Design and construction of an export harbour in Persian Gulf

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Abstract: The Pars Sulphur Export Harbour, designed for berthing 15000DWT general cargo vessels is located near the city of Bushehr in southern Iran on the Persian Gulf within an area known as the Pars Special Energy Zone. The steep drop of the ground near the shore was ideal for ship-berthing facilities; however, the construction of the associated breakwater in very deep waters required a significant amount of land reclamation. This paper describes the design process for this filling of the proposed reclamation area in order to make it economical, as well as the construction management and control issues which allowed for the successful completion of the project within budget.

General

Pars Sulphur Export Facilities are located in the south of Iran (refer to Fig 1) about 250 km east of Bushehr, the nearest major city, along the Persian Gulf shoreline in an area called the Pars Special Energy Zone (PSEZ). South Pars field is the greatest gas resource in the world, for which National Iranian Oil Company (NIOC) plans to construct 4 major petrochemical plants and import-export facilities under the name of South Pars Project. Phases 1 to 8 of the South Pars gas field development are presently in varying stages of design, procurement and construction.

Introduction

National Iranian Oil Company has devised the South Pars Harbour in order to export Sulphur as a by-product of gas plants and for logistic purposes. This harbour is located in an area with approximate coordinates of 27°, 32', 15" N and 52°, 33', 30"E.

The berthing facilities have been design to serve a sulphur carrier with a full load draft of 9.3m, supply boats, tug boats and barges. The diameter of the turning basin is 310m which will be dredged to –10.5m /CD (all elevations are measured relative to local Chart Datum which is the lowest astronomical tide). The proposed berthing structures consist of reinforced concrete caissons with a total length of 758m and with a maximum height of 14m. Onshore facilities include about 6,800 m^2 of buildings and warehouses and about 23,200 m^2 of open storage areas. These facilities have been constructed over 102,000 m^2 of reclaimed land. Fig. 2 to Fig. 4 shows a layout of the proposed harbour and typical sections along the berthing structures and breakwaters.

Table 1 summarizes the geometry and estimated volumes of the main and lee breakwater and reclaimed area.

Table 1: Summary of Geometry and Volumes of Breakwater and Reclaimed Area

Location	Maximum Water Depth (m)	Dimensions (m)	Volumes (m^3)
Main Breakwater	14	Length: 1180 m Crest Width: 12m	Core: 550,000 Filter Rocks and Armors: 204,000 Concrete Tetrapods: 110,000
Lee Breakwater	12	Length: 650 Crest width: 12	Core: 161,000 Filter Rocks and Armors: 62,000 Concrete Tetrapods: 5,400
Reclaimed Area	6	Width: 250 Length: 400	550,000

