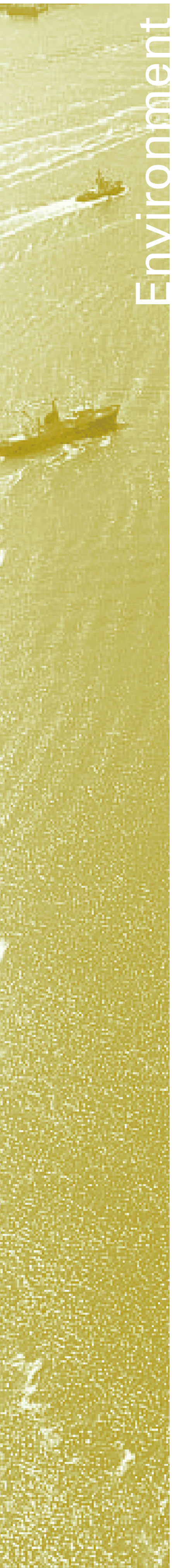


Bert Dijkstra and Stuart McIntyre

Besòs Long Sea Outfall, Barcelona

Abstract

Besòs Long Sea Outfall, Barcelona, Spain, is one of Europe's largest long sea outfalls installed by the bottom pull method. The outfall consists of a cement mortar lined 19 mm thick steel liner pipe with a structural reinforced concrete coating and a total length of 2900 m. This paper provides a brief overview of the project and discusses in greater detail the somewhat unusual dredging activities carried out which allowed its successful installation.
Dredging activities included soil improvement by removal of soft clay and its replacement by compacted sand, the dredging of a 7 m deep trench beneath a high pressure gas pipeline located approximately 1 km offshore and the dredging of a 2900 m long trench in water up to 55 m deep.

Introduction

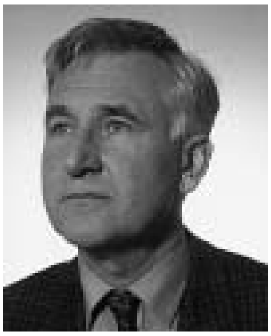
In the light of recent EC legislation, EMSSA (the Barcelona sewerage disposal authority) had been reviewing the performance of the sewerage disposal system to Barcelona. They had identified a need for a substantially improved outfall system to the north of Barcelona that would replace the existing outfall which was leaking badly and not long enough to satisfy EC bathing water quality directives.

An EPIC (Engineer, Procure, Install Commission) contract for the outfall and associated pumping station was then drafted, and ultimately awarded to a joint venture company comprising two Spanish contractors, SATO, and Cubiertas y Mzov, and two Dutch contractors, Smit Tak and Ballast Nedam Dredging. Two British consultants were engaged; Andrew Palmer and Associates were responsible for the detail design of the outfall, and Watson España provided engineering support to the client. A truly pan-European venture.

The contract was awarded in January of 1994 and by January of 1995 the outfall had been designed, built and installed. The final part of the project, Pump Station Commissioning, was completed in May 1995. Figure 1 shows the outfall location.

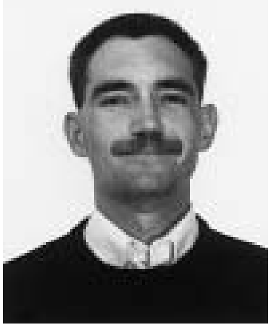
Figure 1. Location of the outfall at Sant Adrià de Besòs.

Bert Dijkstra holds a BSc in Civil Engineering and a BBA in Business Administration. Since 1964 he has work all over the world for Volker Stevin and Ballast Nedam. He is presently Area Manager Europe at Ballast Nedam Dredging.



Bert Dijkstra

Stuart McIntyre holds a BSc in Civil Engineering and is a Charter Civil Engineer. He works as a Senior Engineer with Andrew Palmer and Associates, and was posted to Spain by them for the duration of the outfall design and installation as Assistant Project Manager.



Stuart McIntyre

OUTFALL DESCRIPTION

The outfall consists of a cement mortar lined 19 mm thick steel liner pipe with a structural reinforced concrete coating to produce the following overall dimensions:

Bore	2.10 m
Outside Diameter	2.62 m
Structural Concrete	222 mm thick
Total length	2900 m
Diffuser section (with 15 diffusers)	840 m
Total dry weight empty	16,800 T
Submerged weight	150 kg/m
Maximum flow rate	12.4 m^3/ s.

