SHOAIBA II POWER PLANT HYDRAULIC STUDIES

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This paper presents the results of studies carried out by ARTELIA for the intake and outfall system of the new Shoaiba II thermal power plant, on behalf of DAELIM. These studies included hydraulic desk studies, thermal dispersion simulation study, physical model tests and simulation study of ship manoeuvring for the fuel oil terminal.

Keywords: Intake, Outfall, Wave, Physical modelling, Mathematical modelling, Protection breakwaters, Navigation

INTRODUCTION

The Shoaiba Thermal Power Plant is located on the Eastern coast of the Red Sea, 100 km Approx. South-South-East of Jeddah. This plant was developed up to its second stage with 11 units (Stage I and II) and the Stage III is also under operation.

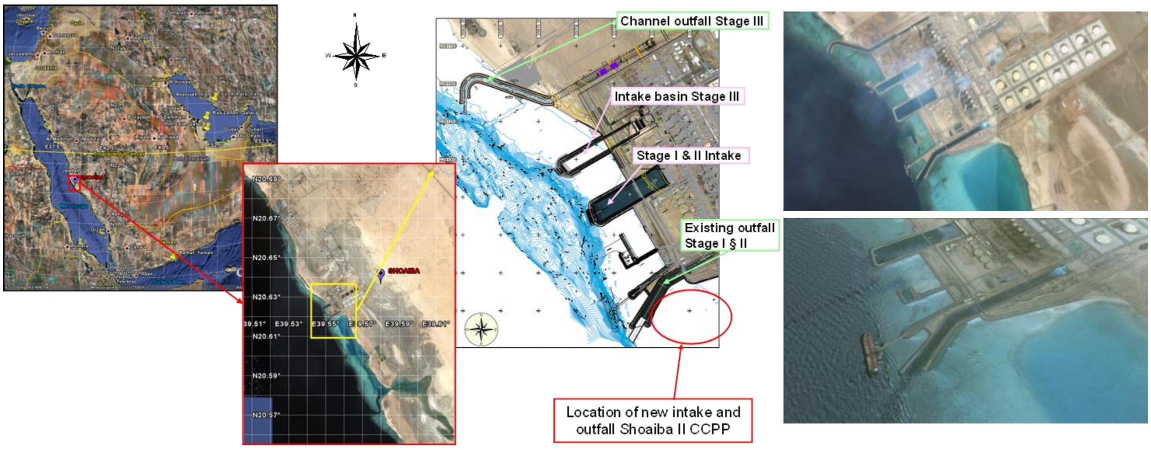

Figure 1. Site location

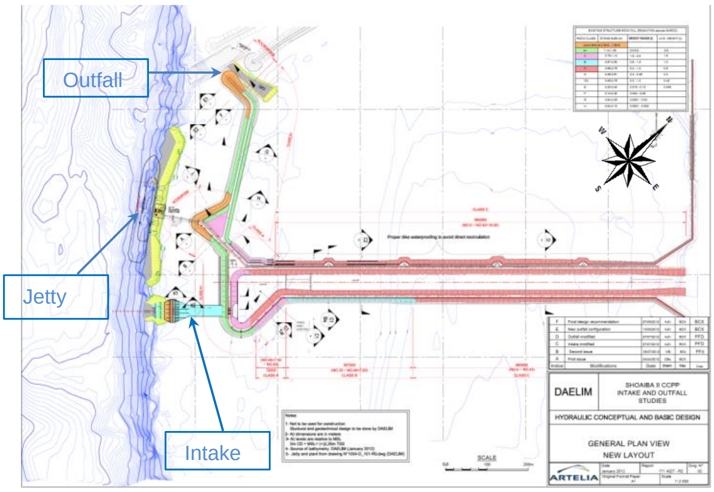

Figure 2. Shoaiba II CCPP intake and outfall final layout

DAELIM is in charge of the upgrade of the Stage II power plant, on behalf of SEC (Saudi Electricity Company). This upgrade consists in the construction of 1400 MW Combined Cycle Power

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Plant and a once through cooling system associated with a discharge of 120,000 m3/h (33.3 m3/s) and a temperature difference with the ambient water of 6.5°C.

The Stage I&II and the Stage III intake systems (see fig. 1) include each a free surface intake channel, extending from the edge of the reef to the circulation water pump house, and a deep water intake pipe system beyond the reef, built with a number of intake pipes anchored to the sea bottom with concrete blocks. The Stage I§II and the Stage III outfall systems include each a free surface outfall channel, extending up to the edge of the reef.