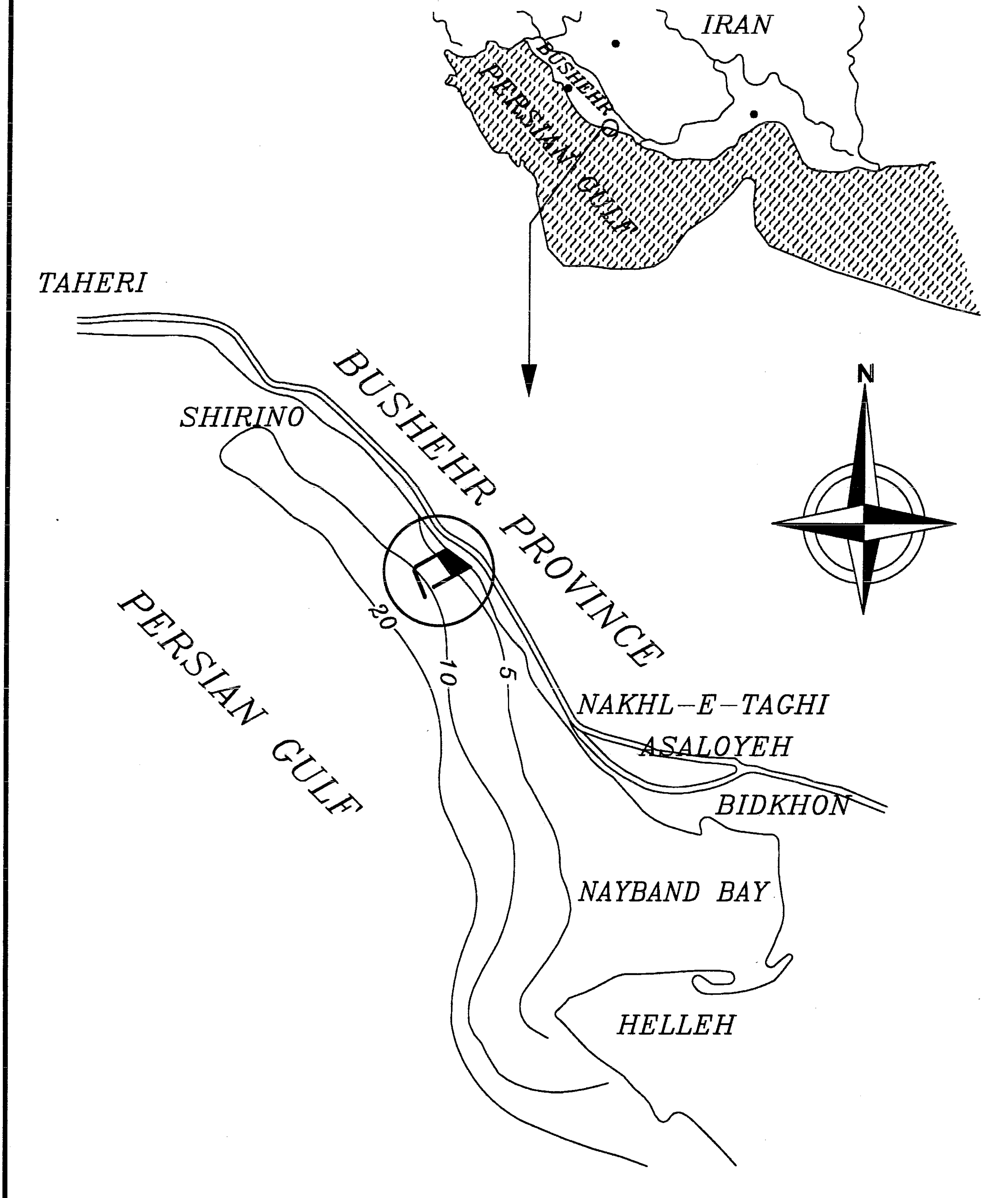


Figure 1: Site Location

Design Background

Basic design for the harbour was completed by John Brown Consultants (United Kingdom) and Sakoo Consulting Engineers (Iran) in 1997 and tender documents were prepared by those companies for detail design and construction of the harbour. NIOC awarded the contract as an EPC package to an Iranian Joint venture comprised of two local companies called Tehran-Berkeley-Perlite. The detail design (which significantly changed the original design) and construction started in 1998. Design changes were made to the layout as well as dimensions of the breakwaters and design of armours (based on the results of detailed wave analysis and physical modeling test).

Construction Schedule

Construction of the harbour commenced in 1998 and the reported progress is about 60 percent. At time of preparation of this paper, main and lee breakwaters were almost complete, the area behind the concrete caissons has been reclaimed, and the buildings were completed. Placement of fill material at the reclaimed area had been completed within about three months. Based on the contractor's report, rate of placement of the material in the reclaimed area varied between 3,500 m^3/day and 11,500 m^3/day with an average of 9,200 m^3/day.

Site Geology and Geotechnical Studies

The site is located on the downslope and south side of a mountain range running east west along the shoreline. The site geology is mostly comprised of Asmari Formation such as light brown limestone and shale. Due to the relatively steep slope towards the shoreline and a relatively short distance between the toe of the mountains and the shoreline, the shoreline is mostly covered with alluvial deposits transported from the numerous creeks and rivers running towards the south during flood events. These deposits are up to 120m deep and mostly comprise of sand, gravel and boulders that may be partially cemented at depth with calcareous materials (such as shells and corals).

