Puerto de Barcelona

PART V

CASE STUDIES

San Ciprian—Lugo

CHAPTER 202

ENGINEERING STUDY FOR A NEW SEAWATER INTAKE SYSTEM

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ABSTRACT

Environmental assessment, engineering studies and designs were completed for a new 26.5 m^3/s seawater intake system in the Persian Gulf. The original intake facility consisted of a curved, 60m breakwater with one end attached to the shoreline, a settling basin immediately adjacent to the shoreline and dredged to a maximum depth of approximately 5m, and a pumphouse structure located on shore such that the seaward wall formed one side of the settling basin. The facility located on an island in the Gulf, which served multiple seawater uses, had experienced both structural and operational problems, the latter consisting principally of excessive ingestion of sediment and seaweed. These factors plus the requirement for additional demands for seawater beyond plant capacity caused the owner to initiate a study of alternative intake systems, produce a design for the most effective solution and construct the new intake system.

INTRODUCTION

The intake system supplies cooling water primarily to a large LNG processing facility. Cooling water enters from the Gulf on the north side of the island through a small 5m deep sedimentation basin into the front bay of a large pump station with seven pumps. The cooling water circulates through the condensers and then back into the Gulf on the east side of the island. The site location is shown on Figure 1. Through field studies and numerical analysis it was shown that the heated discharge did reach the intake at some stages of the tide causing poor cooling performance.

A second problem has occurred seasonally for several years. In particular, at certain times of the year Colpomenia cf. sinuosa (a macro algae) appear in great quantity and clog the cooling water intake. In front of the pump bays, a rotating screen operates behind a bar screen. On several occasions the quantities of macro algae were so great as to totally clog the system and to cause the plant to shut down for several days. The economic consequences of this are obvious.

The third problem which required solution was the identification of the source and elimination of the sediments being ingested into the plant. These sediments were not only filling in the deposition basin but were also going through the pumps causing excessive wear on the cooling system.

Lastly, there was a desire to increase the capacity of the intake plant by 50% to include increased cooling requirements as well as fire water and desalinization needs.

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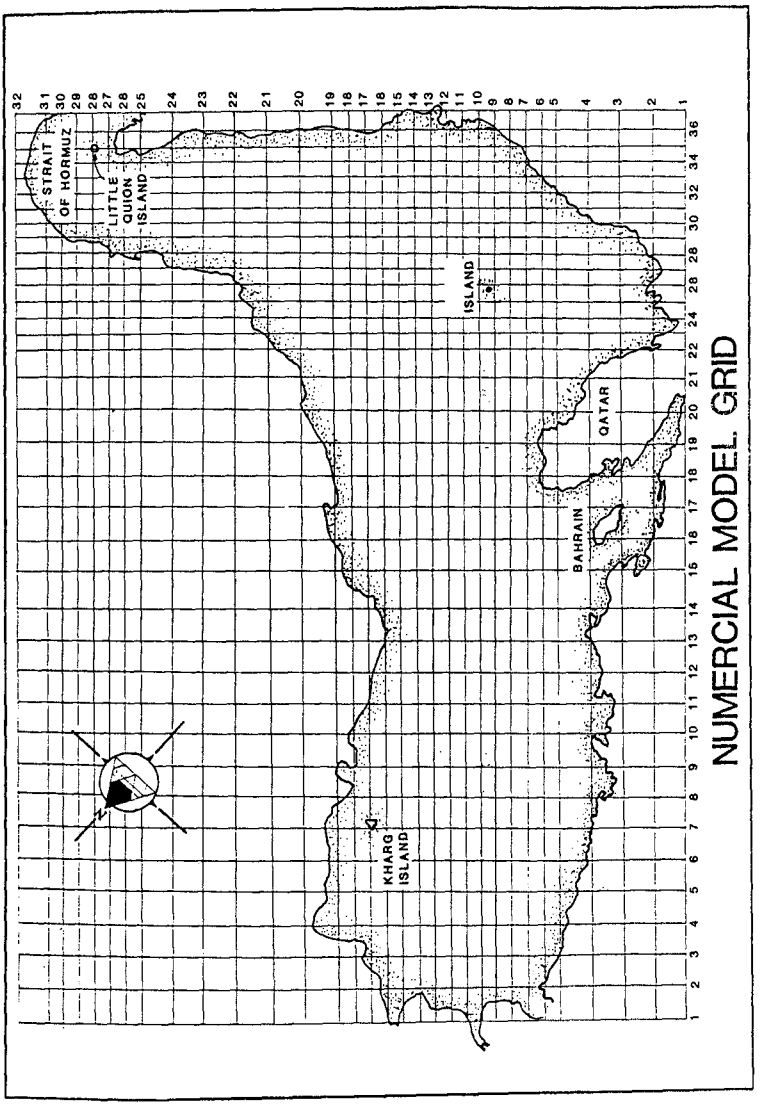

