The development of Aberdeen Harbour Expansion Project, UK

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Abstract

One of Europe's largest greenfield port capital investments projects over the next few decades will be the Aberdeen Harbour Expansion Project. (Figure 1). It has a project investment of over £300 million, the project involves the construction of two new breakwaters each 600m long, quay lengths of over 1.5km, 2 million m^3 of dredging including 0.25 million m^3 of rock dredge and approximately 1 million m^3 of reclamation. The harbour is situated on the east coast of Scotland and is subject to severe wave climate where design waves exceed Hs~8m requiring single layer concrete armour units of up to $16m^3$ to protect the Southern Breakwater.

This paper sets out the elements of the development of the port masterplan including the key engineering design and environmental constraints and operational requirements using many of the principles set out in the forthcoming PIANC WG185 guide to site selection and masterplanning of greenfield ports. The paper presents the context and background of the project, the masterplanning process, numerical and physical wave modelling studies, navigation simulation, aspects of the engineering design and the procurement process. The construction contract was awarded on 20 December 2016 with the project due to be complete in 2020. The construction is now fully underway.

Introduction - Background and context

King David 1st of Scotland, first established Aberdeen Harbour as a business in 1136 and is, according to the Guinness Book of Business Records, the oldest existing business in Britain, with a history that has spanned almost 900 years. Over the last 50 years Aberdeen Harbour (Figure 1) has undergone substantial development, primarily as a result of the growth in the northeast oil and gas industry. The growing trend for new, larger, multi-purpose vessels and the oversubscription of the existing harbour combined with the potential for new business streams, large cruise ships, renewable energy sector and oil and gas decommissioning, indicated there was a case for growth outside the existing harbour infrastructure. Aberdeen Harbour Board therefore proceeded with a series of technical, studies, economic and masterplanning studies (HR Wallingford, 2012) culminating in the Case for Growth (AHB, 2012) and then the Direction for Growth (AHB, 2013) to address these future challenges.

The masterplanning process

The HR Wallingford masterplanning studies applied many of the principles set out in PIANC *'Working Group 185 Ports on greenfield sites – guidelines for site selection and masterplanning (PIANC (2018))'*. When the masterplanning process began in 2000, these guidelines were not available and the masterplanning process drew on a number of publications and good practice including The Maritime Code, BS6349 Part 1 (now superseded by Part 1.1) PIANC 158 and experience. However, the process helped seed, formulate and develop many of the masterplanning principles now being set out in the PIANC guidelines.

The high level process for masterplanning a greenfield port is illustrated in Figure 2. The PIANC process starts with identifying the *future needs and vision* (high level objectives) for the port drawing upon the business case scoping report, which sets out opportunities from future markets. For the Aberdeen project this was undertaken by a joint team culminating in the publication of the Case for Growth (AHB 2012) setting out the markets and the need for development. The next step is to establish the *performance and functional requirements* and constraints based on these future business needs.

Figure 1: Aberdeen's existing harbour

This was followed by establishing key *spatial requirements* for land, water and access allowing the existing port and potential sites to be screened against these requirements. A number of potential development sites (over 20) were identified and matched against these requirements. The next step was to collect data and *develop, evaluate and screen* these sites (undertaken during the prefeasibility/feasibility stage) before identifying the preferred option. A range of drivers and constraints (including performance and environmental drivers) were considered right through the masterplanning process and these were integral to the decision making process.

The results were collated into the Technical Feasibility Study prepared by HR Wallingford and the wider planning document Directions for Growth (AHB 2013) prepared by Barton Wilmore. Directions for Growth considered the wider social impacts, the planning constraints and city's growth agenda.

After initial screening four potential options were considered for detailed review. These were:

- The Existing Harbour
- North Beach
- Nigg Bay
- South of Cove Bay

The three new sites beyond the existing harbour are illustrated in Figure 3. In addition, the existing port operations underwent a business case to assess whether improvements would enable an improved existing harbour to be a viable option. It was established that limiting operations to the existing harbour would mean acceptance of Aberdeen Harbour as a fully mature business, with future development focussed solely on its current estate in a programme of consolidation and internal adjustment. This option remained under consideration as a "Low/No Growth Option" in the event that others could not proceed. The process of identifying and subsequently characterising the three potential sites considered:

