PORT 2000, LE HAVRE’S NEW CONTAINER TERMINAL: BREAKWATERS AND DREDGING OF THE NAUTICAL ACCESS CHANNEL

ABSTRACT
The construction of Port 2000, at Le Havre, France marks a significant expansion of France’s largest port and the fifth largest in Europe. To facilitate the elaborate expansion plans, the project was divided into several phases. These included dredging of an access channel, construction a 10 km protective breakwater, building quay walls and dredging a basin on the river side of the port. In addition two beaches were created and two caissons were manufactured, towed and sunk.

Flexibility in the execution of the works was necessary, as environmental and economic issues arose. The original plans were adapted to mitigate environmental impacts in the Seine Estuary and to maximise the re-use of dredged material. The innovative development of the accurate dynamically positioned and automatically guided spraying pontoon Bayard II was of crucial importance. Being ready and able to take advantage of good weather conditions was also essential as the Channel can be hostile with heavy swells. In addition, because of the presence of ordnance from World War II site investigation was required before work could commence.

Port 2000 is expected to have long-lasting economic impact on the development of container shipping and transshipments in the northern European area.

INTRODUCTION
As the first and the last port of call on the Hamburg, Germany to Le Havre, France shipping route, the French port of Le Havre needs a deep draught for welcoming the newest generation of vessels, for both inbound and outgoing traffic. Located 365 km from Paris at the mouth of the Seine Estuary, the port of Le Havre is the largest container port of France and the fifth largest in northwestern Europe (Figure 1). Existing container terminals at Le Havre have reached their maximum capacity and some are built behind the François I lock making them less accessible for larger ships. The increase of scale of container vessels and the ever stricter time schedules and throughput times prompted authorities to decide to construct a completely new port. The site chosen is south of the existing facilities, and is in a plain estuary subject to tidal movements and directly facing the sea swell.

CONTRACT
In late August 2001, the Le Havre Port Authority (PAH) awarded the main contract for the construction of Port 2000 to a joint venture comprising Dredging International, GTM Terrassement (pilot), Campenon Bernard TP and Vinci Grands Projets. The aim of this project, as far as the “wet” side is concerned, was the construction of the inner and external breakwaters and the dredging of the maritime access and internal channel of the new container port. The contract was awarded for an amount of € 218 million including eight options for a total of € 103 million of which four more will be awarded later. The project was initially scheduled for 37 months and was finalised in 47 months, taking into account the elaborate permitting procedures that were encountered and that final dredging operations were postponed in agreement with the Port Authorities.

The original Joint Venture offer was withheld owing to the introduction of alternative
schedules to minimise the environmental impact of the works on the Seine Estuary. In addition, other optimal economic solutions were sought. In this respect, fine-tuning the phases of execution, the maximising the re-use of dredged material, and the innovative development of the accurate, dynamically positioned and automatically guided spraying pontoon Bayard II have been of crucial importance. Alternative and beneficiary execution methods presented to the client, were clearly decisive in obtaining the contract.

During the first few years of the 21st century, the construction of Port 2000 was the biggest maritime undertaking in Europe. Construction was completed late in 2005 (Figure 2). Remarkably it was exactly a century earlier that the extension of the port of Le Havre had been begun by a number of Belgian-based companies. On March 30 2006, the new port was inaugurated, and reportedly there has been an increase in vessels calling and in container movements per call. Ultimately the new facilities will triple container throughput to 6 million TEU per year.

SCOPE

The Nautical Access Channel

The nautical access channel to Port 2000 is dredged to a level of –16m CMH which allows a tide-independent access for the largest container vessels. The access route comprises:

- An exterior channel of 4000 m presenting a bottom width ranging from 580 m at its connexion with the existing entrance channel up to 300 m at the entrance of the new harbour.
- An internal channel protected by the southern breakwater, having a length of 4000 m as well and a bottom width of 300 m.
- A turning circle with a radius of 353 m.

Channel slopes vary from 5/1 for the exterior channel and 3/1 for the internal channels.