Figure 1. Location of project site in Persian Gulf.

A program was developed to analyze the problem, to identify appropriate solutions and to carry those solutions through design to construction. The study and analysis included:

- Field data collection and analysis covering site physical oceanography, meteorology, coastal geomorphology, biofouling, and thermal dispersion;
- Engineering studies including thermal recirculation, bio-fouling control, and development of design criteria;
- Formulation and evaluation of alternative conceptual layouts for a new intake facility with particular attention directed to construction and operational integration with the existing plant;
- Recommendations for any additional field studies and hydraulic modeling prior to initiation of the final design process;
- Preparation of final design and tender documents and completion of construction.

FIELD AND ENGINEERING STUDIES

Winds

Winds are of primary concern in the design of virtually any coastal or offshore structure because of the direct influence they have upon the wave climate, current circulation, and storm surge phenomena. The dominant extreme wind regime in the Persian Gulf is the winter "shamal", characterized by strong northwesterly winds which generally persist for a period of several days. A statistical analysis of wind velocity maxima was made on the basis of continuous speed and direction measurements during the period 1958 to 1967 (IMCOS Marine, 1969). The analysis indicates that about 50 percent of the time winds are from the northwest. Return probabilities of storm wind occurrence at the site were estimated from this data and are shown below:

Table 1. Extreme wind statistical analysis

Return Period (years)	6-hr Mean Velocity (m/sec)
100	23
25	21
10	19

In support of these figures it should be noted that ship observations in the southern Persian Gulf tabulated by the U.S. Naval Weather Service Command (USNWS, 1971) indicate that during the period 1963 to 1971 no winds occurred that were in excess of 24 m/sec from any direction.

A recent study performed for ARAMCO (Ocean Weather, Inc., 1983) reviewed the storm meteorology of the Persian Gulf since 1963. Historical wind data were compiled, annotated, and reduced to 15 extreme events over the study period. This data base was used to develop design wave and water level criteria.

Waves

A statistical definition of storm-generated wave heights and periods was required to determine (1) the degree of attenuation necessary to protect shoreline pump bays and (2) the structural requirements necessary to ensure the survival of intake structures and breakwaters during adverse weather conditions. Design wave parameters have been previously prepared by A.H. Glenn Associates (1982).

Long-term records of wave data directly relevant to the site are virtually non-existent. Consequently, a description of the design wave condition were made through hindcast techniques. In this analytical technique, the more extensive wind data over the Gulf region is used to reconstruct historical storms of record. Numerical and empirical models are then employed to calculate or "hindcast" the corresponding wave characteristics at the point of interest.

Table 2. Predicted wave heights

Return Period (years)	Water Depth (m ISLW)	Sig. Wave Ht. (m)	Sig. Wave Per. (sec)	Max. Wave Ht. (m)	Max. Wave Per. (sec)
10	4.7	3.4	7.3	---	---
	13.5	4.2	7.4	7.9	8.2
	25.0	4.4	7.4	8.2	8.2
100	6.0	4.4	8.6	4.6	9.6
	13.5	5.4	8.7	10.0	9.7
	25.0	5.7	8.7	10.7	9.7

Based upon 15 extreme wind events compiled in a recent study for ARAMCO (Oceanweather, Inc., 1983), a storm considered to be the largest event over the last 25 years was analyzed for wave incidence at the intake site. This shamal occurred over the period January 19 to 21, 1964 and is estimated to represent a 25- yr event. Hindcast analysis of this storm using the discrete spectral model of Resio (Resio et al., 1981), which has been calibrated for this region of the Persian Gulf, gave a peak significant wave height of 4.5 m and a spectral peak period of 10 seconds.