The new Shoaiba II CCPP is associated with an intake and outfall system located to the South of the existing ones, as well as with the construction of a new terminal for the import of the fuel oil for the power plant (see fig. 2). The intake consists of a deep water pipe system connected to free surface intake channel located on the reef. The outfall is a free surface channel merged with the Stage I§II existing one.

DAELIM commissioned ARTELIA to carry out studies for the intake and outfall system and also for ship navigation, including the following tasks:

- General review of the existing data and design requirements,
- Hydraulic conceptual and basic design for intake and discharge system,
- Thermal dispersion simulation study,
- Physical model tests of intake and outfall protection structures,
- Simulation study of ship manoeuvring for the terminal under various environmental conditions,
- Physical scale model tests of the seal pit structure,
- Physical model tests of seawater pumping station.

METHODOLOGY AND RESULTS

Site data

The physical conditions in front of the site were collected: water levels, bathymetry, wind climate, current velocities, wave climate…. The bathymetry is characterised by a reef with very low water depth (-1m/CD) and very steep slope (30%) at the reef break, down to (-60 to -70m/CD).

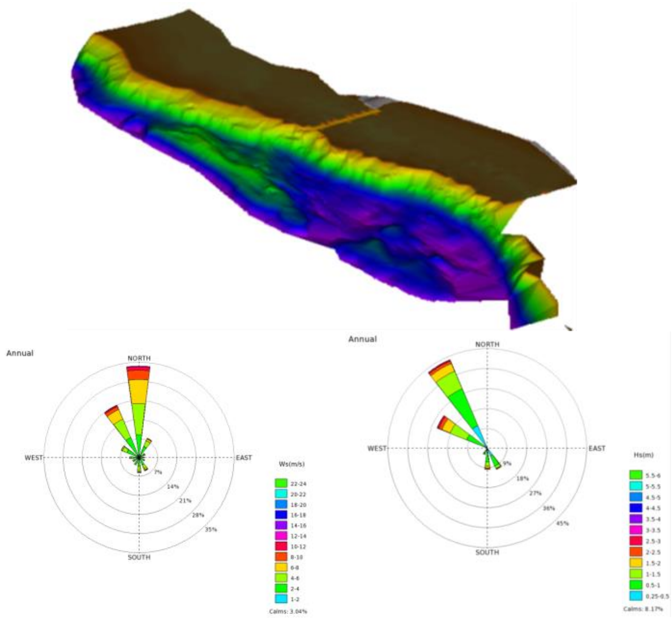

Figure 3. 3D view of bathymetry – Wind and wave roses

Dominant wind directions are North to North-westerly with also strong winds happening from South to South-easterly directions. More than 90% of wind speeds are less than 8 m/s.

Dominant direction of waves is North-westerly and wave heights are less than 1.5 m (about 86% of time). Strong storms come from North-westerly predominant direction but strong gales may also happen from Southerly direction. Due to the orientation of the reef, Southern extreme waves lead to the most severe conditions, as North-westerly waves are decreased by refraction before reaching the site.

Behaviour of storm waves is strongly influenced by the reef with specific breaking and shoaling conditions: plunging on the edge of the reef and spilling after that. Strong wave attack and wave slamming are obtained up to a distance of at least half to one deep-water wave length from the reef edge (about 50 m), before adaptation to the local water depth and decrease in wave height.

Offshore 100-years return period wave height reaches up to 5.7 to 5.8 m but individual highest waves behaviour at the steep reef face that determines the set-up and crest elevation is also difficult to be defined precisely with numerical modelling. Wave conditions in front of the structures are then to be determined with physical model tests.

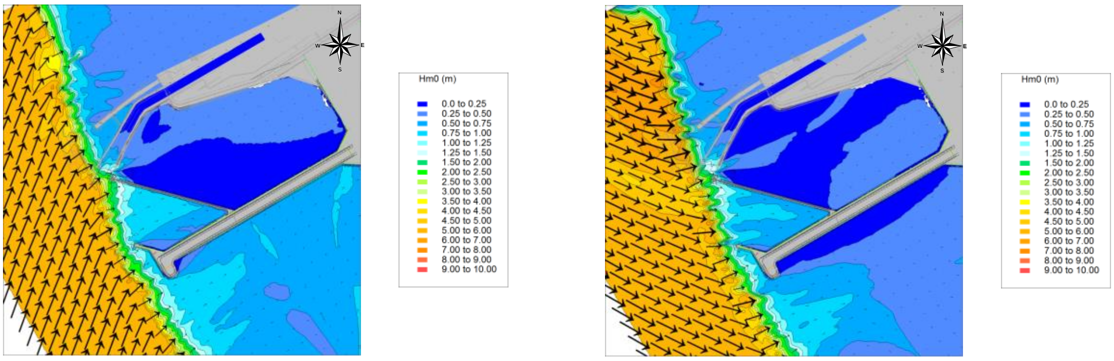

Figure 4. Southern and NW wave propagation

Hydraulic conceptual and basic design for intake and discharge system

On a layout provided by DAELIM, hydraulic conceptual and basic design for intake and outfall system was carried out, including a 3D thermal dispersion study. Adaptations to the initial design were done, based on ARTELIA’s experience on that matter and also gained through physical model tests carried out previously for the Stage III outfall channel.

