New life for historic slate quarries by accommodating the 100 MW Glyn Rhonwy pumped storage hydro scheme

Bernhard Stabel
Fichtner GmbH & Co KG
Sarweystraße 3
Stuttgart
Germany

Tom Clegg
Fichtner Consulting Engineers Ltd.
Kingsgate House, Wellington Road North
Stockport
United Kingdom

Introduction
Quarry Battery Company Ltd. has engaged Fichtner GmbH & Co KG together with Fichtner Consulting Engineers Ltd. to support their 100 MW Pumped Storage Hydro development in Wales. The scheme foresees the connection of two disused quarries with depths of some 50 m providing storage volumes of ca. 1.1 mil. m³ each by waterways and a powerhouse with variable speed pump-turbines, which will have an installed generating and pumping capacity of 100 MW and 120 MW, respectively and a gross head varying between 186 and 292 m. For repurposing the quarries will be reshaped and sealed to achieve stability and water tightness. In order to enlarge the storage volumes, rockfill dams with surface sealings are designed at the lower parts of the quarries’ rims.

The project is already consented, the FEED Design was started and contractors and suppliers have been consulted. At this stage some hurdles still need to be taken to achieve FID.

The Quarry Battery/Glyn Rhonwy PSH will help to achieve a net zero carbon world by providing storage to cover the gap between supply and demand and stabilizing the network frequency in an electricity market more and more characterized by renewable energy sources.

1. Overview
The site itself is within a Landscape Character Area designated for its historical landscape and also Dinorwig Landscape of Outstanding Historical Interest. The site is located approximately 1km outside the Snowdonia National Park on the SW side of Llyn Padarn. The site crosses arable and open grazing land, woodland, quarries 1 to 8 (Q1-8), slate waste mounds, industrial land and roads.

Some key figures for the project are:
Active reservoir volumes: 1.1 mio m³ in Upper and Lower Reservoirs
Capacity for generation: 2x50MW
Capacity in pumping: 2x60MW turbine
Gross head: 292-186m
2. Geological Setting

The dominant rock formation at the project is the Llanberis Slates formation of Cambrian age, predominantly consisting of purple and green mudstones and siltstones with sandstone bands which form a narrow outcrop, between approximately 750 m and 900 m wide, running roughly South-West to North-East. Dolerite intrusions were encountered in all but one of the boreholes realized during the geological investigation campaign and are mainly trending WNW-ESE cutting across the slate bands.

The quarry Q1, which is to be reworked to form the Upper Reservoir (UR), together with the historic tunnels act like a large spring lowering and draining the water down to a level of ca. 350 m. Partially high rock mass permeabilities were measured in the boreholes around Q1 with Lugeon values over 100 Lu.

At Q6, the future Lower Reservoir (LR), the rock mass generally has been tested to have a low permeability, except on the NE-side (towards Llyn Padarn).
Figure 2:

Cross section (NNW-SSE) at Upper Reservoir (top) and (NNW-SSE) at Lower Reservoir Groundwater table and rock mass permeabilities (middle) and Geological Cross section (NNW-SSE) at Q6/Lower Reservoir (bottom)
Preliminary laboratory testing has shown the slate to be petrographically suitable for asphalt and concrete aggregate. Whether the slate can be produced in the required grading still needs to be studied.

The use of the slate muck for rockfill still also needs to be confirmed regarding the requirement of crushing and screening in order to obtain an adequate compactability. Available literature data suggest its suitability.

<table>
<thead>
<tr>
<th>Line</th>
<th>Test</th>
<th>Unit</th>
<th>Value reported</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Oven dried relative density</td>
<td>Mg/m³</td>
<td>2.84</td>
</tr>
<tr>
<td>2</td>
<td>Uncompacted bulk density</td>
<td>Mg/m³</td>
<td>1.79</td>
</tr>
<tr>
<td>3</td>
<td>Bulk density after 8 passes - open ground trial</td>
<td>Mg/m³</td>
<td>Average from 3 tests 2.278</td>
</tr>
<tr>
<td>4</td>
<td>Line 1 / Line 2, bulking factor</td>
<td>Ratio</td>
<td>1.59</td>
</tr>
<tr>
<td>5</td>
<td>Line 3 / Line 1, compaction</td>
<td>Ratio</td>
<td>80%</td>
</tr>
</tbody>
</table>

The above shows that the slates can be expected to be compactable to a bulk density of 80% of the oven dried relative density, which is well suited to a rockfill dam.

3. Special Design Features
3.1 Transient Analysis and Electro-Mechanical Equipment
A key and exceptional feature of the project is the large difference in head under which the pump-turbine (PT) needs to operate. The need to exclude negative pressure in the waterways and the risk for cavitation in the PT required detailed transient analysis under consideration of the PT-characteristics, resulting, after several iterations, in an optimised PT selection, setting height and diameters and alignment of the waterways. This optimisation also allowed the avoidance of any surge tanks and maximum unit utilisation across the variable head range.

