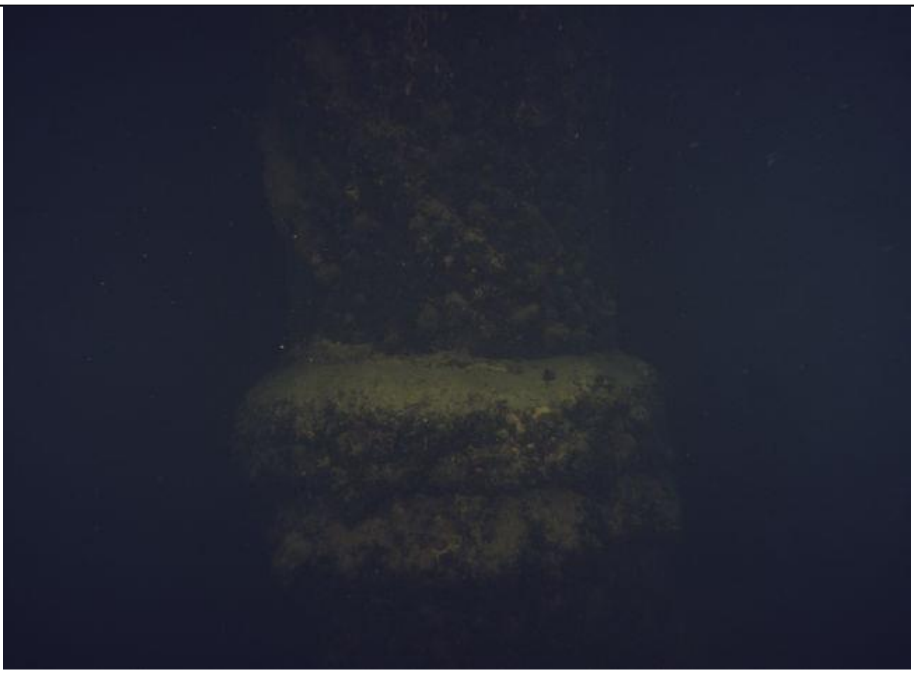


Figure 43 - Inlet pipework appeared to be intact and covered in heavy fouling.

Figure 44 - 3D model of Culvert inlet pipework and bellmouth ([click here]() or on figure above to launch).

