Refurbishment Case Study 23

HISTORIC ENVIRONMENT SCOTLAND | ÀRAINNEACHD EACHDRAIDHEIL ALBA

Cove Harbour, Berwickshire

Pilot masonry repair and consolidation works

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This publication is a web publication and is available for free download from the Historic Environment Scotland website:

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Refurbishment Case Study 23

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Acknowledgements

With thanks to Cove Harbour Conservation Ltd (the Client), Benjamin Tindall Architects and David Narro Associates.

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1. Introduction

This Refurbishment Case Study describes pilot repair and consolidation works to part of the historic harbour of Cove on the Berwickshire coast, in south east Scotland. While the works were relatively simple in concept and modest in scale, they provide some interesting lessons for works on piers in marine locations, and proved essential in order to understand the technical processes that would be deployed at scale for the main works on other parts of the harbour.

Cove Harbour is historically important firstly because of its designer and builder Joseph Mitchell (a pupil of Thomas Telford) and the high standard of work he specified and delivered, and secondly as an example of a well preserved small local harbour that is representative of the lifeblood of Scotland's transport infrastructure prior to the advent of the railways in the mid-19th century. After this time, small coastal harbours gradually ceased to have a trading function, although fishing activity became significant with the rise of the Scottish herring industry; this in turn declined and now Cove is relatively quiet. Despite this, commercial fishing continues and rising recreational use has maintained activity; its repair and continued use is to be commended. Historic Environment Scotland has supported this trial work in order to increase the knowledge and confidence in the sector in order to encourage and inform appropriate work to such structures.

Repairing large masonry structures, especially those in demanding maritime environments, always requires a balance between what is repaired in situ, what is dismantled and rebuilt, and what materials are used. At Cove, repairs to the harbour were clearly necessary in several areas, and the owner, Cove Harbour Conservation Ltd., was keen to develop a repair methodology that had a strong building conservation ethos – the minimum required but the maximum necessary. The owner was also keen to maintain the integrity of the structure through the use of traditional materials, for technical as well as aesthetic reasons. This relatively light touch in the repair trials would also seek to control costs, by repairing the masonry structures in situ. This was achieved by the planned and controlled use of a lime based grout to fill voids in the structures and bind the masonry units together. As this approach was technically sympathetic to the fabric and changes to the surface finish were minimal, Listed Building Consent was not required for the trials.

Through careful testing off site and the configuring of a suitable mix for grouting followed by in situ site trials, a durable and usable technique was developed. Masonry work was also carried out on the facing stones and deck of the pier as part of the trial. Both these aspects of the trial will allow a better degree of certainty when planning the main works for the rest of the harbour at a future date, and also allow other owners of piers and harbours to be familiar of some of the techniques available. This work is also of importance as the rate of damage to coastal structures is increasing; changed climatic conditions are resulting in patterns of weather that come from new directions often with increased intensity; their timely repair will be increasingly important if such valuable historic assets, still in use today, are not to be lost.

2. The site and its history

2.1 Evolution and development

Like many historic structures, Cove Harbour has evolved over time. Its earliest form was a sheltered inlet and a recognised landing place. In the early 18th century, a now lost harbour was built but it was eventually destroyed by weather, and reported as wrecked by 1794 (Stat Acct xiii). During this time the harbour was referred to as Dunglass Harbour. In 1829 The Commissioners for the Herring Fishery and Sir John Hall of Dunglass commissioned Joseph Mitchell, a former pupil of the well-known engineer Thomas Telford, to design a new track and harbour. The harbour consists of the main North Pier, a large angled stone structure facing the NE and a lesser South pier or breakwater, called the Boyne Pier (Boyne being old Scots for basin). It was complete by 1831. Both piers have been built with lugs to take timber fender posts. The Ordinance Survey map of the area in 1863 shows the harbour in its largely present state. The works in this case study took place on the pier in front of the cottages shown in red on Figure 1.