- Marine: Bathymetry, metocean data, currents, sediments geology and geotechnical constraints
- Terrestrial: Road and rail connections, material sources, utilities

- Environmental Constraints: Legislative framework, local planning issues, constraints and consultation. The chosen site included a Site of Special Scientific Interest (SSSI) and was adjacent to a Special Area of Conservation (SAC)

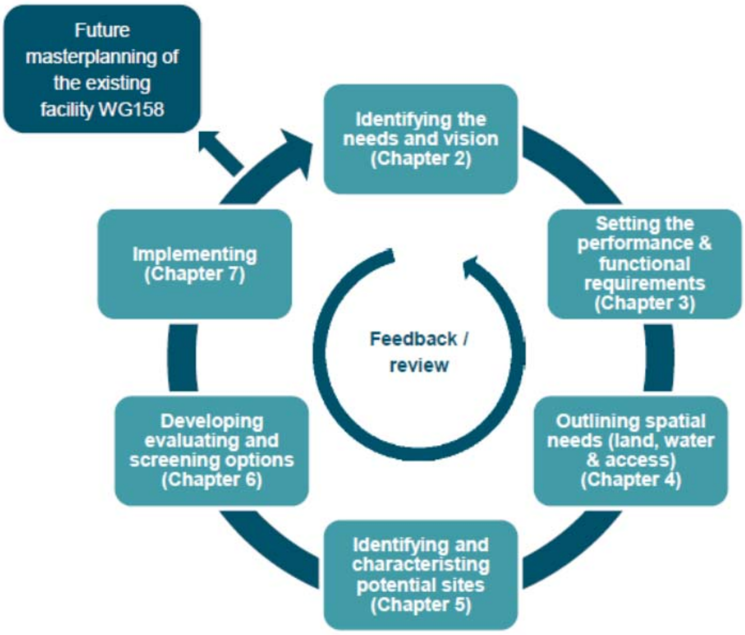

Figure 2 PIANC Outline masterplanning process for greenfield ports (PIANC 185)

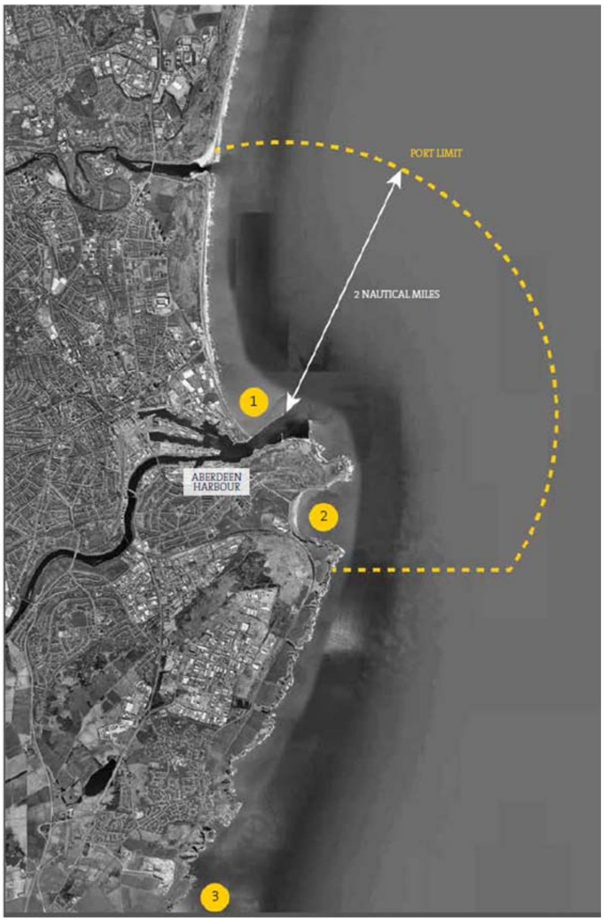

Figure 3 Site options considered

Figure 4 Hinterland links and constraints

Through this process Nigg Bay was identified as the preferred direction for growth. It was apparent that for a facility at South Cove, the lack of natural shelter meant that the costs associated with the creation of extensive new breakwaters, land reclamation and dredging, were greater than at both North Beach and Nigg Bay. The construction costs alone meant that a development at Cove was not financially viable. In addition, due to topographical constraints along this stretch of coastline, accessibility from land to the harbour facility would be challenging.

