Berwick Breakwater Refurbishment, Berwick Upon Tweed, UK

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Summary
Berwick upon Tweed is a traditional market town situated at the mouth of the River Tweed estuary, on the east coast of the United Kingdom. It is the main settlement in north Northumberland and a highly popular tourist destination. As the estuary contains the only commercial port between Edinburgh and Blyth, it is of strategic economic importance.

The town is protected against the natural forces of the sea by the Berwick Breakwater, which is located on the north bank at the mouth of the River Tweed estuary. This is a two hundred year old, Grade II listed, stone masonry pier, projecting 750m out into the North Sea.

This paper describes the development of a complex scheme for the refurbishment of this historic structure in a historic and environmentally sensitive location with limited access. It shows the successful approach used for the generating the repair strategy, repair design and final implementation of the works to a finite budget.

Historical and Background Setting
Berwick upon Tweed has a long and varied history which is reflected in the towns' infrastructure and buildings, which notably include the defensive ramparts which surround the town, barrack buildings, castle remains and the iconic road and rail bridges which span the estuary. A breakwater was originally built at the mouth of the River Tweed estuary in 1577, but on a different alignment to the present structure. The present breakwater, which is classified as a Coastal Protection structure, was constructed following parliamentary approval in 1808, with the lighthouse erected at the end of the pier in 1826. Prior to construction of the present breakwater, the channel of the River Tweed estuary flowed in a more northerly direction; the breakwater now diverts this further east before it discharges to the North Sea.

The breakwater provides protection to the town of Berwick upon Tweed (on the northern bank of the River Tweed estuary) from coastal storms approaching from directions between due north and due east by significantly influencing storm wave propagation before these waves enter the estuary. In addition, the structure provides considerable shelter to the heavily developed coastal frontage at Spittall, on the south bank of the estuary, against waves from due north, which is the predominant direction of approach.

Within the shelter of the breakwater, a large sand spit (known as Sandstell Point) has developed on the south bank of the estuary. This has progressively extended northwards across the mouth to become a substantial feature of considerable geomorphological and ecological interest. This sand spit now provides a (mobile) barrier against waves approaching the estuary from the south and south easterly direction.

The shelter provided by the breakwater and the spit has considerably reduced the wave-driven changes within the outer estuary and this has led to the development of important inter-tidal habitats, many of which now have European and National designations for their nature conservation value.

The breakwater's location at the estuary mouth on the edge of this historic town also provides a popular amenity to the local community for recreational activities such as walking and sea fishing and is a distinctive attraction for both day-trip and longer-staying tourist visitors. Figure 1 shows the general location of the breakwater in relation to Berwick and Spittal and the natural features within the Tweed Estuary.

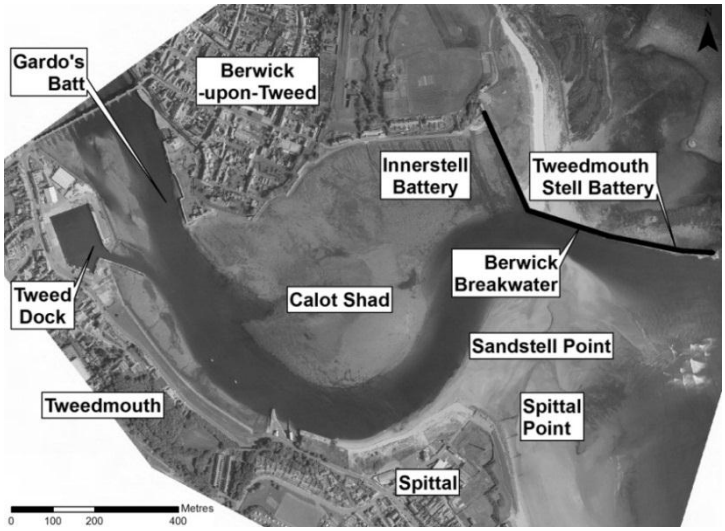

Figure 1 – Berwick Breakwater Location

A structure of this age, location and nature requires regular repair and maintenance to maintain its functionality. This requires a careful balance between providing an effective functioning structure and protecting the quality of the historic and natural environment that surrounds it. In the case of the River Tweed estuary and adjacent Berwickshire coastline, there are a number of national and European sites designated for their environmental importance, including a Special Area of Conservation, a Special Protection Area, a Ramsar site, a European Marine Site, a Special Site of Scientific Interest and an Area of Outstanding Natural Beauty. In addition, the estuary is one of the most important salmon fishery waters in the UK.