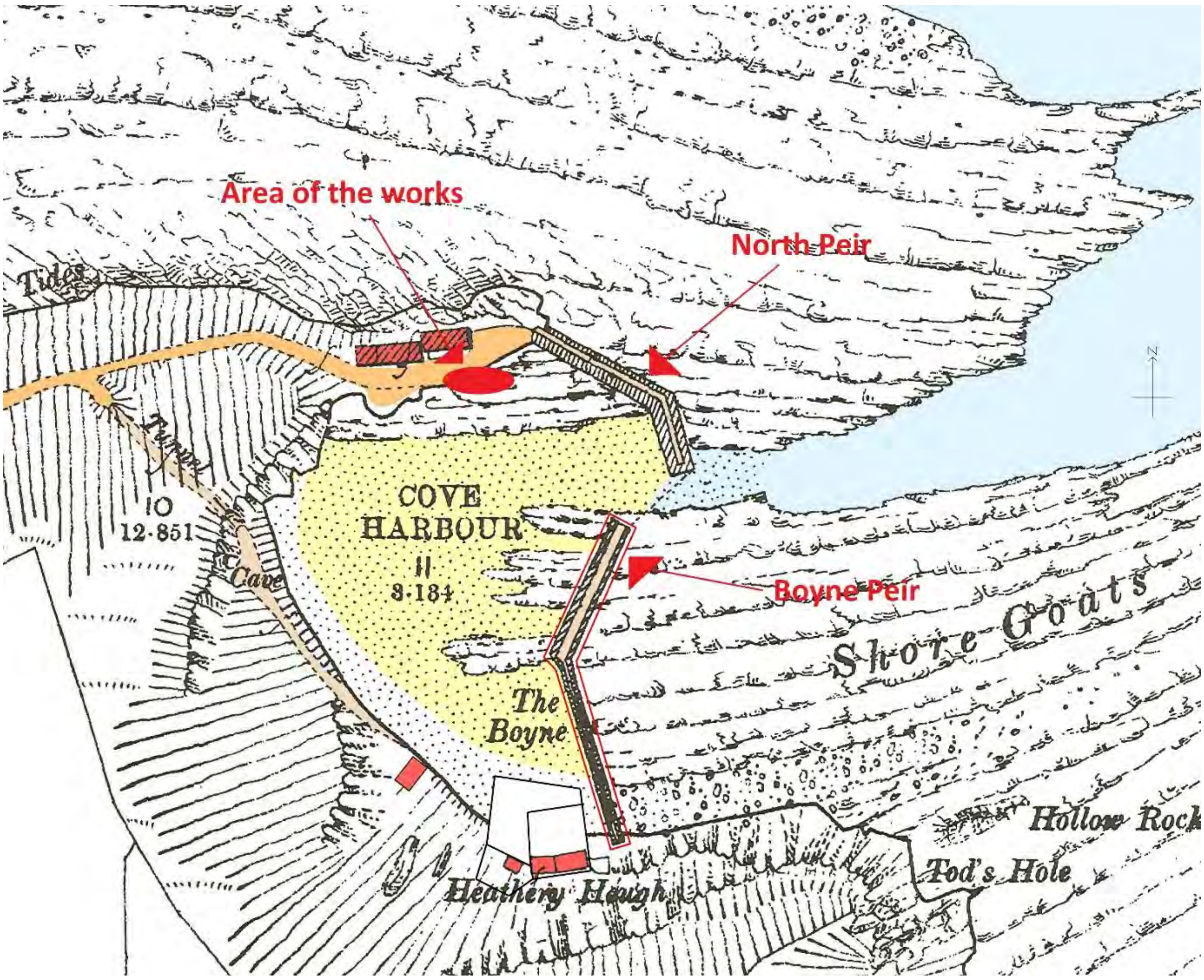

Figure 1. Cove Harbour from the 1863 Ordinance Survey; additional colouring by Ben Tindal Architects

2.2 Records and plans

The Herring Commission specifications and drawings of the harbour construction works are now preserved in the National Library of Scotland. Some details of the executed works were varied from the proposals, but the overall layout remained as designed (Figure 2).