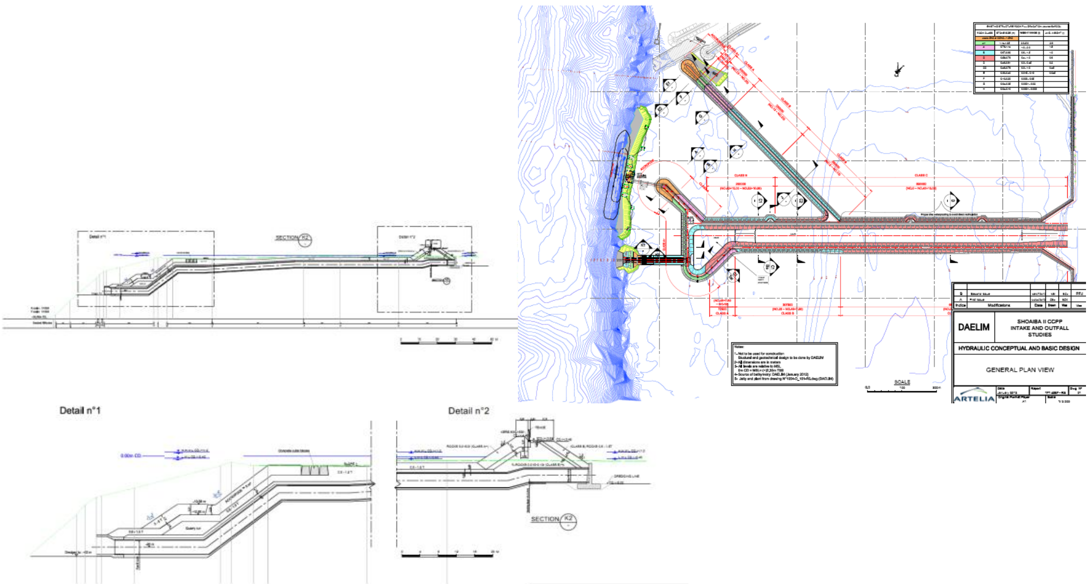

Figure 5. Intake protection cross-section and initial layout

For the thermal dispersion study, the TELEMAC-3D software, part of the TELEMAC-System[3], was used. It solves the 3D hydraulic equations and transport-diffusion equations for intrinsic values (temperature, salinity, surface). The main results obtained at each point of the computed mesh are velocity in three directions and the concentration of transported quantities. The main result for the surface mesh is the water depth. The main applications of TELEMAC-3D are in free-surface maritime or estuarine hydraulics. The model takes the following phenomena into account:

- Influence of temperature or salinity on density,
- Bottom friction,
- Influence of the Coriolis force,
- Influence of weather conditions: atmospheric pressure and wind,
- Heat exchanges with the atmosphere,
- Fluid and momentum sources and sinks within the domain,
- Turbulence models including effects of Archimedes force (buoyancy),
- Tracer transport and diffusion by the current.

The software has many fields of application, the main ones being in maritime studies, especially in relation to currents generated by the tide or density gradients, with or without external forcing due to wind or air pressure. It may be applied to large areas (at the scale of a sea) or more restricted sites (coastal and estuarine areas) to study the impact of a coastal outfall, thermal plumes or other subjects. In the field of continental waters, it may be used to study thermal plumes in rivers, or the hydrodynamic behaviour of natural or artificial lakes.

The structure of the TELEMAC-3D mesh is made up of prisms. The first stage involves constructing a 2D mesh comprising triangles that cover the domain horizontally. This is reproduced along the vertical, in a second stage, following a number of curved surfaces referred to as 'planes'. The links between repeated triangles in two planes of this type form the prisms.

The triangular two-dimensional mesh was built using the mesh generator. The characteristic dimensions of the covered area were 15 km along the coast and 9 km offshore. The horizontal grid contained about 5700 nodes. The size of each element varied from about 800 m near the offshore boundary to 10 m near the seawater intake and outfall. The three-dimensional prismatic mesh was built automatically by TELEMAC-3D from the previous 2D mesh, with 10 vertical plans.