In October 2010, Northumberland County Councilwere informed by the Environment Agency of available grant funding allocation for the financial year 2011/2012 with some funds available at the end of that current financial year. The council took this opportunity to apply for funding for the improvement of the current condition of Berwick Breakwater. This provided very tight timescales to secure funding, design and procure the works order to take advantage of implementation in the 2011 summer weather window. Immediately, work commenced on a Project Appraisal Report,which was completed within four weeks and submitted to the Environment Agency's Project Appraisal Board (PAB) to secure the grant aid.

Formation of a Strategy

The Problem

The breakwater consists of stone masonry walls and block in-fill within the core. A parapet wall is located along the seaward length of the structure on its crest to reduce wave overtopping. Figure 2 shows the typical cross section through the breakwater. A roundhead, strengthened by a buttress wall, has been formed at the distal end. Much of the breakwater dries out on an ordinary spring tide on its northern face, but is usually submerged at its toe on its southern face where it abuts

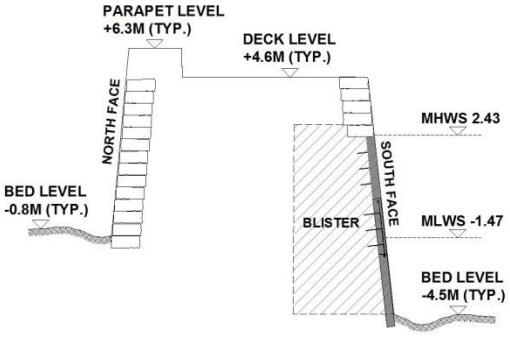

Figure 2 – Breakwater Cross Section

the river channel.

Significant repairs are reported to have been undertaken soon after construction, probably in 1827, with records of other substantial repairs in 1948, the 1950s, the 1970s and the early 1980s. Most recently, urgent repairs were completed at the structure's seaward end in August and September 2009, with replacement of lost bullnose stone to prevent further damage over the following winter.

Whilst the structure has been founded largely on bedrock, the section between Innerstell Battery Rocks and Tweedmouth Stell Battery Rocks apparently extends across the now in-filled former channel of the River Tweed estuary which historically is believed to have flowed through the gap between these two areas of foreshore scar.

Through inspections of the breakwater on seven occasions between 2002 and 2010, deterioration in condition was carefully recorded. This deterioration has occurred despite maintenance and occasional urgent repairs, which have included patching, grouting and skinning as well as construction of the concrete buttress at the roundhead. Concrete bagwork has also been placed along significant lengths of the base of the structure in an attempt to counteract undermining.

The principal defects identified through the regular programme of inspections were:-

- Significant cracking, spalling and abrasion of mass concrete;
- Plucking of facing stones;
- Washout of mortar, (see figure 3);
- Developments of voids within the core (see figure 3), with air and sea water being compressed and forced through cracks in concrete and masonry;
- Undercutting of the basealong approximately 70% of the length of its estuary-facing side, in places by up to 1m but more typically by around 0.5–0.7m;
- Break-up of some previous repairs and strengthening works;
- Vegetation growth in joints.

Figure 3 – Damage to Southern Stone Face

The Consequences of Doing Nothing

In the absence of capital refurbishment works, on-going deterioration and break-up of the breakwater would be expected, initially leading to the collapse of local face sections of the structure and core material both being washed onto the foreshore and into the wider marine environment, causing smothering of designated habitat features. There would also be debris released into the navigation channel, increasing hazards presented to the passage of vessels and increasing dredging requirements.

As sections collapse, so greater wave penetration would occur through failed sections, resulting in erosion of Sandstell Point and loss of the natural protection afforded to the outer estuary by this spit at its mouth. As both the breakwater and the spit further deteriorate and exert weaker influence on the wave climate, so the inter-tidal sandflats and mudflats of the estuary at Calot Shad and along the fringes of the channel would become eroded. This would have a severely deleterious impact on the designated nature conservation interest of the estuary.

The loss of the breakwater, spit and inter-tidal areas would place great pressure on the quay walls and historic town walls since there would be far less attenuation of wave energy, leaving them susceptible to direct wave attack, with a rapid increase in their deterioration due to this. The risk of waves leading to overtopping of the quay walls would also increase, causing more frequent economic damage due to sea flood events. The higher wave energy in the estuary mouth will also lead to navigation problems associated with the Tweed Dock.