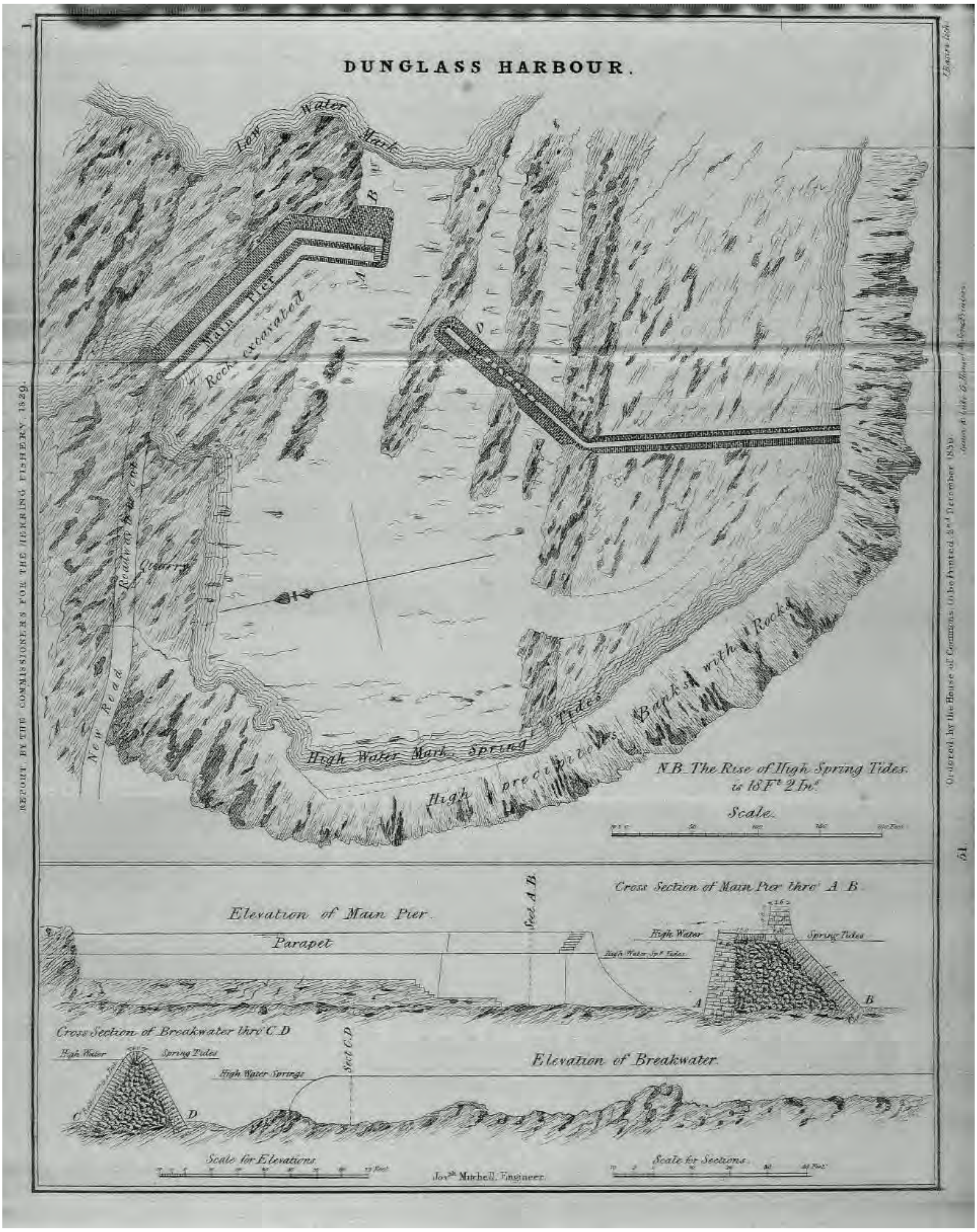

Figure 2. The Harbour layout and sections described in the 1829 report; copy from the National Library of Scotland.

The construction of the breakwater is described by the Scottish author Alexander Somerville in his 'Autobiography of a Working Man', giving a graphic an account of his early life working as a labourer in the area and at Cove in the summer and winter of 1830. This account gives a lively description of working in a 'box', a cassion, to prepare the foundation and build the piers and the quarry. It also lists rates of pay and the tumultuous political times of the Reform Act.

