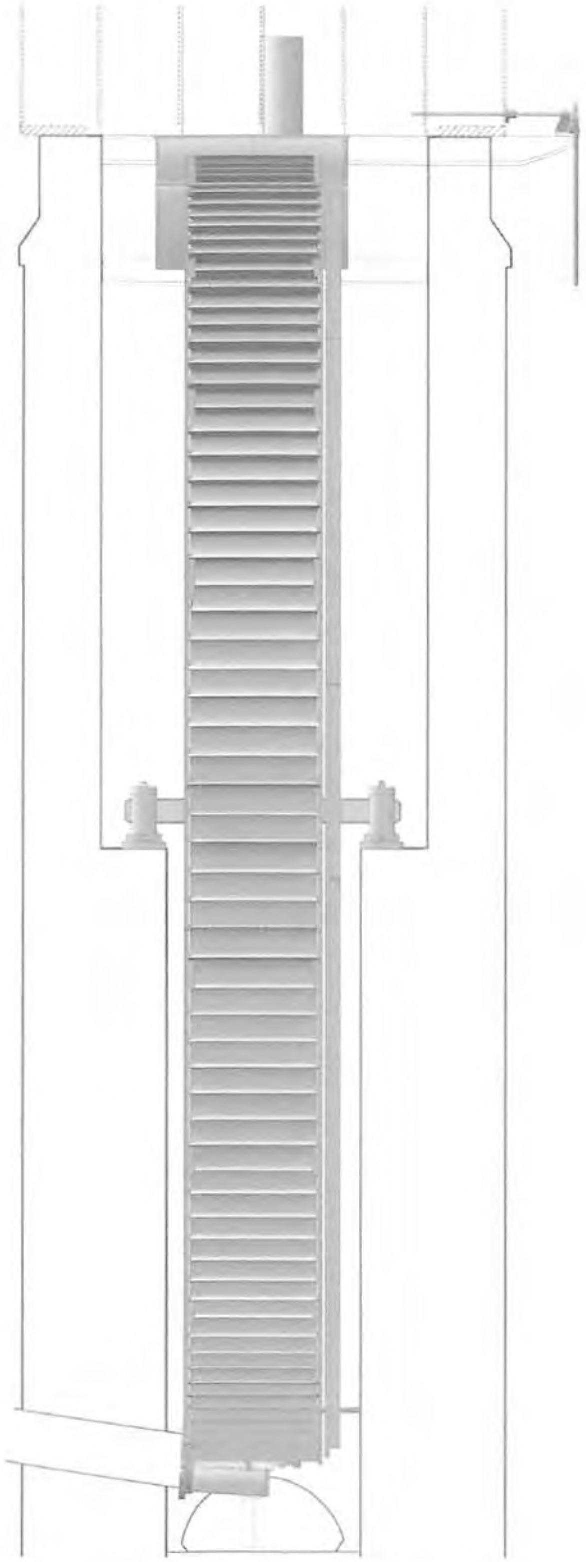
The Iron Waterwheel at Gilfach Ddu

Archaeological Monitoring and Recording at the Welsh Slate Museum, Llanberis



Report number 430

Ymddiriedolaeth Archaeolegol
Gwynedd Archaeological Trust

The Iron Waterwheel at Gilfach Ddu

Archaeological Monitoring and Recording at the Welsh Slate Museum, Llanberis

Report number ~~374~~ 430

Prepared for Posford Haskoning Ltd

By Andrew Dutton

Ymddiriedolaeth Archaeolegol Gwynedd
Gwynedd Archaeological Trust

Archaeological Monitoring and Recording at the Welsh Slate Museum, Gilfach Ddu, Llanberis.

1. The Waterwheel and Wheel Housing

1.1 Introduction

The Welsh Slate Museum at Gilfach Ddu, Llanberis, formerly the Dinorwic Quarry workshops, house the largest surviving waterwheel in mainland Britain; the largest is at Laxey, on the Isle of Man.

The Llanberis wheel is constructed entirely of iron, on the suspension principle devised in the 1820s by the engineer Thomas Hewes. This allows for a large iron structure made up of any number of individual components in suspension to revolve freely on a central axle, in the manner of a spoked bicycle wheel.

The wheel measures 50^{ft} 5^{in} across, is 5^{ft} 3^{in} wide, on a 12^{in} diameter axle borne by two large bearings. The waterwheel at Gilfach Ddu is enclosed on all four sides within a massive wheelpit built out of both hand dressed and sawn slate blocks. The Dinorwic waterwheel provided the primary power source for the Gilfach Ddu quarry workshops that were under construction in 1869/70 at the same time as the wheel was fabricated and installed.

There is no record of the decision that determined the use of this particular method of power as late as 1870, when steam power had been established on a small scale within the quarry workings since 1848. Local technological know-how was not the issue here - neighbouring Glynrhonwy Quarry installed a mill complex powered by compound steam engines at much the same time – but proven tradition and relative cost are likely to have been factors. Steam engines were already a familiar sight within the quarries themselves, whether as locomotives or static engines, but on a relatively small scale. The expense of installing one or a series of steam driven engines capable of powering the multiple tasks required at Gilfach Ddu would however have been considerable. Typically, in slate quarries like Dinorwic where there was an abundant supply of water, other forms of prime mover did not supercede large-scale industrial waterwheels for some years to come.

De Winton's Union Iron Works of Caernarfon, a company that was already engaged in the manufacture of both steam and water driven machinery, was commissioned to construct and install the water wheel, header tank and rising main at Gilfach Ddu. Quarry employees would have constructed the pit and housing in tandem with the workshop complex. (pl.3)

Along with the quarry workshops, the construction and installation of the wheel was completed in 1870. From the existing records, we can assume (an occasional operator error notwithstanding) that the wheel remained a free, and virtually trouble-free, power supply until a pelton wheel superseded it in 1925. By this time the waterwheel had been in almost continuous service for fifty five years. (pl.1)

1.2 Background

The waterwheel is a major attraction at the Welsh Slate Museum and consequently the National Museums and Galleries of Wales initiated a programme of remedial restoration work and repairs to the waterwheel in view of its obvious deterioration. The site is designated a Scheduled Ancient Monument (Cn 164) and required Scheduled Monument Consent prior to any of the proposed works being undertaken.

Archive search and other lines of inquiry suggested that there were no contemporary or later plans or other drawings of the waterwheel in existence and accordingly a drawn survey was undertaken of the wheel, wheel housing, header tank and rising main. This survey was commissioned in advance of any other works commencing and sought to record the location of as many individual components of the structure as possible; the purpose for this level of detail was to allow the identification of specific elements during the restoration process. The initial results of that survey and the earlier phases of work appear in GAT Reports No. 306 and 376 respectively and elements within both have been subsequently enhanced or updated and incorporated within this latest report. (see fig.1 A1 sheet drawing)

Archaeological monitoring and recording on the waterwheel site was undertaken between Spring 1998 and the completion of the restoration works in the early Summer of 2001. Where possible this has coincided with the various main phases of work that directly affected either the appearance or existing structural integrity of the monument.

In addition to recording any physical changes made to the wheel during the works a number of outstanding questions posed during the initial recording of the monument were subsequently addressed.

Restoration and refurbishment work was duly carried out but was split into two separate schedules each addressing particular problems. The requirements of each were outlined in the relevant Contract Documents issued by the Consulting Engineers, Posford Duvivier.

Simplistically, the two major stages of the undertaking can be divided thus:

Stage 1 : THE WATERWHEEL - Spring/early summer 2000 : Dismantling, cleaning and descaling, re-painting, re-fitting and installing newly fabricated wheel components.
Main Works Contractor – Dorothea Restorations Ltd.

Stage 2 : THE HOUSING, HEADER TANK AND RISER - Spring/early summer 2001 :– Cleaning and descaling, consolidating or replacing defective plates, remedial work to tailrace arch and copings. Main Works Contractor – Alan Dawson Associates.

Different main contractors undertook the two stages outlined above. Each required that a suitable level of mutual cooperation be established in order that neither the timing of the project nor the level of archaeological recording was compromised. The nature of the work undertaken necessitated a flexible approach to recording opportunities and inevitably not all instances that might have provided archaeological detail could be addressed by archaeological staff. Nonetheless, a substantial level of additional detail was added to the existing record of the monument.

The findings of this report are presented in the order in which the work progressed on site.

