Entrance lock strengthening at Rosyth Royal Dockyard using rock anchorages

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Introduction

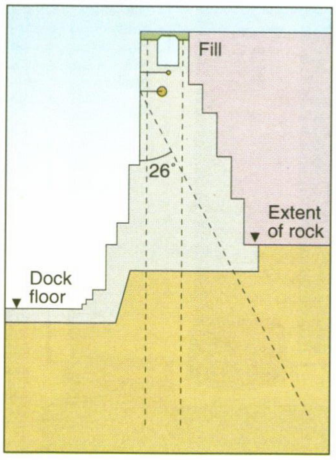
The entrance lock at Rosyth was constructed between 1908 and 1914 under threat of the First World War. Many of the Royal Navy's ships and submarines have since passed through the entrance lock, which forms a link from the River Forth to the non-tidal dockyard basin.

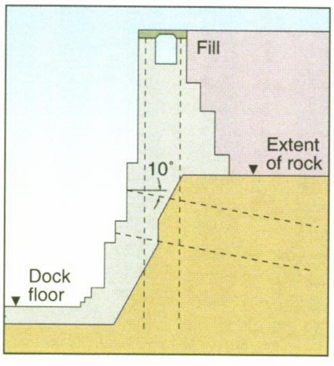
Eighty years on the Navy has vacated the dockyard. However, the entrance lock remains under its jurisdiction, its use primarily as a contingency facility for works carried out on nuclear class submarines. The dock is 259m long, 34m wide and 20m deep. It is sealed by removable, floating caissons.

The original construction was carried out by blasting a channel through a Dolerite island, Dhu Crag, on which the entrance lock was constructed. The blast material was used as aggregate for the mass concrete walls forming the dock. The structure, even by today's standards was an impressive feat of engineering. However today's requirements are very different to those of the early 1900s. Nuclear regulations now require that the structure is strengthened primarily to increase its capacity to withstand seismic activity. After assessing various alternatives, the project designers recommended an anchorage option, which consisted essentially of pinning the dock to the underlying bedrock, thus increasing its effective mass, and therefore its resistance to seismic disturbance.

A Kværner Construction Group joint venture tendered for this contract, comprising Kværner Construction and Kværner Cementation Foundations. The advantages of the Kværner JV was that a project specific team was identified at an early stage. This ensured that any duplication of overheads and potential confrontation, prevalent with main contractor-subcontractor relationships, was reduced to a minimum.

This paper describes the design, fabrication and construction phase of the contract.





LEFT: Figure 1: Typical mass section. ABOVE: Figure 2: Typical intermediate section.

Design

The strata indicated by the site investigation were mass concrete with an average UCS of 30MPa overlying fresh strong Dolerite, average UCS 120MPa. The structural design, carried out by TPS Consults, consisted of three configurations of anchors, depending upon the position of the underlying bedrock. These configurations can be seen in **Figure 1, Figure 2** and **Figure 3.**

Nuclear regulations allowed for no alternative design solutions, the number, capacity and location of the anchors were stipulated. Kværner Cementation Foundations design responsibility was for the anchor head components and the design of the fixed length. The two design load cases were 2,250kN, and 450kN working load. For the two load cases, the design required a 15 strand anchor with a 6m fixed length (2,250kN), and 3 strand anchor with a 5m fixed length (450kN). All anchors were type 5 double corrosion protection anchors complying to BS8081:1989. The design assumed that the anchors would be founded in fresh strong Dolerite.

From investigation of the existing concrete bearing stratum the size of the anchor bearing plates were determined. The 2,250kN anchors required a plate 550mm by 550mm by 60mm thick. Alternatively, a 600mm diameter circular bearing plate was used for the anchors recessed into the dock walls.

The circular plate was used as the anchor recesses could be constructed quickly using a single 800mm diameter core barrel, instead of stitch drilling a square recess. The lower loading case required a 300mm by 300mm by 40mm thick bearing plate.

The remaining anchor components were as per Dywidag Systems International specification.

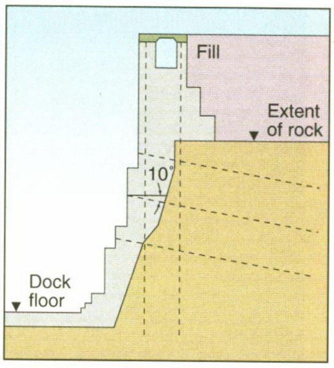


Figure 3: Typical perched section.