2.3 Additional facilities

In addition to the track and two 19th century harbour piers, other man-made structures at Cove include an earlier 18th century access tunnel, cellars, adit mines, a fish house and cottages. All of these structures are Category B Listed.

2.4 Changed uses and decline

While coastal trading all but disappeared with the development of the rail network in the mid-19th century, the fishing remained a significant activity at Cove. Numbers of boats using the harbour have fluctuated considerably. The East Coast Fishing Disaster of 1881 affected Cove with the loss of 4 of its 5 boats, but it soon recovered. Today there are 3 commercial boats, fishing for lobster and crab, and 4 leisure boats. Ownership also changed; it was gifted from the Dunglass Estate to the ownership of Berwickshire County Council in 1972. Borders Regional Council in turn sold it to the current owner in 1992.

3. Background to the works

The owner has been carrying out a phased scheme of repairs on the harbour and access track for some time. This has involved many diverse tasks including ground stabilisation, clearing of debris from the sea caves behind the harbour, and works to the fisherman's cottages. However, it is the masonry of the harbour walls that takes the most attrition from the weather and it was clear through observation that parts of the Boyne Pier were undergoing structural movement.

Further to the observations of the owner, and to obtain a second opinion on the nature of the masonry movement, a firm of Consulting Structural Engineers were appointed. This firm were experienced in the structural repair of a range of traditional and historic structures, and the appointed Engineer was accredited in Building Conservation. An appreciation of the way older structures work means that solutions are likely to be sensitive to the fabric of older buildings, and utilise compatible materials and techniques. Several site visits confirmed the nature of the defects and where repairs should be targeted. Given the challenging scale and exposed location of the works, and the desire to use materials in keeping with the historic fabric, it was decided that a form of pilot was needed to validate the methodology prior to the main phase of repair works being designed and procured. HES supported this work as a way of informing repairs to this type of scheme.

The owner wished for the repairs to be comprehensive and thorough, but not overly invasive. While the use of Portland Cement based mass concrete in repairs to composite masonry structures is generally successful, it is not an approach desirable for historic or traditionally built structures; therefore alternative repair options would be investigated. The complete dismantling of the Boyne Pier and its rebuilding in a traditional way was, while potentially historically accurate, not feasible on cost grounds alone. The structure is Category B Listed, and as such additional considerations of authenticity and patina of the masonry were also relevant.

3.1 Boyne Pier - Investigation works

The central section of the pier appeared to be collapsing and it was capped with concrete. Documentary evidence for earlier repairs was obtained and historical images consulted. Repairs had been carried out to the Boyne Pier in the 1940s and 1970s but little detail was recorded.

The internal structure of the Boyne Pier was investigated with small trial pits and the use of a bore scope. These investigations showed that the core was composed of a sandstone rubble of random sizes, mixed with aggregate, sand and debris with traces of mortar. Extensive voids were noticed. It was assessed that the structure was designed to be solid and without voids as indicated in Figure 2.

The investigations suggested two causes for the structural instability. Firstly a previous weakness of the foundation on the north-west corner, where adherence on the bedrock had not been achieved and it had been scoured away by water movement. This appears to have resulted in the slippage and cracking of the outer skin of masonry. Secondly, the washing out of the aggregate and fines from within the end of the pier, leading to internal collapse of the rubble masonry core and the outer skin of the north end of the pier collapsing inwards by about 300mm (Figure 3). The pier footings are surrounded by large amounts of aggregate and sand visible at low tide.

Figure 3. Masonry movement due to loss of core material can be clearly seen in this image of the north end of the Boyne Pier.

3.2 Main Pier

It was evident that the Main Pier was of the same construction. Evidence of the water washing through the pier could be seen in the spouts of water coming out from the base of the pier (Figure 4). In some traditional harbour structures, mainly those built from local rubble, the fabric is intentionally open for water to ingress and exit. The Cove Main Pier is more formally engineered construction with dressed stones and mortar, forming a solid face, and while a degree of water movement at the footings is likely, it was designed to be solid internally. The bulk movement of water as seen in Figure 4 is unintentional and is likely to be damaging.

Figure 4. Receding wave action revealing the presence of water in the voids of the Main Pier. The trial works were carried out in this area of the harbour.