The model was calibrated by comparison with results obtained during a measurement campaign (current direction and intensity, water temperature, wind direction and intensity, air temperature).

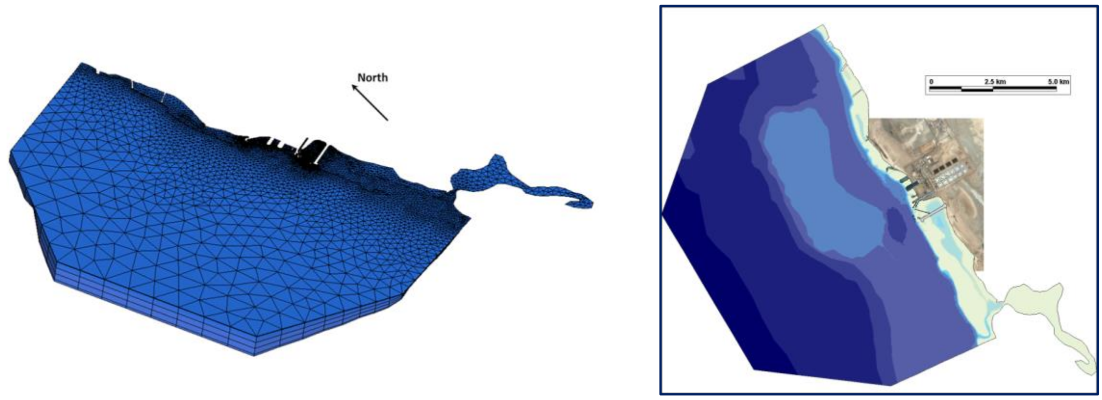

Figure 6. Views of 3D model mesh and bathymetry

Simulations were run for different hydro-meteorological scenarios and it was found that the thermal plume at the surface was less extended with the new outfall flow rate than without it, as the merging of flow rates increased the outfall exit velocity and plume dispersion (see fig. 7). The maximum current velocity at the jetty location was about 0.6 m/s at the sea surface and the risk of warm water recirculation at the future intake was very small (less than 0.1 °C), due to its deep location.

[3] TELEMAC system was developed by the National Hydraulics and Environment Laboratory, a department of Electricité de France's Research and Development Division.

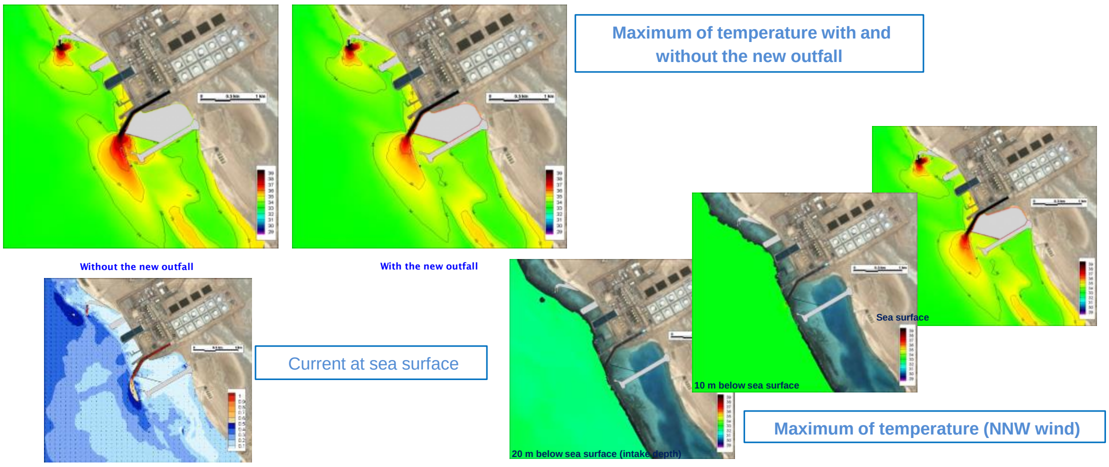

Figure 7. Results of 3D thermal model calculations

Physical model tests of intake and outfall protection structures

Physical model tests of intake and outfall protection structures were then carried out and design modifications were made for these structures according to the model tests results.

The model was built, at 1/43 scale, in the multidirectional wave basin of ARTELIA's Laboratory (Length: 40m; Width: 30m; Height: 1.5m). The basin is equipped with a multidirectional wave generator made of 60 independent wave paddles, enabling to reproduce wave trains according to fixed spectra. The flow rates of the new Stage II CCPP cooling system and of the existing Stage I & II outfall channel were also taken into account (see fig.8).