The total dredged volume was over 45 million m$^3$, principally sand and silex gravel. Where possible dredged material has been reused as reclamation material (11 million m$^3$) and to construct the foundations and the core of over 10 km of breakwaters (6 million m$^3$ of gravel). A disposal site for the rest of the materials was available at the offshore site of Octeville.

Breakwaters

The southern breakwater forms the main protection of the new port over a length of 5900 m. It is a sloped dike constructed on a 50-m wide sub-base realised in dredged gravel. The external protection is completed on the north side by the northern breakwater (300 m), which is linked to the existing concrete breakwater of Le Havre (Figure 3).
Bunds 3660 m long were realised on the northern side to limit the future platforms behind the quays. These bunds will be replaced in the future by quay walls, as the container terminals are expanded. Four quays were actually constructed over a total length of 1400 m, eight more are to be constructed in future contracts. The construction of the quay wall was part of a specially dedicated contract, assigned to a civil contractor.

Inner bunds and outer breakwaters are essentially composed of a core of dredged gravel, covered by a watertight layer and protected by several layers of quarry rocks. The southern breakwater has in its most exposed sections an outer protection made of Accropodes®.

Beaches
As an added, perhaps surprising, plus point the new harbour includes two reclaimed gravel beaches. The first, called “internal beach” is situated just behind the northern external breakwater. Its major purpose is to create an ecologically interesting area to sustain a marine plant called “crambe maritima” which were threatened by the extension works. The second beach, situated at the outer side of the same northern breakwater, is created to ameliorate the wave climate at the new port entrance. It should absorb a complex superposition of waves created by diffraction in the new channel and reflection on existing vertical walls.

“Musoirs”
Musoirs is the French word for the two concrete caissons, placed at the entrance of the port, marking the northern and southern sides. These massive structures (surface: 55 m x 21.5 m x height 30 m) were imposed to reduce the opening at the entrance to 300 m so as to limit internal wave action (Figure 4).

Theoretically, a dike formation could have been created to protect of the fairway. Unfortunately this would have required such an acute slope that a much wider port entrance would have been needed. And a wider port entrance would increase wave movements, agitation and turbulence within the inner port that would have decreased port safety beyond acceptable limits. Hence it became clear that a very narrow entrance, which could not be realised without the huge caissons, was preferable.

For the major part the caissons were constructed in a drydock in the inner harbour, and then set afloat, towed and sunk on location onto prepared gravel bases between –17 m and –20 m CMH. This unusual part of the project will be discussed more thoroughly below.

WORKING IN PHASES
From the preliminary studies onwards, the Port Authority was fully aware that the phasing of the works would have a major impact on the sedimentological evolution of the estuary during and even after the completion of the works. The Port Authority had to consider that diminishing the width of the estuary at the height of Port 2000 by 20 percent, would have a significant influence on flood channel displacements and resulting erosions, as well as sand displacement and deposits. In addition, this is an ecologically and also economically valuable area because of the presence of the entrance channel to the port of Rouen 100 km inland on the Seine.

The 776 km long Seine river discharges into one of the largest estuaries of northwestern Europe, a 30,000-ha maritime, industrial and wetland area spanning more than 5 km which includes both the mouth and the fairway to the port of Rouen. The average discharge of 500 m<sup>3</sup>/s, the important tidal range of up to 8 m, and very strong currents cause a huge sedimentation transport. This, incidentally, moves the mouth of the estuary westward at a rate of 50 m per year.

For these reasons, “phasing the works” was a serious issue for the Joint Venture
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graduated as a Civil Engineer (MSc) from the State University Ghent, Belgium. He joined DEME in 1989 and has worked as desk operations manager and project manager on numerous projects. From 2001-2005 he was co-project manager Marine Works PORT 2000 Le Havre (France) for the DPAM Joint Venture (GTM / DI). Since 2005 he is Resident Manager of Société de Dragage International (SDI), Lambersart, France.

and an alternative solution was proposed to ameliorate the environmental impact. The phasing proposed in this offer is described as follows.