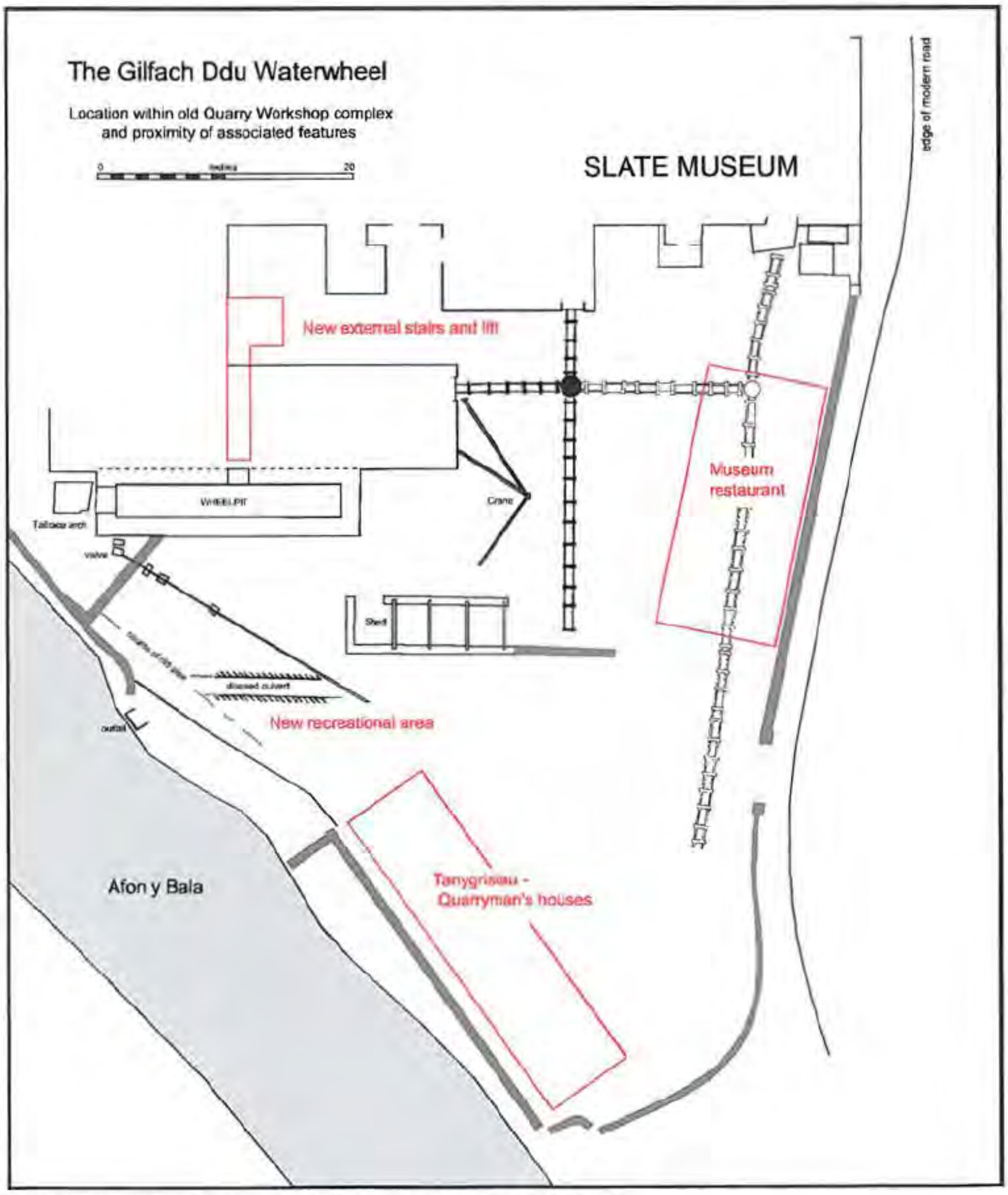


Fig 2 : The location of the wheelhousing within the Museum complex.

1.3 Methodology

As the waterwheel is a composite structure, the survey was able to record accessible components of the wheel and project its remaining circumference. It was possible to obtain a detailed record of the header tank although recording of the riser was restricted to long offset measurements from either the walkway at wheel bearing level or down the inside of the riser. Similarly, much of the structural detail of the housing was obtained in the same way. The record was supplemented during the last phase of the restoration process when scaffolding was installed to access the exterior of the header tank and the full height of the riser. Only the initial survey was partially hampered by the general inaccessibility of some parts of the monument, whether due to lack of space or problems of height.

The field record consists of measured drawings, annotated sketches and accompanying notes. These are held in archive at the offices of Gwynedd Archaeological Trust, Bangor.

2. Recording and Findings

2.1 The Waterwheel

The wheel is a composite structure originally formed of the following components:

•	**Cast iron axle** and **twin hub**		
•	**Wrought iron spokes**	**20**	**per side**
•	**Cast iron shroud plates**	**20**	**west side**
•	**Cast iron shroud with provision for rack mounting**	**20**	**east side**
•	**Wrought iron buckets**	**140**	**total**
•	**Wrought iron sole plates**	**?20/40**	**(30 steel today)**
•	**Rack casting**	**20**	**total**

Despite its size, the wheel is a relatively light affair. The twin hub accommodates 20 spokes per side, inserted into equidistant sockets around its circumference, every other spoke crossing to an opposing interior rim segment, thus forming a cross section, and supported by a two piece brace at their intersection, some ten in total. One of these items needed replacement during the recent works.

The spokes locate into the rim castings by means of 'T' shaped bar ends, which were lead soldered into place. There are correspondingly 20 shroud castings on each side of the wheel, to which are bolted a like number of overlapping, serrated rack castings on the east side. These engage a pinion wheel mounted at the edge of the wheelpit within the circumference of the rack castings. The survey clearly demonstrates just how worn these gears are today and were, perhaps, to much the same extent in the 1920s.

The rim castings made provision for the buckets to be bolted directly to them, and there were 140 buckets in all. The buckets comprised two sheets of cast iron, one of which was curved, rivetted together through an 'L' shape section of angle iron. A series of back plates, or sole plates, extending around the inner circumference of the wheel completed the whole. (Fig.4)

Each major component was designed to overlap with another, ensuring that the entity was inherently stable and efficient as it transferred its power from the rim back to a point close to the hub with a minimum of torque, thereby overcoming any lightness of construction.

Examination of the wheel showed that a number of the extant components were not original. There are references to the removal and/or replacement of specific components in the form of quotations for materials and labour from Hills and Bailey Ltd., dated 1972, D.J.Williams and Son, also dated 1972 and latterly the Snowdon Mountain Railway Ltd., dated 1980, respectively. Both the earlier and later document refer to the provision of new buckets, the earlier quote specifically mentions the removal and replacement of all the sole plates at this time. In addition to that of the pre-fabricated elements the gauges of all nuts and bolts to be used are also itemised, and that some descaling was carried out prior to the application of Red Oxide Primer, is also mentioned. The Williams' quotation on the other hand refers solely to the removal of the plates.

Plate 1 : The Waterwheel at the end of the nineteenth century. Note the spacing of the sole plates, the extant access ladder and the rudimentary safety rail.

Plate 2 : A view of the wheel taken during the initial survey in 1998.
The safety cage has been removed but the latterday safety rail is still in place and the lower section of the ladder has been removed..

Plate 3 : The yard and wheelpit under construction in 1869 - 1870. The wheelpit is located middle right in the photograph.

Plate 4 : Pre-restoration view of the original buckets fixed to the internal flanges of the shroud with square headed bolts.

Fig 4 : Sectional view of the bucket construction and method os fixing

three piece wrought iron bucket rivet joined through angle iron

wrought iron bucket bolt joined through internal flange of shroud.

Plate 5 : The sole plates have been removed and the back of the buckets revealed. Here they have been grit blasted and coated with a weldable primer. A combination of rivets and bolts can be seen and the holes through which the sole plates were attached.

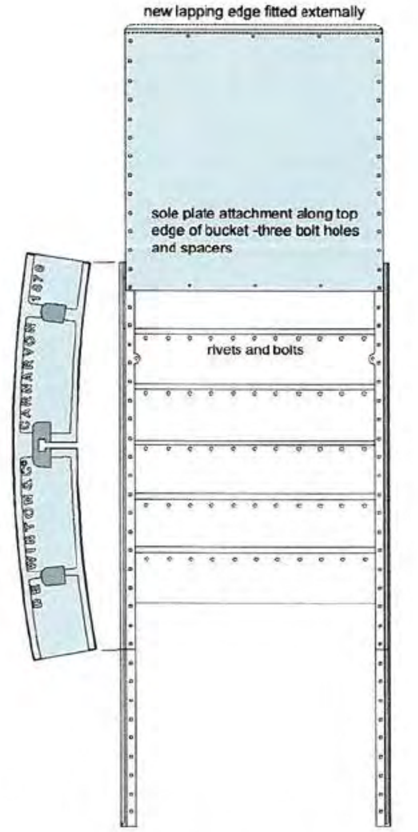


Fig 3 : Diagrammatic plan showing location of rivetted buckets within the shroud. Non-original sole plates vary in size and are located within a recess along the internal edge of the shroud . These later replacement plates were bolted to both the shroud and particular buckets at intervals.