3.3 Interim repairs

A small interim repair had been carried out on the Boyne Pier breakwater corner in 2013, designed to underpin the undermined corner of the pier. This was carried out with sandbags filled with a dry lime concrete mix. The modular nature of this work (the material is contained in the hessian bags) allowed the work to be carried out quickly at spring low tide.

4. The design of the repairs

4.1 Selection of repair techniques

Noting the owner's requirements of modest intervention and minimal impact on the presentation of the pier, a repair strategy was developed, having a full appreciation of site conditions. The voids needed to be filled, and the inside of the wall core had to be stabilised or bound together. This required the addition or insertion of material; and consideration was given as to how this might be achieved. This could be sand or other larger, unbound aggregates such as Leca, crushed stone or gravel. However, there was concern that such unbound material could wash out. In addition, it would not be easy to ensure full spread or distribution of such material without effectively excavating the entire structure. Consideration was therefore given to the use of grout[1]. In addition to specialist advice from the structural engineer, advice was also sought from a Scottish grouting supplier who has been involved in many civil engineering projects with historic masonry. This repair approach, using a lime based grout to fill hidden voids in masonry is used extensively in the rail sector, where older civil infrastructure such as embankments and tunnels needs to be consolidated or strengthened. Such an approach also allows minimal disruption to both the existing core and external masonry. With grouting there are important factors such as the extent of the percolation, the pressure exerted by the grout on the existing fabric, and the suitability and strength of the grout mix itself. In addition to the grouting work, more standard masonry consolidation works such as re-pointing and the repair and replacement of the stone flags on the pier deck were considered necessary.

In order to validate the grouting approach, refine details and prove its effectiveness in the context of the works at Cove, a series of trials were agreed on by the owner and the engineer. The first sequence would be in the grout supplier's yard in Fife, to demonstrate the principle and effectiveness of the basic grout composition. A second trial would be carried out at Cove, on a similarly defective but easily accessible part of the Main Pier. The objectives of the trials were to (1) test different fill materials/grout composition, (2) to test delivery methods for the introduction of grout to the structure, and (3) check that the preferred materials and delivery method were practical and could be adopted on site. Trials 1 and 2 were off site, and 3 was conducted at the Boyne Pier. The trials on site would then inform the design and specification of a full programme for repair to the Boyne Pier.

4.2 The trial works off-site

Grouting technology is well developed in modern civil engineering and is better described elsewhere, but essentially additives and admixtures can be used to alter the flow and setting properties of a binding agent. For example, a more localised fill can be achieved by making a stickier mix that sets quickly, and greater spread can be achieved by a more liquid mix with a longer set. Certain additives can achieve a

[1]this report typically refers to 'grout' as the fill material. However the grout actually comprises of binder and aggregate, the aggregate being added to bulk-up the material to reduce its cost, reduce the likelihood of shrinkage etc. Typically in building situations the aggregate used in a grout is small (sand). Larger voids to be filled would suggest the adoption of larger aggregates, in which case the grout might better be referred to as a concrete (for example – if using aggregates of around 25mm in size).

‘drag’ in the grout; that is to say, the compounds in the mixture hold together and flow very well.

In the planning of a grouting operation, much thought is given to estimating the volume of the gaps in the masonry to be filled. This relationship of the amount of stone in the core and the amount of air is called the void ratio. In most cases clients overestimate the voids and therefore the amount of grout required. Grouting mixes, configured for each project, can be expensive and economic use of material is an obvious requirement. The expensive part of the material is typically the binder. This binder is bulked out through the use of aggregates such as sand and gravel.

The offsite trial sought to establish how effectively the various grouts filled the voids and establish an outline void ratio, as well as establish how the grout might behave in the situation at Cove. Trials were designed at the grout supplier’s yard in Fife, and comprised the following:

i. Tests of different binders to establish initial curing time. These tests would inform the binder to be adopted in the new fill.

ii. Small-scale trials of different grouts with different sizes of aggregate to establish their percolation through small voids.

iii. Large-scale trials of mocked-up pier cores to establish the behaviour of the preferred fill material.

