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Engineering a new Port at Hazira, Gujarat, India

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Background to Project

Hazira in the State of Gujarat in India was designated as a port location by the Gujarat Maritime Board (GMB). In 1997, the GMB invited applications by international competitive bidding for the development of an all-weather, multi-cargo port at Hazira. The initiative was LNG driven in response to the increasing requirement for natural gas as a fuel in North-West India. Following a rigorous evaluation process in November 1999, GMB selected Shell Gas B.V. to develop, operate and maintain the port on a BOOT (build, own, operate, transfer) basis.

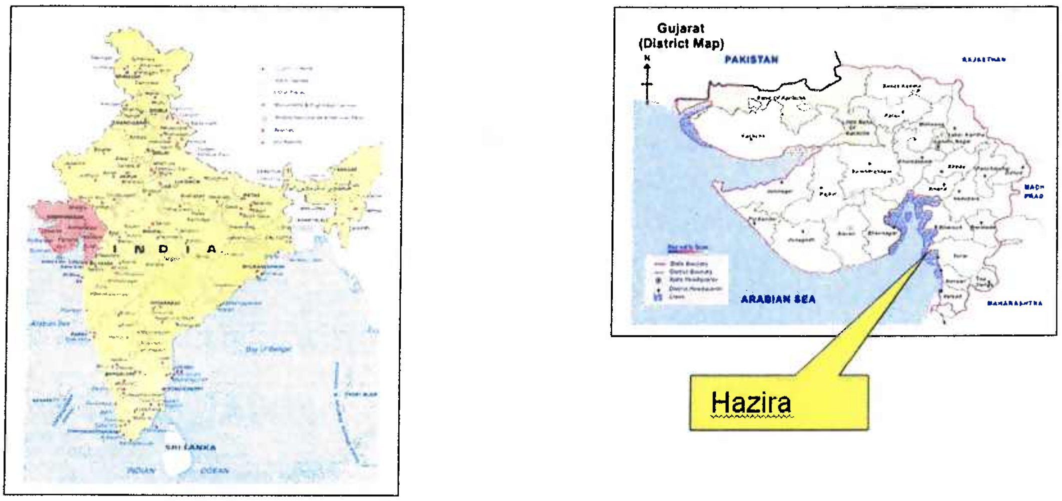

Figure 1 Project Location

There then followed an intensive period of surveys, engineering and environmental studies to develop both the terminal concept and the phased master plan for development of the port facilities for LNG, containers and other cargoes. These studies and survey were managed by Shell Global Solutions International BV (Shell GSI) which awarded the engineering of the marine facilities to Delta Marine Consultants (DMC). For part of the investigations, studies and surveys DMC engaged several subcontractors: Studies on sedimentation, currents and nearshore wave-analysis (Svašek), Nautical studies (Alkyon), Cyclone modelling (HR Wallingford). Shell GSI separately awarded a contract for metocean data collection to Fugro GEOS.

This paper will give an overview of these investigations and studies with emphasis on issues of particular interest including:

- meteorological and oceanographic data gathering (currents, waves, water quality)
- coastal structures design and physical model testing
- moored ship response
- navigation studies and channel design optimisation
- marine operability (downtime) modelling
- sedimentation and coastline development studies
- quarrying and logistics issues

The implementation of Phase 1 of the port started early 2002 with design, procurement and construction of the port infrastructure undertaken through a management contract with Hazira Marine Engineering Private Limited (HME). Capital dredging works were implemented under a separate contract with Alar Infrastructure Private Limited. The port and LNG terminal became operational as of April 2005.

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Planning and Layout Overview

The development of the port comprises three phases:

- Phase 1: LNG terminal
- Phase 2: Bulk and General cargo terminal
- Phase 3: Additional LNG berth and container terminal