Geotechnical studies at the site comprised of wash boring and continuous coring auger-holes with adjacent Dynamic Cone Penetration Tests. Five auger holes were drilled using a barge-mounted auger to a depth of about 40m below seabed. Two simplified geotechnical profiles are presented on Fig. 5. In general, the soil encountered at the site was comprised of a partially conglomerated sand and gravel with occasional cobbles and boulders (up to several meters in diameter). The in-situ material, up to about 40m below the seabed, was generally transported from the north side of the site and deposited to a distance of about one kilometer from the shoreline.
Table 2 summarizes the geotechnical properties of two identified layers on the site.

Table 2: Summary of Geotechnical Properties of Soil Layers

Geotechnical Property	Layer 1	Layer 2
Description	Sand/ Silty Sand with apparent cohesion and with corals at depth.	Sandy Gravel with occasional boulders and partially conglomerated at depth.
Buoyant Density (kN/m^3)	9.5	12
Average SPT	23	50
Angle of Internal Friction	27	33
Long-Term Cohesion (kN/m^3)	0	0
Modulus of Elasticity (MPa)	240	530
Poisson's Ratio	0.35	0.3
Modulus of subgrade Reaction – based on the plate load test on land (kN/m^2)	Not measured.	250

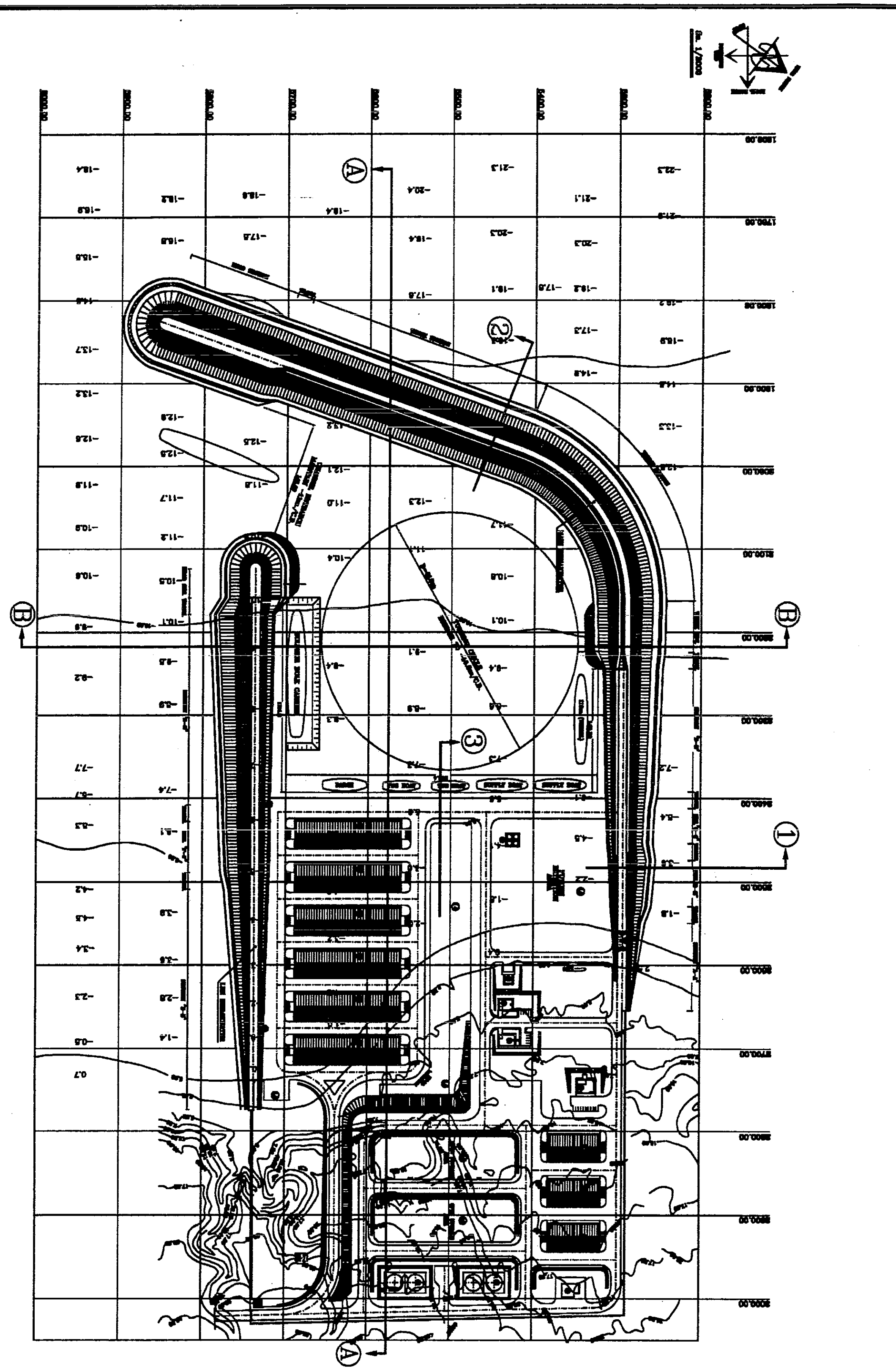
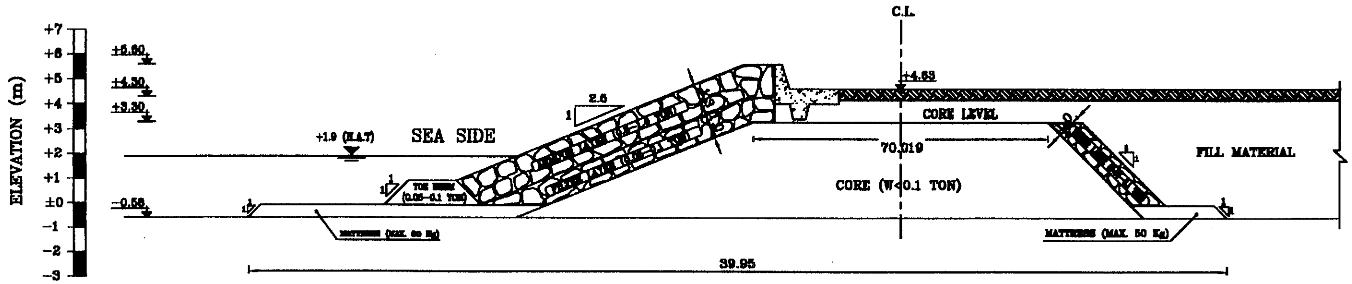
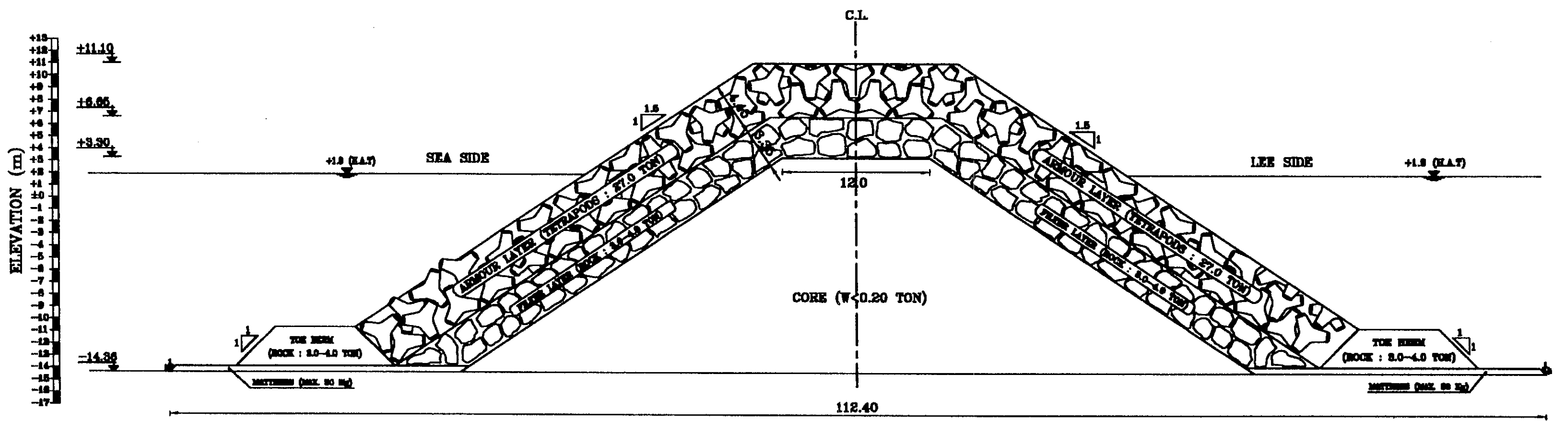