The outfall was installed to a maximum water depth of 55 m using the bottom pull method. Installation to this, in the context of outfalls, extreme water depth, with such a large diameter pipe, required state-of-the-art pipeline analysis using finite element analysis.

The large diameter of this pipe is considered close to the practical limits for the bottom pull method of installation because with a submerged weight of only 2 to 3 per cent of its dry weight, factors such as concrete density, water absorption and construction tolerances may determine whether the pipe floats or is too heavy to pull. Recognition of this led to the somewhat unusual step of concrete coating the individual 9 m steel pipes off site. This ensured that the concrete coating was of the highest quality.

The high concrete quality achieved will help ensure that the outfall fulfils its 100-year design life. Further measures used to maximise longevity included coating the concrete reinforcement with fusion bonded epoxy, and the liner pipe with a two pack epoxy paint and connecting the liner to an impressed current CP system.
Although the pipe is enormously heavy when dry (5800 kg/m), because of its large displacement, the pipe has a low submerged weight (150 kg/m) when empty. Traditional two-dimensional stability models indicated that the pipe was only stable in very small waves, and more sophisticated three-dimensional analysis was required to determine the limiting installation weather conditions.

LAND-BASED CONSTRUCTION

This part of the work was undertaken by SATO and Cubiertas. The outfall is made up of 9 m long steel pipes, fabricated near Barcelona. These pipes were individually concrete coated in a specialist factory, again near Barcelona.
When the pipes were delivered to site they were welded together to form strings 117 m long.

The strings were then moved sideways into stock and the joints between pipes completed with the concrete coating. The temporary works required to allow the handling of such large pipe strings was one of the major investments onshore; its successful operation determines whether welding is completed on time. Figure 2 shows the partially completed string number one about to be moved sideways into stock.
During the welding and fabrication process, the offshore trench was being dredged. The dredging of the trench is the primary focus of this paper.

DREDGING ACTIVITIES

Planning

The dredging works consisted of dredging the 4-m deep, 2900-m long trench and, after installation of the pipe, backfilling of the trench with sand. The overall

Figure 2. The first pipe string being moved from the welding area to the stock area. The structures on top of the pipe are the starters for the diffusers.

Figure 3. Cutter dredger Rozenburg, 160 m from cofferdam and hopper dredger Lelystad, 600 m from cofferdam, launching preparations on shore side.

programme was for construction to begin in February of 1994, with completion in May 1995.

The critical path for the project lay through:
- welding of the pipe strings on site;
- trench dredging;
- pipe pulling;
- testing;
- backfilling; and
- pumping station construction.

Because of the client’s extreme concern that dredging activities should not cause turbulence which could arrive on the beaches during the holiday periods, strict controls were enforced. These included limiting the dates during which dredging could take place, and requiring the suction hopper dredger to work without overflow.The above restrictions effectively resulted in two periods of dredging activity: a period in the spring of 1994, prior to the peak summer holiday period, and a period after summer and into the autumn/winter of 1994.

The first season of dredging work comprised the dredging, backfilling and compaction of a soil improvement area designed to support a future breakwater crossing of the outfall. The second season of work comprised the dredging of the main trench. The activities in these two seasons are discussed below.

Four different dredgers were utilised (Figure 3):

- trailing suction hopper dredger *Lelystad* to dredge up to 55 m below seabed;
- trailing suction hopper dredger *Poseidon* to facilitate backfilling of the trench through one of the suction pipes;
- cutter suction dredger *Rozenburg* to make the trench in the nearshore shallow waters; and
- submerged jetpump in combination with FLYGT pump (2 cutter system) operated from the pontoon *Kutxa* to allow for very accurate dredging near the existing pipeline.

SPRING 1994

Breakwater Soil Improvement

The future harbour breakwater will be constructed over the outfall, in approximately 20 metres of water. To support this massive construction so that it does not damage the outfall required the removal of 200,000 m^3 of soft clay and mud.

The soft material was removed by the suction dredger *Poseidon,* and on acceptance of the dredged area by the client, was backfilled by the same vessel with sand with a D50 of 400 µm.

The borrowing of sand for this purpose is controversial, as sand is particularly valuable in Spain for the formation and maintenance of beaches.

After backfilling, the area was compacted using twin torpedo vibro-compactors supported from the crane pontoon *Kutxa* (Figure 4), in a pattern that compacted 5 m^2 per point. Design of the soil improvement area to support the breakwater and protect the outfall, even during earthquakes, used specialist three-dimensional consolidation, finite element models developed by Cambridge University, followed by finite element dynamic earthquake analysis using real earthquake recordings, scaled appropriately to the design criteria at Barcelona.