0 2m

Plate 6 : Sound elements from the most corroded buckets were salvaged for re-use. The buckets were dimantled on site prior to being taken away to be cleaned and incorporated with newly fabricated components.

The present arrangement comprises 30 plates, all of which vary in size. It seems highly unlikely, given the corresponding numerical balance of the surviving original components, that this reflects an earlier configuration. The most likely number would be 20 or 40. The favoured number is 40 based on the archive photograph (pl.1). This variation in the size of the existing plates meant that, if these were to be reused, it was essential to record the unique position of each *in-situ*, to assist in the reconstruction process. It is fairly certain that these plates, made of steel, are those referred to in the 1972 document. Each plate was recorded and its location incorporated into the drawings of the monument that had been prepared previously. Each was allocated a number and tagged for reference prior to removal.

2.2 Recording Strategy

The methodology required to dismantle the waterwheel, that is removing components at 180 degrees to each other by turn, meant that the numbering system used on site by the contractor becomes non -consecutive when the wheel is viewed as a whole. To assist in the retrospective identification of particular elements the archaeological recording identified each component consecutively from a common point of reference. Viewed from the west (entrance) side of the wheelpit there is a single shroud casting, ***segment 1***, bearing the maker's name and a date, DE WINTON & C° CARNARVON 1870. The reference point is the ***left hand*** (leading) edge of the casting, where it would butt against segment 20. Hence, bucket number one (B1) is the first entire bucket held within the internal flanges of that segment. Sequential numbering runs in an anti-clockwise direction (the direction that the wheel turns). It should be noted that a similar casting, a component of the opposite shroud bears the date 186 (presumably originally 1869?) although the 9 appears to have been deliberately removed. This may be an indication that the project was delayed or that some considerable time elapsed between the casting of each rim segment.

The sole plates are similarly numbered in an anti-clockwise direction. Plate number one (S1) is wholly located between the emblazoned shroud casting (see Fig.5).

2.3 Sole Plates

The contractor responsible for the removal of the sole plates and buckets, Dorothea Restorations, was notified of the preferred numbering strategy, thereby employing a common point of reference and making it possible to correlate both sets of records more readily.

All components were stamped or metal tagged and their location within the shroud castings correspondingly marked.

It seems certain that the replacement sole plates are non-original in size and appearance and that they did not fulfill the function that the originals would have done. The manner in which the wheel is constructed allows overflow from the buckets to run between the back of the bucket and the sole plates to ensure that the lower buckets remained partially filled, so maintaining balance. The replacement plates did not fulfil this function efficiently as they were butt jointed and consequently leaky. It is most probable, given the symmetry and overall integrity of the rest of the wheel that the originals consisted of a regular series of smaller lapped plates (see above), a feature common to other waterwheels of the period.

This feature was incorporated into the restoration process by the addition of a narrow external-lapping strip, fitted (welded) before being reassembled.

2.4 Buckets

The work detailed above confirmed a methodology for the continued restoration of the wheel, as it was apparent upon removal of the sole plates that the condition of the buckets was better than anticipated, and that entire replacement buckets would be unnecessary. Of the total number of 140 buckets, 34 were identified as being steel replacements of the wrought iron originals. All buckets are made up of three principal components riveted or bolted together and as such enabled partial repair where required. A total of 15 defective buckets were identified and subsequently removed off site for renovation, this included a number of modern replacements. The location of these particular buckets is indicated in Fig.5. The main failing of all buckets was the corrosion of the angle iron bracket that formed the lap joint at the rear of the bucket.

Due to the integrated nature of the wheel components considerable difficulty was encountered in removing a number of the buckets. In some instances this required that individual buckets had to be cut or have rivets burnt out whilst still in place. It became apparent that the installation of the existing replacement buckets in the 1970s had also been problematic. These were not as wide as the originals (one assumes that a lesson was learned during attempts to remove the originals) and consequently not held in place by the shroud castings but by the bolts around the inner circumference of the casting only. This anomaly was manifest after the removal of the sole plates, as these buckets were clearly not flush with the surviving originals.

The specified buckets were dismantled on site prior to being removed for grit blasting and renovation. The remaining wheel components were grit blasted on site and *in-situ*.

North facing elevation

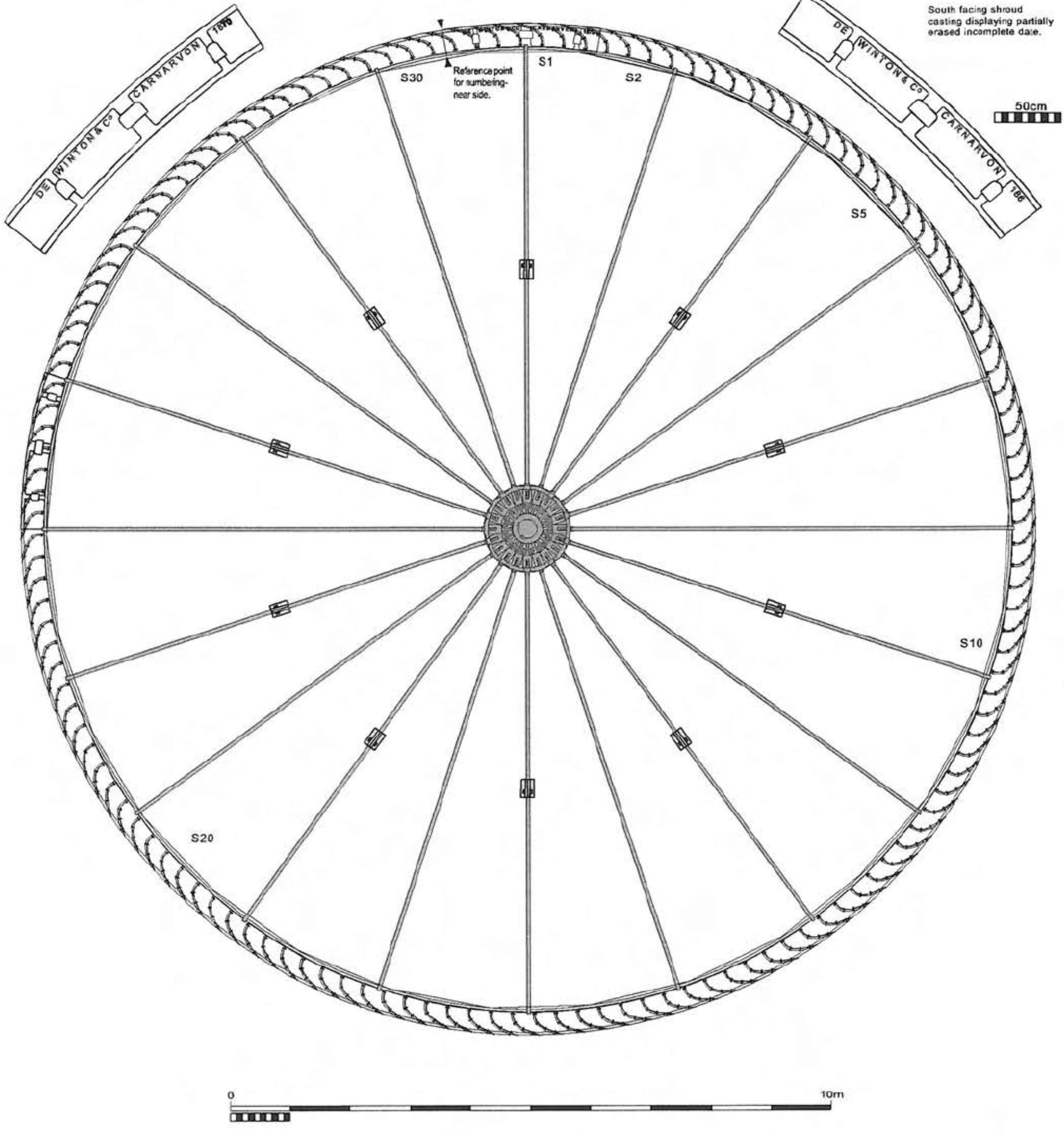


Fig 5 : North facing elevation of the wheel as viewed from the entrance. The left hand trailing edge of the shroud casting dated 1870 is the reference point for the numbering of the sole plates and the buckets. Buckets removed from the shrouds and subsequently replaced are indicated as is the replaced spoke brace.

A total of 15 buckets were removed and either entirely or partially replaced. Each replacement component is formed of steel with riveted construction as in the originals and date stamped in three places along the leading edge.

Prior to the entire structure being cleaned to bare metal a paint sample was taken for chemical analysis to enable the original coating to be identified. Not surprisingly, this transpired to have been red lead oxide. A proposal to use this same agent as a sealant in the re-assembled buckets was subsequently approved.