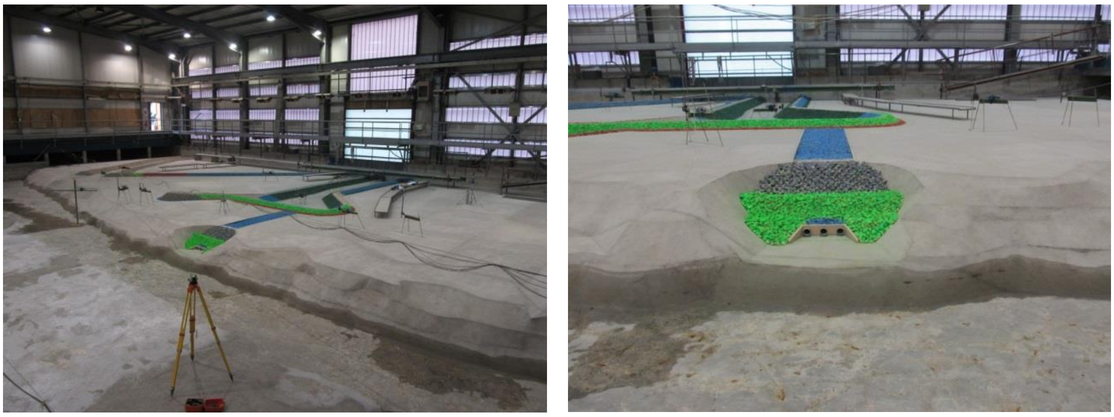

Figure 8. Views of 3D physical model construction

These modifications concerned mainly the intake pipelines protection, intake rear side protection and outfall dike structure. In particular, as shown during model tests, the pipelines protection at the reef edge was strongly solicited and modifications had to be brought to this protection, together with the strengthening of the intake channel backside protection.

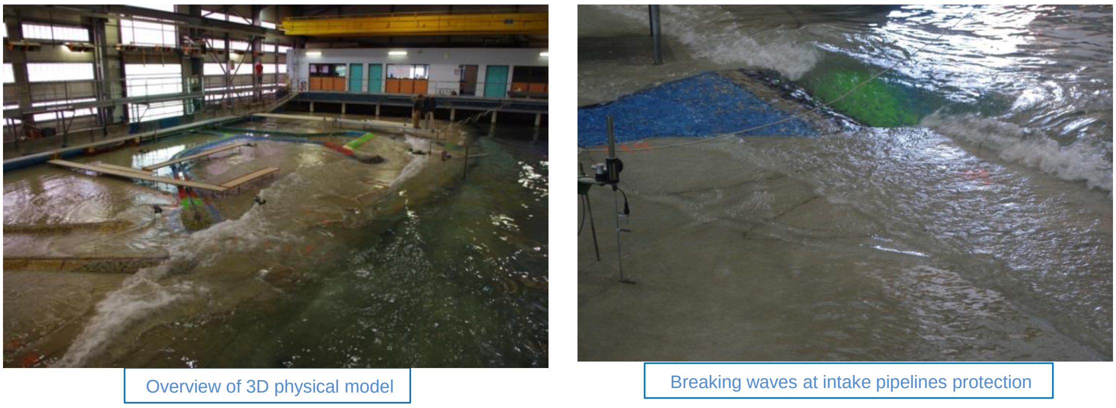

Figure 9. Views of 3D physical model tests

Water accumulation between intake and outfall dike, especially for North-West conditions, induced important water level increase and overtopping of the intake dike that could destroy the inner side rock protection. As a consequence, it was decided to change the alignment of outfall dike to avoid this corner effect while keeping a similar distance from the reef edge (see fig. 10). Due to the protection offered by this new outfall dike layout, it was possible to change the rock categories on protected part of the intake dike.