North Beach offered some greater scope to create the required berthing space but this came with traffic and environmental impact which would have proved problematic to mitigate against. The development of this area would offer little in the way of community benefits and would result in adverse impact upon the amenity of the city centre and local residents.

Nigg Bay offered the greatest scope to accommodate a new deep-water facility with potential for the lowest environmental and traffic impact. The facility will be constructed with little to no impact upon the operations of the existing harbour with considerable potential for regeneration of nearby communities. At the same time the site was close enough to the existing harbour to ensure that the logistical and operational management aspects could be efficiently addressed. The natural topography means that landside access was relatively straightforward. These combined to make the overall construction and operational costs of Nigg Bay the most commercially attractive option with the lowest environmental impact.

For all sites landside storage area was limited. More port area could be created through providing greater areas of reclamation albeit at a cost premium. The required areas were reviewed in with the port to ensure future flexibility. The present and expected future operations required little storage area and the proposed facility provided greater storage area behind the quay than the harbour had at present. The final Reference Design layout is shown Figure 5.

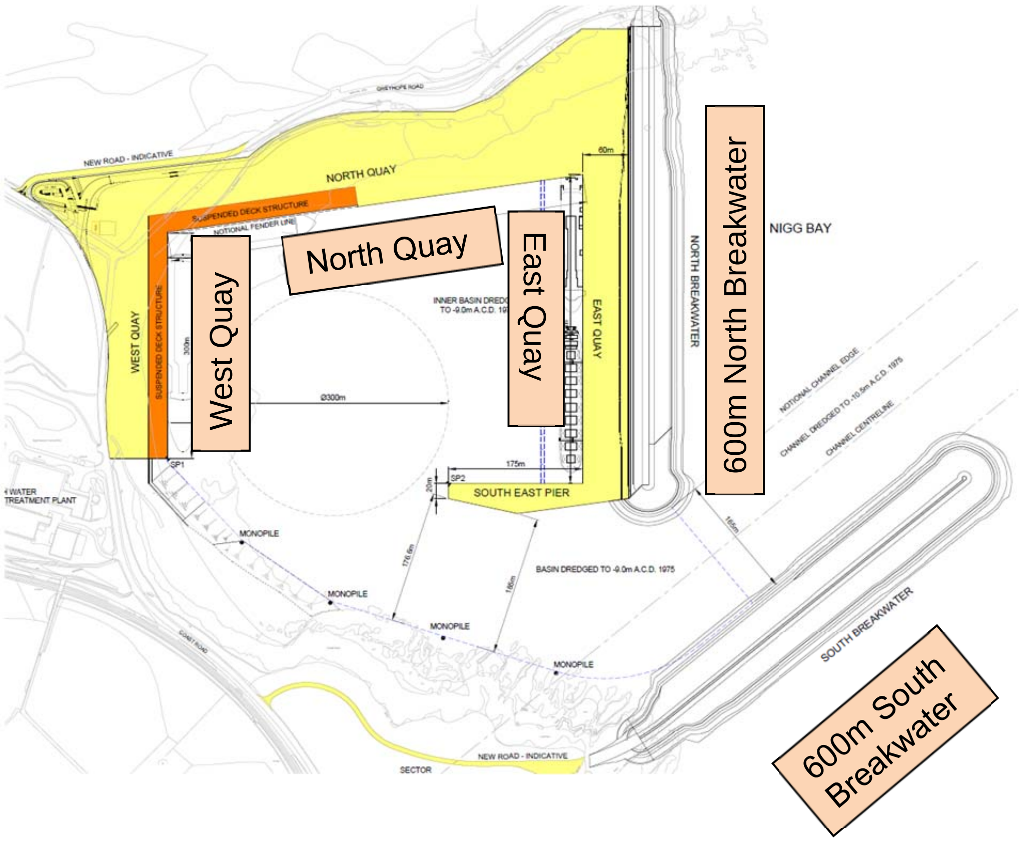

Figure 5 Overall port masterplan (Reference Design)

Simulation and modelling studies

Existing bathymetry and ground conditions

The existing bathymetry slopes steeply within the bay from the rock outcrops to the north and south and the boulder, cobble and sand beach in the west to approximately -7mCD at the entrance to the bay. Outside the bay the seabed slopes quickly to -20mCD within 600m of the entrance.