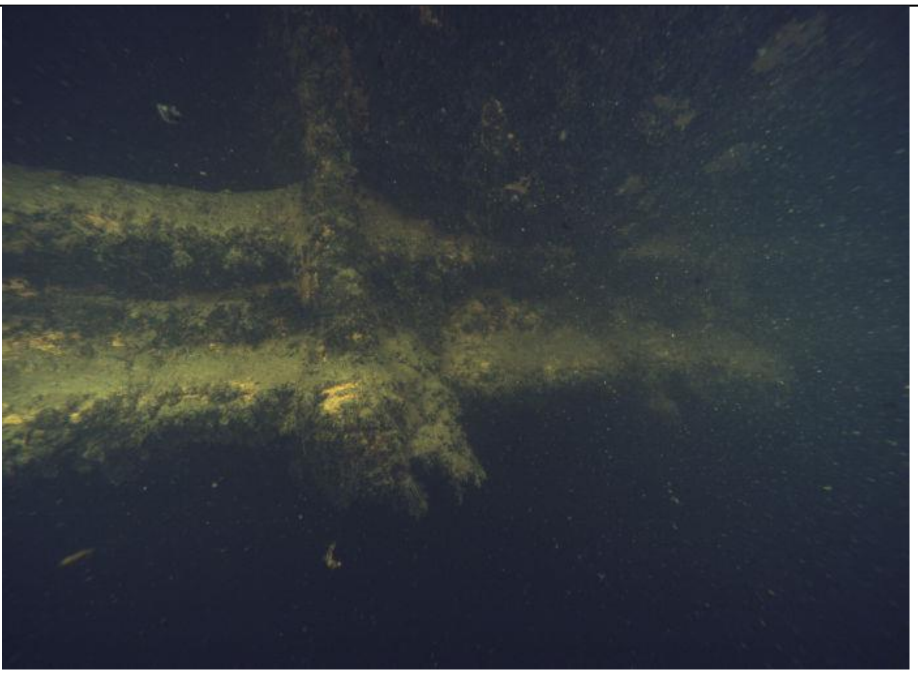


Figure 45 - I-beam and pipe support brackets beneath inlet pipe. The I-beam and support brackets appear heavily fouled and are likely deteriorated. Nevertheless, they appear to be intact.

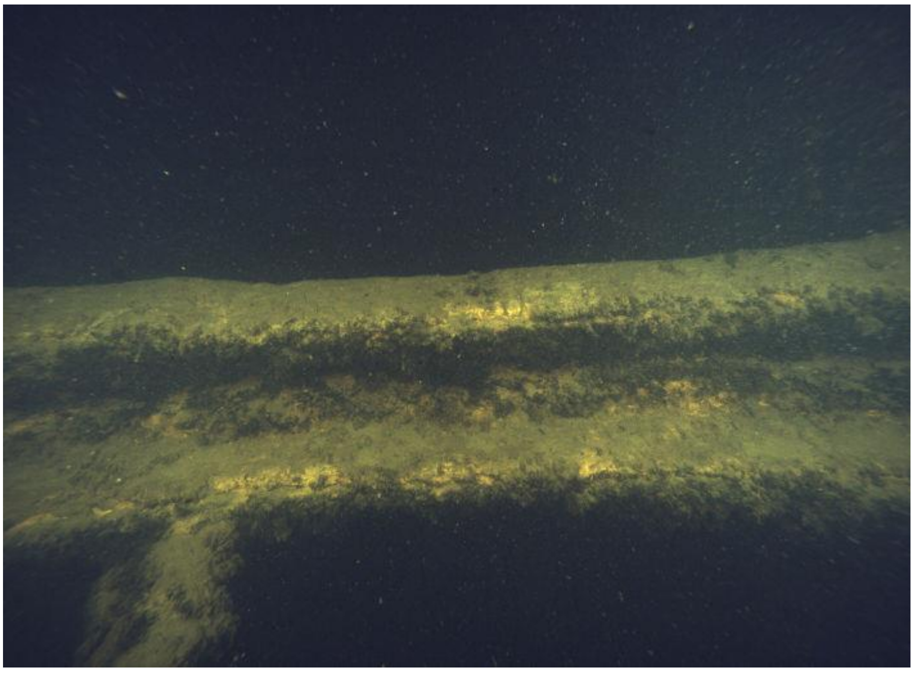


Figure 46 - I-beam beneath inlet pipe. The I-beams appear heavily fouled and are likely deteriorated. Nevertheless, they appear to be intact.