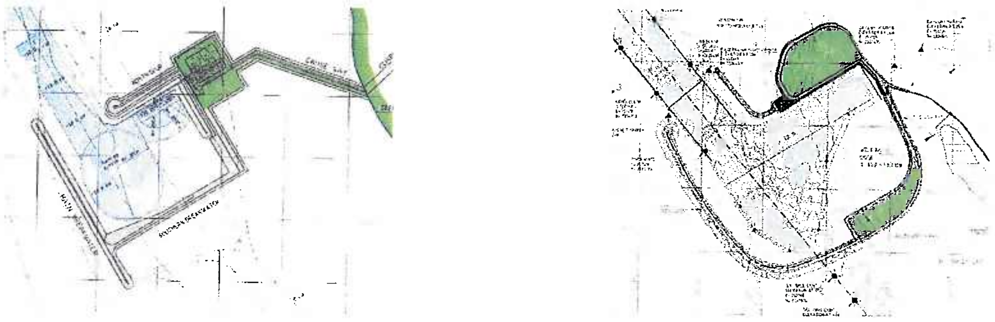

Figure 2 Early harbour development concepts

In Figure 2 the full port layouts developed in the early stages are shown. The initial concept is shown in the left picture. After the first nautical-, operability and current/wave studies the layout as shown in the right picture was developed. The breakwaters were streamlined to reduce eddies and turbulent tidal current behaviour, consequently the velocity at the harbour entrance was reduced.

Following changes in the Coastal Regulatory Zone (CRZ) legislation, the reclamation for the LNG terminal was shifted to shore, which resulted in additional studies to further optimise the layouts.
Figure 3 shows the phase 1 layout (LNG terminal), which resulted from these studies.
moved north of the northern spur. Near the southern spur the facilities for non-LNG vessels were provided. The breakwater dimensions were optimised on the basis of nautical studies (stopping length).

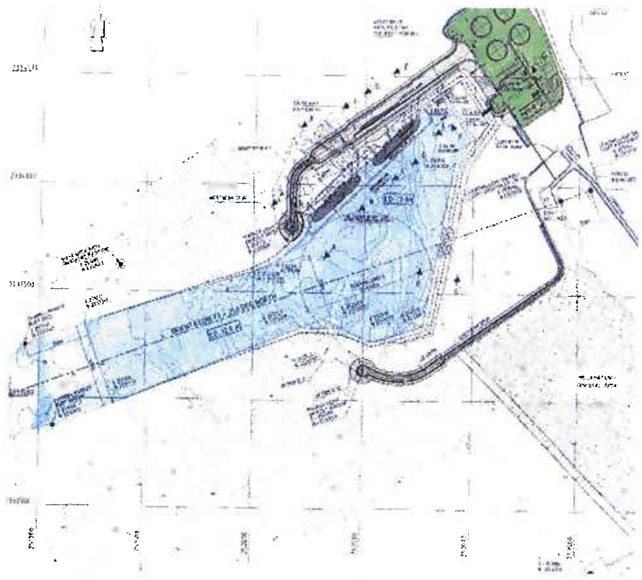

Figure 3 Phase 1 layout (LNG terminal) (final version).

The initial layouts focussed on an approach in line with the predominant current (NW) for a fully protected port layout in line with the master plan concept shown in Figure 2. It was later decided to limit the extent of the breakwater constructed at the first stage of port development. In so doing, it was also decided to adopt a revised approach and departure philosophy with an approach channel aligned closer to the prevailing SW monsoon

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winds to in the NW-SW direction. The feasibility was confirmed on the basis of ship navigation studies and metocean data monitoring campaign.

The selection of a SW approach with predominantly cross currents results in a reduction of dredging costs and navigational benefits at Phase 1.

An additional study was made on the length and orientation of the south spur in combination with a siltation and maintenance dredging study. Three alternatives of the southern spur have been envisaged. The main difference was to which extent they shelter the port. This will be described further on in this paper.

Metocean Study

The metocean study was essential for the understanding of the environmental conditions at this specific location. The Hazira project is located in a challenging physical environment with a high tidal range, significant tidal currents, exposure to the influence of the southwest monsoon weather patterns and to tropical cyclones.

In Table 1 a summary is made of the main characteristics:

Mean High Water Spring (MHWS)	MSL + 3.8 m
Mean Low Water Spring (MLWS)	MSL -4.0 m
Mean High Water (MHW)	MSL + 2.5 m
Mean Low Water (MLW)	MSL -3.5 m
1: 100 year significant wave height near shore $H_{s\ 1/100}$	5.4 m
Cross current spring tide	2 m/s

Table 1 Main metocean characteristics

Fugro (GEOS) measured the nearshore waves at a waterdepth of 20 m from June 2000 to August 2001. This period included two monsoon seasons approximately mid May to the end August). A wave buoy was used with a back up wave gauge.