If the breakwater was to fail, the main channel of the River Tweed estuary would be expected to force its course out towards the north-east along its previous alignment. This would make continued use of the harbour untenable. It can therefore be seen that the economic and environmental damages associated with failure of the breakwater would be large. It is this concern that prompted investigation of options for its management.

Options Considered and the Preferred Solution

The main options that were considered within the Project Appraisal Report for the breakwater were:

- **Do Nothing** – undertake no FCRM activities.
- **Do Minimum** – inspection and reactive maintenance or urgent repairs (as is currently undertaken).
- **Do Something– Advance the Line of Defence** – protect the breakwater using some other offshore structure such as a detached breakwater.
- **Do Something– Realign the Line of Defence Landwards** – remove the breakwater and rebuild on an alternative alignment further landward
- **Do Something – Hold the Line** – works to the breakwater to improve its condition along the present alignment.

From this process, the preferred option was to "**Hold the Line**" by refurbishing the breakwater wall, toe and deck through localised repairs to defective areas.

Design Stage Challenges

The timing of funding availability for the scheme and the benefits of working through the summer months to avoid disruption to over-wintering birds and to minimise construction risk during stormier sea conditions, meant that a rapid programme of design, procurement and construction was required. Accordingly, site investigation, detailed design, produced contract documentation, including obtaining all necessary environmental consents and licences were undertaken within a condensed period of ten weeks.

Site Investigations

The initial stage was to undertake a suite of site investigations to the structure in order to determine the extent of the repairs required and inform the approaches for the repair techniques. The surveys undertaken were visual inspections (with some defect measurement where accessible) above and below the water through walkover surveys boat surveys and dive inspections, research into historic reports and investigations, and intrusive coring into the structure body at strategic locations.

Restricted timescales and access constraints limited the scope of the physical investigations,although the main defect areas were included. Some investigations such as the intrusive coring works required Assent from Natural England before they could proceed which impacted their timing and informing process to the design. The coring was also constrained by the available equipment that could fit through the small archways in the town's defensive walls and on the narrow deck of the breakwater, although cores were required at 5-6m depth of the breakwater face. This was achieved with a small mobile crane with man rider basket. The visual inspections were limited by marine growth which was not removed during this stage due to the need for significant contractor mobilisation and Natural England Assent.

The timing and site constraints meant that some of the investigation works were moved into the early part of the construction stage. These included marine growth clearance, detailed dive survey, geophysical survey of the deck, and a topographical survey (required for future works).

Design Considerations

The design produced was required to overcome key challenges that were set out from the initial consultation with the statutory authorities at the feasibility stage which included:-

- Not extending the existing footprint of the structure to avoid damage to the seabed,
- Maintaining and improving the current aesthetic appearance of the structure taking account of the listed status,
- Protection of the seabed from damage and pollution during construction,
- Avoiding pollution and damage to the adjacent water bodies and designated sites,

- Enabling works to be undertaken above and below water in a difficult tidal environment,
- Identifying construction methods achievable with the access limitations, and
- Funding limitation for the construction works due to available budget.

Design Approach

The overall breakwater stability was proven to be adequate from its size, founding and past exposure to storm events. So the global stability of the structure was not a concern in the design. The investigations undertaken established the majority of the structure body to be in good condition particularly in the core with some soft spots around defective face areas. The key approach to the design was to re-establish the outer structure shell of the pier to protect the core. The investigations identified numerous structural defects across the whole structure that were to be addressed within design and construction stages. The scale, position and nature of the defects varied significantly, requiring different approaches to address and meet the above constraints. The approach taken was to identify standard details for several repair types that could then be applied to a schedule of defects compiled for the structure. The standard detail types were identified as:-

- Pointing and grouting repairs,
- Isolated stone block replacement,
- Concrete bagwork repairs to the structure's toe,
- Concrete face repairs,
- Large stone block face repairs,
- Stone coping and deck repairs, and
- Concrete deck repairs.

The approach of the stone face design was to reuse as much of the existing stone blocks from the structure as possible or salvage from adjacent to the foreshore, if possible. Previous investigations had identified that the stone blocks in the structure were of a considerable size (1-1.5 m deep from the face). Whilst much of the stone was thought to have deteriorated, significant quantities of blocks were still intact and with adequate strength to be reused. These blocks were cut into smaller pieces in depth and were used as facing blocks to the outer extremity. The voids left behind the face were then filled with concrete which was tied to the face blocks using anchors (as seen in Figure 4 adjacent).This aided in minimising the quantities of new stone required for the scheme.

