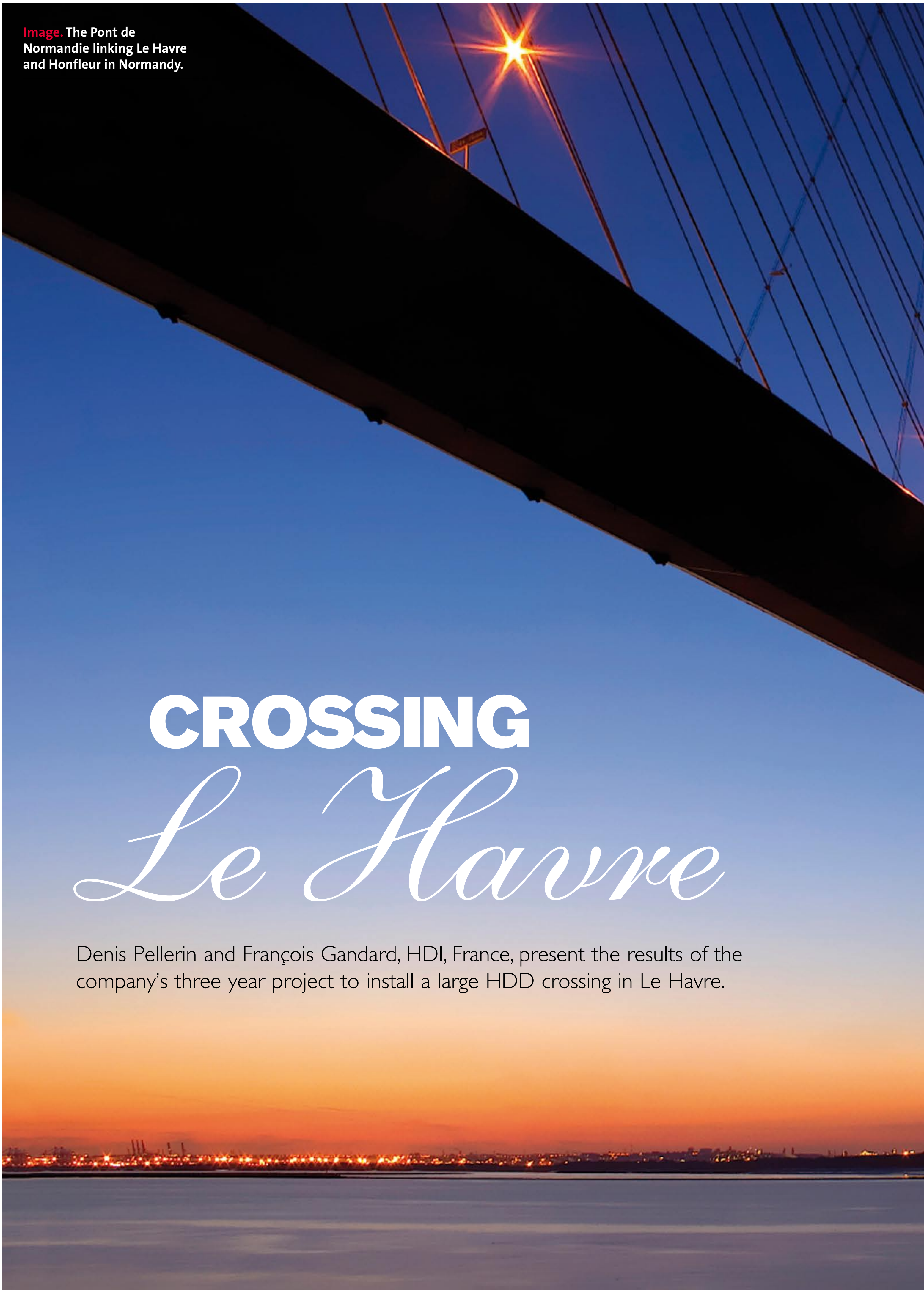

Image. The Pont de Normandie linking Le Havre and Honfleur in Normandy.

CROSSING *Le Havre*

Denis Pellerin and François Gandard, HDI, France, present the results of the company's three year project to install a large HDD crossing in Le Havre.

Horizontal Drilling International, based in Paris, France, was amongst the first HDD contractors to install very large HDD crossings, including the first ever 42 in. diameter pipeline for SNAM in Italy, as early as 1985, or the first ever 48 in. diameter pipeline for NV Nederlandse Gasunie in 1991. With an international history of innovation and technical achievements in the field of HDD, over its 25 years of continuous activity and across five continents, HDI is now very pleased to be given this opportunity to expose one of its most original projects, although this one, for once, was done very close to home.

The project presented here spans three years, and is an interesting example of a win-win partnership between the owner and a contractor specialised in trenchless technologies.

Main topics

- Combination of innovative techniques; exploration pilot hole with horizontal coring, inclined entry and exit shafts with retractable microtunnels and directionally drilled intercept.
- Conception of a 850 m long launching ramp on a 600 m radius with 6.8 m air clearance.
- Partnership between owner and contractor from the engineering phase of the project until completion and innovative contractual conditions.