Besides the wave measurements, the metocean campaign contained:

- Current measurements using an Acoustic Doppler Current Profiler (ADCP)
- Water quality sampling and testing
- a metstation to measure wind speeds, temperatures and pressures
- a tidal gauge
- Ocean Surface Current Radar (OSCR)

The results of the metocean data gathering campaign were used to validate a 10 year hindcast of the nearshore wave climate based upon offshore hindcast data and SWAN analysis by SVASEK. Comparison of the simultaneous offshore British Meteorological Office (BMO) Global wave model data and nearshore wave measurements showed that especially at low water the measured sea and swell waves were lower than the computed waves. This was explained by the presence of shallow banks relatively close to Hazira port.

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Southern spur and dredged channel optimisation

Three options have been considered for further optimisation of the southern spur namely:

- C1 A short spur with high crest height in the shallow area and a crest around MSL in the deeper areas.
- C2 A longer spur with a crest over the entire length.
- C3 A short spur with a high crest over the entire length.

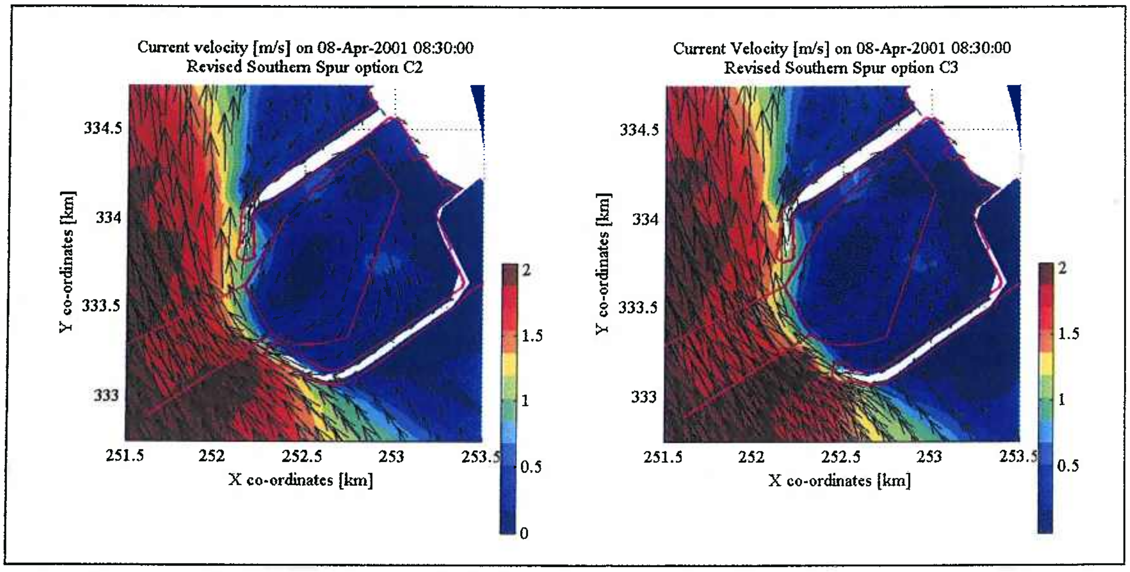

Figure 4: Calculated current patterns during strongest flood currents (Svašek)

Hydrodynamic studies have been performed by Svašek to firstly compare the current pattern around the breakwater heads (Figure 4). Subsequently the siltation rates could be determined. It was concluded that mainly sand is deposited in the approach channel, while silt is deposited in the basin. The silt is deposited in the basin by exchange through the large tidal range and the eddy current exchange. As C1 and C3 were both having the same layout the impact on sedimentation was equal. Siltation for the C2 alternative was slightly lower.

To assess the effect of the sediment changes due to the port development on the existing shoreline, a simplified coastline development study was done also using satellite images. It was concluded from this study that the effect of the port on the shoreline would be limited.