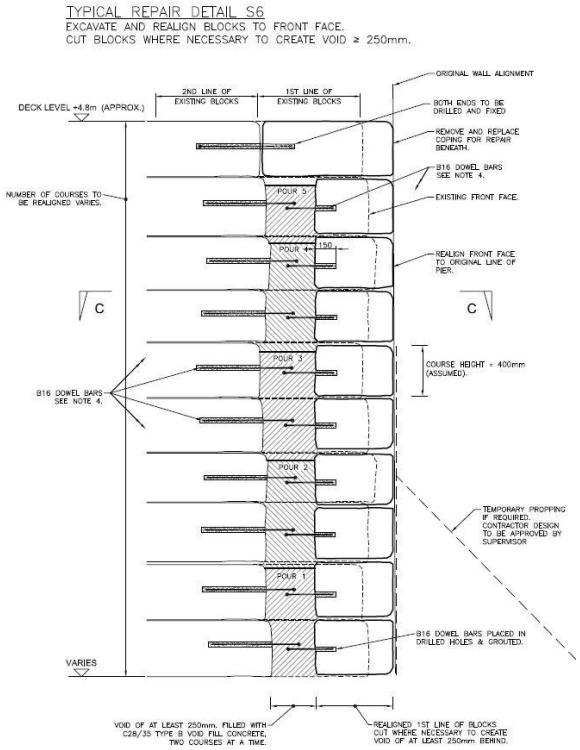

Figure 4 – Stone Face Repair Detail

In considering the conservation value of the structure, the approach to the concrete facing repairs was viewed to return some of the aesthetic nature of the original stone to the pier face whilst improving the durability of the surface material. This was achieved by removing the damaged concrete facing from the structure and replacing with a new reinforced concrete face tied into the body of the structure. The concrete appearance was enhanced by use of pigmented concrete to match the natural colour of the original stone, and by addition of patterned formliner finishes to give the appearance of natural stone work repairs to the face. This was agreed with the County Conservation Officer.

The design of the larger repair areas consider the effects of water retention from within the structure (hydrostatic loading), and sediment abrasion action from non-breaking waves and river flows to the outer face in accordance with BS 6349. The primary action was to limit water ingress into the structure. However, the sandstone structure does absorb water from tide and overtopping that could apply a hydrostatic head to the repairs. Wave impact loading was considered although its effect was minimal as it imparted force on to the repair element which transferred to the mass of the structure. The loading analysis identified a tie force for the anchors into the sandstone, which were designed following strength tests on the existing stone. These loads were verified by pull out tests on site. The reinforced concrete panels were designed to Eurocode 2.

At this stage of the scheme, there was an element of uncertainty over available funding for the implementation of the repair works (identified as £700,000 for construction). Thus, a strategy was discussed and agreed with Northumberland County Council in preparation of the tendering process. It was agreed that all the defects identified within the schedule would be included within the work scope in order to identify the full cost required but a prioritisation scheme would be applied to the defect schedule to identify the importance and necessity of each of the work items. The strategy also set out the order in which the priority works would occur, so that if costs for the top priority works escalated significantly, the lower priority works could be removed from the scope to remain within budget.

The prioritisation for the defect repair was based on the structural significance and exposure of each of the defects in the schedule. The primary objective of this approach was to provide a solid and secure outer facing the structure to protect the core material inside. Thus, the more exposed and structurally significant the defect, the higher the priority. Similar decisions were made for the lower priority repairs based on health and safety over aesthetics to the finished scheme.

Consultation and Consents

Throughout the feasibility, design and construction processes, consultation was undertaken with the relevant statutory authorities to gain engagement and consent for the works to proceed. This was essential to the success of the implementation stage and required good clear communication of the works involved and the cooperation of these parties to achieve consent within the time frame provided. The key consultees were Environment Agency, Berwick Harbour Commissioners, Natural England, Marine Management Organisation, Crown Estate, River Tweed Commissioners, and NCC Conservation Officer. This approach to the consultation process meant that the formal consents required were limited to Assent from Natural England due to buy in by the other parties, provided the design constraints identified above were adhered to.