Figure 2: South Pars Export Harbour Plan



① SECTION

Km 0+105.00 (MAIN BREAKWATER)



② SECTION

Km 0+180.40 (MAIN BREAKWATER)

Figure 3: Breakwaters Typical Section

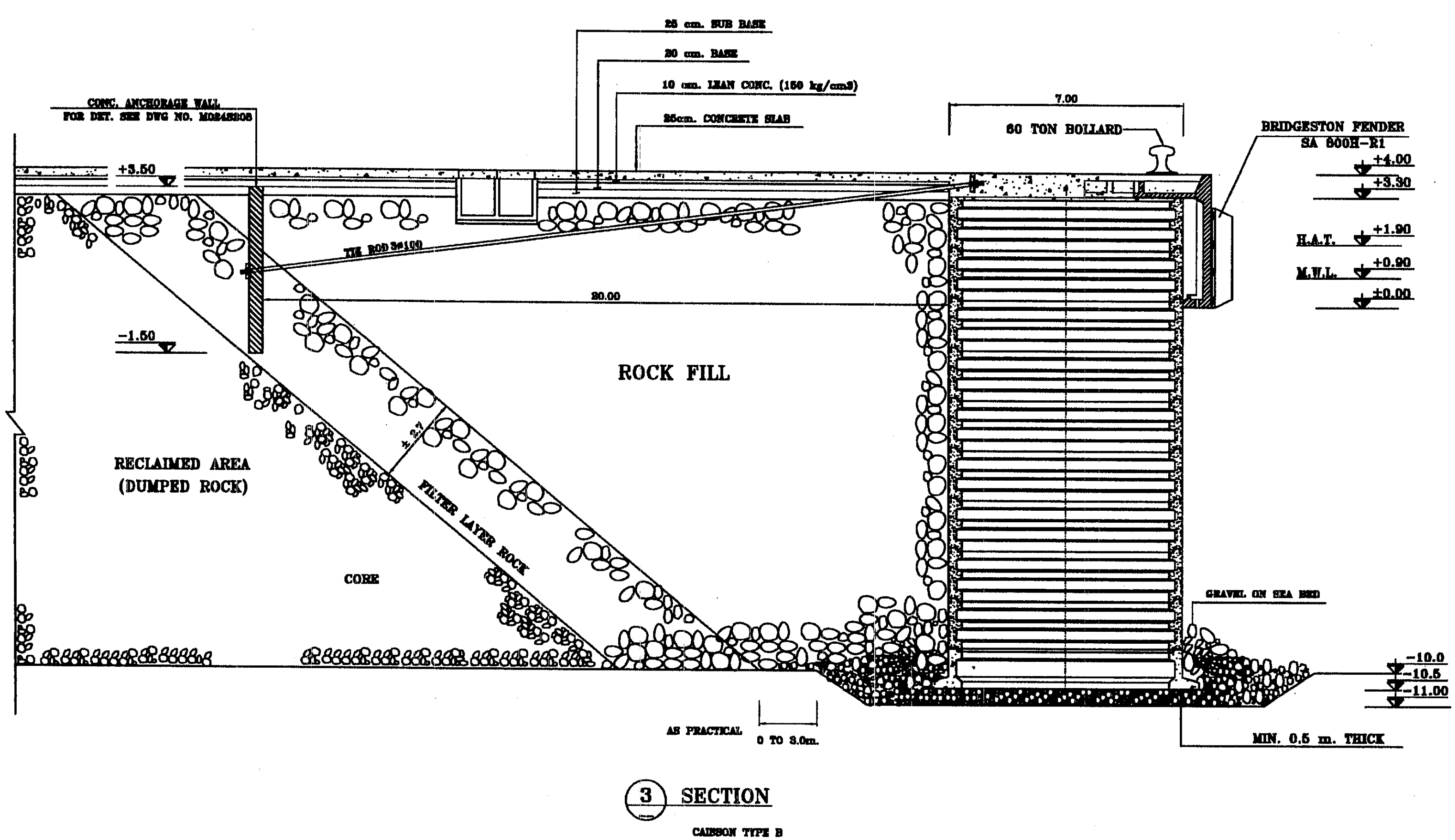


Figure 4: Berthing Structure Typical Section

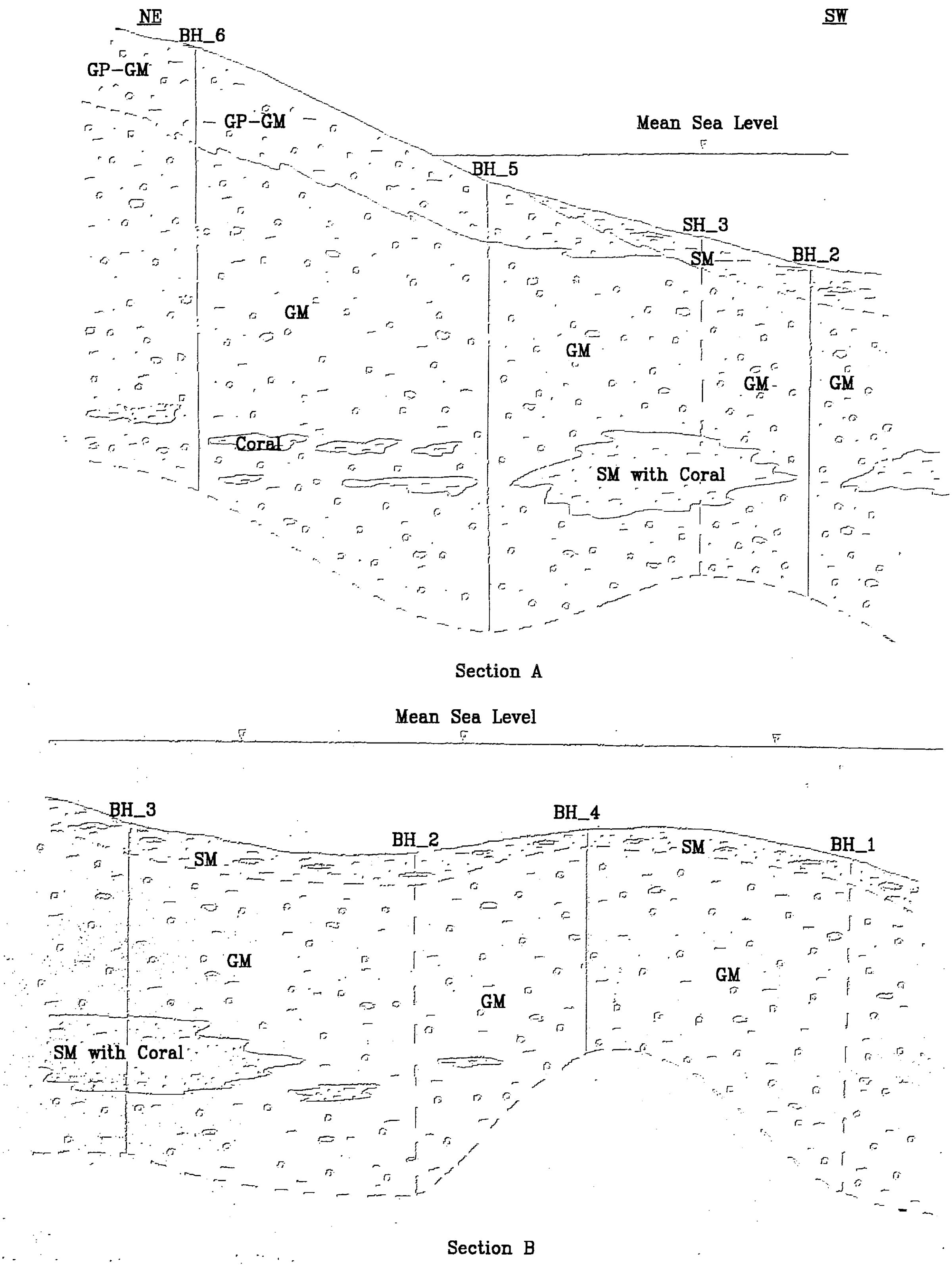


Figure 5: Simplified Geotechnical Sections

Laboratory tests were conducted on selected samples. These tests included gradation, density and specific gravity measurements, shear tests, as well as measurement of sulphate, chloride, carbonate and pH value of the soil.

Borrow Material

The original contract documents recommended the same specifications for the quality of fill material in the reclaimed area as the rock armours. This specification is presented below:

- Apparent Density

  Average: 25.5 kN/m^3
  More than 90% more than 24.5 kN/m^3

- Water Absorption

  Average: 3%
  Maximum: 6% (not more than 20% of the samples)

- Aggregate Impact Value

  Minimum: 30%

- Chemical Reactivity with Sulphate

  Maximum Loss of Weight: 5%

Based on a reconnaissance study, a suitable borrow area that met the above specifications was about 100km away from the site and was considered to be uneconomical. An extensive study was carried out to identify a borrow area within the vicinity