The lowest pressure at the turbine outlet following optimisation is 22.7 mWc and it appears at a load case with load rejection with 1 second delay time between the two power units. Almost 23 mWc safety cushion against negative pressure is more than 50% of the lowest static pressure at the turbine outlet. See figure below. To achieve such results the maximum unit capacity was increased to a pumping power of 2x60 MW, while complying with the limit of 2x50MW generating power. After consultation of the E&M suppliers, it became obvious that a full-scale power converter (FPC) solution for the var-speed application is necessary to maximise unit operation across the head range. The general arrangement of the single line diagram is shown in the Figure below.

![Figure 3: left: Pressure downstream of the turbines for unit 1 and unit 2 during delayed load rejection (delay 1 second) right: General arrangement of the single line diagram](image)

3.2 Upper Reservoir at Q1
The desired reservoir volume of 1.1 mil m³, required a Full Supply Level (FSL) of 392m AOD, which in turn required a dam at the Southern rim of Q1, which is to be formed by an asphalt faced rockfill dam (AFRD). Due to the partly high rock mass permeability around Q1, the UR needs to be completely sealed. The invert of the UR shall be sealed by an asphalt sealing with drainage layer and gallery to avoid uplift when the reservoir is empty. A sprayed
membrane sandwiched between two shotcrete layers with systematic rock bolts shall stabilise and seal the slopes of the reworked Q1. The “Guide to Drawdown Capacity for Reservoir Safety and Emergency Planning” (2017) required the provision of Outlet/Scour Facilities to draw down the reservoir by 1m in one day or 50% of the reservoir volume in 7 days.

Figure 4: Upper Reservoir Section and Sealing Detail

3.3 Powerhouse Cavern with Access Shaft

Due to the conditions of the existing Development Consent Order (DCO), the location of the powerhouse was confined to a limited area to the South-East of the LR with a surface level at ca. 157.50m AOD. The setting height of the PT resulted from the transient analysis to 60m AOD with the powerhouse foundation at ca. 52m AOD. Initially two PTs were foreseen in a single shaft. A twin shaft solution was then also studied. After several rounds, including the consultation of contractors and suppliers, the below shown cavern option was developed, which includes an access shaft for lowering the equipment to the erection bay of the powerhouse cavern (PHC). The Access Shaft also foresees HVAC ducting and segments for cables, elevator and a fire save staircase. Attached to the Access Hall on top of the Access Shaft is the control room and other rooms typically included in an operating building. The FPC and Unit Transformers are located next to the Access Hall.

The PHC was oriented normal to the strike of the foliation/cleavage plains. For the rock support two classes of rock mass were assumed with corresponding resulting rock support measures. For the PHC roof systematic support with double corrosion protected (DCP) pre-stressed anchors is envisaged. For the side walls the support for the better rock class consists of rock bolts, while for the worse rock class the need for long DCP pre-stressed anchors resulted from FE-analysis. The total amount of seepage water has been estimated in FE-analysis ca. 5 l/s in the powerhouse, when assuming a full LR.

Figure 5: Powerhouse Cavern with Access Shaft and Cross Section through Power Unit
3.4 Lower Reservoir at Q6

To obtain the required reservoir volume of 1.1 mil. m³ a FSL of 154m AOD needs to be achieved, which in turn requires a dam at the North-Eastern rim of the Q6. Like for the UR a AFRD is foreseen. The asphalt face is connected to the foundation by a concrete plinth and due to higher rock mass permeabilities on the NE-side, a grout curtain is foreseen below the plinth to avoid seepage towards Llyn Padarn. Due to low rock mass permeabilities the remaining part of the quarry can be left untreated.

However, the steep and partly overhanging rock slopes, left behind by the previous quarry operations, cannot be considered completely stable, esp. in view of the future operation of the pumped storage scheme with frequent and rapid water level changes. The design foresees a permanent access ramp down to the base of the LR, which will leave stable rock faces and slopes behind. This ramp will mainly remain in the NE part of the LR. The transition to the SW part of the LR is marked by a prominent Dolerite Dyke exposed in Q6. For the SW part of the LR slope stabilisation is only foreseen at the Intake/Outlet structure and the temporary Construction Access Tunnel. During construction temporary rock fall protection measures need to be foreseen. During operation of the scheme some parts of the unstable rock faces in the SW may fall into the reservoir and rock debris will accumulate at the base of the LR. A rock trap is foreseen in front of the Intake and removal of the debris can be done via the Access Ramp when the reservoir is drawn down.

The existing historic tunnels, remaining from the quarry operations, will need to be located and closed to avoid water losses from the LR.