The superficial sediments within the survey area are sands, underlain by horizontally bedded silts, sands and gravels. However, Nigg Bay is a former (geological) channel of the River Dee, which has been partially infilled with glacial tills and sediments associated with the last Ice Age. The channel is carved into the underlying bedrock and descends to up to 40 m below sea-level. Part of the upper cliffs in the SE corner of Nigg Bay is an area classified as a Special Site of Scientific Interest (SSSI) due to the glacial sediments within the surrounding cliffs, some of which have been transported from as far as Scandinavia.

The bedrock which encircles the bay comprises of Dalradian Psammites and Semipelites, originally formed in shallow seas as sedimentary rocks and transformed by low grade metamorphism, with igneous intrusions having subsequently altered the sequence. The igneous rock within the survey area is unnamed but is estimated as Archaean to Silurian in Period. It was originally formed by silica poor magma. Subsequently these rocks have undergone metamorphism associated with the Caledonian Period.

Rock levels rise at the north and south of the bay. The masterplan layout was optimised to reduce the founding depth of the breakwaters but this meant in turn that it was necessary to dredge some 250,000 m^3 of hard rock, although this rock would be reused in the works.

Metocean – Waves, currents and sediments

Figure 6 Wave condition at the existing South Breakwater, Aberdeen Harbour 7 January 2016

a) Nearshore wave conditions

The project used MetOffice and ReMap data sets. Aberdeen is characterised by severe waves conditions (Figure 6) from three primary sectors, 60 degree, 90 degree and 120 degrees. The extreme waves from all three sectors are similar, but the 90 degree sector, followed by 120 degree produce the largest waves.

a) Tidal currents
The tidal currents were generally weak (approximately <1m/s) flowing north south across the bay.

b) Sediments
The seabed consists of fine to coarse sand. The combined waves and currents mean that there is significant potential for sediment transport just outside Nigg Bay with potential for significant sedimentation inside and at the entrance to the proposed harbour.

Table 1 Predicted all direction wave heights at the -19mCD contour for a water level of 5.1mCD at the entrance to the bay

Wave RP (years)	Hs (m)	Tp (s)
50:1	3.1	8.8
10:1	4.2	10.2
1:1	5.3	11.5
1:10	6.2	12.5
1:50	7.3	13.5
1:200	8.2	14.3

Numerical and physical modelling of wave disturbance

ARTEMIS numerical modelling was initially undertaken to define, refine and optimise the harbour layout. Due to the significant wave energy present at Nigg Bay, providing a suitably sheltered environment inside the harbour was challenging and required substantial engineering design to block much of the wave energy, using the north and south breakwaters, before it could access the harbour. In addition, features were incorporated within the proposed harbour to dissipate the residual energy from waves that did enter the harbour. Wave absorbing features were included; revetment under the west quay and along the north quay to reduce the wave energy. Following the numerical modelling, 3D physical modelling was undertaken (see below) to confirm the wave conditions and refine the design. In the physical model, it was clear that the southern cliff area was particularly sensitive regarding wave reflection during numerical modelling and a lot of attention was placed into refinement of this feature in the physical modelling.