of the site. Concurrently a study was initiated to review the specifications for the quality of the fill material behind the caisson type berthing structure. The study covered an assessment of the performance and durability of local materials that have been used for the similar projects in the vicinity of the site and assessment of the performance of the sites constructed with lower quality materials (than specified in the South Pars Project contract documents).

To evaluate the identified borrow areas, a systematic ranking chart was prepared based on the results of these studies. This ranking chart categorizes the results of the relevant tests and provides an overall ranking for each borrow site based on the laboratory test results. Weighting for each parameter was based on the relevance of the test to the usage of the material for port construction. For instance, those tests that simulate the soundness (such as chemical reactivity with sulphate, water absorption and apparent density), and compactness and physical strength had equal weighting. The following is the ranking system for usage of rocks for construction of marine structures (Table 3).
It should be noted that some of the tests that have been referred to in the following table (such as Impact Resistance, Point Load and Rupture Index) are mostly used for evaluation of rock armours resistance against wave action.

Table 3: Criteria for Evaluation of Durability of Rocks for South Pars Port

Test	Qualitative Ranking Description				
	Very Poor	Poor	Medium	Good	Very Good
Apparent Density	<1.9	1.9-2.2	2.2-2.5	2.5-2.7	>2.7
Score	1	3	6	8	10
Water Absorption (%)	>10	6-10	3-6	1-3	<1
Score	1	3	6	8	10
Soundness –SST (%)	>15	12-15	5-12	2-5	>2
Score	1	3	7	12	15
Abrasion Test (%)	>30	20-30	15-20	10-15	<10
Score	1	2	5	8	10
Rupture Index – K_{IC} ($MN/m^{1.5}$)	<0.3	0.3-0.8	0.5-1.5	1.5-2.2	>2.2
Score	2	4	8	12	15
Point Load Index - I_S	<1	1-2	2-4	4-8	>8
Score	1	3	6	8	12
Impact Resistance - A_{IV} (%)	>25	18-25	12-18	10-12	<10
Score	1	3	5	7	10
Uni-axial Compressive Strength (Mpa)	<5	5-20	20-70	70-140	>140
Score	0	1	2	4	6
Rock Characteristics	Weathered rocks with significant soluble minerals and more than 15% void ratio	Weathered rocks with soluble minerals and several joints and cracks	Igneous and metamorphic rocks with joints and cracks or moderately weathered – Unweathered Sedimentary rocks with no significant joints and cracks	Intact Igneous, Metamorphic and Sedimentary rocks with no significant joints and cracks	Intact, massive Igneous rocks
Score	2	3	5	8	12
Total Scores	10	25	50	75	100