The current profile around the breakwater heads is also used to compare the situation at the moment of the arrival of the LNG carrier. Figure 5 shows that for a longer spur the current velocities in the port entrance and turning circle are higher. Outside this area, the current velocities in options C2 are higher due to the fact that the C2 spur protrudes further into the sea. This extra deflection of the tidal current results in higher velocities in the approach channel near the port.

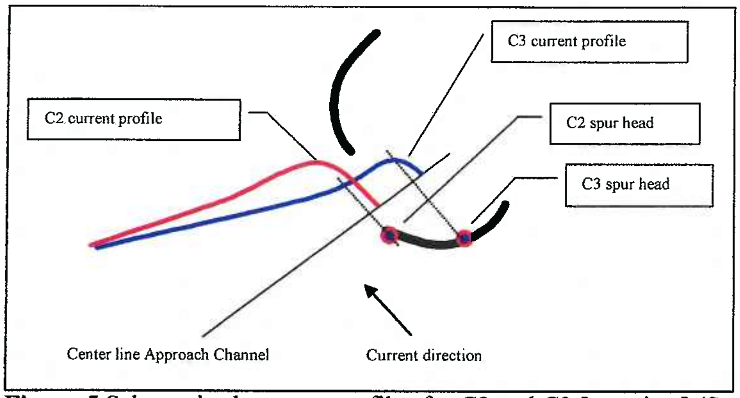

Figure 5 Schematised current profiles for C2 and C3 [top view] (Svašek)

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A wave penetration study was carried out to determine the influence of various spur layout options on the wave climate in the Port of Hazira. Special interest has been paid to the wave patterns at the position of the planned LNG berth, as this determines the anticipated downtime of the berth.

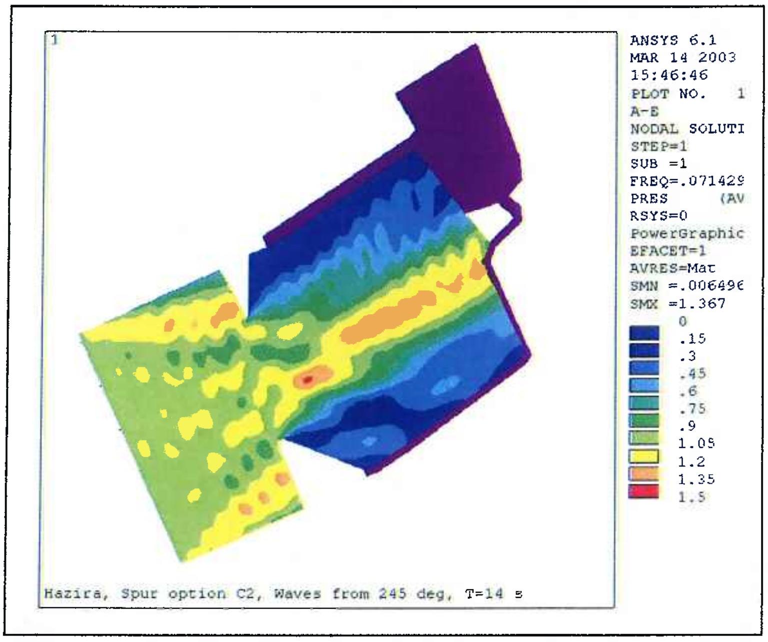

Figure 6 wave diffraction study 245 ° T=14 sec.

Nautical studies & channel optimisation

On the basis of the results of the wave diffraction study a downtime analysis was made for the LNG berth location. A minimum uninterrupted off-loading period of 14 hours was considered. The operations that are performed during an off-loading cycle in monsoon and the required checks on limiting criteria are shown in n Figure 7. To analyse the moored ship response and determine the operability limits a TERMSIM study on the moored ship response was performed. Limiting metocean arrival and departure condition have been assessed on the basis of navigation studies carried out by Alkyon.