Following grit blasting it was apparent that only a single spoke clamp of the ten originally fitted needed to be replaced. Dorothea Restorations fabricated a replacement clamp, cast from a surviving pattern provided by the Museum, and this was duly fitted.

3.0 Transmission and associated features

3.1 The Pinion Shaft

Excessive wear in the bearing of the pinion wheel shaft was evidenced by uneven wear in the teeth of the gear wheel, further reflected by the wear on the teeth of the rack castings mounted onto the shroud of the waterwheel itself. The extent of the wear suggests that this process has been ongoing for some considerable length of time. The marked wear however, defined by a re-cutting of the teeth of both cogs, might indicate a more rapid decline of the bearing, or movement of the bearing mount.

The removal of the safety cage and railings around the wheelpit, pending repair, allowed easier access to the bearing and it was subsequently inspected and stripped by DR staff (pl.9). As might be expected, the lower bearing liner was heavily worn whilst the upper liner was still in good condition. The liners were made of brass and steel, lower and upper respectively, and it was decided to reverse their respective positions. There was also some settling of the bearing mounting and it seems likely to have created the problem with the bearing in the first instance (but see above). The mounting was jacked up and a spacer of plate steel inserted below. This combined action successfully re-aligned the shaft and the power take-off to its original position, clearly noticeable once the wheel was back in commission.

3.2 Gear Supporting Bracket

Motion from the waterwheel was transferred to the line shafting in the quarry workshops via a crown wheel gear system, supported by a substantial cast iron bracket on the external face of the wheel pit housing, opposite the pinion shaft bearing. Moisture penetration from the wheel pit had caused extensive corrosion of the bolts supporting the bracket. The bolts pass through the wheel housing as witnessed by the twin column of patress plates in the pit wall below the walkway (Fig.6).

3.3 Access ladder

An inclined timber ladder, located on the south side of the walkway was used to access the header tank during its working life, and is an original feature of the housing. Although still extant it has been modified in the past to allow public access around the walkway. Proposed further modifications to the timber ladder have not been implemented at this time although it has been repainted in keeping with the other restored features within the housing. (pl.1, 2 and Fig.1)

4.0 The Power Supply

The proposal to locate the workshops and waterwheel at Gilfach Ddu had one obvious drawback, given the dimensions of the wheel and the fact that it was housed above ground, to provide a suitable water supply to drive the wheel in an efficient manner.

A waterwheel the size of that proposed at Gilfach Ddu would benefit considerably from an overhead water supply, enabling it to be backshot. The drainage water from the upper quarries above Vivian would only have been of seasonal value, at best, and therefore an alternative was sought. Across the valley, approximately 1kilometre away to the west, the Ceunant waterfall was at a sufficient elevation to provide the necessary head of water to bring energy to the wheel. The water was carried through a subterranean, 24in diameter pipe that entered the back of the wheel pit and was forced up one side of the vertically divided riser into the header tank above the wheel by gravity. The riser served a dual purpose, allowing water to enter the header tank on the one side, whilst allowing excess water to flow back down the other section of pipe to the bottom of the pit and hence out through the tailrace gate into Afon y Bala. (Fig.1 and 2)

The rate of flow to the header tank was controlled by means of two valve houses, one situated below the waterfall at Ceunant and another, closer to the wheel, on the banks of the Afon y Bala, between Llyn Peris and Llyn Padarn. Water was introduced onto the wheel via a sluice gate that was manually operated by a geared rack, pinion and rod system connected to a regulating wheel in the workshops below.

Plate 7 : West facing view of the riser elbow before restoration. The plastic pipe used to carry water to the modern cistern feeder can be seen to enter the outlet side. The smaller packing around the inlet pipe can be easily distinguished.

Plate 8 : The pinion wheel before remedial work. Note differential wear on teeth.

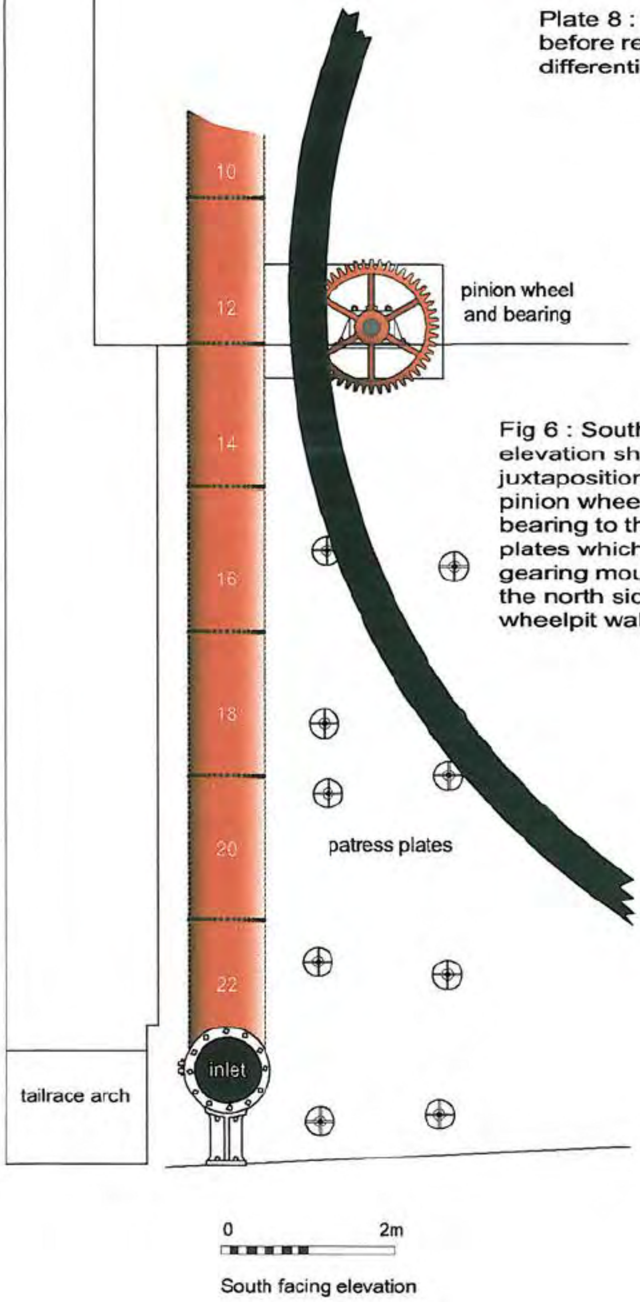


Fig 6 : South facing elevation showing the juxtaposition of the pinion wheel and bearing to the pattress plates which hold the gearing mounted on the north side of the wheelpit wall.

Plate 9 : Reversing the bearings supporting the pinion wheel and relevelling the shaft.

When full, the header tank could hold 14,000 gallons of water, the weight of which was borne by the wheelpit walls and a series of 'H' section iron beams that supported the underside of the tank. Iron rods angled from the floor to the lip of the tank braced it internally. (Fig.7 and pl.10)

4.1 Header Tank and Riser

Scheduled Monument Consent accepted that all or substantial parts of both tank and riser might require complete renewal within the scope of the restoration process. An initial, largely visual appraisal of the overall construction had suggested that there was likely to be considerable deterioration of the metal at a number of structurally key locations where the metal was badly corroded or holed.

The integrity of much of the tank panel surfaces was found to be generally quite good following more rigorous testing. Significantly the most badly holed or corroded areas were largely confined to the perimeter of the tank, in discrete areas between riveted seams. This factor gave rise to a revised approach to the conservation of the structure as it was realistically realised that both tank and riser could be repaired *in situ* by welding in new material, rather than the previously envisaged, logistically problematic, lifting or jacking.

The revised work programme required that the tank be scaffolded out to provide a safe working space. To avoid the structural stability of the tank being compromised the base of the scaffolding was rested directly onto the housing parapet via holes cut in the tank floor. In direct conjunction with this procedure the rising main was surrounded by scaffold providing a total of six levels from which to access the riser, working from the top down, as the strength of the riser was progressively increased.

Restoration work in both locations involved thorough cleaning to bare metal of all surfaces by appropriate means prior to identifying and cutting out defective areas and welding in new items.

4.2 The tank

To ensure the structural stability of the header tank the existing internal bracing was replaced wholesale. The replacement components were welded to the existing toe of the original, which was retained for this purpose. Although the replacements are more substantial, the result reflects the nature of the original. Likewise new gussets were welded in as required to both wall and base to reinforce the more wasted areas. When this work was completed the tank was cleaned and those areas requiring new metal were clearly identified. Affected areas were cut out and used as templates for the new patches, which in order to remain readily identifiable were not ground off (pl.13). Although remaining visible the patches are not incongruous to the overall appearance of the monument especially when viewed from a distance.

