# BERESFORD FORESHORE COASTAL PROTECTION PROJECT – GETTING DIRTY IN THE WEST

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Beresford is located in Geraldton, approximately 400 km north of Perth, Western Australia. In recent years, the foreshore has eroded. The City of Greater Geraldton is responsible for managing the foreshore and nearby assets including road and stormwater. The objectives of the foreshore coastal protection project were to:

1. protect community infrastructure and community assets;
2. minimise the long term annual requirement for sand bypassing; and,
3. enhance the foreshore environment including Midalia Beach swimming area.

The assessment of options, site investigations and design were completed by Royal HaskoningDHV (RHDHV) in 2014 and 2015. Construction of the project was undertaken by a local Contractor and commenced in January 2017 with the Date of Practical Completion set at 31st July 2017. The design included:

- 100 m long extension of an existing detached breakwater and 45 m long extension of an existing groyne to create an enclosed embayment;
- beach nourishment with approximately 60,000 $m^3$ of sand; and,
- three separate back beach revetments, each approximately 300 m in length.

This paper discusses design and construction related issues encountered throughout the project, and suggests mitigation measures to prevent similar issues occurring in the future.

## Rock

Sourcing suitable rock in WA is problematic as the geology is some of the oldest recorded on earth. This results in geological units that are extremely weathered and/or fractured. Two available quarries with suitable sources of rock were identified by RHDHV during the design investigation phase of the project within an economically viable distance of Beresford Foreshore. These were:

i. a granite quarry operated by Holcim, primarily operated for manufacturing crushed rock aggregate; and,
ii. an inactive limestone quarry, which could be reopened to supply an economically viable quantity of limestone. The required rock size and quantity was considered to be economically viable by the quarry owner.

Material certificates were obtained from the quarry owners and both quarries were inspected by RHDHV for suitability during the design investigation phase of the project.

However, no formal geotechnical investigation was conducted by RHDHV or the City of Greater Geraldton.

A proliferation of foreshore rock structures in Geraldton over the last century caused community concern and local campaigns and petitions for 'no more rock structures' had been lobbied in the past. As a result, the City's preference was to ensure all future rock structures were constructed of limestone to ensure the form is consistent with existing structures and the colour blends in with the surrounding sandy environment.

The limestone quarry is underlain by Tamala Limestone, a widely occurring eolianite limestone deposit with a yellow to cream appearance. Tamala limestone had been used for a number of coastal protection projects between Perth and Geraldton and this particular limestone quarry had supplied rock for the Department of Transport Marina located in Geraldton, immediately south of the Beresford Foreshore. With the exception of the Los Angeles Abrasion test, the limestone satisfied the *Australian Standard - Aggregates and rock for engineering purposes – Part 6: Guidelines for the specification of armourstone (AS 2758.6-2008)*. The material properties and previous use of the rock was sufficient to satisfy RHDHV that the rock source was suitable for coastal maritime works.

The community perception, City requirements, and findings from the design investigation resulted in limestone selected as the preferred rock type for the rock structures. The structures were designed accordingly and limestone was specified for use in the Technical Specification produced by RHDHV. The estimated quantity of rock for each structure is outlined in **Table 1**.

**Table 1: Estimated quantity of rock in tonnes.**

| | **Armour** | **Underlayer/Core** |
|---|---|---|
| **Groyne** | 12,000 | 3,000 |
| **Breakwater** | 3,400 | 2,100 |
| **South Revetment** | 13,500 | 2,300 |
| **Middle Revetment** | 12,300 | 1,500 |
| **North Revetment** | 6,600 | 500 |

Some 18 months later, at the time that the project was out to tender for the construction works, the limestone quarry had changed ownership and was now in the hands of a local Contractor. Whilst other sources of limestone had been identified, the rock quality, distance from Geraldton, lack of land clearing and/or quarry permits made these alternate sources unfeasible for immediate quarrying.