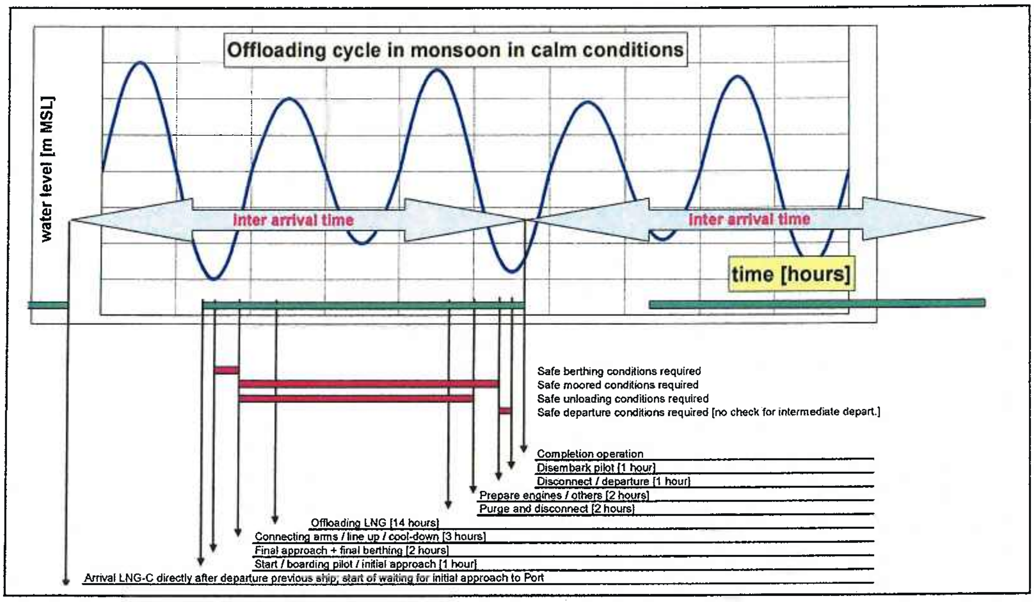

Figure 7 Offloading cycle in monsoon in calm conditions

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This study concluded that the size of the proposed dredged area in the harbour was sufficient and that the vessels could safely approach and enter the harbour under the tested conditions. A permanent wave buoy (including current reader), metstation, tidal gauge have been installed to provide required environmental data to the pilots.

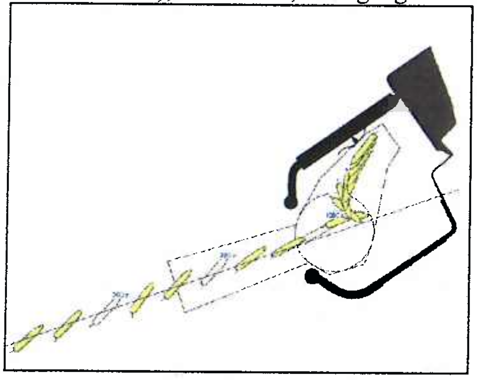

Figure 8 Arrival LNG. Tidal phase average tide HW + 3.0 hrs; wind 9,0 m/s Dir 260 °. Swell waves H_s = 0.8 m, Dir 245 ° Sea waves Hs = 1.3 m, dir = 250 °.

A layout of the LNG berth was developed for LNG carriers of 75,000 m^3 DWT to 145,000 m^3 DWT consisting of a short approach trestle, a platform 4 breasting dolphins and 5 mooring dolphins as indicated in figure 9.