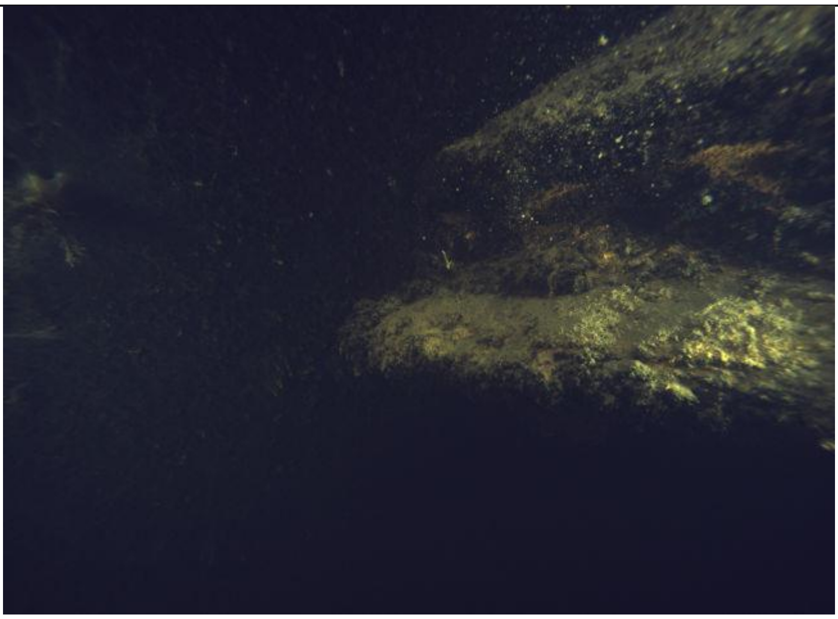


Figure 47 - Interface between I-beam and culvert headwall. The I-beams appear to be embedded within the concrete. The interface appears free of major spalling.

Figure 48 - 3D model of trash screen grate at 1m depth on the western wall of the outlet tower ([click here]() or on figure above to launch).

Figure 49 - Inspection video of outlet tower earthing and lightning cables ([click here]() or on the image above to launch).

(f) Scour Outlet and Valve Headstock

The scour outlet valve headstock was located near the centre of the dam wall. The scour outlet could not be located beneath near silt level. Therefore, the scour outlet was determined to be below the silt level. However, the valve operation rode was found to protrude from silt level along the dam wall up to the headstock gearing.

The scour outlet valve headstock operation rod and gearing appeared intact. However, these were heavily fouled. The fouling combined with likely surface corrosion renders the headstock gearing inoperable. The scour outlet and headstock mechanism are likely inoperable. Rehabilitation works will be needed to restore their function.

Figure 50 - Scour outlet valve headstock gearing. The gearing appears intact however is heavily fouled and likely to have experienced surface corrosion.

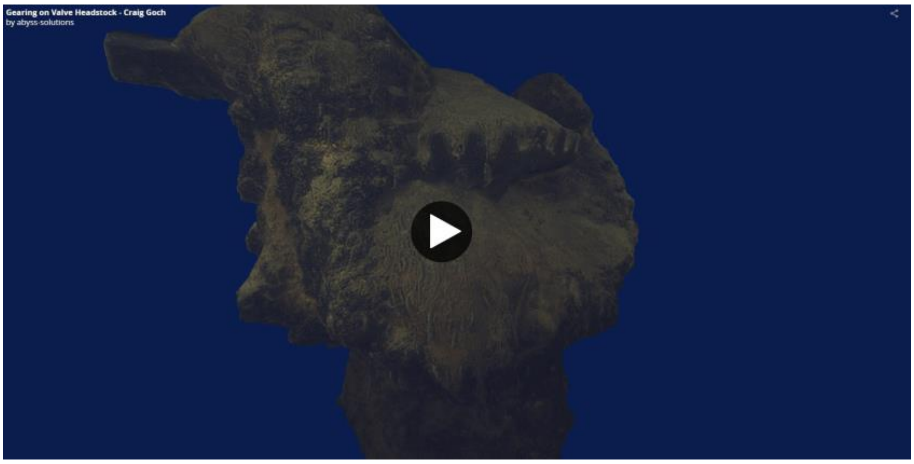


Figure 51 - 3D model of scour outlet valve headstock gearing (click here or on the figure above to launch).