Wave refraction analysis was performed to evaluate the transformation of deeper water waves to the near shore region on the northern side of the island. Wave behavior for waves with periods of 6, 8, 10 and 12 seconds approaching the site from the northwest, north and northeast sectors was analyzed. These conditions were chosen as representative of those generated by the shamals.

Water Levels

Anticipated extreme water levels over the design life of the intake system determine requirements for pump machinery protection. Furthermore, they govern the maximum wave height which can propagate to the intake. Conversely, the minimum water level to be expected at the site is an important

consideration in terms of insuring enough water depth to maintain the design cooling water flow rate. Astronomical tidal information relative to the site is summarized below:

Table 3. Astronomical tide summary
(elevations in meters relative to Chart Datum)

Level	Elevation (m)	Reference
Highest astronomical tide	1.7	A.H. Glenn, 1982
Mean Higher High Water	1.2	U.S. NOS, 1980
Mean Tide Level	.8	A.H. Glenn, 1982
Mean Lower Low Water	.5	U.S. NOS, 1980
Lowest Astronomical tide	-.1	A.H. Glenn, 1982

Storm surge and seiche resulting from sustained winds blowing over the Gulf can create an additional rise or fall of the water level. The northwesterly shamal is capable of generating storm surges via wind stress effects over the axis of the Gulf. IMCOS Marine (1969) predicted a still water level of +3.05 m and it is assumed that this value represents a 100-yr event.

To confirm this value, one and two-dimensional numerical storm surge models were run over the entire Persian Gulf using hindcast wind fields obtained from Oceanweather, Inc. Surge was assumed to be coincident with a Mean Higher High Water tide and results indicated that a maximum still water level on the order of +2.76m and possibly lower may be a more likely expectation over the project design life.

Southerly winds which persist for some duration are capable of lowering the still water level at the southern end of the Persian Gulf. A simplified one-dimensional drawdown calculation was made using bathystrophic storm tide theory. Preliminary and uncalibrated results indicate that drawdown on the order of 0.75 m may be expected over the project life of the intake structures.

Currents

Determination of predominant flow characteristics provides important operational design information related to net flow rates of fouling organisms or other material toward the intake as well as thermal plume recirculation. No historical, site specific data were available on currents in the vicinity of the site. Consequently, a brief field measurement study to record in situ current speed and direction was undertaken.

Thermal Recirculation

The hydrodynamic and thermal characteristics of the LNG intake and discharge structures are reasonably complex due to the poorly defined advection and mixing conditions and complex bathymetry. The discharge volumes and velocities of the proposed new discharge channel are large as is the temperature difference between the discharge and ambient waters. The

discharge is into shallow waters which are subject to complete current reversal as the tide sweeps around the island.

The field study results of the vertical profiles of temperature and the synoptic temperature plots indicate that the discharge plume remains attached to the surface and shows relatively little vertical dispersion. Field studies also indicate that during conditions of tidal cycle which carries the discharge plume towards the intake, the observed temperature rise was primarily confined to the upper water layer.

Because of the complexities stated above it was decided to divide the analyses into two phases, the first analyzing the near-field plume and the second the far-field effects. The near-field is defined as that region in which the discharge plume characteristics are dominant. The far-field is defined as the region in which the larger scale oceanic forces dominate.

Modeling of the far-field, where tidal and wind forces are dominant, poses different problems from the near-field. Due to the location of the site, a conventional hydrodynamic modeling effort is complicated by the difficulties to determine appropriate boundary conditions. With the surface plume stratification, use of a three-dimensional or stratified model would be desirable. However, given the lack of information regarding vertical mixing and the far greater amount of boundary information required by a three-dimensional model, such an approach is not justifiable. Therefore, it was decided to use a depth averaged model and apply various sets of assumptions which would bound the extreme case conditions. Boundary conditions were determined by running a two-dimensional model for the entire Gulf as schematized in Figure 1.