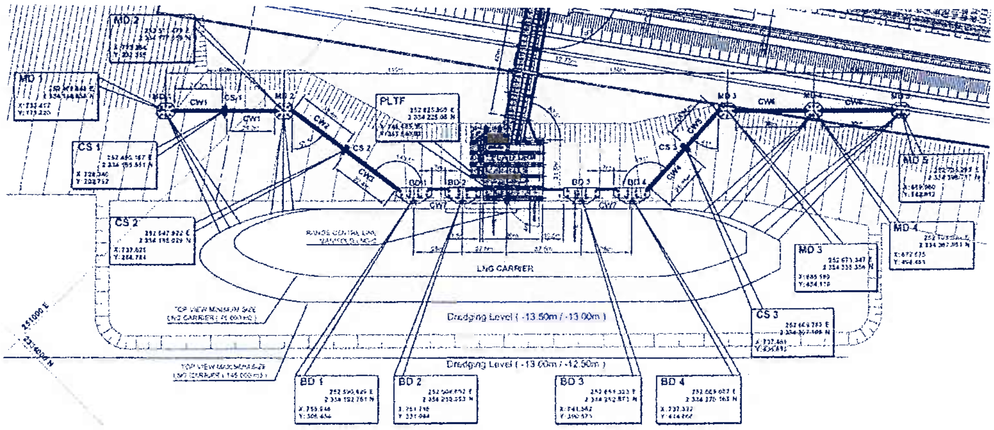

Figure 9 LNG Berth

Breakwater design
After the optimisation studies the final layout was determined.
The detailed design of the original main breakwater was made by DMC and model tested at Sogreah. The detailed breakwater design of the final layout was done by Saipem SA under the HME management contract and tested at HR Wallingford. Both designs use Accropodes as main armour. A low crested breakwater design was adopted with the primary armour continuing over the crest and onto the back face. Because of the high tidal currents, extensive granular scour protection is used.

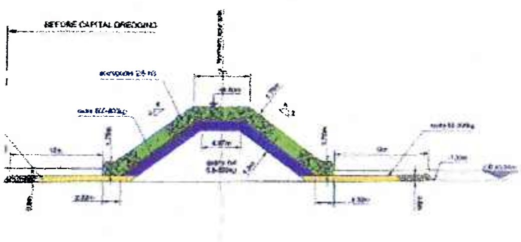

Figure 10 Breakwater design with Accropode Armour layer.

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Quarry and logistics

Figure 11 Trial blast at Dhrupka

Given the anticipated volumes of rock a quarry investigation and logistic study were carried out at an early stage in project planning. Trial blasting and laboratory testing on samples were carried out at four sites between late June and October 2000.

A logistic and cost study was carried out to determine the most economic ways to supply the harbour with sufficient rock volumes. A quarry on approximately 100 km from the site was selected and the supply of material was via land based transport.

Figure 12 Initial dirt road along the coast and completed access road to Hazira port

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Harbour under construction

Figure 13 Construction ongoing 2003

As the SW monsoon season sets the criteria for the design of the port it also limits the possibilities during construction. During the monsoon season, from approximately mid May until the end of August marine operations are almost impossible in an open sea environment. This was taken into account in the planning of the construction works.

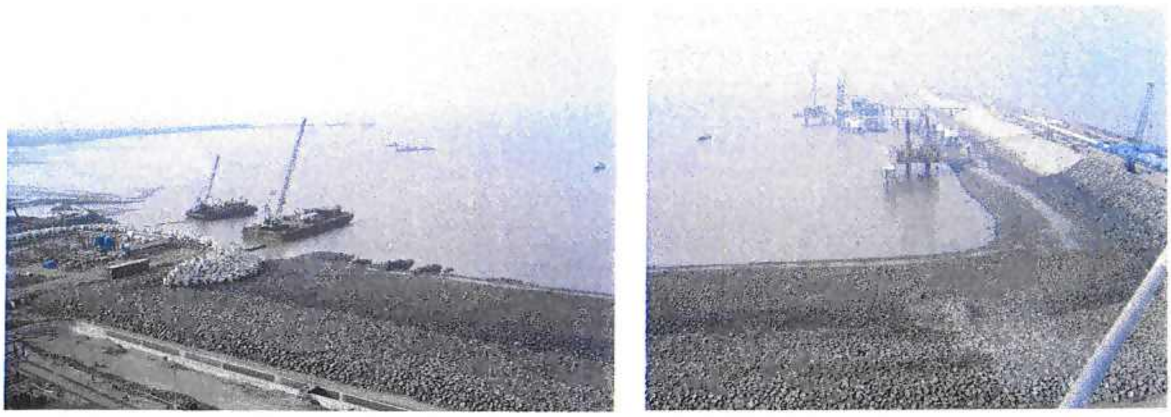

Figure 14 Overview from LNG storage tanks, October 2004. Left: Cooling water intake, Right LNG Terminals

Conclusions

Hazira Port Private Limited became operational in April 2005 when the first cargo of LNG was received. The port and LNG terminal is a joint venture between Shell Gas B.V. (74%) and Total Gaz Electricité Holdings France (26%).

A major port development has been realised in a short period of time. The specific location of the port and the prevailing environmental conditions, like high tidal range, significant tidal currents and the influence of the southwest monsoon, made design and construction challenging. It required the involvement of many specialists with different fields of expertise. In this paper only a part of this has been discussed.

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