Presentation of the project

A few years ago, the Port Authorities of Le Havre in France decided to increase the traffic of containers, and a new terminal called Port 2000 has been recently constructed, allowing direct access from the sea for the biggest cargos. Nevertheless, the main traffic is still done by the old harbour and the large shipping lock François 1er which leads to many canals where most of the docks for container traffic are set-up.

In the harbour of Le Havre, TOTAL owns one of its largest refineries in France, which is fed by a 34 in. pipeline meandering through the harbour from distant crude oil storage tanks belonging to the Compagnie Industrielle Maritime (CIM). Because of repetitive maintenance problems at the crossing of the François 1er lock, TOTAL and its consulting engineer Sofresid were looking to relocate its pipeline along a more direct underground route, crossing the two large waterways separating the oil storage from the refinery; but this quickly became complicated because of the congestion of the port installations, as well as the very unfavourable geology of the site.

At this point, HDI was approached by Sofresid, and offered a partnership to TOTAL, aimed at evaluating the feasibility of a 1500 m HDD crossing under the Grand Canal and the Darse de l'Océan, as shown in red in Figure 1.

Figure 1. Satellite view of Le Havre industrial harbour.

Trenchless solution proposed by HDI

HDD crossing

HDI knew from previous experiences in Le Havre that the geology of the site is unfavourable to HDD and microtunnel; indeed, the bedrock is found at 35 m depth, and is overlaid by a thick layer of flint cobbles. The depth of the harbour is preventing any drilled profile above this layer.

The solution imagined by HDI was innovative and audacious, and was combining microtunnel and HDD:

- Installation of two inclined steel casings from the surface down to the bed rock by two retractable microtunneling machines.
- Drill two pilot holes through the tunnels with an intercept in the middle at a depth of 70 m.

Instead of expensive and sometimes not relevant site investigations, HDI proposed to drill an exploration pilot hole to confirm the assumptions concerning geology and the feasibility of the project. This approach has brought many advantages:

- The investigation is carried out 10 m away from the project and at the same depth, hence the core samples as well as the drilling data are really relevant to evaluate the feasibility of the project.
- The investment is a bit higher than for a standard investigation, but requires much less permitting since there is no interference with the shipping activities.

- In case the project is unfeasible, the owner can stop the project early on, since only a drill string needs to be retrieved from the hole.
- In case the feasibility of the project is confirmed, the owner already saved a lot of time on his schedule, since the exploration hole can be used to install a 6 in. casing useful for later steps of the project, as a reference line for the steering intercept and as a mud return line during reaming operations, before receiving the fibre-optic control cable for operating the new pipeline.

Pipe-string preparation: launching ramp

Another major difficulty of the project was due to the necessity to keep roads and rails permanently open for container traffic.

The HDD method requires the pipe-string to be prepared if possible in one continuous section and in the alignment of the crossing. This was not possible here since the only available space to weld the pipe-string is located along the road leading to the CIM, but is not aligned with the crossing, and is only long enough for the preparation of the pipe in two strings, as shown on Figure 2.

For this reason, HDI engineered a non-conventional launching ramp to allow the pipe-string to travel from its pre-fabrication area to the entry of the drilled hole, passing over three roads, a roundabout and two railroads with an air clearance of 6.8 m, and a horizontal radius of 600 m, without over-stressing the pipeline.

Execution of the works

Exploration pilot hole

The exploration hole has been drilled over a period of two months. This hole required the temporary installation of 210 m of 14 in. casing, through the flint layer down to the bedrock. The drill string has been tripped-out three times to send down a 8.5 in. x 9 m long coring tool, which was able to take 4 in. core samples, with a full closure system allowing it to core in unconsolidated soils when necessary. Laboratory tests were performed on selected core samples. A geologist analysed all data, including mud returns and cuttings during the whole process, and was able to fine tune the initial assumptions about the local geology.

Upon completion of the exploration hole, a 2 $^{7}/_{8}$ in. drill string was installed to replace the 5 in. string used to drill the pilot hole. This allowed the drilled hole to be put on standby during the time necessary for the review of all data, while the owner was making his final decision.

Engineering and procurement

Once the owner was convinced of the feasibility of the whole concept as imagined by HDI, an engineering and procurement phase could start, mainly consisting of:

- The modification of an existing AVN 1200 microtunneling machine for the retraction process.
- The procurement of 1500 m of 6 in. steel casing.
- The procurement of 400 m of 66 in. steel casing.
- The complete engineering of the launching ramp including the calculation of the stress level in the pipe-string during all work phases and the behaviour of the supporting piles.

Figure 2. Overview of the project.

Figure 3. General view of the launching ramp.