The works would start with dredging the inner basin and creation of the inner bunds. In the first phase this would allow:

- only a very limited deviation of the flood currents, which reach peak values of 5 knots (2.5 m per second at high tide).
- and the ability to take advantage of the presence of gravel in the upper layers, making an immediate construction of the eastern bund possible.

After closing the bund, a reclamation area was made available in which sand could be stocked. The eastern and central sections of the reclamation cover an area of 78 ha and provide a fill of 7.7 million m³. Underneath the dredged sand other gravel layers were situated so that in a second phase further bunds could be realised with this gravel. This was continued till a maximum distance was reached between dredging area and the bund realisation. At a distance of longer than 750 m the economical and technical advantages of directly pumping gravel decreased significantly, because of the massive pump capacity required for the transport of the gravel.

At the same time on the western part of the channel an access channel was created, requiring small hopper dredgers with limited draughts as the area was very shallow. In a later phase the channel permitted the use of bigger (and more economical) hopper dredgers. It also allowed the transport of 3 million m³ of gravel present on the western area to be imported to underwater stock areas as close as possible to the western bunds and dikes to be constructed. This allowed direct pumping from these stocks by cutter suction dredgers into the gravel basement in a second phase.

Once the inner bunds were realised and sufficient gravel stored by the hopper dredgers in the underwater stock areas, a new phase was started: the construction of the western sub-base. The two underwater stock areas had a total capacity of no less than 3 million m³. In order not to obstruct totally the flood currents, only the sub-base was constructed in this phase; the upper dike construction was started several months later.

The sub-base reaching +3 CMH was submerged at high water. This means that only a part of the flood is deviated. The creation of this barrier has as a natural consequence the deviation of the flood stream and the creation of a new flood channel, south of the southern breakwater. The partial deviation combined with a close follow up of this evolution allowed a continuous assessment of the evolution of the estuary and the possibility to adapt the phasing whenever required.

One of the economic risks was the displacement of huge quantities of sediment and their deposit in the navigation channel towards Rouen. Therefore this flood channel creation was “accompanied” by dredging works along its path, removing the sediments in a controlled way and disposing of them outside of the estuary on the site of Octeville. A complementary measure with the same objective was the 750 m elongation to the west of the submersible dikes on the north side of the same navigation channel.

Once the western foundation was realised, the upper dikes were constructed, using a temporary access dike in the middle of the port. This allowed work to be done simultaneously to the east and to the west thus accelerating the construction process. The total length of the protection dikes was 5.9 km, to which another 3.66 km of the closing dike had to be added. On average, width at the top was about 50 m.

The temporary division of the inner waters of Port 2000 made by building this temporary access dike had created separate basins with a length of 1 to 2 km each. Finally, in order to eliminate the strong currents which generate erosion risks, the temporary access dike and the eastern dike were opened and closed in one operation, thereby sustaining the equilibrium between two huge basins.

DREDGING WORKS

From the beginning several factors influenced the mobilisation schedule of the equipment and in particular the preparation of the dredgers, especially those designated
To operate in the gravel areas: These included a very tight schedule, combined with offshore conditions like huge tides up to 8 m and strong currents. For these reasons the following dredgers were deployed.

Cutter suction dredgers (CSDs) were chosen to dig the internal channel, pumping the gravel through the dynamically positioned and guided diffuser Pontoon Bayard II directly into the sub-base of the future bunds and breakwaters. Sandy materials were reclaimed in the areas limited by the inner bunds. Significant investments were made in dredgers like the Vlaandern XIX, for instance, by introducing wear-resistant layers in the pipelines and the pump houses before starting the works so as to be prepared for gravel dredging.