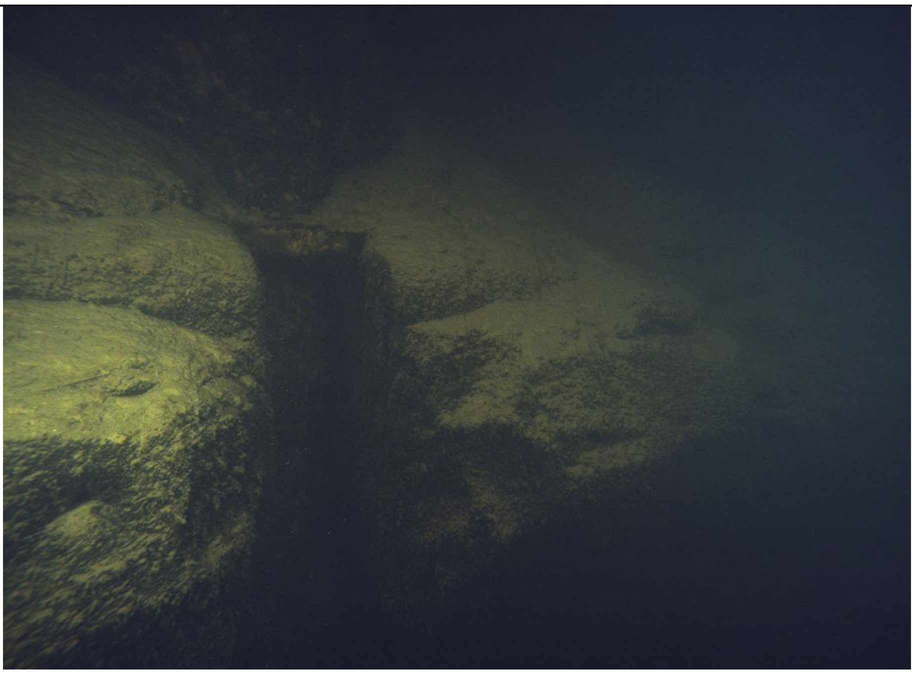


Figure 52 - Scour outlet valve operation rod. The rod appears intact however is heavily fouled and likely to have experienced surface corrosion.

Figure 53 - Inspection video of scour outlet valve headstock (click here or on the figure above to launch).

(g) Coffer Dam Wall

A rectangular concrete coffer dam wall was found 12.5m away from the dam wall. The dimensions of the coffer dam wall were found to be 15m(L) x 3m(W) x 3m(H). The concrete coffer dam wall appeared intact with no sign of major cracking or spalling. The coffer dam wall appeared to be in adequate condition.

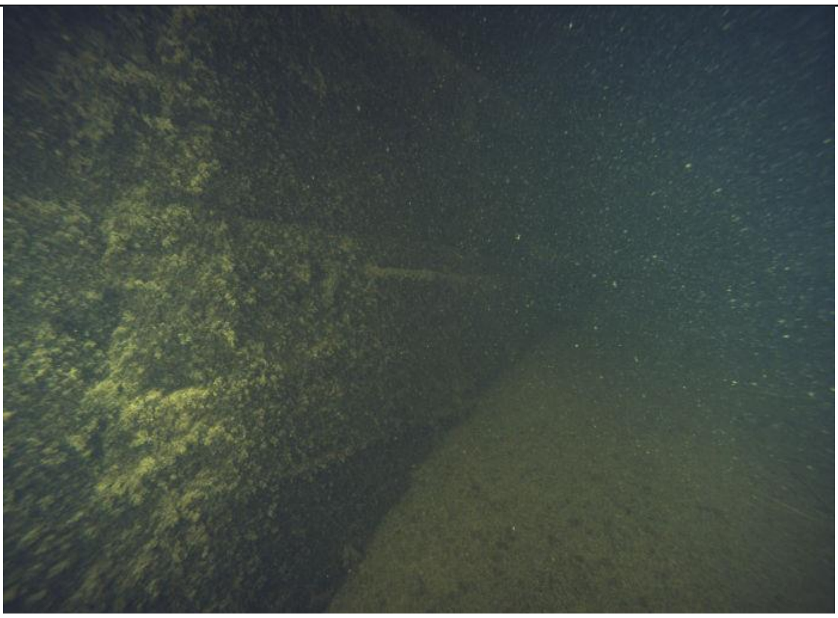


Figure 54 - North western end of coffer dam wall. The concrete coffer dam wall appeared intact with no sign of major cracking or spalling.