Construction Procurement

The construction value required a procurement strategy involving pre-qualification and tender in accordance with the European directive. The pre-qualification was run during the design stage, identifying six contractors for the tender from twenty. The tender was let with a tight return period of three weeks. The contract form used was NEC3 Engineering Construction Contract using Option B – lump sum with bill of quantities. By providing a quantified bill, the tenderers were able to provide a swift response and it would provide a price guide for variations through the contract. This option selection also limited the risk exposure to the client during the contract compared to other options available under NEC3 or similar contract types such as target sum or cost reimbursable. The design and tender documentation was achieved a week earlier than programmed.

The tenders were assessed on a split Quality/Price basis of 60%/40% on return. The combined team efforts with tender appraisal enabled an award to be made two weeks after tender and provide the contractor with adequate time to mobilise.

Construction Challenges

This stage was considered by the project team to be the most challenging due to the restrictions and environment encountered, despite the wealth of experience provided by the whole team.

On commencing work, removal of the extensive marine growth was required by high pressured washers. From this activity, it soon became apparent that the extent of the repair work required would exceed the programme and budget initially available, as the clearance identified extensive damage to the structure beyond that previously known. The extended areas required priority repair in order to comply with the strategy as shown below.

- Priority 1 – Repairs to the Southern Face of the Breakwater, seaward leg
- Priority 2 – Repairs to the Northern Face of the Breakwater, seaward leg
- Priority 3 – Deck Repairs, seaward leg
- Priority 4 – Pointing to the parapet and Deck repairs, landward leg

The clearance works identified that the priority 1 works would significantly increase the budget (see Budget Management below).

Site Access

Construction access to the breakwater was restricted by Ness Arch, part of Berwick upon Tweeds defensive ramparts. In order to service the repair works with materials, a site compound was located within the town walls where materials could be delivered, then broken down into smaller loads and transported to the breakwater.

Figure 5 – Ness Arch

The restrictions on access to the site imposed by Ness Arch, as shown in Figure 5, meant that careful consideration to construction plant was required. Cranes, large excavators and concrete wagons were all too large to pass through the arch. The contractor chose to use 360 degree slewing MerloRotos (small telescopic boom cranes) to position manrider baskets against the face of the breakwater, a 12m telehandler to deliver materials, and 6T dumpers with drop down roll over bars to remove materials that arose from demolition. In order to perform demolition operations and reach the toe of the breakwater, 7m below deck level, a 20T wheel mounted excavator was used. This equipment required alternative access to the breakwater via Berwick Golf Course, although this was with conditional use. In order for the wheeled excavator to reach all required repair areas bespoke extension arms were manufactured which would attach to an underwater breaker, clamshell and rock wheel.

Prior to any large construction plant accessing the breakwater a ground penetration radar survey was performed to identify any soft spots directly beneath the breakwaters deck. Three areas of concern were identified and plate bearing tests were subsequently performed in these areas, to check that the breakwater could withstand the loads to be imposed by the selected construction plant.

Edge protection using water filled barriers demarcated the open edge of the breakwater to all personnel and maintained them a safe distance from the open edge. It also provided a visual aid for moving plant, when reversing as the narrow deck width prevented plant from turning round. Logistically the repair sequence was carefully planned as once plant was in position, access past was prevented.

Temporary Works

Access

It was initially planned to access the repair areas on the southern and northern faces using scaffold platforms, and manrider baskets suspended from 360 degree slew MerloRotos, However, it soon became apparent that scaffold platforms suspended from the breakwater deck would not withstand the flows from the River Tweed and sea conditions so required daily maintenance to make safe prior to every working shift. The contractor decided to access all the repair areas out of manrider baskets positioned by the MerloRotos under banksman supervision, as shown in Figure 7 below.