Like the UR the LR has the same draw-down requirement. Additionally, the LR needs a spillway in order to release excess water accumulating in both reservoirs because of more precipitation onto the reservoir than evaporation or losses from the reservoirs.
3.5 Connection to Lynn Padarn and First Filling

At the LR the draw-down and spilling mentioned above will be towards Llyn Padarn. The first filling of the LR will be done with a pipeline connection to Llyn Padarn, where the water level is at about 100m AOD, i.e. equal to the base of the LR. The LR will probably be filled in several stages. After the first stage wet commissioning of the power units may start and water can be pumped up to the UR. Water from Llyn Padarn will be added until 1.1 mil. m³ are shared between the UR and LR.

3.6 Achieving Mass Balance

An important condition from the DCO is that material should not be exported from site and also not be transported between Q1 and Q6. The excavation material from most of the water way, powerhouse and LR will accumulate at the LR. Here only a limited amount of muck can be utilised in the rockfill dam itself. More material will be used for landscaping downstream of the LR AFRD, including the filling of the Q7 at the downstream toe of the AFRD.

4. Outlook

The table below outlines the existing pumped storage capacity operating in the UK.

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Owner</th>
<th>No of Units</th>
<th>Capacity [MW]</th>
<th>Storage [GWh]</th>
<th>Storage [h]</th>
<th>Year commissioned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dinorwig</td>
<td>First Hydro</td>
<td>6</td>
<td>1,800</td>
<td>10.4</td>
<td>5.8</td>
<td>1983</td>
</tr>
<tr>
<td>Ffestiniog</td>
<td>First Hydro</td>
<td>4</td>
<td>360</td>
<td>1.73</td>
<td>4.8</td>
<td>1961</td>
</tr>
<tr>
<td>Foyers</td>
<td>SSE</td>
<td>2</td>
<td>300</td>
<td>6.4</td>
<td>21</td>
<td>1974</td>
</tr>
<tr>
<td>Cruachan</td>
<td>Drax</td>
<td>4</td>
<td>440</td>
<td>7</td>
<td>16</td>
<td>1965</td>
</tr>
</tbody>
</table>

These projects are integral in contributing to the network stability and regulating and storing the volatile wind and solar power production. An independent study by Aurora Energy Research (2022) states that the UK requires approximately 10 times its current capacity of Long Duration Energy Storage (LDES) to support renewable energy generation. That is, that 24GW of LDES and 10GW of 8-to-16-hour LDES (PHS) is required by 2035 (the target year for the decarbonisation of the electricity system).

With more renewables on the grid and progressing decarbonisation of the industry more regulating pumped hydro projects should be welcomed by the grid, which is also reflected in the activities in the market - see figure below.
Cap and floor mechanism.
The Cap & Floor mechanism was introduced by Ofgem in 2014 to support construction of new interconnectors between the UK and other European countries. The cap and floor mechanism provides a balance between incentives to stimulate competition and investment and ensuring that the risks and rewards are bounded. The provision of the floor overcomes some of the uncertainty associated with wholesale price fluctuations between markets, and other income streams. In doing so, this seeks to ensure that the benefits of interconnection can be realised. Further, the presence of a cap ensures that consumers are protected from unbounded developer revenues. The UK government has been considering such support for LDES technologies. A consultation was launched by the Department for Business, Energy and Industrial Strategy (BEIS) in July 2021. The response in August 2021 provided the following statement “Considering these conclusions and as outlined in the British Energy Security Strategy, we will ensure the deployment of sufficient LDES to balance the overall system by developing appropriate policy to enable investment by 2024.”¹. This has been taken a positive signal by developers of UK PSH to continue their efforts bringing new projects to the market which presently continue at pace.

References
1. Dr. W.D.H. Woodward, Dr. J.H. Jellie & Prof. A.R. Woodside, PREDICTING THE PERFORMANCE OF TYPE 1 SLATE AGGREGATE, University of Ulster, Transport & Road Assessment Centre, School of the Built Environment, HERG Project 04267

The Authors
Bernhard Stabel is a civil engineer (Dipl.-Ing.) from the University of Karlsruhe and holds an MBA degree from the University of Edinburgh, with 30 years experience in hydropower & dams in all phases of project implementation. He technically specialized in geotechnical, dam and rock engineering. His experience includes construction design and supervision of several pumped storage schemes. Since 2022 he is Principal Hydro & Water with Fichtner GmbH & Co KG. Before he was Executive Director for Hydropower and Water Resources with Tractebel Germany, who acquired Lahmeyer International in 2015, where he joined in 1991.

Tom Clegg is a mechanical engineer and holds a Master’s degree in Mechanical Engineering with Renewable Energy from the University of Edinburgh, is a Chartered Engineer with the Institute of Mechanical Engineers and is a certified Functional Safety Engineer (SIS) with TÜV Rheinland. Tom is the Head of Hydropower for Fichtner in the UK and Ireland responsible for managing Hydropower projects in development across the UK. Prior to joining Fichtner in 2018, Tom was a Senior Engineer at hydro turbine manufacturers, Gilbert Gilkes & Gordon. Here he was responsible for technical and project management for new and refurbishing hydroelectric turbine packages for projects around the world.