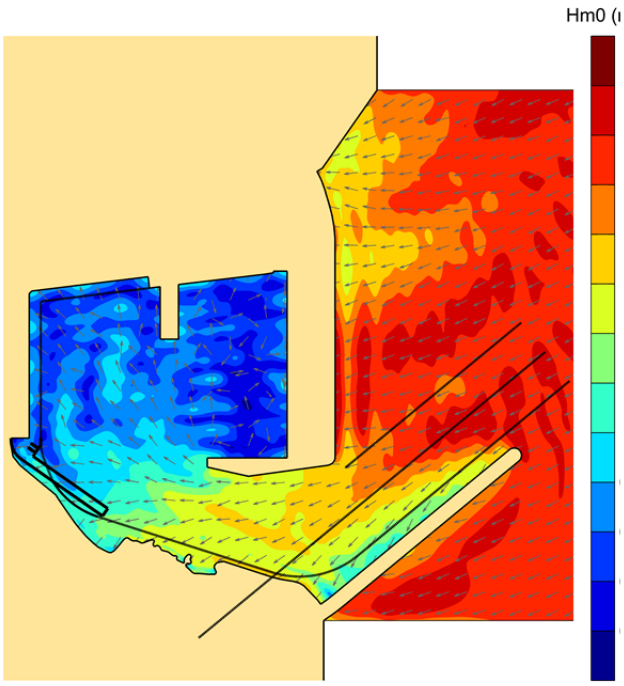

Figure 7: Initial ARTEMIS Wave modelling

Navigation simulation

Real time navigation simulation was undertaken (Figure 8 and 9) to prove the navigability of the proposed layout, refine and optimise the design and examine operational limits. This was particularly important to ensure safe navigation was possible, whilst keeping the entrance width to a minimum due to the severe wave conditions at the site. The navigation simulations showed that the design vessels could safely navigate the entrance, identified the operational limits, the tug requirements and the navigational aids. It also showed that the South East Pier could be extended to provide a longer berth and more sheltered conditions. The simulator was also used later to confirm an anticlockwise rotational change the SE pier could be adopted.

Figure 8: Real time navigation simulation

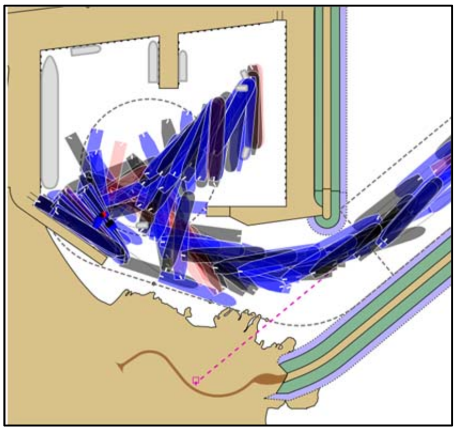

Figure 9: Real time navigation simulation track plots

Design development of the breakwater

The breakwater construction was the single biggest cost element in the project. Various options were considered including rubble mound with crown walls and caissons. The final Reference Design breakwater design solution adopted a lower crested breakwater concept to reduce cost. There was a need to minimise wave overtopping and protect the quays. The adopted design concept allowed significant wave overtopping of the breakwater where the residual overtopping water was collected in a drainage channel at the rear of the breakwater. It also provided the residual benefit of lower visual impact.

Physical modelling

2D Physical modelling of the northern breakwater

Initially 2D Physical modelling of the northern breakwater (Figure 10) was undertaken to prove project concept. The design was refined and the design of the drainage trench improved.

3D physical modelling of breakwater stability, waves and vessel motions

3D physical modelling to test breakwater stability, wave disturbance within the harbour and vessel motions with monitoring of mooring line and fender loads (Figure 11) was then undertaken. The physical modelling compared relatively well to the previous numerical modelling although the physical modelling showed that some improvements were necessary. The 3D physical modelling showed that the harbour, particularly underlining the make-up of the southern cliff shore, was sensitive to wave conditions. As the wave conditions outside the harbour were very severe and there was a need to provide calm conditions at the quay it was necessary to implement as much wave absorption as possible into the layout. Thus the profile in this key area was engineered to provide additional wave absorption by providing shallow slopes and revetments.

During and following the tender period the Contractor (Dragados) elected to undertake additional modelling to optimise and validate the design. In particular the SE pier was rotated anticlockwise to help reduce the wave conditions in the harbour and a crown wall was introduced on the north breakwater (see below) as the contractor considered this change would produce a cost saving, whilst delivering the required performance

Figure 10: 2D Physical modelling of breakwater performance

Figure 11a (top)and b (right): 3D physical modelling of armour stability, waves and ship motion.

Environmental impact

The environmental drivers were considered right through the masterplanning process and these were integral with the decision to develop a new harbour and site selection. The independent Environmental Impact Assessment (EIA) was undertaken, led by Aberdeen Harbour Board, to identify the potential for the development to cause significant effects on a range of physical, biological and human receptors. The results are presented in the Environmental Statement (ES) which accompanies the consent applications. Where the EIA identified significant adverse effects on the environment (e.g. loss of green space (local amenity) and habitat (intertidal and subtidal sands and gravels), mitigation measures have been proposed to reduce the significance of the effects. These mitigation measures, which were brought together in an Outline Environmental Management Plan forming part of the ES, will be developed into a Detailed Environmental Management Plan by the appointed contractor. The key environmental impacts identified in the EIA were underwater and airborne noise during construction, visual impacts, construction traffic, and loss of habitat. The mitigation measures proposed (for example, the use of bubble curtains during blasting to reduce propagation of underwater noise) enabled the regulatory bodies to determine that the environmental impacts were acceptable and to grant consent for the development. Consents have been obtained with respect to the Harbours Act 1964, Town and Country Planning (Scotland) Act 1997 and Marine (Scotland) Act 2010.