At no point was it envisaged that the header tank would function as it was originally designed to, and the repairs have not sought to make the tank watertight. Isolated deep pitting and puncture holes in otherwise sound plate have been left to aid drainage.

The pre-existing arrangement that introduced water onto the wheel for display purposes via a plastic pipe and galvanized cistern (and probably exacerbated corrosion within the feeder) has been modified.
The cistern has been removed and the pipe has been extended through the feeder to fall on the wheel via a distributor.

During the pre-restoration survey it was apparent that the remains of the original draw gate for the sluice was incomplete and the arrangement had been modified to accommodate the galvanized cistern. Subsequently the missing components have been identified in the quadrangle yard of the Slate Museum. The original location of these is shown in Fig.7.

4.3. The feeder

The availability of scaffolding below the floor of the header tank afforded the first opportunity to access all sides of the feeder tank and gain visual access to its interior. The interior was found to be essentially void excepting a quantity of rusted fragments of iron plate resting above the lower lip of the feeder. It appears that the internal arrangement was less sophisticated than first assumed. (Fig.9). There were traces visible of two parallel internal veins, part of a chute leading from the underside of the header tank to the mouth of the feeder above the wheel. The width of the chute corresponds to, or is slightly less, than the width of the buckets on the waterwheel. It was fixed at top and bottom only and was angled at 45 degrees onto the wheel. The purpose of this feature was to direct and confine the flow of the water from the header tank into the buckets so preventing spillage outside the shroud, and to maximise efficiency. It is probable that a significant proportion of the corrosion that occurred on the wheel side sections of the riser - below the tank but above the walkway – resulted from the fact that this feature had latterly completely deteriorated.

Plate 10 : general view of the header tank before restorationn. Note the scaling and the holes in both tank and riser overflow stack.

Plate 11 : New upstand, gusseting and internal bracing. Compare with the originals shown in Plate 10. The scaffold is supported on the wall top through holes cut in the tank base and were welded back later.

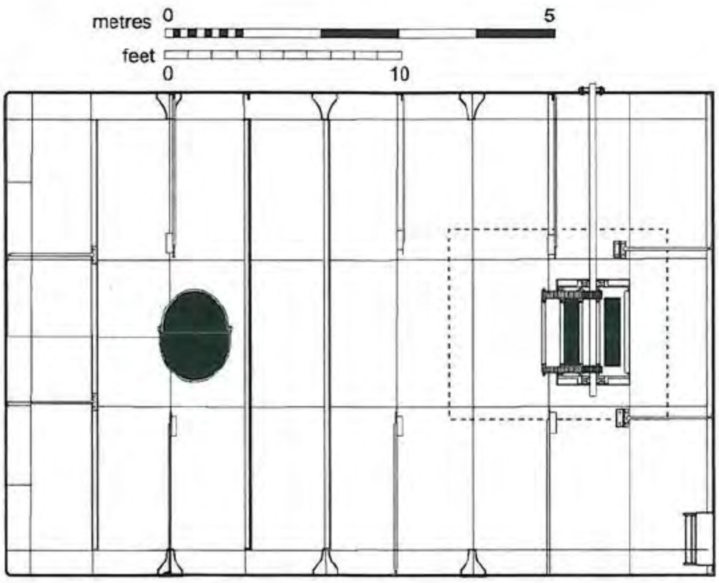


Fig 7: Plan view of the header tank showing its original configuration and with the double sluice gate in the open position.

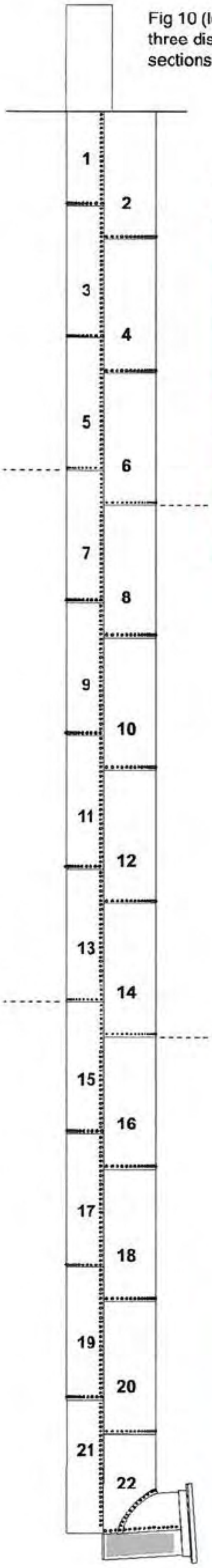
Plate 12 : In the foreground are the two additional remains of the rack and pinion draw-gate system found in the museum quadrant yard. These were removed in order to install the cistern and pipe in the 1980s.

Plate 13 : The external north side of the tank during repairs. New metal has been welded in where necessary and the patches of non-original material left visible as indicated here. Bowling Mill stamp was found on sheet at north-west corner.

Fig 8: Detail of the reconstructed sluice gate mechanism, shown in the open position.

Fig 10 (left) : Indicates the three distinct pre-fabricated sections of the riser.

Fig 11 (right) : Identifies the individual sections of the riser referenced to the photographic record.

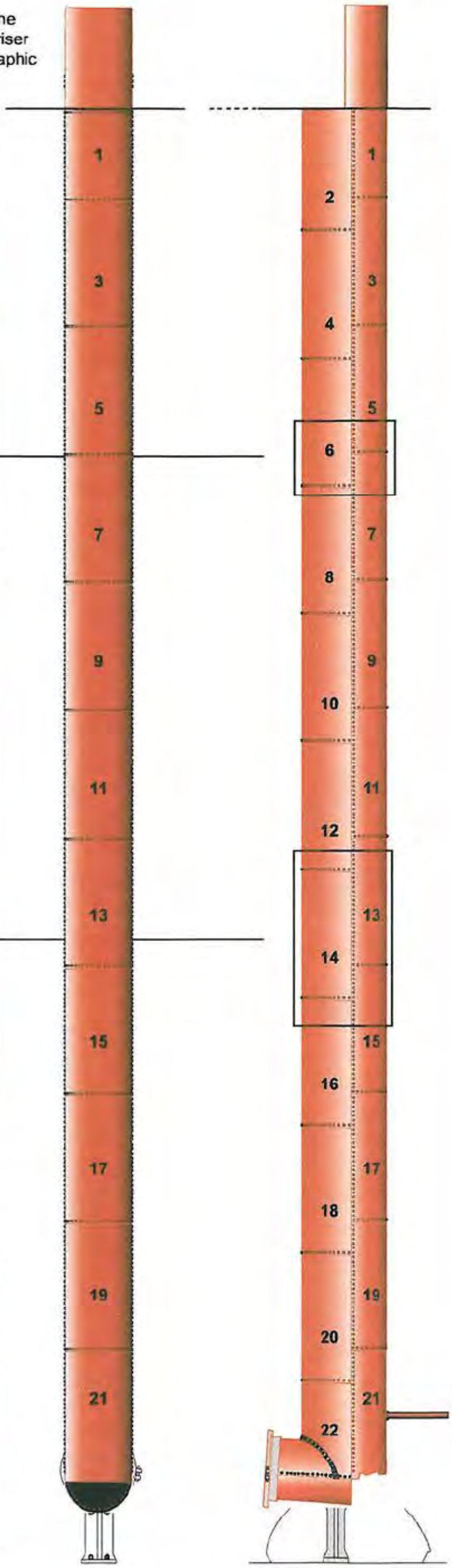


West facing
(outlet-inlet)

Plate 14 : Hand riveted, staggered seam joining together plate sections 5,6 and 7. Compare the clean dome headed, hydraulically welded seams with the cone shaped hand riveted seams.

Plate 15 : The mid to lower sections of the riser joined betwen plates 13,14 and 15. The hand welded seams here are distinguishable by both external cone shaped heads and studs which indicate that the head of the rivet is inside the riser. Note the sections of new metal welded in place.

Plate 16 : The riser inlet elbow - note the rectangular access hole cut in the end plate that revealed the contemporary concrete repair.



North facing
(outlet)

East facing
(inlet-outlet)

After cleaning and priming the external surfaces of the feeder were shown to be in remarkably pristine condition compared to other areas which had been exposed to more persistent weathering for example the header tank and forward sections of the riser. There was very little surface pitting apparent and much of the plate, angle and riveting had the appearance of being very fresh. Tooling marks were plain to see, as was the quality of the workmanship. The figs. (xxx) show examples of countersunk riveting through plate, angles and caulked seams. (See below for further discussion on riveting)

Note also the fabricators stamp in fig (xx). It has been possible to provenance some of the components from three instances where the manufacturers or millers stamp were revealed after grit blasting. Two occur on the plate of the header tank and both appear incomplete as BOWL..? . This probably read BOWLING, a reference to the Bowling Iron Works in Bradford, Yorkshire, who were producers of high quality iron and steel. The other instance was on an angle section on the underside of the header tank connecting to the feeder. This clear stamp reads C.C followed by a simple crown symbol. The crown stamp is common to many iron products of the period and is not necessarily synonymous with particular quality. The initials C.C. could not be provenanced at the time of writing but could refer to Carron, a Scottish mill.