Sediments

Required seawater quality in terms of undissolved solids for the new intake system were defined as 1.5 ppm for calm conditions and 5 ppm for storm conditions. In addition, it was stated that water for the new firewater system should not contain solids which will block a 3.5-mm diameter spray nozzle. These requirements essentially define the limitations on sediment ingestion by the new seawater intake system.

Significant sedimentation within the existing pump forebay area was reported but no quantitative information adequately delineated the problem. Therefore, it was necessary to conduct an investigation to determine the origin and magnitude of this sedimentation problem.

While the rate of intake of sediments rises during storms, it is reported to be a minor problem. The sediments appearing just on the outside of the breakwater are not in sufficient quantity to create an ongoing problem. In addition, because of their coarseness, they are not readily mobilized and do not appear to be moving toward the mouth of the intake at a rate to create a problem. Moreover, these sediments do not appear to have been transported into this area from a remote distance.

Field studies determined that the breakwater was responsible for the majority of sediment build-up. Improperly graded filter stone was placed beneath the 15-ton tetrapod armor units and significant leaching of the core material occurred. Furthermore, poor stone materials, including breccia from

the island, were used and a breakdown toward fine material began via water induced deterioration and wave generated abrasive stresses.

Geotechnical Factors

The site is one of a number of diapiric structures which occur in the Persian Gulf and which are part of a major province of salt diapirism centered in southern Iran. During the early Pleistocene epoch, tectonic pressures within the crustal rocks at depth beneath the Gulf initiated a redistribution of a major evaporite horizon within the Cambrian Hormuz series. The low specific gravity and viscosity of this evaporite as compared with the surrounding rock types resulted in the upward movement of the evaporite mass through the overlying strata forming a salt plug.

The northern part of the island is the gypsum cap of the salt plug. Severe disturbance of surrounding rocks occurred during the upward movement of the evaporites. Large masses of rock have been detached and reoriented and a wide variety of rock fragments were mixed into a gypsum matrix. The subsequent dissolution of the salt plug by seawater has resulted in a chaotic aggregation of evaporite, sedimentary and igneous rocks around numerous domes of gypsum and gypsum breccia, and today, no orderly geological sequence can be established within the rocks. However, it is estimated at this time that the near shore region sub-bottom most likely consists of a layer of coral rock underlying breccia or sandstone.

From an engineering standpoint, offshore excavation will be difficult and require powerful dredging equipment as some of the coral and breccia can be moderately strong (unconfined compressive strengths for coral and breccia reaching values of up to 5 MN/m^2 and 17 MN/m^2, respectively). Breakwater protection can most likely be placed directly on the sea bottom without any risks for a base type failure. The rock will need to be imported to the island.

EVALUATION OF ALTERNATIVE SYSTEMS

Several onshore and offshore alternative cooling water intake system concepts were evaluated during the course of this study. Each concept was formulated to satisfy the following basic design requirements:

1. Provide the necessary cooling water volume
2. Eliminate sediment ingestion
3. Eliminate entrainment of biological foulants
4. Not interfere with the existing intake during construction
5. Afford practical construction methodology
6. Minimize thermal recirculation of discharge water.

In developing alternative system configurations, the primary concern was system reliability since the present facilities provide unacceptable levels of downtime associated with fouling and unacceptable rates of wear and high maintenance due to sediment ingestion.

Because of the large expense associated with shutdowns of the seawater system, a more reliable system having a higher initial construction cost may

provide a more economical long-term solution when total costs are considered. Consequently, hydraulic performance and antifouling characteristics were heavily weighed evaluating the alternatives. Secondarily, construction logistics were considered in terms of the ease of building the various schemes at this site in the Persian Gulf.

Table 4. Cooling water intake alternatives

Onshore Concepts

1. Extension of West Breakwater to create a calming zone and construction of new intake pump chamber near existing structure.
2. Porous dike.