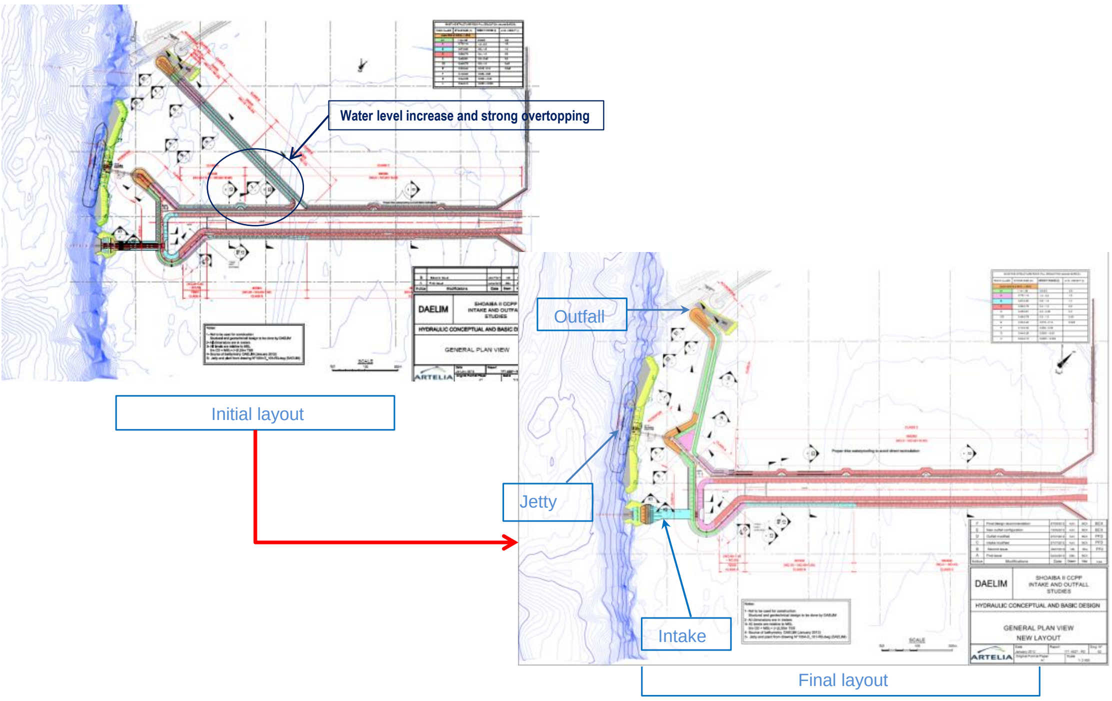

Figure 10. Modification of outfall dike layout

Simulation of ship manoeuvring for the oil terminal

The mathematical simulator was built on the SIMFLEX software[4]. It is a flexible and reliable 3D navigation simulator enabling ship's trajectories to be simulated and taking into account:

- The orders given by the pilot (rudder angle, engine orders, bow thrusters, etc.).

[4] Developed by Force Technology

- The local environmental conditions (current, wind, waves, water depth variations, effects of the bank or mooring lines, etc.). Both current and waves may be integrated, either as fixed values which may be modified in an interactive way during the simulation or on a basis of a 2D-grid.
- Forces induced by different types of tug. Up to four tugs may be individually operated and their activities and towing forces are continuously displayed on the screen. Towing power and towing direction as well as the length of the trial rope can be adjusted continuously. All typical tug types are available, with specific functions for towing, pushing, pulling and escort towing. Tug efficiency in waves may be limited in an interactive way, considering the local wave height appearing on the screen.
- Wind attenuation effects of buildings,
- Wave-induced forces with six degrees of freedom,
- Reactions due to quay walls or dolphins and allowance for mooring lines,
- Use of anchors,
- Bank and confinement effects.

The model is designed to run on a PC and is controlled interactively from a plan view and a 3D view of study area. Ship manoeuvres are performed in real time.

In addition to the position and trajectory of the ship, certain items of information (travel speed, ship’s heading, currents, wind, etc.) are displayed during the manoeuvre to allow suitable responses to be made in time when faced with different conditions. This information can be saved after each test.

Simflex simulation in course

Figure 11. Views of Simflex simulator

The simulations were carried out under the responsibility and orders of a highly experienced professional Pilot, who is also instructor at ARTELIA’s Ship handling Training Centre of Port Revel. Ships calling at the future terminal were tankers up to 100,000 DWT.

The aims of this task were to:

- Determine the influence of the environmental conditions (current wind and waves), including the possible influence of the jet current induced by the existing and new outfalls, for the approach and departure manoeuvres,
- Assess potential navigation problems when approaching and leaving the jetty, according to its specific position,
- Assess critical current, wind and wave thresholds for safe berthing and departure from berth,
- Define requirements for tugs.

From the simulations tests, it was then concluded that:

- Wind and wave action were predominant for the approach and departure manoeuvres, with nevertheless a certain influence of current
- The waves limited strongly the tug effectiveness and two tugs of 40 t BP each were at least necessary for arrival and departure. The 2 x 60 t BP tugs did not improve significantly the berth availability.
- Downtime estimates were defined to less than 4% of time. Downtimes resulted mainly from waves coming from N300° and N330° directions and environmental limiting values for these directions were not changed with the both nominal tug capacities.