Development of the engineering design

HR Wallingford and Arch Henderson were responsible for developing the design of the new harbour, with HR Wallingford taking responsibility for the design of the overall harbour layout and breakwaters and Arch Henderson leading the design of the quays, dredging, reclamation, paving, drainage and other quay ancillaries. Due to the nature of the project a wholly collaborative approach was required with significant overlap in roles.

The breakwater design

Following the physical modelling testing described above, the adopted Reference Design (Figure 5) incorporated the use of $8m^3$, $10m^3$, $12m^3$ and $16m^3$ concrete armour units with crests at +12.6mCD and toes founded at levels reaching -11mCD and founded deeper in places (Figure 12). The Contractor maintained a similar deign for the southern breakwater, but elected to reduce the overall width of the northern breakwater by incorporating a large crown wall (+16mCD) at the crest instead.

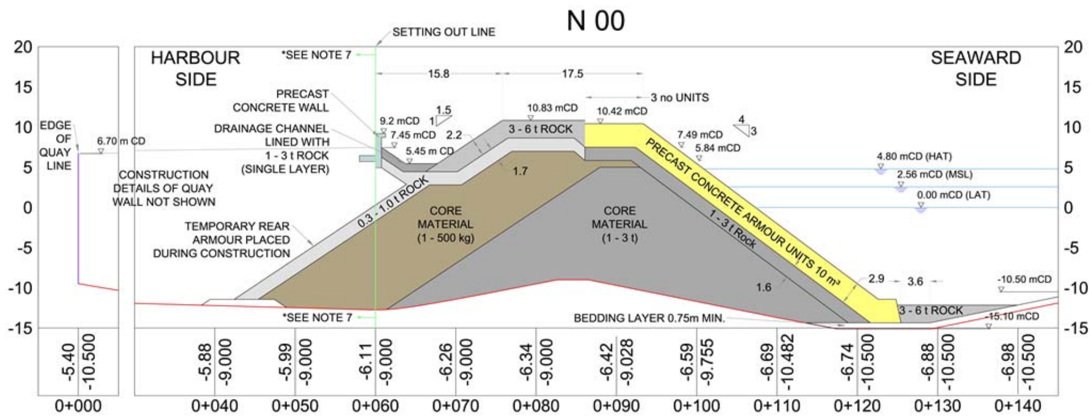

Figure 12 Breakwater (Reference) design

The quay wall design

Various forms of quay construction were developed incorporating the client's operational requirements and preferences whilst taking cognisance of the differing ground conditions and the performance criteria associated with limiting the wave disturbance within the harbour. To allow Aberdeen Harbour to best cater for modern Offshore Supply Vessels (OSV) solid un-fendered quays were adopted where possible. However, due to the requirements to mitigate wave agitation within the harbour, open piled quays with wave absorbing rock armoured revetments below were introduced. Thus solid quays were adopted at the northeast quay, east quay and southeast pier with open piled quay structures being adopted at the west and northwest quays. The channel side of the southeast pier, due to its increased exposure to wave impact, was further developed such that increased durability was achieved at this location. All quays were designed to accommodate a range of design vessels which are included within Table 2.

Table 2 Design vessels used in master planning and quay wall design

Range of Bulk Carriers	
Smallest Vessel	Largest Vessel
Deadweight Tonnage (DWT) 5,000 t	Displacement Laden 48,000 t
Overall Length 95 m	Overall Length 185 m
Range of Cruise Ships	
Smallest Vessel	Largest Vessel (West Quay Only)
Gross Tonnage (GT) 2,100 t	Displacement 54,500 t
Overall Length 70 m	Overall Length 290 m
Range of Offshore Supply / Construction Vessels	
Smallest Vessel	Largest Vessel
Gross Tonnage (GT) 1,500 t	Gross Tonnage (GT) 14,000 t
Overall Length 60 m	Overall Length 150 m