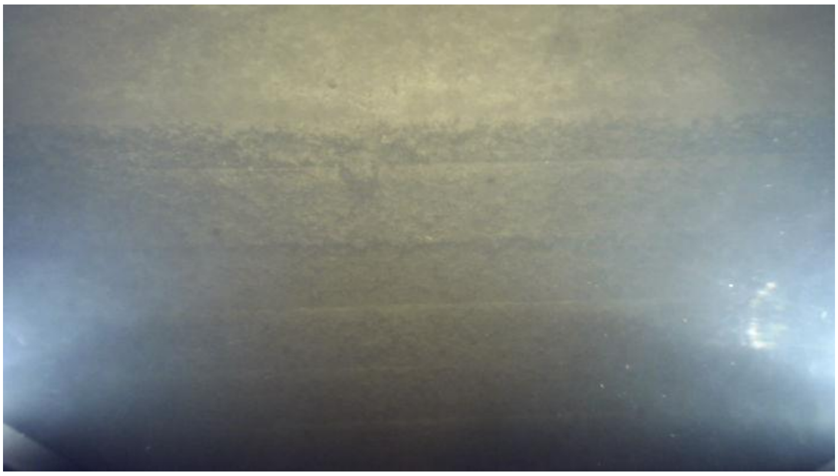


Figure 55 - Centre of northern face coffer dam wall. The concrete coffer dam wall appeared intact with no sign of major cracking or spalling.

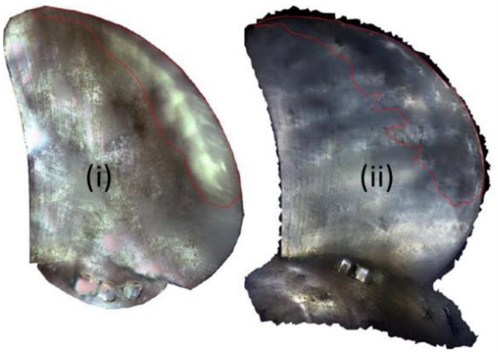
Figure 56 - North eastern end of coffer dam wall. The concrete coffer dam wall appeared intact with no sign of major cracking or spalling.

Figure 57 - Inspection video of downstream coffer dam wall (click here or on the figure above to launch).

4.5 Temporal Comparison of Asset Condition

The data collected as part of this survey can be used to track changes in the condition of key elements of the reservoir during successive inspections. However, given this inspection is the first of its kind and no comparable legacy data is available, this cannot be demonstrated as part of this trial.

Nevertheless, an example of fault evolution tracking for another application, the shipping industry, is shown Figure 58. The deterioration of asset condition can be quantified between successive inspections to better schedule maintenance for cost and disruption reduction.



Blade	Fault	Increase in affected surface area
1/SIM003-2	Pitted surface	8.7%

Figure 58 - Pitting corrosion highlighted on 3D models of a propeller blade between successive inspections. The change in affected surface area is estimated between the (i) first and (ii) second inspections.

5 Asset Configuration

The following 3D and 2D plans show the internal configuration of the dam. The plans were produced using data from the inspection. Approximate dimensions have been included based on onsite measurements. Click on the 3D plan in Figure 59 for an expanded and interactive view.

Figure 59 3D plan of dam configuration. [**Click here or on the image above for an expanded and interactive view.**]