4.4 The Rising Main

When viewed in cross section the riser describes a blunt oval, with an off-centre partition running top to bottom. The partition segregates the pipe into the inlet (the larger capacity north section) and the overflow (south section) which stands proud of base of the header tank.

The majority, vertical section of the riser is comprised of 22 curved sections of wrought iron, fabricated from sheets approximately $5^{ft}6^{in}$x $4^{ft}6^{in}$ and $4^{ft}6^{in}$ x $4^{ft}6^{in}$ and 12 internal dividers some $4^{ft}6^{in}$x $2^{ft}4^{in}$. Elements of the rising main (more strictly riser and overflow) were recorded both at the onset and during the restoration process. In keeping with the necessity to begin stabilization at the top of the riser and work down, the numerical sequence that identifies particular major components accords with this. (Figs. 10,11 and 12). Numbers shown in sequence refer to visible external sections of the riser only.

First impressions as to the stability of the riser were poor and there was evidence of widespread scaling within both sides of the pipe. Subsequent cleaning and grit blasting demonstrated that a greater part of the riser than anticipated was stable and that holing was generally localised. This enabled repairs to the riser to be carried out on a similar like-to-like basis as the header tank, only patching or inserting larger new sections as required. Inevitably the worst corroded area was the lower mid-section, where a number of original plates were entirely or partially replaced. This area coincided with a blockage in the riser side of the pipe, caused by wedged scale fragments and other detritus. This was in some ways fortuitous as it enabled access to the divider without having to remove sections of good metal and also provided additional clues as to the method of construction. None of the original rivets were removed from the riser as areas to be replaced were cut out from within the area of the riveted seams.

Physical access to sections of the riser was constrained by the location of the six levels of staging within the scaffold tower, and the apparent vertical discontinuity of the photographic record is due largely to this. Nonetheless it was possible, probably for the first time since its installation to move around and investigate the full length of the structure. Up close it was clear that at least two styles or methods of riveting had been used to join the plates together. This occurred in three distinct zones and indicated the demarcation between initially homogeneous, pre-fabricated sections of the pipe before being joined together. The bottom two sections are of similar length with a shorter upper section below the header tank.

The distinction between the appearance of the rivets is the result of the difference between hydraulic riveting and hand riveting. In addition there is the evidence of the reversal of the direction of side from which the rivets were placed. This is an interesting scenario and will be discussed further below.

The three sections can be identified in Fig.10 and the distinction between the rivets is shown in plates 14 and 15.

4.4.1 Discussion

There are a number of possibilities to consider given that the available evidence indicates that the riser was prefabricated. The first consideration is whether the sections were fabricated on site or whether they are products of De Winton's Caernarfon workshop. Logistically it is quite feasible that the sections were transported to Gilfach Ddu by rail as none of the three exceeds a length of 20^{ft} (6.1m).

The next consideration is the evidence of the riveting techniques employed. The crisp rivets are probably indicative of either manual hot riveting or hydraulic riveting in a reasonably controlled environment. The evidence of the manual riveting to link the prefabricated sections together is perhaps telling. Following basic procedure we can expect that the sections were primarily hoisted and bolted into place before being replaced by rivets. Accessibility was perhaps the prime factor in the techniques employed here. Hand riveting is a two-man job, necessitating one man to insert and hold the, preferably red hot, rivet in place using a tool known as a *snap* whilst another forms the head of the rivet on the other side of the plate. Even with a riveting oven available on site it is not hard to imagine the awkwardness of transporting a hot rivet to a man inside the vertical riser quickly enough for the heat to be sufficiently maintained. The cone shaped deformation of the rivet heads seen on the outside of the riser suggest that the rivets were cooled if not cold when they were formed.

actually　　　　or outside

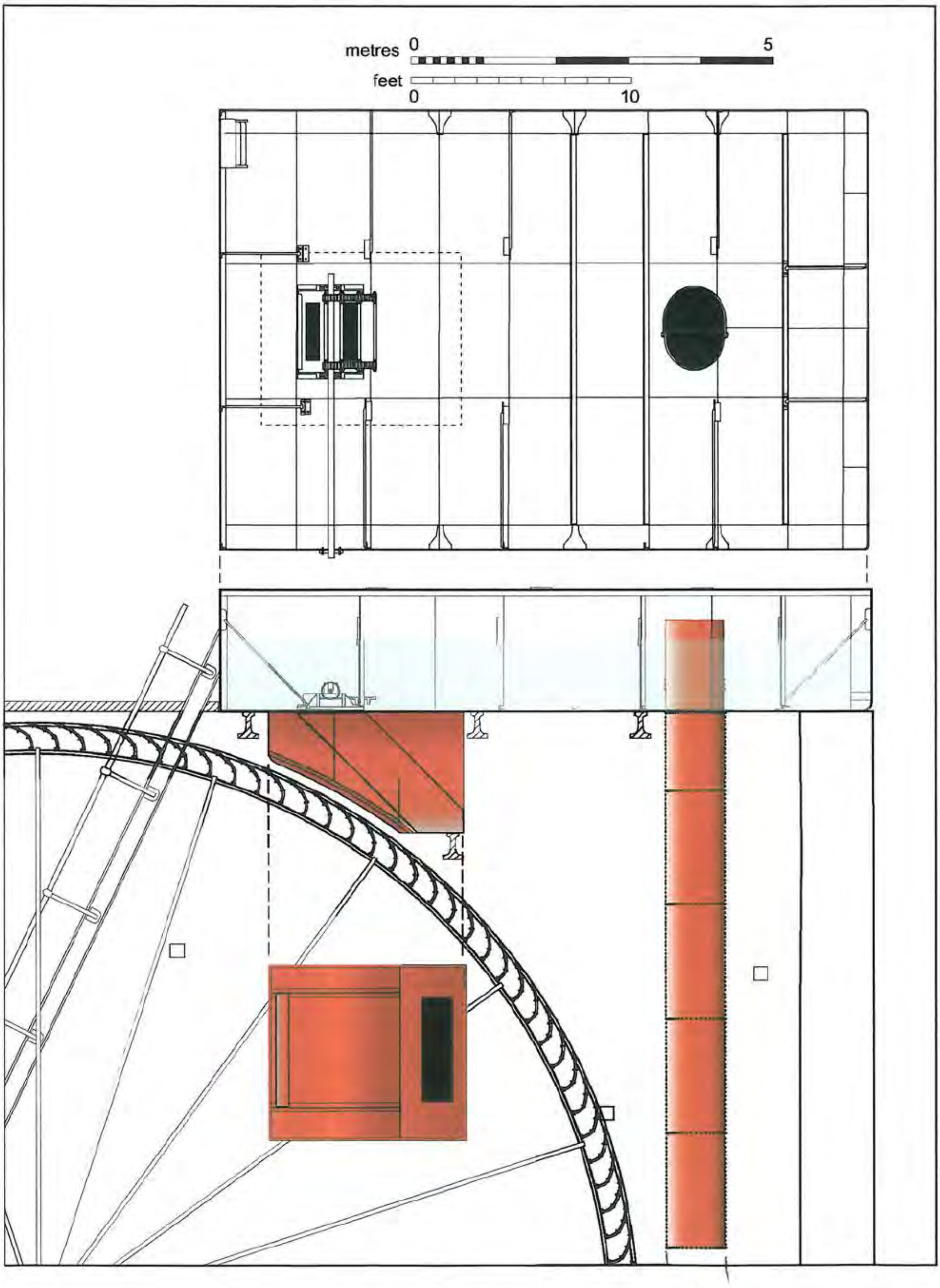


Fig 9 : Composite plan and elevation of the header tank, feeder and rising main viewed from the north. Note the potential maximum water level in relation to the overflow stack and the indicated angle of the water chute inside the feeder.

There is some evidence of hand riveting in localised areas of the header tank but not in the quantity or manner that might more easily demonstrate that significant sections of the tank were also prefabricated elsewhere and subsequently riveted together on site.

The sales catalogue of De Winton's equipment following the works closure in 1903 makes mention of a hydraulic riveter, but the late date of the document makes any assumption inconclusive. However, the crisp, partially countersunk rivets evidenced on other parts of the structure, particularly the tank and feeder, do suggest the availability of a hydraulic riveter to the fabricators in 1870.

4.5 Construction method

One of the vexed questions posed during the survey was how the wheel, header tank and riser were installed in the housing and logistically in what order.