Trailing hopper suction dredgers (TSHDs) of different capacities were needed. At first, small and medium dredgers having a limited draught were deployed, so as to initiate a minimum channel in the shallow areas. Thereafter high capacity dredgers as Antigoon (8000 m³), Lange Wapper (13,700 m³) and Uilenspiegel (13,700 m³), to accelerate the creation of the channel and to import the gravel from the western area into the underwater stock areas were introduced. Dipper dredgers such as the Big Boss and Zenne were brought in for particular operations during archaeological investigations on historic wrecks and assistance with complementary ordnance clearing operations, as well as the lengthening of the submersible dikes alongside the navigation channel to Rouen.

Pontoons with heavy cranes like De Bever plus an armada of tugs, multicats, floating and submerged pipelines as well as crew vessels and a survey boat equipped with latest technologies as multibeam sonars provided general assistance (Figure 5).

Table I presents an overview of the main equipment used. Up to 250 people were mobilised for the operations which continued for three years continuously on a seven days a week, 24 hour a day.

**SUB-BASE CONSTRUCTION**

The sub-base of the dikes had been designed as a massive construction situated in gravel with a top level at +3 m CMH, directly placed on the seabed. Therefore the construction has a variable height going from 3 m for the shallowest areas up to 6 m for the deepest. On the top, it has a 50-m width, with a mean section of 350 m². With a total length of 10 km, 3,500,000 m³ was thus required to be placed.

Taking these quantities into consideration, combined with the offshore circumstances, a major concern for the Joint Venture from the beginning was to develop a technique which could manage the quantity of reclaimed materials as well as expedite the progress of the works. This demanded being able to take advantage of favourable weather conditions whenever possible.

To meet these requirements a technique was devised in which the gravel was directly pumped using a CSD as the dredging unit and a dynamically positioned and guided diffuser (DPGD) pontoon as reclaiming unit. The DPGD measures the density and the velocity of the materials delivered by the CSD, calculates the quantity of materials needed on the spot to realise the sub-base, and automatically controls the winches of the unit. These techniques allowed the work to progress at 300 m sub-base per week, compared with progress of less than 100 m using the classic dipper and split-barge techniques.

Table I. Overview of the main equipment used during the three-year project.

<table>
<thead>
<tr>
<th>Type</th>
<th>Name</th>
<th>Installed Power</th>
<th>Hold capacity</th>
<th>Principal task</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSD</td>
<td>Vlaandern XIX</td>
<td>11,728 kW</td>
<td></td>
<td>Dredging of gravel material, pumped directly into the sub-base through DPGD Bayard II. Reclamation of gravel beaches</td>
</tr>
<tr>
<td>DPGD</td>
<td>Bayard II</td>
<td></td>
<td></td>
<td>Gravel sub-base construction Ballasting caissons after their installation</td>
</tr>
<tr>
<td>CSD</td>
<td>Rubens</td>
<td>10,896 kW</td>
<td>13,700 m³</td>
<td>Sand dredging and reclamation</td>
</tr>
<tr>
<td>CSD</td>
<td>Vlaandern XI</td>
<td>9,862 kW</td>
<td></td>
<td>Sand dredging and reclamation</td>
</tr>
<tr>
<td>THSD</td>
<td>Lange Wapper</td>
<td></td>
<td>13,700 m³</td>
<td>Channel dredging</td>
</tr>
<tr>
<td>THSD</td>
<td>Uilenspiegel</td>
<td></td>
<td>13,700 m³</td>
<td>Final Channel Dredging</td>
</tr>
<tr>
<td>THSD</td>
<td>Antigoon</td>
<td></td>
<td>8,400 m³</td>
<td>Dredging and transport of gravel to the under water stock areas</td>
</tr>
<tr>
<td>THSD</td>
<td>Vlaandern I</td>
<td></td>
<td>2,065 m³</td>
<td>Minimum channel realisation and accompanying dredging works in the new flood channel</td>
</tr>
<tr>
<td>THSD</td>
<td>Vlaandern XXI</td>
<td></td>
<td>1,751 m³</td>
<td>Accompanying dredging works in the new flood channel</td>
</tr>
<tr>
<td></td>
<td>Charlemagne</td>
<td></td>
<td>5,000 m³</td>
<td>Gravel dredging for the realisation of the caisson foundations</td>
</tr>
<tr>
<td>Dipper</td>
<td>Big Boss</td>
<td>1,928 kW</td>
<td></td>
<td>Wreckage removal and complementary ammunition removal</td>
</tr>
<tr>
<td>Dipper</td>
<td>Zenne</td>
<td>805 kW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Split barge</td>
<td>DI 68</td>
<td></td>
<td>1,000 m³</td>
<td></td>
</tr>
<tr>
<td>Split Barge</td>
<td>DI 69</td>
<td></td>
<td>1,000 m³</td>
<td></td>
</tr>
<tr>
<td>Heavy Lifting pontoon</td>
<td>Rambiz</td>
<td></td>
<td></td>
<td>Installation of the « musoirs »</td>
</tr>
</tbody>
</table>
As explained in the “phasing” chapter above, the western part of the sub-base was planned to remain unprotected for several months before construction of the upper dike. Furthermore, the gravel layers present in the areas to be dredged contain a significant quantity of sand, which is even more susceptible to erosion.