The local Contractor that purchased the quarry was awarded the project through a competitive tender process. Their proposal was based on sourcing the required limestone from this newly acquired quarry. However, the quarry purchased by the local Contractor and specified for use in their Tender submission was ultimately not suitable due to the low yield that was achieved. This identified that there had not been sufficient investigation during design and tender stage to confirm the quantity or quality of rock available from this quarry.

After the low yield problem had been identified, the Contractor investigated nearby sources to expand the quarry and began quarry operations at these locations. The geotechnical investigation undertaken by the Contractor consisted of rotary-percussive drilling and downhole seismic investigations. RHDHV advised the Contractor of the risks involved with the proposed approach as it is not possible to determine layering or fracturing of the rock mass by rotary-percussive drilling as this only produces rock chips at the surface. Subsequently, the rock was found to be layered and not suitable for supplying the required rock mass and dimensions. Obtaining drill cores would have provided confirmation of the rock fabric prior to commencing quarrying.

While the geotechnical investigation was underway, the Contractor applied for an extension to the quarry license and commenced preparatory work for quarrying and carting rock from the site including construction of haul roads and the like. Obtaining the license and preparatory work commenced in February and took approximately five weeks to complete. During this time minimal work was completed at the Foreshore and minimal rock was yielded from the previous quarry site. The Contractor was relying on rock from this new source to supply the remainder of the project. Various quarrying methods were adopted including drill and blast operations and ripping using a dozer. Neither procedure produced any suitable rock for the Foreshore coastal protection project. The project experienced further delays and lessons were learnt by the Contractor and all involved that highlighted the need for suitable and appropriate geotechnical investigations prior to quarrying.

In April 2017, four months after formal project commencement and five months after the Contractor commenced quarry operations, the Contractor requested permission to alter the rock type to granite. Granite was readily available from Holcim, which was identified during the design investigation phase. At this point in time, the groyne was complete and the Contractor had a sufficient quantity of limestone for:

- breakwater core;
- revetment underlayer; and,
- approximately 3,500 t (out of 12,000 t) of armour for the breakwater.

However, the change to granite presented a number of new challenges. For example, the granite is considerably denser than the limestone at 2.7 t/m$^3$ compared to ~2.3 t/m$^3$. This meant that the rock size could in theory be reduced as the design mass would be retained. However, as the breakwater was now to be constructed from a combination of limestone and granite armour, the proposal was accepted on the basis that the design dimension of the limestone armour units also be adopted for the granite armour units to ensure acceptable interlocking of the armour units. This resulted in a 20% increase in the armour mass for the granite units and a structure that was over engineered. The granite was placed below the water level, in the lower layer of armour and in the toe scour protection whilst the limestone was used to ‘cap’ the structure above the water level.

While the granite satisfied requirements of AS 2758.6, the rock mass was heavily fractured. The fracture spacing was approximately 400 mm and the orientation was in an east-west direction. The required armour diameter for the revetment was approximately 800 to 1000 mm, which is more than the fracture spacing resulting in the suitability of the rock source being questioned. Most of the rock test procedures in AS 2758.6 including density, water absorption, Los Angeles abrasion, sodium sulfate soundness and wet/dry strength ratio, are conducted on crushed rock samples. The crushed rock samples are not always representative of armour rock as the testing does not consider fracturing in the armour units. Whilst the point load strength index can be conducted on fractures in a drill core, it is not common practice when determining armour rock properties as armour units that contain evident fractures are generally not considered suitable for use in coastal works.

The drop test briefly discussed in AS 2758.6 and The Rock Manual (CIRIA, 2007) is perhaps the most conclusive test for determining rock suitability and is recommended for use in future projects as it is indicative of the strength of a particular size armour unit rather than the strength of a rock fragment or crushed rock. A drop test was conducted on five armour units for the breakwater and indicated a breakage rate of 60%. The breakage rate is the ratio of the number of rocks with more than 10% loss of mass to the total number of rocks in the test sample. A breakage rate higher than 35% indicates poor quality rock (CIRIA, 2007). However, it is noted that the drop height of 3 m in The Rock Manual (CIRIA, 2007) is stringent and this force is not likely to be exerted on armour units during placement or operation.