AUTUMN/WINTER 1994

Main Trench Dredging

This season of work comprised dredging of the outfall trench and was divided into four sections:

1. Beach cofferdam to water depth 15 m (chainage CH 40 m to 430 m).
2. Water depth 15 m to gasline crossing (chainage CH 430 m to 1125 m).
3. Gasline crossing (chainage CH 1120 m to 1165 m) at 35 m water depth.
4. Gasline crossing to end of trench (chainage CH 1165 m to 2920 m)

Longitudinal Profile

Because of the very high longitudinal stiffness of the pipe, the trench longitudinal profile had to be very carefully designed and executed, particularly through sag curves and at the end of the 'launch ramp'. The analysis ensures that if the pipe is very stiff and light, it will not 'lift off' in sag bends, particularly underneath the gas line. Similarly, when soils are very soft and the pipe is not able to lift, at the end of the launch ramp for example, it does not plough-in and become embedded.

Figure 4. After backfilling, the area was compacted using twin torpedo vibro-compactors supported from the crane barge Kutxa. Kutxa is seen here dredging under the gas line, with a pull barge behind.

The high stiffness of the pipe determines that changes in the longitudinal profile must occur slowly. This meant that, although the target trench depth was 3.6 m below original seabed, the trench was frequently deeper than this in areas of profile change. A major part of the profile design process was therefore the optimisation of stresses within the pipe to minimise dredge quantities and ensure that the pipe would follow the design profile. The trench profile adopted is shown in Figure 5.

To allow accurate dredging of the trench to a maximum water depth of 55 metres required a large trailing suction hopper dredger, *Lelystad.* This vessel uses extremely sophisticated positioning and control equipment which allows very tight dredge tolerances and ensured that the position of the suction head was exactly known at all times.

Trench Section 3: Gas Line Crossing

The first item of work to be started on the dredging of the main trench was the offshore crossing of a 20 inch outside diameter high pressure gas pipeline. This was located 1 km offshore in approximately 26 m of water. Because of its arterial role in the distribution of gas

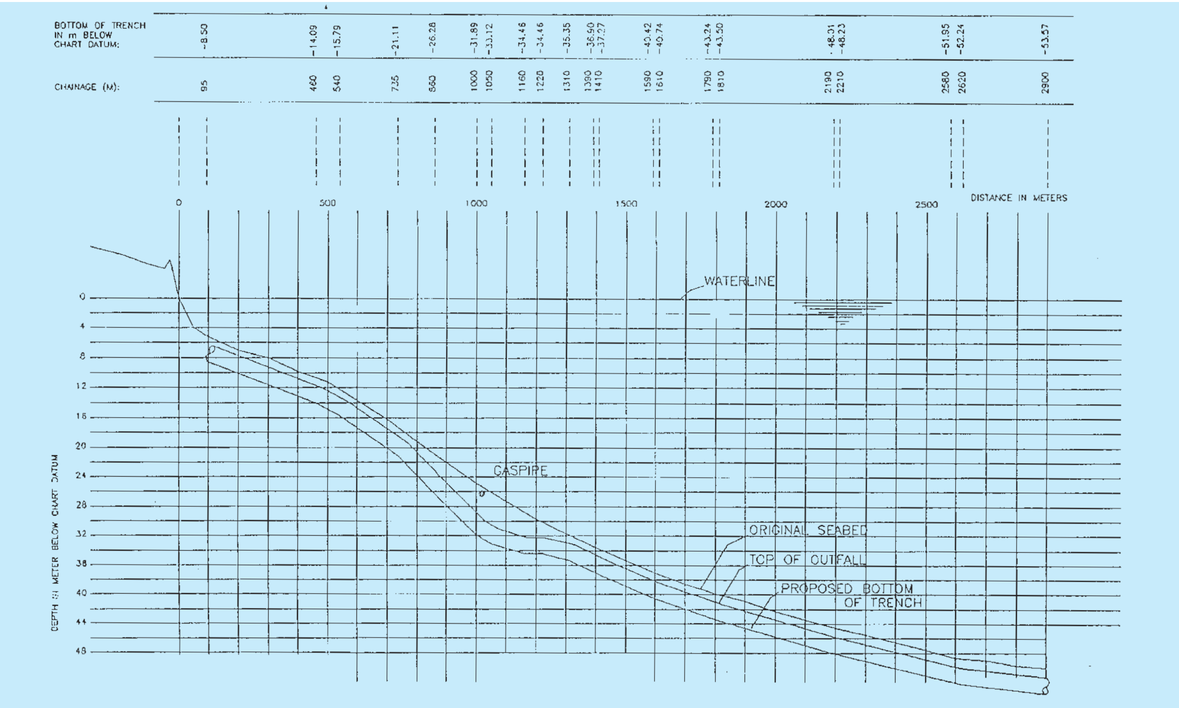


Figure 5. Basic design, longitudinal profile. Minimum radius at gasline crossing: 4500 m.