Using a partnering concept between client, contractor and the engineering company Sogreah, a detailed study programme was set up to search for a solution. Combining mathematical and physical models, as well as experimental try-outs on site, did ultimately help to adapt execution methods aimed at reducing the erosion of sub-base material. Mathematical modelling was followed by physical modelling and trials on site.

The solution found was to anticipate partially the movement the gravel would undergo and to adapt the sub-base design in its first phase. It was estimated that 300,000 m$^3$ of gravel consumption was economised thanks to this adaptation.

Special attention was paid to the construction of the foundations, which also used dredged gravel delivered by the gravel dredger Charlemagne. Before placing the caissons, the foundation bed at –16.50 m had to be levelled with a precision of 5 cm. To meet the demands of this precision, the CSD Vlaanderen XIX was equipped with a levelling plate instead of the standard cutterhead and a tension wire for precisely double-checking the exact level of the plate. Good weather conditions prevailed once again, and allowing use of this technique, which proved decisive for the successful completion of construction.

**CONCLUSION**

There is no doubt that the realisation of a project like Port 2000 demands the combined experience of engineers, superintendents, captains and their crews. On the other hand, a project like Port 2000 results in broadening the experience of all the participants.

Amongst the challenges faced by the Joint Venture were the exposure to difficult weather circumstances with heavy sea swells, reckoning with strong tidal and current changes, the safety factors of the possible presence of military ordnance and limiting the displacement of large quantities of sediment and their deposit in the navigation channel of the Seine. This latter item has both economic and ecological consequences.

During the 47 months of work 250 people were continuously on the job and each and every piece of major plant in the Dredging International fleet was occupied. Thus as an economic driver, the development of the Port 2000 project was a significant force. In the future as well this role will continue, as the long-term aim of the new Port at Le Havre is to become a logistics hub for container vessels in northern Europe. In this way, the port of Le Havre will provide the local population with sustainable growth that is environmentally acceptable and beneficial for the development of the region as a whole.

### VIRGINIE AND STEPHANIE

Two concrete caissons (L x W x H = 55 m x 21.5 m x 30 m) were constructed in the drydock “Forme 7” inside the existing harbour. They weighed 13,000 tonnes each and represented, after flooding, a draught of about 13 m. These two caissons marking the entrance of the new port were named after the two site secretaries, Virginie and Stephanie, in tribute to their work.

To stabilise these floating “matchboxes” posed on their side during transport, the heavy lifting pontoon Rambiz was used. By lifting about 1000 tonnes, it reduced the draught to 12 m.

Utilising pre-installed anchors, the pontoon could be positioned very accurately allowing a tolerance of a few centimetres. Taking advantage of the outgoing tide and by ballasting the caissons, the sinking was realised in a controlled way. Once touch-down took place on the foundations at –16.50 m CMH, further ballasting was immediately executed by pumping gravel through the DPGD Bayard II especially adapted to this particular situation.