These trials are summarised below:

i. Binder

The binder mix was established by the grout supplier. The initial mix was based on mortar used successfully for years at the harbour for general pointing and small-scale masonry construction work. The basic binder ingredients of this mortar were a moderately-hydraulic Naturally Hydraulic Lime gauged with Natural Cement. This binder was brought to a pourable consistency through the introduction of rheology modifiers and super-plasticisers. The intention was to achieve a binder that would achieve a quick initial set (the purpose of the natural cement) but that would have sufficient flow-characteristics to spread through the structure (the purpose of the rheology modifiers and super-plasticisers).

Aggregate – sands and/or gravels - would be added to the binder to create the eventual grout/concrete.

ii. Small-scale trials with aggregate

Investigations undertaken at the pier showed that the voids within it were large in places and interlinked. This being the case, it seemed reasonable to assume that large aggregate could be added to the basic grout to bulk it out. For such an approach to work, the aggregate must be carried by the binder such that spread of both is even throughout the voids to be filled. If the binder is too liquid it will not carry the aggregate; conversely, if the binder is too thick neither it nor the carried aggregate will flow. This issue was explored by trialling the spread of grouts containing sand aggregate with up to 20mm aggregate in buckets containing large rounded pebbles (Figure 5). It immediately became apparent that the larger aggregate would not be carried by the basic grout: the larger pieces of aggregate locked together at constrictions between the pebbles and the remaining sand-filled grout merely passed through, filling up the voids between the pebbles and leaving the larger pieces sitting proud on the top of the trial unit.

Figure 5. One of the early off-site trials to establish if larger aggregate could be transported by the grout – a wall core mock up in a large plastic bucket.

iii. Large-scale trials

Three mocked up wall cores were created, all about 1m² and 750mm high. The faces the cores were created within faces of sand-filled hessian bags. The first mock-up involved building a lime-bonded masonry core, and then dropping that core from height into a large boulder; it was intended that this core would simulate a broken and damaged mortared core. The second mock-up was composed of large rounded pebbles, sand and 20-40mm aggregate to simulate a largely washed-out core of a maritime structure (Figure 6). The third core was built using larger dry-laid squared blocks of stonework with smaller packing stones. Plastic tubes were inserted through the hessian-bag containing walls of the mock-ups. These tubes would allow real-time assessment of the progress of the grout as it percolated through the structure. As each trial would require a good quantity of grout, too much than could be delivered in a single operation, dye was applied to different batches to allow assessment of the percolation through the simulated structure.

Figure 6. The trial grouting rig at the yard in Fife, prior to the pouring tests.

The grout was fed into the pier from above by gravity alone; there would be no pumps or pressure. The grout adopted used concreting sand as aggregate (i.e. sharp particles up to about 6mm in size). In places the grout began to leak from between the hessian bag outer walls, and of course through the plastic weephole tubes. These leaks were plugged with neat natural cement (the cement set pretty-much immediately) and the tubes were plugged with paper.

The dry grout was mixed on site by weight. To this was added the water. The grout was mixed using a hand mixer then poured into the mock-ups either through the top of the mock-up or through tubes built into the core (the tubes comprised 100mm diameter plastic pipes with holes drilled in its sides to allow grout to pass where it wanted).

After a period of curing and hardening of between 12 and 24 hours, the hessian-bag facings were broken away and the grout percolation in the different types of simulated core assessed (Figure 7). In all cases the group penetration was very thorough, with all voids filled.

Figure 7. Opening up the grouting rig to assess penetration and the degree of set of the grout.

On opening up is was clear that the grout had penetrated all the voids and a reasonable set had been achieved. Following the yard trials it was estimated that the void ratio for the rig was approximately 30% voids. For many lime bonded walls this figure is much less, often around 10%.

4.3 Strength and characteristics of the grout

In traditional structures most masonry components are acting in compression, and the dimensions of such constructions mean that such forces are modest. Likewise, tensile strength in a binder is not normally needed in traditional masonry work, especially so in the core of a pier. It is helpful when considering traditional structures to be mindful of the phrase “Mortar is a spacing agent not a glue”. In addition, a degree of physical flexibility in the components is needed. In this case the requirement is to hold the large masonry units and the aggregate of the core in a tight matrix. If the pier were not in a marine environment, arguably its core could be filled with dry sand or small stones.