Mid-West Port Authority (MWPA) had previously used the granite in rock structures around Geraldton Port. The Port Authority advised that while the rock fracturing is an issue that requires additional care during handling and placement, there has been no observed breakdown of rock after placement as a result of the fracturing. Fractured rock such as this particular granite source may not be suitable in areas prone to freeze-thaw cycles, which is not applicable to Geraldton. On this basis, the granite was accepted for use. However, it required considerable sorting and 'heavy handling' at the quarry to identify unsuitable armour units that would be otherwise prone to breakdown during placement. Following sorting and during transport of the armour units, breakdown was reported to be 10%, which highlighted the need for careful sorting.

The Contractor planned for an expected high yield of rock from the quarry. However, due to the weathered and fractured nature of the material in Western Australia, achieving the typical quarry yield of 10% was difficult. Furthermore, drill and blast quarry operations in Western Australia primarily target the yield of crushed rock aggregate or crushed iron ore using high velocity explosives and a relatively closely spaced drill pattern. These drill and blast practises are not suitable for yielding armour rock. Multiple drill and blast operators were engaged at the limestone quarry to increase yield to no avail. Planning and trial blasting was required at the granite quarry to achieve the required rock mass and dimensions. On multiple occasions, work at the Beresford Foreshore ceased for up to two weeks at a time to allow the quarry additional time to sort and stockpile the required rock prior to transporting to site. At one point, five pieces of machinery were located at the granite quarry specifically to sort, stockpile and load revetment armour rock. These costs and delays would not have been expected by the Contractor at tender stage. The City, RHDHV and the Contractor worked closely to overcome these issues.

## Toe scour protection

The bedrock along the Beresford foreshore is relatively shallow and up to 2.5 m below the surface level of the beach. The revetments were designed to be founded on bedrock with toe scour protection to prevent sliding of the rock armour. Trenching of the lower units into the bedrock was an option, which would have significantly reduced the required quantity of rock armour. However, the limestone deposits in the region typically comprise a relatively thin, strong calcrete caprock. Trenching into the thin layer of caprock was not desirable but trenching should be considered for similar projects elsewhere.

## Construction tolerances and survey methods

The Rock Manual (CIRIA, 2007) presents a discussion on both construction tolerance and survey methods. In regards to construction tolerances, The Rock Manual poses four questions:

1. What is possible?
2. What is required?
3. What is necessary?
4. What is affordable?

The Rock Manual provides guidance on practical, achievable vertical placing tolerances with land based equipment. The guidance recommends a construction tolerance of $\pm 0.3D_{n50}$ for individually placed armour units above the water level and $\pm 0.5D_{n50}$ for armour units up to 5 m below the water level where $D_{n50}$ is defined at the nominal armour diameter. This guidance is recommended for future projects.

The Rock Manual provides a discussion on three different survey methods, which are:

1. highest point;
2. spherical foot staff; and,
3. conventional staff.

It is critical that the designer specifies the intended survey method in the technical specification and designs accordingly. The survey method influences the armour layer thickness. Highest point survey is thought to be the simplest survey method to implement as it does not require any specialist equipment and is quick and simple to implement. However, this survey method results in an over estimation of the armour layer thickness, and this should be considered in the design of rock structures.

The identification of the construction tolerance and survey method in the technical specification could have been improved to be more specific and detailed. However, uncertainties regarding these issues were identified early in the construction process and resolved by RHDHV, the Contractor and the City.

## Sand

The sand placement was designed to form a stable beach between the breakwater and groyne. The breakwater and groyne were intended to form an enclosed embayment meaning that there is minimal exchange of sediment in or out of the embayment. However, to achieve this, the sand grade must be selected to ensure dynamic stability.