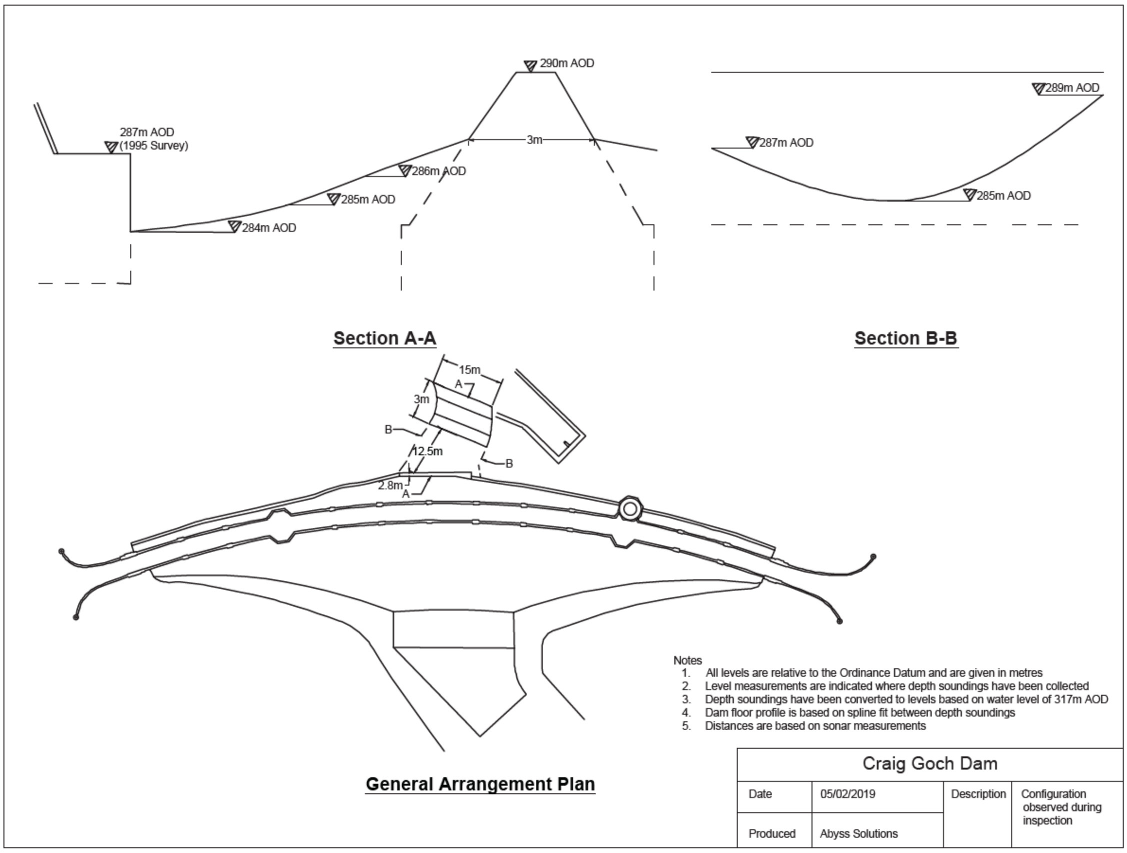


Figure 60 2D plan of dam showing general arrangement and details of coffer dam.