Offshore Concepts

3. Offshore pipeline and intake; pipeline laid on bottom surface.
4. Offshore pipeline and intake; pipeline buried below bottom surface.
5. Offshore tunnel and intake.
6. Offshore pipeline trestle and suction riser.

Onshore Concepts

An onshore intake withdraws seawater from the entire nearshore water column because of the relatively shallow entry depth compared to the large pumping demand. Any onshore system will be exposed to the same loading stresses which the existing pump station has experienced. Therefore, facility improvements are required so that sand entrainment, biological fouling, and pollution contamination can be handled with no loss of plant efficiency.

Two onshore concepts were reviewed. The first concept is shown in Figure 2 and is essentially an extended modification of the existing intake layout with the breakwater running parallel to the shoreline. The stilling basin would be designed to provide sufficient wave protection and a sufficiently low current that sediments would be induced to settle out in the deepened basin. This would allow a longer accumulation time between maintenance dredging.

Entrained Colpomenia and other biota would still require mechanical screen removal. However, it is possible that some improvement over the present design could be obtained through careful specification of filter systems and screen wash management.

The second onshore alternative incorporates the use of a porous dike--a rubblemound structure constructed of highly permeable material--to completely enclose the onshore pump station. In this scheme, seawater filters through the structure's voids en route to the pump station and undesired foulants and sediments are virtually precluded from entry.

The principal drawback to porous dikes are their uncertain history regarding long-term clogging. The structure must be designed to anticipate a degradation of porosity. Calculations were made to determine the length of

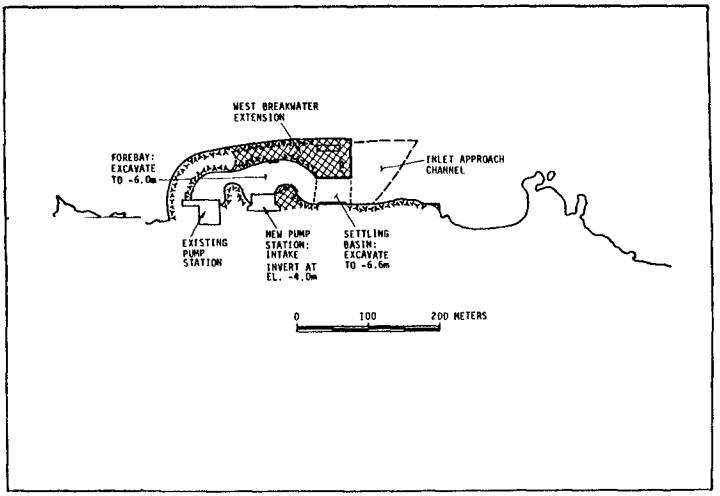

Figure 2. Onshore intake with parallel breakwater.

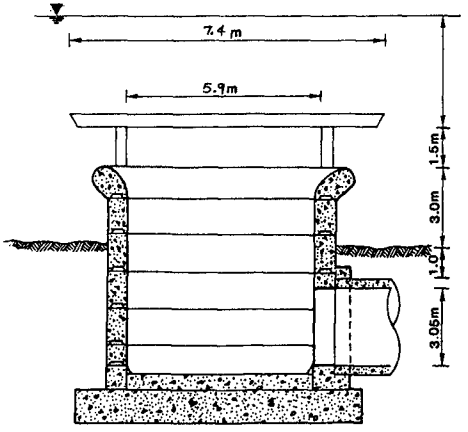

Figure 3. Offshore submerged intake riser.

dike needed to provide the design flow rate. Assuming a cross section constructed with fine gravel, a dike length of at least 1,200 m would be required. Furthermore, the ability of the system to prevent infiltration of floating pollutants is unknown. For these reasons, the concept was rejected.

Offshore Concepts

An offshore intake is often employed to withdraw large quantities of water when onshore intakes are not acceptable. Furthermore, an offshore intake can be used to access ambient water with cooler temperature characteristics. Consequently, this concept has important, attractive features that allow it to meet the design specification for the cooling water system.