The longshore design planform of the sand placement was developed on the assumption that a crenulate shaped static equilibrium bay profile would form in the lee of the rock structures, which are hard control points. This occurs as a result of the rock structure extensions altering the diffraction point of waves entering the embayment. The equilibrium crenulate bay shape was based on the work of Hsu et al (1989) who defined an empirical approach to predict the stable crenulate bay shape based on the existing environment.

The selected sand size is based on the need for a grading that is suitably coarse so that the beach profile is dynamically stable, but also fine enough to achieve a flat beach profile suitable for public amenity. Ultimately, there was a trade-off between the two requirements. The numerical modelling indicated that the existing sand at the beach was too fine and coarsening of the beach material was required. The design median sand grain diameter (D50) was 0.35 to 0.4 mm and the existing median grain size was approximately 0.2 mm. Dean's equilibrium profile was adopted to determine the equilibrium beach profile in a cross shore direction.

It should be noted that the existing foreshore is partially reclaimed land. The existing beach is also nourished biannually through the MWPA sand bypassing scheme. The existing beach material is therefore not considered to be 'native' material. What is known however is that the MWPA sand placement was not stable and was transported longshore by coastal processes within a couple of weeks, which supported the finding of the numerical modelling that coarsening of the beach material was required.

Typically, sand placement (beach nourishment) is intended to replicate the existing median sand size and grading. Where the grading of the imported and native sand source is different, an overfill factor can be applied to determine the volume of imported material required to achieve the desired volume of placed material. These calculations allow for washing of the material, sorting of sand grains, and loss of fines. However, as noted above, coarsening of the beach material was desired. Determining a suitable grading proved to be difficult. The design specified less than 5% fines (0.075 mm) and less than 2% exceeding 2 mm. The former requirement was developed for practicality of sourcing material from a land based source and the latter requirement was developed to ensure suitable public amenity. The limit on percentage fines content also reduces the risk of losses after sand placement. An overfill factor was not included in the design volumes.

In addition to the sand grading requirements, community expectations dictated that the sand should be a cream colour to match the existing beaches in the Geraldton region.

The design investigation stage considered eight potential sand sources identified below:

1. Pages Beach;
2. Point Moore;
3. Southgates Dune;
4. Greenough River;
5. Geraldton Port Shipping Channel;
6. Oscar Delta Sand Supplies;
7. Patience Bulk Haulage; and,

8. Holcim Commercial Quarry Products

Oscar Delta sand supplies was identified during the investigation stage as the designers preferred source. However, the quarry was approximately 50 km from Geraldton.

The tender was for supply and placement of sand, which allowed Contractors to source and supply sand from an economically viable source. The selected Contractor tendered an alternate sand source, located at Kojarena, which was accepted by the City. The sand source was identified as containing 7% fines. The increase in fines from 5% to 7% represents an increase of 40% above the maximum allowable fines content. The proposed sand source was a greenfield site and the grading included in the tender was based on one surface sample. Following award of the tender, additional sand grading was undertaken and it was found that the surface material was coarser than the material at depth. As a result, the sand source contained up to 10% fines and the median was approximately 0.32 mm.

After extensive investigations into nearby alternate sand sources, the Contractor proposed to mix the tendered sand source with material from Narra Tarra to achieve the required grading. The mix ratio was 75% from Kojarena and 25% from Narra Tarra. The resulting product contained less than 2% exceeding 2 mm and the median grain size was 0.35 to 0.4 mm in accordance with the Specification. The fines content was 7 to 8%, which was previously accepted by the City. While the specified grading was achieved, the resultant product was widely graded, which is not desirable for beach nourishment applications. In hindsight, the technical specification developed for this project should have included a standard deviation in addition to the upper limit for fines and coarse fraction to ensure the sand source was relatively uniform.

The accepted sand was darker then specified. However, the dark colour was a result of fines in the sand. Following removal of fines and bleaching by ultraviolet (UV) light from the sun, the sand colour matched the existing material and was visually acceptable.