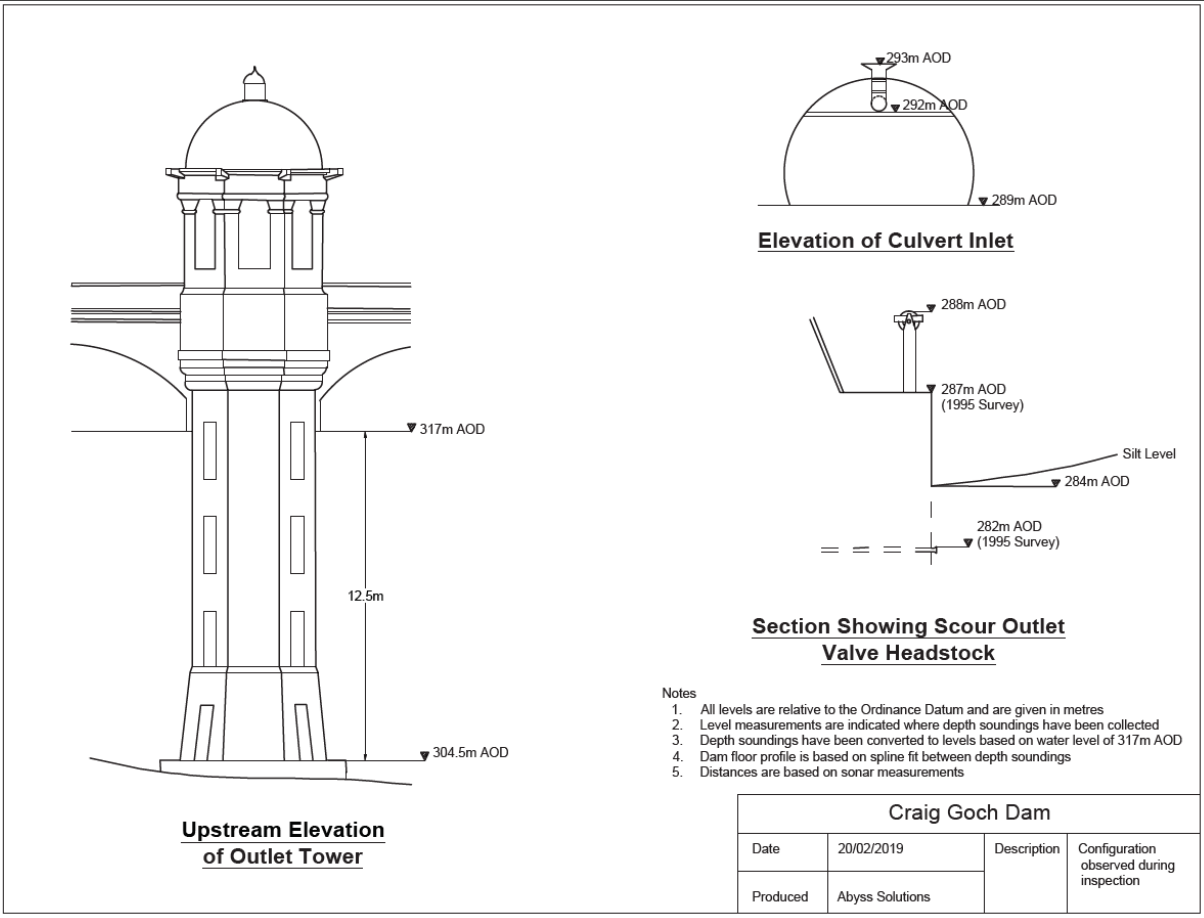


Figure 61 2D plan of dam showing details of tower, scour outlet and culvert inlet.

6 Conclusion

Abyss Solutions demonstrated an alternative approach to inspecting and documenting the condition of underwater assets that avoids the disruption, safety risks and quality issues of traditional diver and dewatering inspections. Abyss Solutions' underwater remotely operated vehicle (ROV) equipped with high-fidelity visual and acoustic imaging systems was used to conduct a baseline survey of Craig Goch Dam. Abyss Solutions produced a visual record of the inspection, the internal configuration of the dam and a condition assessment of key features. The inspection and analysis work revealed:

- The outlet tower and dam wall were aligned with no separation.
- The outlet tower intake trash screen grates were heavily corroded.
- The tower and dam wall blockwork were intact with no major cracking or missing grout.
- Termination devices were missing at the ends of the earthing and lightning cables.
- The culvert inlet pipe was intact, free of obstructions and supported on 4 I-beams embedded within the surrounding concrete headwall.
- The scour outlet was determined to be below the silt level and the headstock is likely inoperable.
- The coffer dam wall was found above silt level and appeared intact and free of major deterioration.

Based on the outcomes of this trial, Abyss Solutions recommends implementing the approach to underwater inspections presented herein as part of Welsh Water's routine inspection program. The ability to collect high quality underwater asset and condition information as well as document the state and configuration of assets with minimal operational disruption, safety risks and resources will lead to better and more frequent condition assessment, cost-effective maintenance and enable temporal tracking of fault evolution and asset condition.