Offshore intakes have been successfully used in a variety of marine cooling water applications. By submerging the point of water withdrawal sufficiently below still water level, operation can continue uninterrupted even during severe storm wave activity.

Based on available information, the offshore intake concept was recommended for design. Because of its proven operating capabilities, it offers the highest potential for alleviating the problems which are presently being experienced at the existing onshore intake.

The cooling water intake for an offshore system consists of three components:

1. The pump station and forebay;
2. The seawater intake; and
3. The connecting corridor between the pump forebay and seawater intake.

The following sections discuss desirable design features of each component in formulating a complete offshore system.

Pump Station and Forebay

The pump station should be designed so that the area is sufficiently protected from destructive waves, affords the opportunity to clarify the intake water prior to pump suction, and prevents fouling from nearshore waters. All three objectives can be met by completely enclosing the pump station within a small stilling basin. Little difference is expected between the design for the pump station with an offshore intake and that for an onshore intake.

Of primary importance, incorporation of a stilling basin provides a quiescent area for settling of any sand ingested at the offshore intake. This settling basin limits the entrainment of particles to sizes and concentrations required by design requirements. Construction of the settling basin can be achieved by extending the west breakwater to the east or building an entirely new breakwater for the new pump station. This will also preclude oil pollution, wave action, sediments, and seaweed from directly entering the basin. In short, the enclosed forebay greatly enhances pump station efficiency and reduces maintenance activity.

Seawater Intake

The primary function of the intake is to eliminate ingestion of large quantities of foulant which would overload pump station screens or harm internal cooling water components. The intake should be located in areas which exhibit reduced concentrations of Colpomenia populations and minimal sediments.

Offshore seawater intakes are simple structures which rest on the sea bottom and are elevated sufficiently above the seabed to minimize entrainment of sediment or bottom dwelling organisms. Figure 3. illustrates the chosen concept. The intake consists of prefabricated annular sections, normally of reinforced concrete, which are pieced together onsite. The assembled structure is then floated to the site and sunk into position. The horizontal velocity cap atop the structure induces lateral inflow of seawater thereby minimizing vortex generation and entrainment of bottom or surface floating material. The entrance slot is sized so that the velocity through the intake is no greater than .3 m/sec to minimize fish entrainment.

Intake Corridor

The most standard scheme is an offshore buried pipe. In this design, shown schematically on Figure 5, a trench is excavated to accommodate a large diameter conduit which is then covered for wave protection purposes. The diameter of the pipe must be sufficient to maintain velocities and hydraulic head losses within reasonable limits. A single conduit with a 4.27 m internal diameter (ID) would be required to satisfactorily convey the required flow from the offshore intake structure to the nearshore forebay.

Burial of a large diameter pipe involves extensive excavation of the marine bottom. The trench must then be lined with a gravel bedding to provide uniform foundation support for the heavy pipe segments. Select backfill is then placed to the crown elevation of the pipe and the trench is capped with suitable armor material.

An unburied pipe section would be fully exposed to the hydrodynamic loadings of storm generated waves and currents. Estimated wave forces would be of such magnitude that they could not be resisted by conventional pipeline anchors. An exposed conduit is therefore not recommended for further consideration.

Because of the hard bottom material found at the site and a sensitivity to the use of explosives to aid in excavating such strata, a tunneled conduit was considered. A tunnel can be considerably less disruptive to the marine environment and operation of the present intake. The total length requirement of 200m for the tunnel proved too costly for implementation of this alternative.

The third alternative, an over-water pipe system, is one in which water is drawn from an offshore location and pumped/siphoned via several smaller conduits to the depressed forebay. The siphon would be elevated over water by a conventional trestle-type structure as depicted on Figure 4. This concept can make use of smaller, lightweight, and hydraulically smooth Fiberglas reinforced pipe. Based on the flow requirements of the site, three 2.44-m ID pipes would satisfactorily deliver the cooling water from the intake to the