The sand placement caused a number of issues, which are identified below.

- Washing of the imported material led to a loss of fines and turbid plumes. The turbidity was exacerbated by the high fines content. The Environmental Protection Agency of Western Australia determined that an Environmental Impact Assessment was not required for this project. As such, there was little guidance on acceptable turbidity for the Contractor or the City. The technical specification did include requirements for monitoring of the turbidity. However, the acceptable limit for turbidity was dictated by the Contractor in the Construction Environmental Management Plan. In general, the turbid plumes remained within the confines of the rock structures and were only transported offshore through wind shear. Reducing the fines content would have reduced the extent of turbidity.

- The high fines content resulted in a material that was relatively cohesive. Fine material (less than 0.075 mm), including silts and clays, are considered cohesive, while sands and gravels are cohesionless. The natural angle of repose of dry loose sand is approximately 30 to 35$^{o}$. This angle of repose leads to slumping of a beach face following erosion as the sand dries. However, the imported material at Beresford would form near vertical scarps due to the cohesive nature of the material. The scarps appeared to be partially cemented and they did not readily breakdown, even when dry. The observed partial cementing may have been due to the high calcium carbonate content, which is common in the lime sands around Western Australia. There is little guidance available on the suitable chemical compositions of sand for beach fill applications and this is a potential area for future research and inclusion in future specifications.

- Liquefaction of the sand was observed following placement. Liquefaction is a process whereby saturated soils lose strength and stiffness in response to an applied stress causing it to behave like a liquid. It occurs in soils where the pore water pressure cannot rapidly dissipate and is common in fine sands. When walking on the saturated material near the waterline, the material that appeared to be firm would suddenly slump. This phenomenon occurs naturally on a number of beaches. The liquefaction in the sand placement settled down over time due to loss of fines through washing, which allowed for rapid dissipation of pore water pressure. Furthermore, the sand placement would have been compacted by surf beat. After approximately four weeks, liquefaction was no longer observed. As the site was fully fenced during construction, the liquefaction did not present a risk to the public.

- The high fines content and wide grading resulted in a relatively impermeable sand. This is documented in The Beach Manual (CIRIA, 2010) to result in increased wave run-up as the beach face does not dissipate the wave energy as effectively as permeable sand. It is unclear what impact this had on the sand placement in regards to erosion.

One positive of the high fines content was that the dune vegetation at the rear of the beach established and flourished rapidly. It is hypothesized that the fines in the soil contain nutrients and retain soil moisture, both of which are essential for plant growth. In addition, land based sand sources generally contain significantly less salt compared to marine sand, which supports vegetation growth.

The design arrived at an equilibrium beach profile in the longshore and cross shore direction. However, the coastal processes that establish an equilibrium beach profile are extremely complex and it was expected that the natural equilibrium beach profile would vary from the design. Reshaping of the beach would not have been an issue except that dune vegetation planting was required at the rear of the beach fill placement to assist with stabilisation and minimise wind-blown sand. The vegetation was setback 7 m from the crest of the sand placement to allow for reshaping of the beach during storm events.

However, the initial recession due to reshaping of the beach exceeded 7 m in some sections. The technical specification stated that '*planting of dune vegetation shall be carried out following the initial response of the Beach Post-Fill profile to coastal processes. This timing shall be determined by the Principals Representative'*. As the contractor was behind schedule, and the vegetation ideally needed to be planted during the wet season (April-August), dune planting was undertaken before reshaping of the beach was completed. As such, the setback of the dune vegetation varies along the beach.

From the plan form that was placed, both ends of the beach placement were observed to recede whilst the central section of the beach accreted. The median grain size of the sand that was accreting at the central section was found to be significantly coarser than the placed material and the grading was more uniform. This is due to washing of the sand and removal of the fines. The erosion scarps did not naturally breakdown and mechanical reshaping of the beach profile was required to breakdown the erosion scarps in the placed material.