Fabrication of anchors at Bentley Works

A substantial cost element in this contract was the manufacture of the anchor tendons. Kværner Cementation Foundations set up a dedicated fabrication facility, in conjunction with Dywidag Systems International, at their northern office and plant depot at Bentley Works, Doncaster. The setting up of the facility allowed the fabrication to be directly controlled to suit site requirements, and provided a significant reduction in the cost of the anchors.

The anchor components were factory made permanent strand

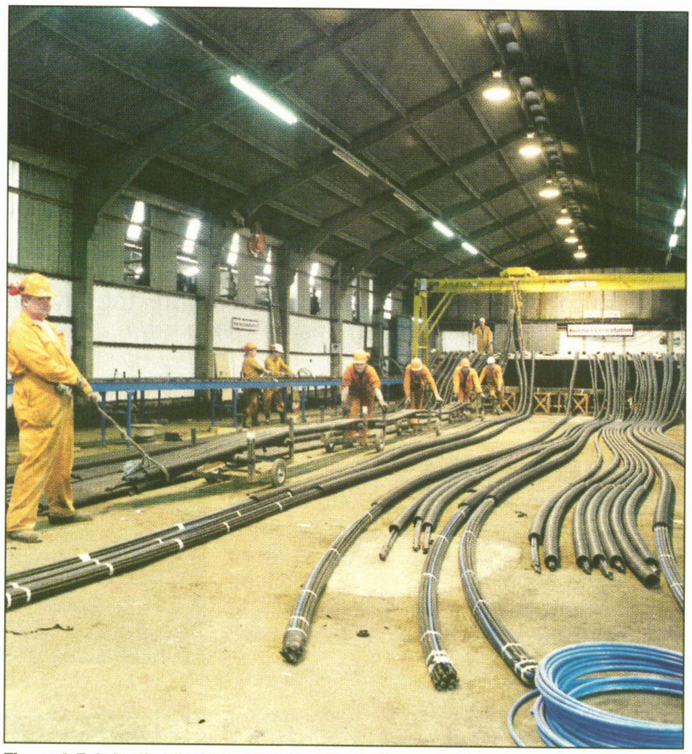


Figure 4: Fabrication Facility at Bentley Works, Doncaster.

Figure 5: Anchor Fabrication Facility, Bentley Works, Doncaster

Construction process

The construction sequence was as follows. (Typical vertical anchor sequence)

1. Drill the bore.
2. Demolish the service subway roof.
3. Flush the bore with clean water, check for watertightness.
4. Primary grout and home the anchor.
5. Construct spreader beam around the anchor.
6. Position the anchor bearing plate.
7. Secondary grout the anchor.
8. Stress the anchor.
9. Crop and grease the anchor head, place the top hat, paint with Bituthene paint.
10. Reinstate the subway roof, and anchor pocket covers.
11. Carry out lift off test on anchor after 12 months.

Drilling

The drilling was carried out using six of Kværner Cementation Foundations Casagrande C6's and two hired ROC604's. The drilling utilised down the hole hammer (DTHH) air flushing techniques throughout. A nominal 200mm diameter bore was formed for the 2,250kN anchors, and a nominal 130mm diameter bore for the 450kN anchors. During the trial anchor period, borehole verticality was checked by the Kvaerner Construction group's consultancy Kværner Technology, and results indicated a maximum of 220mm deviation off vertical at a depth of 31m.

The C6's used 750cfm compressors with average outputs of approximately 90m per shift vertical 200mm diameter drilling, and 70m per shift inclined drilling, and 125m per shift for the 130mm diameter bores (drilled vertically). The 601's, totally air powered, used 850cfm compressors with lower outputs and were used for the 64 degree to the horizontal inclined anchors.

Inclined anchors through the dock walls were drilled via temporary works platforms consisting of portal towers supporting Bailey Bridge decks. At any one time five drilling levels needed to be supported. Inclined anchors were drilled at 10° and 64° to the horizontal, ranging in depth between 16.5m and 29m. The 64° raking holes advanced using the weight of the hammers themselves, while the 10° inclined anchors required a nominal crowd force from the rig to progress the bore.

Movement of the platforms was via extensive cranage both from the quays, and from within the dock itself. Inclined anchor recesses were formed using 800mm diameter core barrels to a depth of 1.6m maximum. Formation using this method was substantially quicker than conventional stitch drilling and required the use of 600mm diameter

anchors with double corrosion protection based on 15.2mm diameter, seven wire stabilised strand to BS 5896:1980 (dyform), each strand having an ultimate strength of 300kN.