Based on the above ranking criteria, the qualitative description for different ranges of scores was introduced in Table 4:

Table 4: Qualitative Description of Rocks Based on Ranking Scores

Category of Rock	Very Poor	Poor	Medium	Good	Very Good
Range of Scores	<25	25-50	50-75	75-90	90-100

According to the above ranking, the material meeting the contract specifications would fall under the Good to Very Good categories. The purpose of this study was to evaluate the performance of lower quality materials for filling the reclamation area. Borrow areas within 10km from the site were studied thoroughly and extensive laboratory tests were carried out based on the above ranking criteria. A summary of the results is presented in Table 5.

Table 5: Summary of Test Results for Borrow Areas in Vicinity of Site

	Water Absorption (%)	Density (gr/cm^3)		Los Angeles Abrasion (%)	SST	A_{IV} (from Los)	I_s
		Apparent	Saturated				
No. of Samples	37	37	37	37	37	37	37
Minimum Value	1.20	2.48	2.29	20.0	9.0	14.44	4.65
Maximum Value	10.94	2.69	2.60	34.0	18.0	28.88	4.87
Average	4.70	2.61	2.42	28.5	12.1	23.19	4.72
Standard Deviation	1.89	0.05	0.06	3.5	1.7	3.61	0.09

According to the above results, about 30% of the samples fell into the Poor, 50% fell into the Medium and 20% into the Good ranking categories. From density point of view, about 33% fell into the Medium and 67% into the Good ranking categories.

Rationale and Interpretation of Results

The proposed specifications for the use of rock material in marine structures should be critically reviewed for sites with no suitable borrow areas that meet ideal specifications. For large volumes of backfilling materials, an unnecessary stringent specification will be considered unreasonable and not economical. The proposed specifications for the rock armour and filter to be used for construction of breakwaters usually should fall into the Good and Very Good categories, proposed above.

Rock as armour and filter, should withstand the forces due to wind and wave action and probable loss of the breakwater free board. In comparison, backfilling material may require different criteria for selection of material and method of placement depending on the magnitude of surcharge in the reclaimed area and type of structure to be constructed on backfill. In most cases, the final stiffness of the placed material and resistance to degradation due to chemical reaction would be an issue. The proposed approach can be either to accept a lower quality rock (eg Medium or Poor categories), or to use only two or three items that mostly represent the required quality of rocks for filling the reclaimed areas.

For the purpose of this project, the most relevant test criteria were chosen as below:

- Water absorption and density test results: the most relevant
- Soundness test results: relevant
- Compression Resistance test result: relevant

It was proposed to accept the Medium quality rocks for filling and reclamation purposes. Based on the above evaluation criteria, some of the borrow areas were considered suitable and proposed to the client. The client accepted the proposed criteria for the filling material.

To date, the performance of the reclaimed area has been satisfactory.

Summary and Conclusion

Construction of South Pars Export Harbour required reclamation of about 102,000 m^2 with a depth of backfilling up to 8m and volume of about 550,000 m^3. The original specifications for the backfill material required imported material from about 100km away from the site, which made the project unfeasible for the EPC contractor. A ranking system was developed to evaluate the quality of potential borrow sites in the vicinity of the proposed port. Based on the proposed ranking system the contract specification for the fill vicinity of the proposed port. Based on the proposed ranking system the contract specification for the fill material fell into the Good to Very Good categories, while most of the borrow sites in the vicinity if the projects fell in to the Medium category.

Comparing the criteria for the use of rock as armour and filter to the criteria for the backfilling purposes, it has been proposed that a lower quality rock may be accepted for backfilling. These criteria may be different for each project depending on the magnitude of surcharge and nature of the loads on the reclaimed area. For the purpose of the South Pars Project Harbour, the dominant criteria were water absorption and density test results (the most relevant), soundness test and compressive strength test results.