While the strength of the cured grout was important, more so was the rapid setting time of the grout, as the site would be subject to the rising and falling of the water level within the base of the wall core due to tidal action. If the set time for the grout was too long, the grout would be washed out by the incoming tide. Exact selection of the grout mix was therefore based on its ultimate strength and durability in a salt water environment. In addition to the ultimate structural performance of the grout, consideration had to be given to environmental factors, that is any effect of the grout should it escape in volume into the adjacent seawater and affect local flora and fauna.

4.4 Nature and selection of the aggregate

Trials with aggregate size showed that a balance was needed between the maximising aggregate quantity and size, and preventing blocking of the grout pathways due to settling of the aggregate. Increasing the size of the aggregate in the grout reduces the cost, as less grout mix is required, but this leads to less flow and poor distribution. This could be offset by the digging of additional pits in the pier deck, to account for the reduced travel distance.

4.5 Operational factors

The trials also sought to establish a suitable working rhythm of batching up, mixing, handling and pouring of the grout mix. That is taking the finished material to the point of delivery. Assessing the optimal interval while waiting for the next pour was also developed.

4.6 Planning and Listed Building Consent

With the grout mix confirmed, the repair strategy was discussed with the Local Authority Planning Department. As the work was essentially a like-for-like repair with no changes being made to the structure, Listed Building Consent for the trial works was not required.

5. The trial works on site

5.1 Selection and site establishment

The area chosen for the site trials was the landward end of the Main Pier, close to its junction with the bedrock. This was because the base of the pier in this location was showing a washed out core and displaced masonry similar to that observed at the Boyne Pier. There was reasonable shelter from the weather and easy access for plant and equipment. The contractor for the site work was selected on the basis of having undertaken successful work at Cove for many years. While the company had not done grouting before, they were keen to learn. The attitude of the contractor was considered important; in this sort of work a flexible and adaptable approach is required. There were considerations of working in a marine environment adjacent to water, and the pre-tender Health and Safety Plan, and the Construction Phase Health and Safety Plan reflected this. Welfare facilities were provided in the normal way, and a small portable generator gave power for the mixer and other plant.

5.2 Tidal considerations

It was immediately obvious that the site working rhythm would be largely dictated by the tides. The need for mortar repointing of the pier face at all levels to contain the grout meant that a decent working interval was needed at the base of the pier. This required certain tidal conditions – Spring tides with the maximum tidal range, giving longest drying time at the foot of the pier. With the use of tide tables these working windows can be established in advance and works programmed accordingly.

5.3 Works to the pier face

To ensure that the grout entering the top of the pier could not run out through gaps in the bottom, the openings in the face would have to be pointed up. This was done using the designed mix from the supplier, selected to quickly set in salt water conditions. The repointing was done in the normal way, with lime mortar and pinning using small stones to reduce the volume of mortar in the joints (Figure 8). As with the trials in the yard, weep pipes were formed in the wall to assess the penetration and flow of the grouting mix.

Figure 8. Partially completed pointing of the face of the main pier to the grouting trial.

During this work it was observed that at low water there was a considerable amount of water flowing out from within the pier, and this ran for up to an hour beyond the time of low water. This had to be allowed to dissipate, otherwise the new pointing would simply be washed out. Likewise, new mortar placed shortly before the rising tide came up would not have a chance to take a set, and therefore wash out as well.

5.4 Opening up the pier deck

During periods when the preparatory pointing work was not possible on the pier face, the pier deck above was opened up to investigate the condition and composition of the core, and establish locations to begin the grouting. Three pits were excavated along the length of the work area, using a mechanical excavator. Following this, various previous repair materials were removed by hand, as well as large masonry units during the formation of the pit (Figure 9). Several large voids were also observed.

Figure 9. One of the pits opened up in the pier deck to expose the core beneath.

It was quickly obvious that there was an absence of smaller stones and larger aggregate. Even at a depth of only 750mm substantial voids were discovered. As this was at the sheltered end of the pier where wave action and suction is modest at lower levels, the likelihood was that the situation would be much worse in the more exposed sections further down the pier.