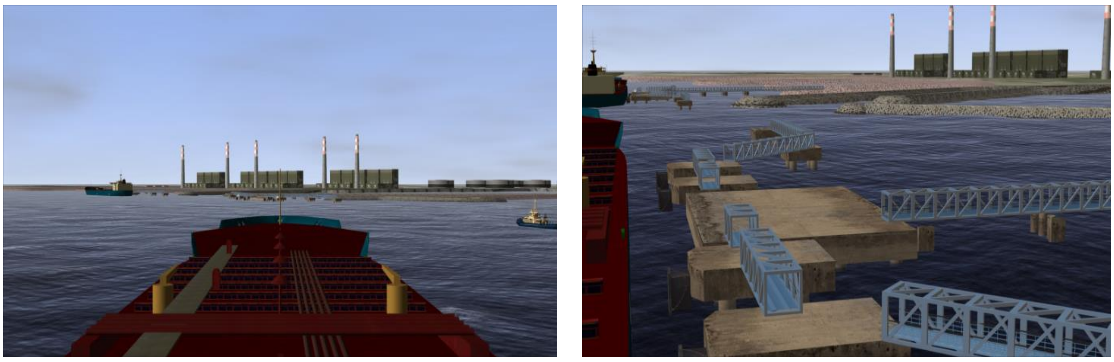

Figure 12. Examples of site 3D view pictures

Physical scale model tests of the seal pit structure

The seal pit structure is composed of a dissipation basin, a weir, a converging basin connected to the outfall structure by pipes (see fig. 13).

The scale model represented one longitudinal half of the seal pit structure and was built with a scale factor of 1/10. The model represented the seal pit from the outlet of the incoming upstream pipe to the intake into the downstream pipe.

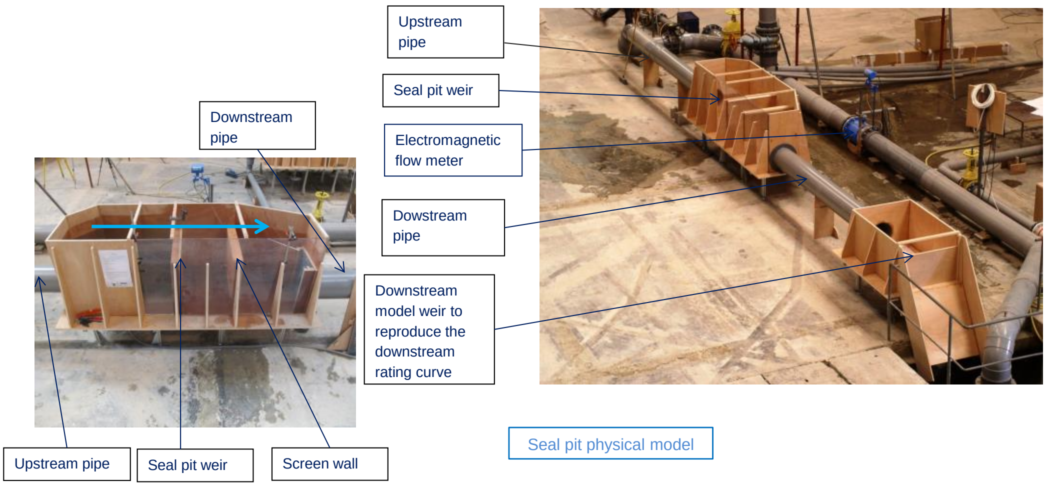

Figure 13. Seal pit physical model

The aim of the scale model was to:

- Verify the flow conditions (air entrainment), in the initial seal pit design, between the seal pit weir and the intake into the downstream pipe,
- Test additional devices, such as upstream screen wall, horizontal slab above the pipe inlet, perforated plate, diaphragm, in order to improve the flow conditions at pipe inlet.

The observed flow conditions at pipe inlet for the initial design were as follows (see fig. 14):

- The air entrainment (air bubbles) into the downstream pipe due to the falling nappe from the weir appeared to be too important.
- Some air entrainment from the surface was observed periodically, due to the very low submergence of the downstream pipe.
- No vortex was observed, as the flow was too turbulent.

Figure 14. Seal pit initial design physical model tests

Several devices were tested in order to improve the downstream flow conditions and reduce the air entrainment by air bubbles and low water level:

- The screen wall alone and the horizontal slab above the pipe inlet did not prevent the air bubbles to reach the pipe inlet.
- Results obtained with diaphragm or perforated plate, were interesting as they allowed for cancelling totally the air entrainment risk by fluctuation of the water level close to the pipe soffit elevation and reducing considerably the air entrainment risk due to the air bubbles generated by the falling nappe.