The evidence for some form of staging being in place in the form of putlog holes in both the inner face and outer face of the housing masonry is intriguing but inconclusive. The best scenario is that this was a component that served a number of practical functions, facilitating the construction of the housing as well as the installation of the wheel, tank and riser. On the basis of the evidence, albeit largely circumstantial, a broad sequence of events on site may be put forward but is open to modification.

- Majority construction of the housing, incorporating staging.
- Installation of the iron support beams for the header tank.
- Construction of header tank and feeder
- Construction of riser
- Construction of wheel
- Removal of staging

This simplified overview assumes the riser to have been constructed, logically, from the bottom up, installing the two equal sized prefabricated sections and a shorter section above. This may account for the irregular dimensions of the plates comprising the upper third section of the riser. With the housing walls complete it is probable that prefabricated sections were brought in through the tailrace arch.

The custom-made union section that converts the incoming circular section main to the D section riser is angled slightly down and not square on to the mouth of the pipe, yet there seems to be some purpose here. The stantion supporting the base of the riser has been cast to hold an angled, not horizontal cylindrical section. Does this suggest that an original intention was for the inlet pipe to enter at an inclined angle and that the present alignment is botched or perhaps a later replacement?
This seems to be the best explanation for the anomaly considering the available evidence.
The structural evidence suggests that the housing foundations were constructed with an aperture for the inlet pipe to be inserted on an as-when basis, and with enough space to be able to conform to the angle of entry suggested by the riser elbow. The smaller blocks surrounding the pipe that is extant today are clearly only packing.

The construction and overall finish of the tank and riser are fine testament to the abilities of the De Winton workforce. The techniques employed were those used in shipbuilding and boiler making, these being the staple of De Winton's contracts. The tank and riser were constructed entirely from overlapping wrought iron plate, angle and rivets. The seams were to some extent self-caulking; being red leaded and close riveted, or in some instances hammered and beveled out. The manner of construction used on the split riser, from evidence during repair of the feature, can be seen in fig.12.

During the grit blasting of the riser it was inevitable that an amount of sand and scale would become trapped in the riser pipe above the bottom elbow. In order to remove this material a small rectangular hole was cut in the end plate, below the overflow outlet. This in turn revealed that the base of the pipe was lined with a cement based concretion some 100mm deep at the end plate but tapering back for some 400mm, and rising to the height of the horizontal seam. This was a common repair technique used in the shipbuilding industry to effect repair, stop leaks and to reinforce stress zones. The lining must have been in place before the union with the inlet was completed.

Plate 17 : The uppermost sections of the riser were still in very good condition and after grit blasting and painting appeared as new.

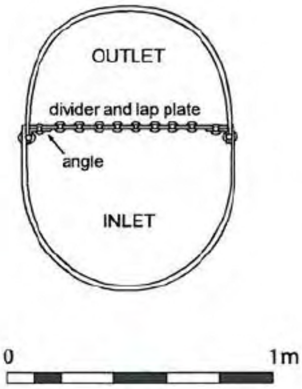
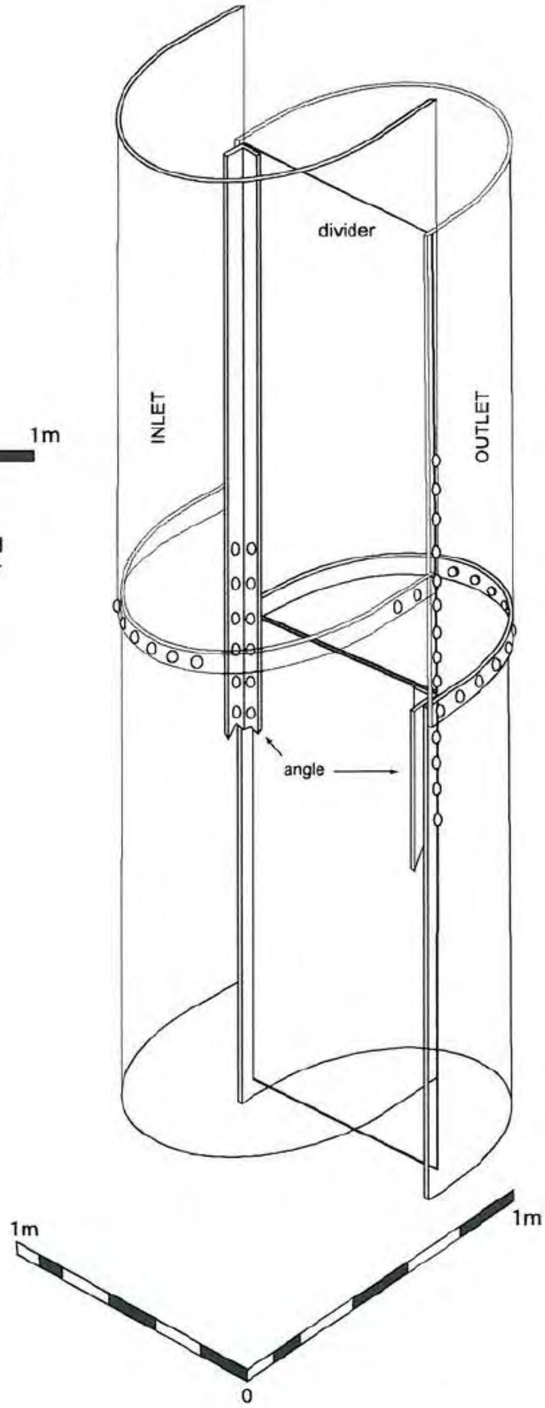


Fig 12 : cross-section and Isometric view of the riser construction.



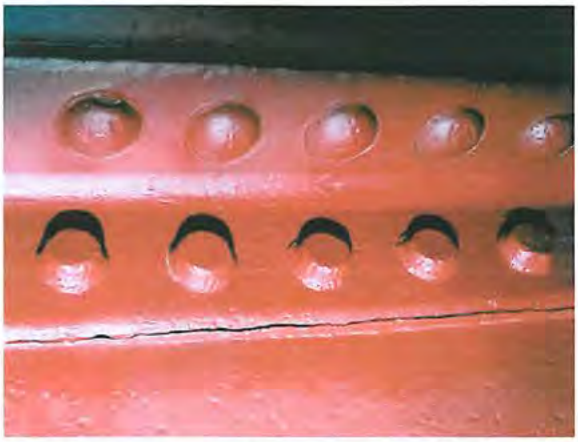


Plate 17 : Revealed on one of the angles connecting the feeder to the header tank - a milling stamp C.C ♔

Enlarge

Plate 18 : Where whole new sections were required to be fitted these were welded in inside of the original area so leaving the riveting as original throughout.

Plate 18 : New sections tailored from dimensions of removed sections used as templates.

5.0 THE WHEEL HOUSING

5.1 The tailrace arch

A number of structural defects in the fabric of the wheel housing were identified from the surveys and these were addressed during the second phase of the refurbishment. The first and potentially most serious of these was the stability of the tailrace arch. It was previously noted that the base lintel was cracked through and that beneath this was a shallow arch, the keystone of which was held in by iron wedges, now much corroded. The arch is built of sawn and shaped slate blocks and is mortar bonded, and was probably a later insertion to lend support to the cracked lintel above. The old wedges had the appearance of being "foxed" and it was proposed to replace these on a like-for-like basis. Removal of the originals showed them to be nothing more than four irregular lengths of scrap iron wedged in on top of each other. Replacement "foxed" wedges were inserted over the keystone and into the gap both sides and mortar pointed (Fig.14).

5.2 Coping stones

The water wheel housing is formed of roughly dressed massive slate blocks, in drystone construction. The wall is topped by a series of substantial sawn and dressed coping slabs, the lower outside edge has a bullnose profile and overhangs the external wall face. The bevel imitates the curved profile of the base of the header tank up to which they butt. The coping stones are the width of the wall top but overhang the outside edge thereby forming a berm along the inner top edge of the wall face. This detail is curious and could be evidence of human error in providing the correct dimensions for the copings!

The copings were not set on a mortar bed and had been brought to level by introducing smaller packing stones. A number of the coping stones had become misaligned and some of the smaller elements were absent. The stones have subsequently been re-aligned and secured. The copings were lifted and re-levelled on a mortar bed. Missing or broken elements were replaced with Dinorwic slate cut to measure. The slabs were pointed and a mortar fillet introduced from the inner edge of the stone to the inside of the wall.

Due to its location this non-original detail does not impinge on the visitor's perspective of an entirely drystone structure.

6.0 Conclusion

The repair and restoration of the waterwheel, header tank and rising main provided a unique opportunity to obtain first hand information about their construction and overall condition. The scheme has provided a wealth of previously unrealised information that has enhanced both the current understanding of the monument and provided a template to assist in its future management.