The fixed length strands were noded and pregrouted under factory conditions within 2 No concentric centralised ribbed plastic sheaths. The grout was mixed using a Colcrete 4/10 colloidal mixer consisting of a neat Portland Cement mix with a water/cement ratio of 0.40.

The free length strands were greased and individually protected by 1mm thick plastic tubes, overlapped by 100mm into the fixed length. The smaller diameter ribbed sheathing was continuous along the length of the free length, the uppermost section passing through a transition sheath to allow the strands to splay at the head.

Anchors were laid in protected storage areas until site required their transportation, which was carried out using purpose built transport carriers, for ease of carriage and off-loading on site. A photograph of these frames can be seen in **Figure 6**, as well as the storage of anchors prior to transportation to site **Figure 7**.

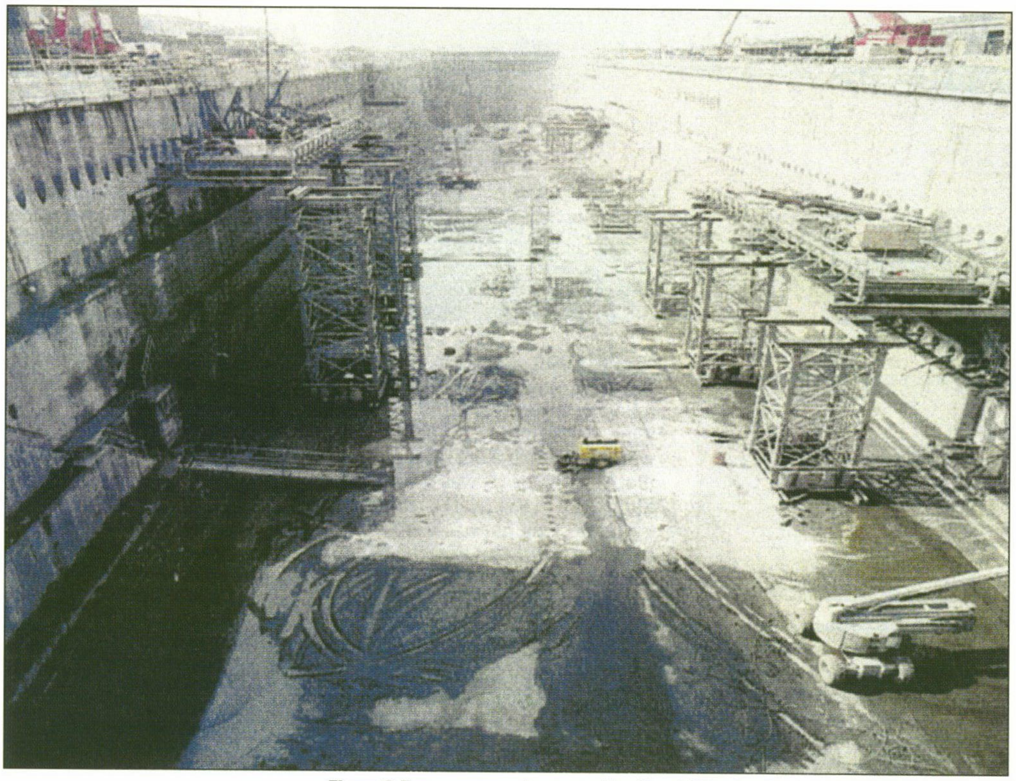
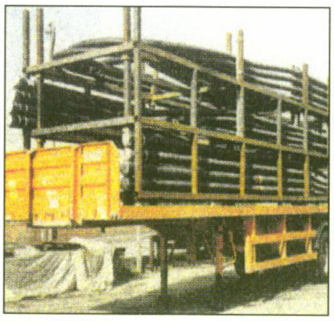


Figure 8. Temporary works supporting five drilling levels simultaneously.



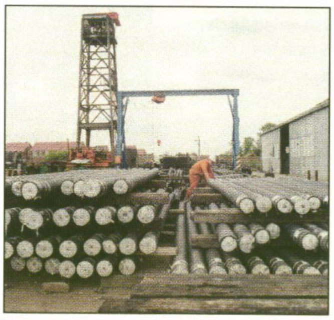


Figure 6. Anchor transportation frames (LEFT).
Figure 7: Anchor storage area, Bentley Works, Doncaster (RIGHT).

circular bearing plates instead of the more traditional square plates.