As a consequence, the most efficient tested configurations were found to be (see fig. 15):

- Screen wall combined with a diaphragm (circular coaxial diaphragm at pipe inlet),
- Screen wall and perforated plate (Arrangement of holes: circular, regularly spaced vertically and horizontally).

Figure 15. Seal pit additional devices physical model tests

Physical model tests of seawater pumping station

A scale model of the pumping station was built and operated in ARTELIA’s hydraulic laboratory, taking into account the modifications recommended by the previous design review.

The aims of the model were to:

- Check the shape of the pump sump and bays and approach conditions to avoid unacceptable pre-swirl, vortices and air-entrainment at the pumps,

- Identify and test upgrading solutions.

The model was built at the scale 1 / 17.5 and represented the structure from the drum screens outlet to the circulating water pumps. The auxiliary pumps were represented without pumped flow, as the corresponding discharges were too low to be reproduced.

Different configurations were tested, corresponding to various operation modes and discharges:
- Normal or maintenance conditions of the screen lines (3 or 4 screens in operation),
- Normal or maintenance conditions of the circulating water pumps (3 or 4 CWP in operation),
- Nominal discharge or 150% of nominal discharge.

Operated according to the Froude similitude, the model showed that the global flow pattern within the station was satisfactory and that no vortex stronger than Class 2 was generated. This is considered as acceptable.

However, the flow conditions in most of the tested configurations generated pre-swirl at the bell mouths, with a swirl angle exceeding the upper limits given by international standards.

The implementation of anti-vortex devices was therefore recommended and a floor splitter plate under each of the 4 main pumps was proposed to be implemented (see fig. 16). Such plate is longitudinal, vertical in the axis of the pump bay and joins the invert to the bell mouth.

A second series of tests showed that the addition of such structures was very efficient, as the pre-swirl was almost totally annihilated. The global flow pattern within the pumping station was not modified and the strength of observed vortices remained fully acceptable.

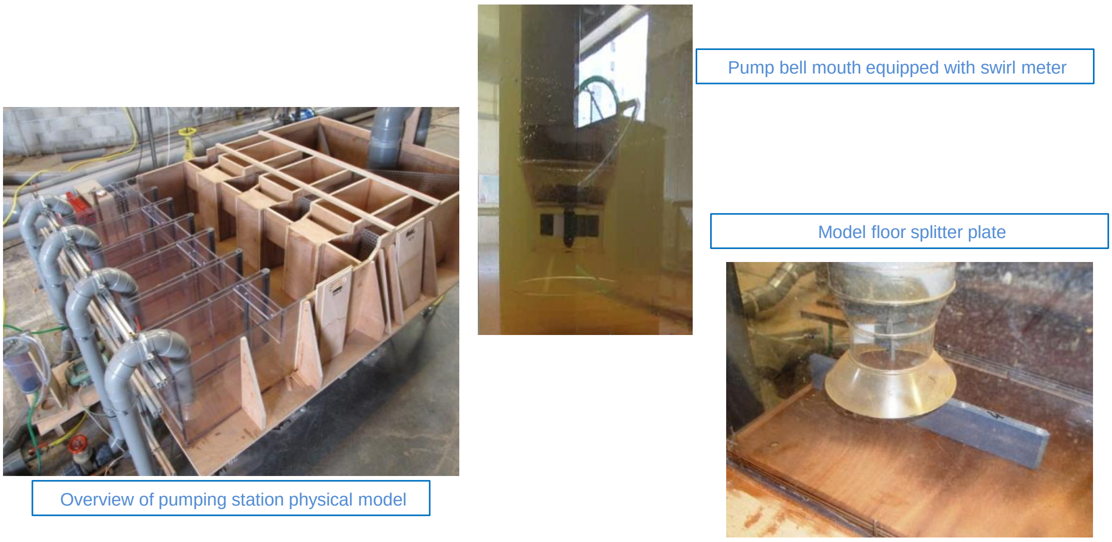

Figure 16. Pumping station physical model tests

Conclusions

The main points of these studies concerned:

- The specific bathymetry that induced strong wave attack and wave slamming up to a distance of at least half to one deep-water wave length from the reef edge (about 50 m), before adaptation to the local water depth and decrease in wave height.
- The wave conditions difficult to be defined precisely with a numerical model.
- The good combination between mathematical and physical modelling.