The discovery of any new documentation notwithstanding, the scheme has allowed archaeological evidence to shed some light on the logistics of installing such a feature at Gilfach Ddu, with particular details providing a very human face to the proceedings.

The works that are the subject of this report have ensured the survival and smooth operation of the waterwheel, as well as the structural integrity of the housing, header tank and riser, for the foreseeable future. Subsequently its appearance presents a very reasonable indication of how the whole may have looked shortly after its installation back in 1870, some 131 years previously.

7.0 Acknowledgements

My thanks to the staff of the main contractors, Dorothea Restorations and Alan Dawson Associates respectively, during both phases of the scheme, for their willing cooperation in accommodating the recording needs, often at very short notice. I am additionally grateful for their insights into particular aspects of the monument and its construction, elements of which are incorporated into this report.

Special thanks go once again to David High of Posford Duvivier for his continued personal interest and advice during the project, and to Hadyn Lewis of the National Museum of Wales, for advice, on-site assistance and whose anecdotes made otherwise routine visits memorable occasions.

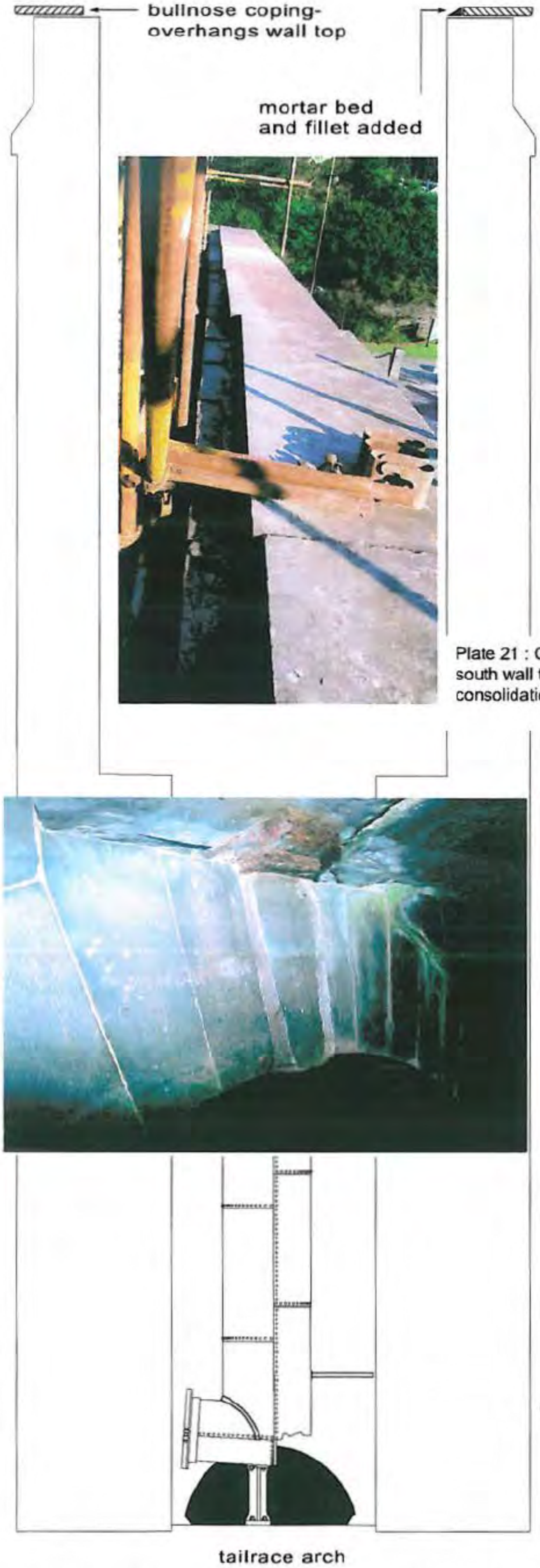
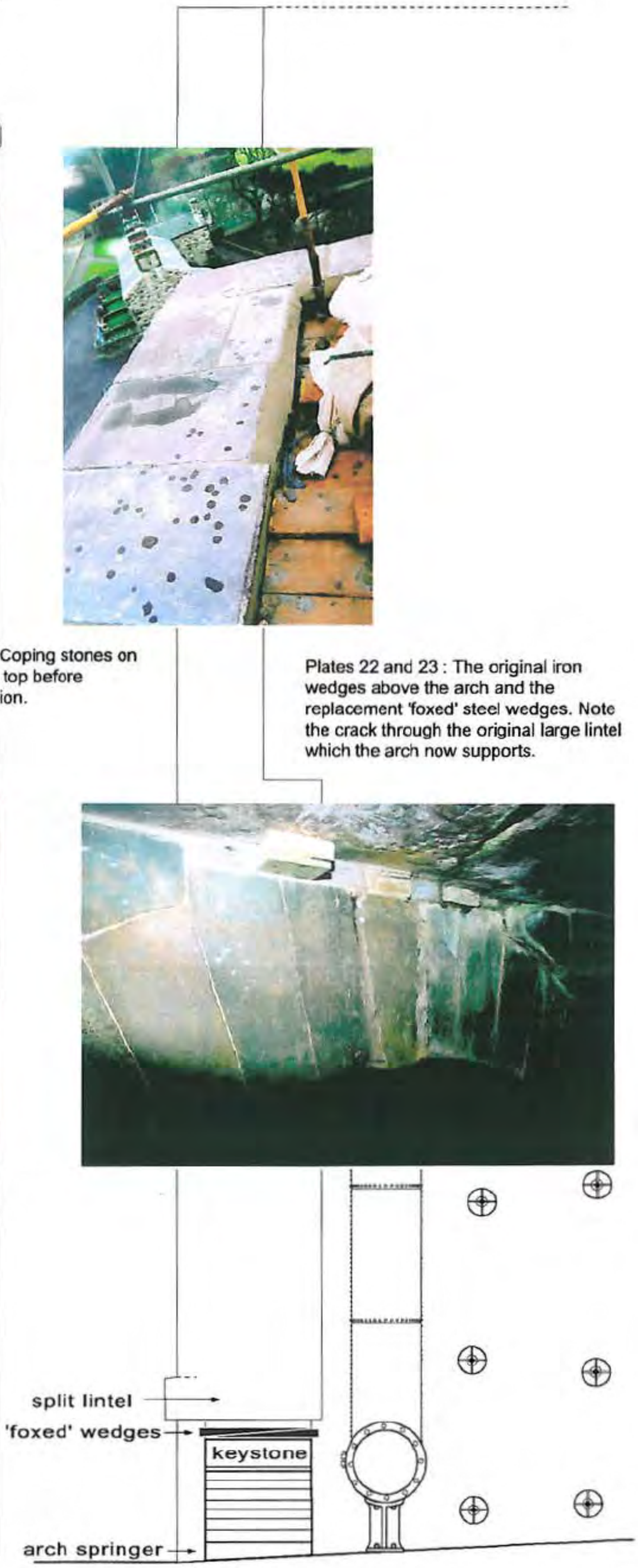


Plate 21 : Coping stones on south wall top before consolidation.



Plates 22 and 23 : The original iron wedges above the arch and the replacement 'foxed' steel wedges. Note the crack through the original large lintel which the arch now supports.

Fig 13 : East facing section / elevation showing tailrace arch and position of coping stones on north and south wall tops.

Fig 14 : South facing section / elevation showing tailrace arch and location of wedges above keystone.

8.0 References

PUBLISHED SOURCES

Dutton, Andrew. 1999 ***An Iron Waterwheel at Gilfach Ddu*** Industrial Gwynedd, Volume 4

Lloyd, Lewis. 1994 ***De Wintons of Caernarfon 1854 - 1892***

UNPUBLISHED SOURCES

Davidson, A. 1999 ***Project Design for Archaeological Recording of Waterwheel, Welsh SlateMuseum, Llanberis*** (G1625)

Dutton, L.A. 1998 ***Measured Survey of the 55'5" Waterwheel at Gilfach Ddu, Llanberis*** **GAT Report No.306**

Dutton, L.A. 2000 ***Restoration of Waterwheel, Header Tank and Rising Main at Gilfach Ddu, Llanberis*** GAT Interim Report No.376

Posford Duvivier November1999 ***Repairs to Waterwheel, Welsh Slate Museum*** Contract Document

Posford Duvivier November 2000 ***Repairs to Waterwheel, Header Tank & Riser, Welsh Slate Museum*** Contract Document

ARCHIVE SOURCES

Gwynedd Archive Services **XS/1217/1** and **XS/621/87**

Archives of the University of Wales, Bangor. ***Sales Catalogue No.317***

MAPS

County Series 25" ***Caerns. XVI 8***

Gwyn. Power Sources etc.

Bills of sale NMGW. invoices

1:10,000

+ Survey?

add notes section page →