Placement of sand near the rock structures also caused issues during construction. The original design required sand to be placed level with the crest of the groyne and ~300 mm below the crest of the breakwater. The core of the rock structures was designed to be impermeable to prevent settlement of the core material into the underlying sand. The armour on the other hand is not impermeable as there are large voids present between the armour units. To prevent the loss of beach fill through the armour a geotextile curtain was placed vertically through the armour material. However, it proved difficult to ensure sufficient lap between sections of the geotextile material, particularly as the voids between the armour units were relatively large. It was also difficult to secure the geotextile material between armour units as there is minimal lateral force exerted between adjacent units. Ultimately the geotextile material solution proved to be ineffective. The design was changed so that the sand battered landward from the crest of the groyne and breakwater core (0.9 m AHD and 1.4 m AHD respectively) to the design level of the sand placement (2.5 m AHD) at a slope of 1V:10H. Three months after placement of the sand, the refined profile was stable.

## Survey monitoring

Given the issues experienced during construction of the rock structures and placement of the sand, survey monitoring has been recommended by RHDHV. The City understands the need for the survey monitoring, which will be undertaken throughout the defects liability period. The monitoring is proposed along the seaward crest of the breakwater and groyne at 10 m intervals and at predefined locations along the sand placement to ensure stability of both structures.

## Selecting a Contractor

The Tender documents for a project typically include information on the selection criteria for prospective tenderers. The selection criteria for the Beresford Foreshore Construction Project adopted a best value for money approach that considered:

1. price; and,
2. qualitative criteria.

Review of the pricing included a preference for regional pricing that benefitted the local economy. The weighting of the qualitative criteria and items for consideration in the qualitative criteria was as follows:

- Tenderer's Experience – 15%
- Key Resources – 30%
- Proposed Methodology – 30%
- OHSE Management – 10%
- Sustainability – 15%

Pricing was a major consideration for the City in achieving 'value for money'. It is difficult for larger contractors with experience in coastal works to be cost competitive in a regional location when there is a regional preference. In addition, the contractors experience and past performance only accounted for 15% of the qualitative criteria. Whilst this is suitable for smaller project to remove barriers to entry, large projects such as the Beresford Foreshore Protection project should place a higher emphasis on experience and past performance.

The Contractor's turnover of staff was an issue throughout the project. This included the Contractor's Representative changing five times and the sites Occupational, Health, Safety and Environment (OHSE) manager changing four times during the course of the project. Each time the change in management was due to personnel leaving the company. The turnover of staff was extremely high over the nine month construction period and resulted in significant challenges to maintain continuity throughout the project. Although there is no way to guarantee that personnel will stay on for the full duration of a project, information regarding the amount of time an employee has been with the company and what resources are available as contingency replacements should be collected and assessed during Tender stage.

The selection of the preferred local Contractor has resulted in the need for a review of the City's tendering and tender legislation procedures, in particular the criteria adopted for reviewing tenders. Coastal protection projects are unique and complex and require a certain level of understanding and experience. Treating these projects in the same way as projects that are delivered on a day-to-day basis will not result in the desired outcome.

The City called on RHDHV, as the designer, to provide input during the tender review process. Having the designer provide input during tender review stage allows for concerns that the designer may have that the Client had not identified to be raised and is recommended on all coastal engineering projects.

The City's staff and key resources were well organised and this no doubt contributed to the successful outcome of the project. The staff fulfilling the role of Superintendent and Superintendent Representative did not change during the course of the works. It is also worth noting that the Superintendent's Representative was seconded from RHDHV, which enabled input and clarification on any items in the design where there was some uncertainty or ambiguity, and allowed for early input into design amendments requested by the Contractor. Having a member of the designers team involved during construction stage had clear benefits for the Client and also meant that there was minimal delay in dealing with Contractor queries.

## Conclusion

Overall, despite the challenges, a positive project outcome was achieved. However, through collaboration and patience, the City received coastal protection structures that achieve the projects aims and satisfy the design intent.

## References


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