6. Grouting

6.1 The grouting operation

With access to the pier core now open, and the pointing to the external face complete, grouting trials to the core were started. The grout was delivered to site in 20Kg bags, and mixed with water in a standard Belle type mixer to a defined consistency as advised by the supplier (Figure 10) of one bag of dry grout mix to 8 buckets of water. The easy handling of the bags suited the site conditions, although delivery of the material in larger amounts would have been cheaper. Using buckets, the liquid grout was then poured into the voids at the bottom of the pits, as shown in Figure 11.

Figure 10. Mixing the grout in a small standard Belle type mixer.

Initially, 5 buckets were poured and an interval of 30 minutes was allowed to pass. As with the work in the yard, the weep pipes were important to assess the penetration and rise of the grout in the core; after 30 minutes grout started to show, and pouring was stopped for a period to allow a set to take place. Too much pouring of grout, with insufficient setting time, resulted in the repointing being pushed out by the pressure of a still liquid grout. This required quick re-sealing of the holes with a clay and hessian plug. Sometimes this had to be done quickly to avoid excessive loss of grout. Generally however the grout appeared to route its way into the pier core as planned. Occasionally grout would start to egress at certain points in the wall where the repointing had been missed. These leaks were stopped with a mortar and hessian plug.

Figure 11. Pouring in the grout into the opened core with a builder’s bucket.

6.2 The spread of the grout

As the grouting progressed, and successive layers or fills cured and stiffened, the 'lenses' or layers of grout rose, and grout spread progressively to the east inside the pier core. After a period of time some grout started to appear in the water some 10 metres away from the entry pit (Figure 12).

Figure 12. The grout was able to flow some distance within the structure and can be seen coming out of the pier face approximately 10 metres from the point of pouring.

This was not unexpected as there was underlying bedrock to the west and north of the pier structure preventing exit of the grout to anywhere else. While such penetration of the core by the grout was desirable in the context of a full repair (that of the whole of the Boyne Pier) it was less desirable in seeking to demonstrate consolidation to a more controlled narrow vertical section of the pier.

To address this problem a thicker mix with a quicker set time (10 minutes) was then used, whereby the grout would not be able to flow laterally so far; this was achieved by varying the moisture content of the grout. In terms of site workflow it was disruptive, as the grout pouring became intermittent, as time was required to allow the grout to set before the next pour.

Controlling the lateral flow of the grout might be easier at the breakwater where side access for grouting would be possible, and where work was starting from a confined or fixed end. Once it had been confirmed that good control of the grouting process had been achieved, the grouting trial was stopped.

6.3 Managing the grouting and the tidal heights

Any construction work in the maritime sector has to take account of the environment and the tidal conditions. At Cove the pointing and the grouting operations were governed entirely by the times of high and low water. Through experience with batching and pouring, the last pour before an incoming tide had to be completed 30 minutes before the water level reached the base of the pier.

6.4 Grouting volumes and timescale

In total 200 bags of material, making 300 buckets of grout (3000 litres) were poured into the core over a period of 5 days. On the last day of work 50 bags were batched and poured.

6.5 Closing up and finishing the pier deck

Loose material and gravel were used to refill the pits made for the grouting trial. The deck was closed off with salvaged flat stones of a good size. As this area of the pier was not exposed to spray and seawater the surface was left of stone and packed gravel.

7. Lessons from the project

Traditional marine structures like the Boyne Pier at Cove Harbour are typically repaired using mass concrete. The trials sought to demonstrate that sensitive repair techniques using materials more compatible with the existing fabric were feasible and could be procured at reasonable cost; the results suggest that they are. On a technical level the works proceeded more or less as planned, but with a greater volume of grout used than anticipated.

For the main phase of works on the Boyne Pier, it has been decided that aggregate will be used to bulk-fill voids where access routes to the decayed core is easy. As a result of the trails, the contractor has gained experience in a niche but important area of activity where more work in other locations will be likely. The finish and appearance of the repaired part of the pier has not been unduly affected and its durability and resilience has been considerably enhanced.

This trial has given a sound technical and financial basis on which planning for a much larger phase of repair on the Boyne Pier can be based, as well as informing repair strategies for works on similar structures in other locations.

Further reading

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