Problems were encountered during the drilling, in that flush medium was being lost through a system of interconnecting weepholes that not only ran perpendicular with the wall, but also in parallel to the wall, therefore linking all the weepholes perpendicular to the wall. This rendered the bores permeable. In the original construction of the dock, the engineer thought it prudent to incorporate a system of weepholes into the structure to reduce hydrostatic pressure from the rising tides surrounding the structure. However, the weepholes running parallel to the dock walls were not apparent on any literature. Thus extensive pregrouting and redrilling was required, adding approximately one third onto the meterage drilled.

Subway roof demolition

Once vertical anchor drilling was completed, the service subway roof was carefully removed using a drum cutter mounted on a 360° excavator. Existing services within the service subway were protected with the installation of timber covers along the length of the subway. Demolition rates were of the order of $3m^3/h$. Demolition was carried out in very close proximity to existing services located in the dock quays which were carefully exposed and removed. A photograph of the subway demolition can be seen in **Figure 9**.

Figure 9: Subway roof demolition

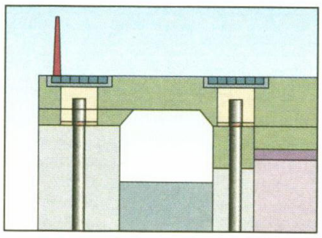


Figure 10. Cross-section through subway roof.

Installation

Inclined anchorage installation followed directly behind inclined anchor drilling. Inclined anchors were installed from the drilling platform, before it was progressed along the dock walls. However, vertical anchors were not installed until the area had been drilled, and the subway roof had been demolished. In some instances, this required leaving the bores open for up to six weeks prior to homing the anchor. On consultation with Kværner Technology, it was confirmed that due to the nature of the drilling strata, the stability of the bores would not cause any problems. Indeed, no detrimental effects were noted from anchors with long periods between drilling and installation.

Prior to anchor installation, borehole watertightness was verified, in accordance with BS8081:1989, section 20.4.2.4. The anchor was then homed, and withdrawn to check the borehole for blockage. The bore was then primary grouted to a depth greater than the fixed length of the anchor. The anchor was then homed, with lantern spacers placed at 3m centres along the fixed length.

A tremmie was placed through the grout in the hole to the top of the fixed length and the bore was filled with grout until clean grout appeared at the top of the bore. The first metre of grout was then removed. The grout was a colloidally mixed neat Portland Cement mix with a w/c ratio of 0.40. Cube strengths achieved range between 50MPa-70 MPa at 28 days.

The anchor bearing plate was then placed centrally around the anchor on a 40MPa cementitious grout mortar bed, ensuring that no air voids were present.

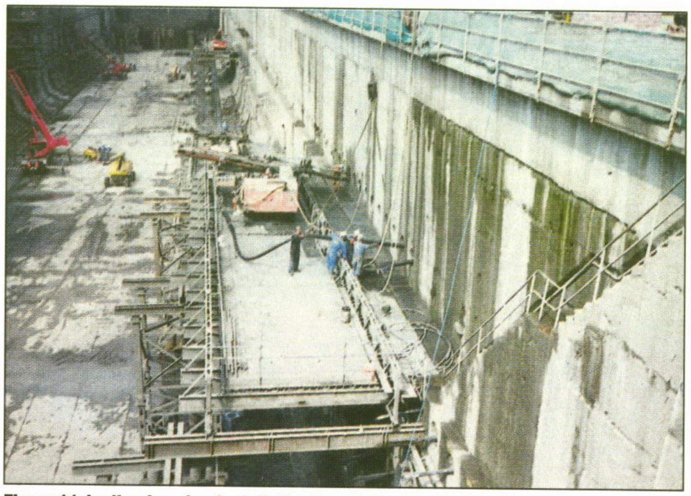


Figure 11: Inclined anchor installation from temporary works platforms.

Construction of spreader beam and subway roof reconstruction

Prior to back row vertical anchor stressing a 600mm deep spreader beam was constructed to spread the load from the anchors into the underlying stratum. The anchors were then stressed, once the spreader beam concrete had gained sufficient strength. Once stressing was complete, the subway roof was reconstructed, incorporating access recesses for the anchors. A photograph of typical stages in subway reconstruction can be seen below.

Stressing

Stressing proceeded once the anchor primary grout reached a strength of 30MPa, typically four days after installation. Initially it was attempted to fully or at least semi-automate anchor stressing in the same way that pile tests are now carried out. It was hoped that all measurements could be automatically logged using transducers mounted on the stressing jack. However trials proved that manual stressing was a more realistic option.

All anchors were stressed in accordance with BS8081:1989, section 11. A total of four proving tests were carried out on working trial anchors,

Figure 12: Spreader Beam construction on the Dock Quays.

Figure 13: Subway Roof Reconstruction following Anchor Stressing