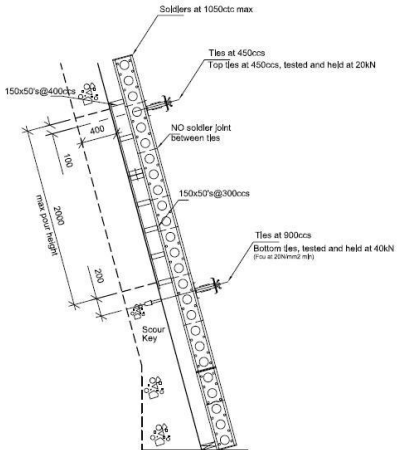

Figure 6 – Shutter Design

Figure 7 – Manrider Basket Access/ Top shutter Installation

Formwork

All formwork on the scheme was single sided shutters. To accommodate tide works, repairs commenced from the top and bottom of the structure simultaneously. The top concrete pours adopted a single sided soffit shutter cantilevered from deck level, lower pours being a more traditional single sided shutter design tied to the wall. Care had be taken at design stage to allow for the poor condition of the existing sandstone and low pull out test results (20kN in existing sandstone) achieved from the tie bars, all tie bars were fixed in to the structure with resin and were tested prior to installing the shutter and pouring concrete. The temporary works were designed for formwork forces as these exceeded the environmental loadings. Tie bar loads were the governing factor, which meant primaries were closely spaced with walers spanning along each row of tie bars. (Refer to Figure 6 above)

Shuttering installation in the tidal zone of the structure was programmed during spring tides, to take full advantage of the low water levels to facilitate fixing the bottom row of tie bars. Shutters & concrete were placed on a rising tide which helped reduce the river velocity past the work area, allowing divers to safely enter the water and materials to be lowered and held in placed.

Material Selection

Part of the scheme strategy was to replace existing repairs with more aesthetically pleasing repairs. Construction materials were agreed through close working with Northumberland County Council's Conservation Officer. Concrete with a red / pink pigmentation was selected to blend in with the existing Northumbrian sandstone; a formwork liner with blockwork pattern was chosen to provide the appearance of sandstone blocks, although it was difficult to achieve an exact match to the existing random pattern of the stonework. Sandstone from a nearby quarry (Doddington) was chosen for its likeness to the existing stone and suitable durability. The existing sandstone properties were tested along with that of the Doddington Stone to ensure that the newly sourced stone was of equal/ better quality than existing.

Repairs

Stonework Repairs

The localised areas of existing stone was lifted out of the structure and placed on the deck. Stonemasons then assessed the condition of the blocks for existing faults/ fissures and determined which blocks could be cut and redressed to form replacement blocks with a minimum depth. Limited quantities of new stone were ordered from the approved local quarry to make up the shortfall. Anchors were drilled and fixed into the back of the blocks prior to lifting back into position. Mechanical anchors were drilled and fixed into each block to allow a lifting eye to be attached in order to lift the blocks into the repair area. All blocks were pointed using a mortar containing an accelerant to ensure it would set prior to being covered by the tide. Figure 8 show a typical stone repair.

Figure 8 – Blockwork repair mid structure

The blockwork and compacted concrete backfill was placed in lifts of a maximum of two courses of blockwork to maintain stability. Initial attempts using grout fill were abandoned after it was found to run through the voids in the structure. So visible gaps in the recess were pointed prior to block placement and concrete fill to the top course was placed via a letter box in the stone face. This ensured the void space was filled and compacted.

Reinforced Concrete Repairs

The reinforced concrete repairs totalled an area of approximately 130m^2 in two locations along the southern face, Figure 9 below shows one of these areas. These repairs spanned above and below mean high water level and consequently were carefully programmed to coincide with spring tides to maximise construction time at the lower levels of the repair area. Where spring tide did not provide an ample working window, a diving subcontractor was used to assist in the installation of reinforcement, shutters and concrete. The defective concrete patch repairs were removed using either a breaker or rock wheel attached to the wheeled excavator.

Figure 9 – Reinforced Concrete Repair

Figure 10 – Concrete Placement

Toe Repairs

There were numerous voids highlighted at design stage, however in order to determine the precise location and size of each void a diving subcontractor was procured to inspect the entire southern toe as tide levels meant that these voids were permanently submerged. The initial design for these void repairs was to install grout bags secured in place by injecting grout behind, this was altered to a steel shutter detail approach recommended by the Contractor, infilled with underwater concrete pump mix. The condition of the structure and size of the voids made grout bags and grouting costly and impractical, as grout would flow indefinitely through the joints between blockwork within the core. Concrete helped seal joints between the blocks, prevent grout loss to the surrounding marine environment and reduced excessive waste of construction materials.