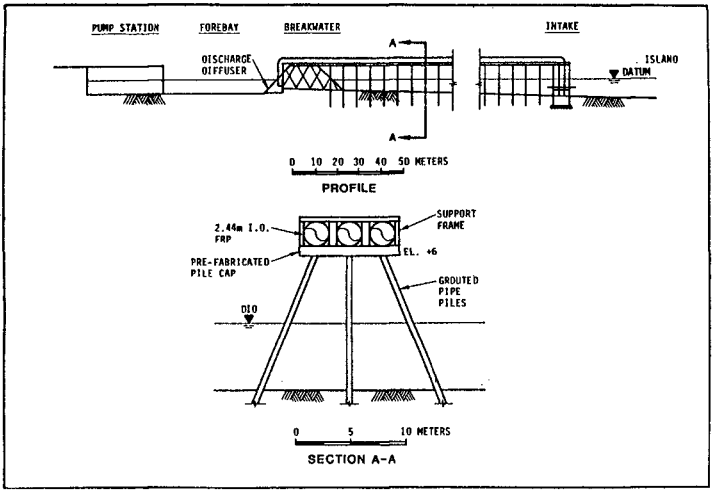

Figure 4. Pump/siphon water intake on trestle.

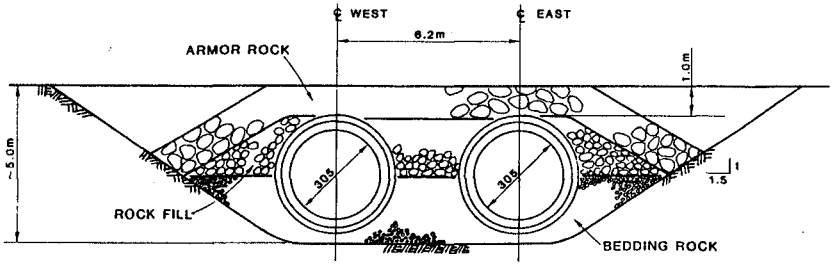

Figure 5. Buried concrete pipe design with backfill.

forebay. Additional advantages include ease of construction and an exposed pipe which facilitates operational maintenance. The elevated trestle allows waves to pass beneath it such that only the piling requires wave force design.

ENGINEERING DESIGN

Based on the above criteria, an intake system comprised of an onshore pumping facility and an offshore intake structure best met all relevant criteria and provided a proven, workable system. Key characteristics of the recommended system are given below.

Intake Design

1) Two partially buried, cylindrical offshore intake structures 5.88m in diameter are located approximately 175m offshore at the 8m contour. Each riser structure including velocity cap is approximately 9m high with the intake gap protruding 3.5m above the seabed.

2) Each riser is connected to a shoreline stilling basin via a buried concrete pipe 3.05m in diameter as shown in Figure 5.

3) The stilling basin is formed by a horseshoe shaped breakwater designed around the new pump station. The entrance to the 30m long stilling basin is a 20m long concrete diffusor structure which transitions the flow from the concrete pipe(s) into quiescent flow in the stilling basin. The enclosed stilling basin provides the desired water quality and protects all shoreline structures from surge and waves.

4) The intake stilling basin is dredged to -5.0m and will require only infrequent dredging for maintenance purposes.

5) Construction of the system can be achieved through positive isolation of nearly all of the new facilities from the present operating facility. Changeover from the old facility to the new is required to be achieved in a smooth transition period without loss of cooling water service to the island.

Hydraulic Model and Design Criteria

As part of the preliminary design, an extensive series of two and three dimensional model tests were conducted at the Delft Hydraulics Laboratory. Horizontal and vertical loadings on the intake risers were measured and the required pipeline armor stone size was determined. The wave tests were also used to confirm the design horseshoe breakwater. Separate model tests were conducted for the stilling basin diffusor and pump bay.

The allowable damage for the breakwater was 3% for Tr = 50 years. The allowable damage for the armor cover and the pipeline was 1% for Tr = 100 years. Damage was defined as movement of an armor unit more than 1.5 units away. One of the interesting results of the model tests was that the breakwater responded best to the placement of a berm at the toe as shown in Figure 6. This allowed the tetrapod layer to be reduced from 15 ton to 10.6 ton units and eliminate the observed Mach stem effect at wave breaking.