Dredging design

The ground conditions at the site vary considerably. The dredging will involve removing sand and gravels from the surface layers and glacial till at depth accompanied by drilling and blasting of hard rock prior to removal. The works will require, as a minimum, utilisation of both cutter suction dredgers (CSD) and backhoe dredgers (BHD). Dredging will be performed 24 hours a day, 7 days a week. The TSHD will most likely utilise its own hopper for storage and transportation of material, whereas the BHD will place dredged material into self-propelled dump barges. The material will then be transported for offshore disposal where not suitable for re-use within the works. A licence has been obtained from Marine Scotland to dispose of all dredged material at an existing sea disposal site; however, both from a commercial and environmental respect, an emphasis has been placed on the beneficial re-use of suitable material within the site. An extensive sediment sampling campaign has determined that the material is chemically suitable for disposal at sea or to be used in the reclamation. Where possible, physically suitable material (i.e. gravels and sands) will be used in the reclamation or inside the caissons. All dredged rock will be reused (and cannot be disposed offshore).

3D Visualisation

Several fly through 3D visualisations of the proposed works have been produced to enable the client and stakeholders to understand the nature and scope of the works being proposed (Figure 13).

Procurement strategy

Key to achieving best value in procuring the marine construction was configuring the design to suit the operational limitations of a tendering contractors' plant and equipment, the construction method, the environmental constraints and possible sources of available material. It was seen that significant optimisation could be achieved if the tendering contractors were empowered to refine the design to suit their preferred method of construction. Hence, the procurement strategy was configured to enable this goal and a Design & Build form of contract was adopted using the NEC3 Engineering and Construction Contract with a Reference Design forming the basis of the tender. Key parts of the tender package were:

- Definitive drawings setting out the fundamental project requirements
- Reference drawings setting out design development of the scheme
- Illustrative drawings setting out how the clients' requirements may be achieved
- Detailed reference design reports
- Design and performance requirements
- Construction and material requirements
- Environmental Impact Assessment
- Site information and ground investigation.

Figure 14: Visualisation of the project

Construction update

The works are well underway with the north breakwater expected to be complete in 2018 and the rest of the project in 2020.

Figure 14: North breakwater under construction

Conclusions and lessons learnt

The Aberdeen Harbour Expansion Project is to be one of Europe’s largest greenfield port capital investments projects over the next few decades and has developed from realisation of a need for growth through to conception and start of construction in just over only 6 years. The masterplanning process helped seed, formulate and develop many of the masterplanning principles now being set out into the PIANC Working Group 185 Ports on greenfield sites – guidelines for site selection and masterplanning. This project, like all port projects, benefitted from early engagement with the consultees and the planning framework and careful technical, and iterative, evaluation of the technical issues. These principles have been integrated into the PIANC guide.

It is still too early a stage to set out lessons learnt with the benefit of hindsight, but it is clear that a combination of detailed technical assessments and early and clear communication to stakeholders of the vision was essential to enable development of the project and progress it through the planning process. In terms of technical aspects, whilst it was always known that the severe wave climate would dominate the design, ensuring the target wave conditions were met through the design process of computation then physical modelling whilst at the same time optimising the design has been challenging.

Acknowledgements

The authors would like to thank wider project team for providing information in this paper including those at Aberdeen Harbour Board, HR Wallingford, Arch Henderson, Doig & Smith, Barton Wilmore, Fisher Associates, Harris Holden Ltd, Arup and Dragados and in particular, , Colin Parker, Ken Reilly, Katherine Harris, Ian Taylor, Stephen Cork, Jamie Holmes, Keith Powell, Mark McBride, Jonathan Woodhams, Nigel Bunn and Stephen Grey, Jim Clarke, Vince Crockett, Tim Pullen, Martina Melas, Ian Chandler, Ross Matthews, Tom Matthews, Richard Rankine and Grant Alexander.

References

PIANC 158 Masterplans for the development of existing ports, Report of MarCom Working Group 158.

PIANC 185 (Planed to be published 2018), Ports on greenfield sites – guidelines for site selection and masterplanning, Report of MarCom Working Group 185.

AHB (2012) Case for Growth, Aberdeen Harbour Board, Barton Wilmore, September 2012

AHB (2013) Directions for growth, Aberdeen Harbour Board, Barton Wilmore,

HR Wallingford (2012) Aberdeen harbour expansion, Technical feasibility report, DKR4708-RT001-R03-00.