The stress calculations were made with a finite elements software, and highlighted the high lateral forces created by the 34 in. pipe-string progressing along the 600 m horizontal curve during the approach, during pre-hydrotest and during pullback. Stormy wind conditions, as well as the impact of a failing pile, were evaluated. These results were then the basis for the design of the elevated supports and the calculation of the piling depth as well as for the design of the pipe rollers. All calculations were reviewed and validated by Sofresid, the project Consulting Engineer.

Launching ramp

The launching ramp was then constructed over a period of six months, involving:

- The installation of 45 piles vibrated 15 - 19 m deep into the ground.
- The installation of 12 piles sealed in reinforced concrete poured in open top containers for the sections located above existing pipelines corridors.
- The fabrication of 54 purpose-built pipe rollers able to overcome a 30 t vertical load, as well as 15 t lateral loads in either direction.

Microtunnelling

The two inclined shafts have been executed over a period of five months, including the reconditioning of the microtunnelling equipment before the second drive. The works were performed with an AVN 1200 machine belonging to HDI and modified on that occasion by Herrenknecht for the retraction process. The machine was equipped with a lost extension kit for each drive.

Figure 4. Installing one of the 66 in. entry shafts.

North tunnel

This 1635 mm inside diameter tunnel is 175 m long according to a 12° slope; it was drilled down to the bedrock in 31 working shifts. But the first retraction process failed for an unconventional reason. A small flint stone entered the tunnel at the back of the machine as a result of an accidental flooding of the tunnel created by the rupture of the slurry line, itself caused by the excessive working pressure due to the depth of the tunnel. The flint stone got lodged inside one of the safety locks keeping the microtunneling machine inside the front sleeve. When the retraction process started, the lock was not completely disengaged although the hydraulic sensors indicated that all the locks were open, with the consequence that the retraction plate became detached from the machine.

Because of the groundwater level at the front end of the tunnel (3.8 bars were monitored at the cutting wheel before retraction), the retraction procedure was calling for the complete flooding of the tunnel before initiating the retraction process; thus the tunnel was no longer easily accessible to visualise the cause of the problem and develop a solution. This was done with the assistance of a complete diving team. A drilling rig was then mobilised, and a drill string was pushed down through the tunnel and connected with the divers' assistance to the rear of the microtunneling machine. This operation succeeded, and the tunneling machine was retrieved just three weeks after the first retraction attempt.

South tunnel

This second tunnel also has a 1635 mm inside diameter and is 204 m long according to a 10° slope; it was drilled down to the bedrock in 36 working shifts, and the retraction process was, this time, an immediate success.

HDD

Two complete drilling spreads (including a HK400 t rig and HK100 t rig) were mobilised for these operations.

First, a 6 in. casing pipe was pulled in place of the 2 7/8 in. drill string waiting into the exploration hole, and its position was re-surveyed with a gyroscopic probe.

Then, one of the preoccupations was to properly centralise the drill string at the transitions between the 66 in. tunnels and the future HDD hole. For this purpose, 375 m of centralisers made of 12 m long pieces of 14 in. casing equipped with two sleeves and flanges each, had been prefabricated. They needed to be installed in the tunnels for the pilot hole drilling as well as for each reaming phase, so that the drilling and reaming tools were always perfectly centralised when entering or exiting the drilled hole.

The presence of an inclined shaft at each extremity of the crossing, made it necessary to drill simultaneously from both ends with an intercept of the two pilot holes in the central section. An electrical cable, pulled inside the 6 in. casing installed into the exploration pilot hole, was used as a reference line for the pilot hole drilling phase. This phase lasted one month in total, and the intercept was completely successful, at a depth of 70 m under the shipping activity of the harbour.

The reaming phase was then executed in three successive steps up to the final hole diameter of 48 in., with a series of rock hole-openers and centralisers. Systematic intermediate cleaning runs with barrel reamers were conducted after each ream. The 6 in. casing installed inside the exploration hole was used to transfer mud from one site to the other when needed. These works were carried out without interruption on a double shifts basis over a period of six weeks.

Finally the pullback of the 34 in. pipe-string lasted 20 hours, and the pull force never rose over 60 t, thanks to a buoyancy control system aimed at neutralising the weight of the pipe inside the drilled hole.

Figure 5. Pulling the buoyancy control system inside the 34 in. pipe-string.

Contractual issues

The contract between owner and contractor was unconventional in many respects:

- It was a contract including the site investigation, the engineering and partial procurement.
- It was a mix of lump-sum prices and day-rate activities.
- A system of bonus - malus, aimed at sharing the profit and the risk between the contractor and the owner, was implemented based on comparison of actual drilling times and costs to a target time schedule and a target price.

The pipeline is now connected to the refinery. Thanks to a partnership concluded early enough in the life of this project of high technical complexity by TOTAL and HDI, a win-win situation has developed, allowing the owner on one side to optimise its construction schedule while staying well within budget, and on the other side allowing the specialised contractor to fully express his know-how and expertise. WP

Figure 6. Spread HK 400 and entry shaft at north side of the crossing.