Deck Slab Replacement

The original work scope was to replace approximately 80 m length of full slabs and a few part slabs. However, due to the deck slabs poor condition, large amounts of reflective cracking and minimal concrete depth, the slabs rapidly deteriorated under the trafficking of construction plant. The decision was made to replace all deck slabs to two thirds of the structure (460m), so providing an even walkway and sealing the top of the structure. The existing deck slabs were demolished, raised areas of sandstone below the slabs were reduced locally using a rock wheel attached to the excavator arm to ensure a minimum of 75mm slab thickness was achieved. The new slabs were cast in 15m long bays with crack inducers installed at 5m intervals. Fibre reinforced concrete was delivered in $3m^3$ loads by the site Utranaaz mixer (small concrete mixer – see Figure 10 above). Slabs where placed to accommodate deck features, (bollards, mooring rings) to maintain the heritage of the breakwater.

Disruption

Lighthouse Electric Cable

A wall mounted electric cable feeding the lighthouse on the end of the breakwater, was originally attached to the southern breakwater face. The cable was in fairly poor condition and on arrival to site we were informed that in poor weather conditions the electric cable arced. This matter prevented repair works on the piers southern face commencing due to resultant Health and Safety concerns.

It was decided that the electric cable should be removed and replaced with a new electric cable installed in a duct within the breakwater deck at the toe of the parapet. A spare duct was installed at the same time to facilitate future alterations including lighting provision if so desired. Whilst the cable was being relocated, pointing works commenced along the parapet and a mobile generator provided power to the lighthouse, to mitigate programme delay and costs. Repairs on the southern face did not commence in earnest until the end of August rather than the beginning of July as originally planned.

Difficult weather, fluvial, tidal and sea conditions

It was intended that the construction stage would occur during the summer of 2011, demobilise at the end of September for the winter period and remobilise in April 2012 to complete the works.

Figure 11 – Breakwater battling the elements

Whilst initial progress on site was good following the removal of the electric cable, the repair works became increasingly affected by weather, river flow, and sea state. High winds prevented lifting operations, large swells and high river flow prevented divers entering the water and waves washing over the structure (Figure 11) prevented access to the breakwater on a couple of occasions. All these events caused prolonged delays to the works and moved the 2011 demobilisation date back into December. This required an extension to the Natural England Assent to remain on site to try and close open repair areas in order to safeguard the structural stability of the breakwater during the further winter months.

However, in early December with continuing poor weather conditions a decision was made to demobilise and return to site in 2012. It was agreed to leave 66m^2 of breakwater open to the elements and monitor for deterioration until return to site in April 2012. This approach paid as the structure remained intact, although some reinforcement had to be replaced due to corrosion during the exposed period.

To minimise delays in 2012 due to weather and sea conditions, works on the southern face of the structure were re-sequenced to coincide with spring tides and summer months.

Budget Management

With the increased priority work scope and programme delays, good budget control was required and achieved by the project team through accurate forecasting. The scheme budgets were controlled and reviewed using a contract tracker and construction programme with inputs from all parties to provide a live picture of expenditure and delay. This forecasting and monitoring enable early warning of budget issues that were then resolved through early cooperation and discussion between the project parties.

By winter, the construction cost estimate had risen to £2.6million, requiring additional funding. During the winter closedown period a major reappraisal of the outstanding repairs and repair types was undertaken by the project team. This was principally as a result of budget issues due to the increase in repair areas and disruption suffered. Whilst the cost and programme of the works each doubled original estimates, a value engineering exercise initiated by the project team identified ways to undertake the repairs by different approaches but maintaining quality required and achieving savings of around £800k to cap the increased spend. Additional funds were also gained in advance through a further application to PAB for grant aid. Timely forecasting in advance allowed the approach to be made before expenditure was incurred and continual consultation between the Council and Environment Agency enabled the additional funds to be provided.

Conclusion

The Berwick Breakwater Refurbishment scheme has proved to be a very challenging project due to its nature, location and environment. The breakwater provides and will continue to provide a significant coastal defence to the River Tweed estuary and adjacent coastline. The project team has delivered the design and implementation of a difficult series of construction works within the hostile environment of the River Tweed estuary and North Sea. The key lessons learnt through this scheme were:-

- Early consultation with statutory consultees quickly established working constraints in an environmentally sensitive area;
- Combined approach to sustainable design whilst achieving acceptable aesthetic appearance;
- Expedient engagement between designer and contractor overcame challenges on site; and
- Accurate cost forecasting and monitoring enabled budget control and early resolution.

The scheme has provided an improved coastal defence sympathetic to the historic and environmentally sensitive area, for the benefit of the Berwick Community for many years to come.

Acknowledgements

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