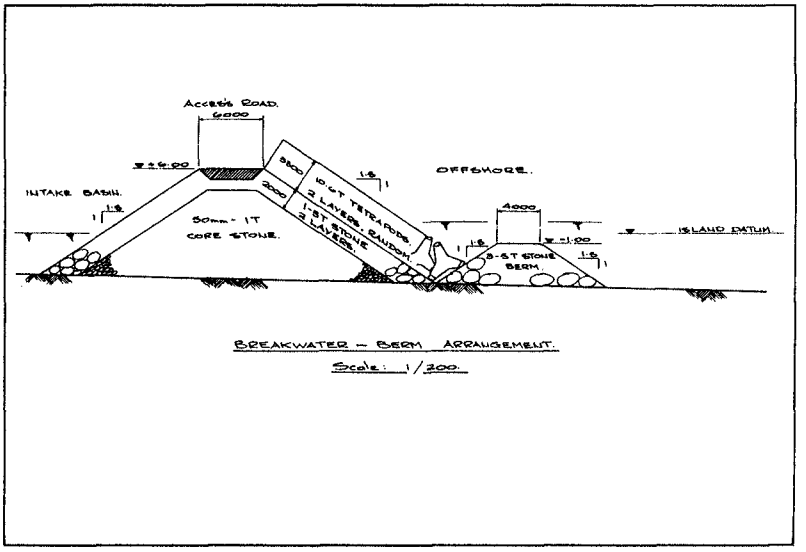

Figure 6. Breakwater cross-section showing berm and tetrapods.

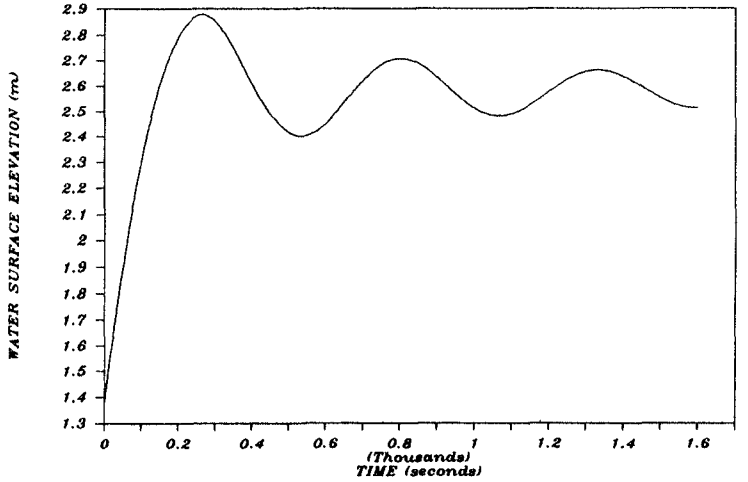

Figure 7. Surge analysis for pump shut-down conditions.

In addition to the above there were several additional specific criteria which were used in the design and the model studies. In the two and three dimensional wave tank tests a Jonswap spectrum was used having the following characteristics:

$\gamma = 3.3$
$\lambda_a = 0.07$
$\lambda_b = 0.09$

Hydraulic performance of different components of the system were tested at different design water levels. For example, the breakwater was tested at a HWL of +2.67 representing a 50 year event whereas the pipeline armor was tested at a HWL of +2.76 representing a 100 year event. The significant wave height for the breakwater is Hsd = 5.23m for a return period of Tr = 50 years.

During the hydraulic performance tests three discharges were applied:

- half normal flow: 13.25 m^3/s through 1 pipe
- normal flow: 26.5 m^3/s through both pipes
- maintenance flow: 25.4 m^3/s through 1 pipe

Both numerical and physical tests were performed to ensure that the settling basin would not be subject to surging problems due to external wave conditions.

SUMMARY

No difficult or insurmountable final design, construction or operation issues were revealed in the selected alternate for this replacement of the cooling water intake. Nevertheless, there were a series of critical design issues which required satisfaction in the final design.

Construction of this facility is currently proceeding to completion. The offshore parts of the new intake system is expected to be completed in 1988.