around Barcelona, the gas line could not be shut down to allow dredging of the trench. It was therefore supported on a lattice 'bridge' with a length of 60 m and a clear central span of 40 m. The bridge was designed in accordance with API RP2A (Figure 6). Although this solution worked well, considerable restrictions were placed on dredging activities.

Before dredging could begin, the owner of the gas pipeline, Gas Natural SA was provided with detailed method statements and work procedures. These procedures considered contingencies and were developed in conjunction with Gas Natural so that risks to the pipeline were minimised. In this way, should an unfortunate event have occurred, the dangers to crew

Figure 6. The gas pipeline bridge is lowered into the harbour in preparation for towing out to site. This support bridge is 60 m overall length.

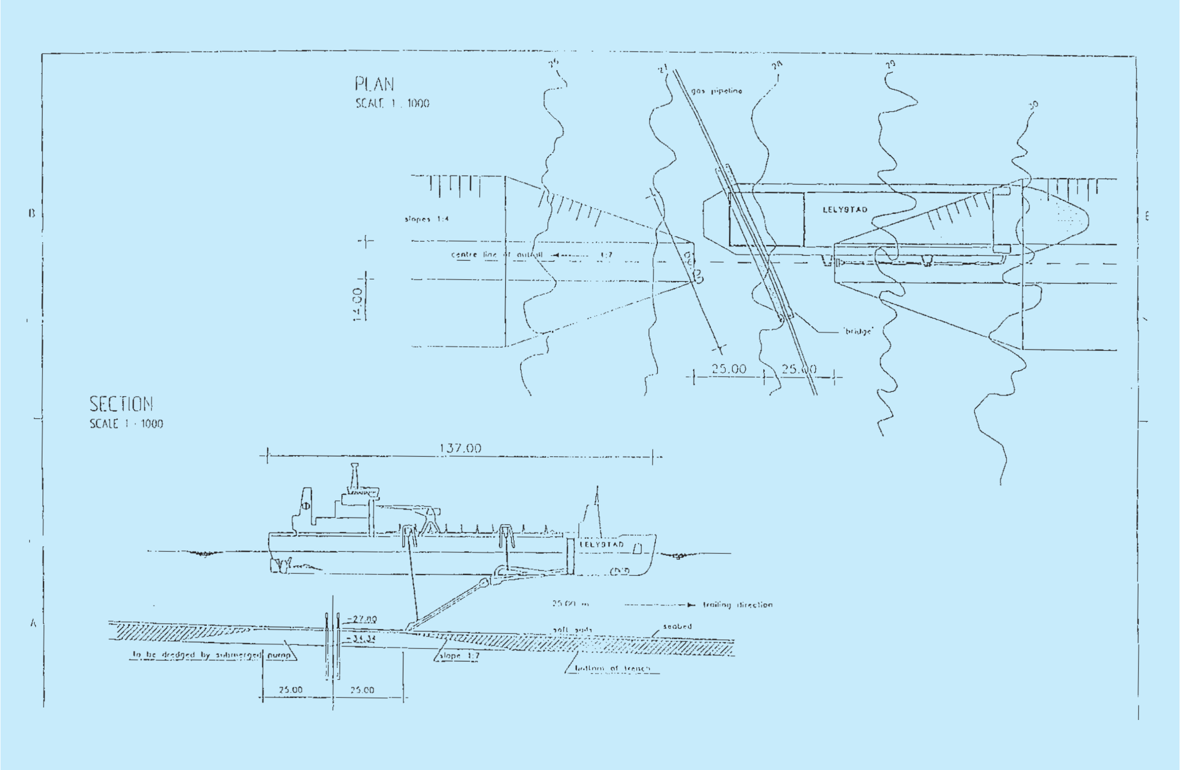


Figure 7. Situation at the pipeline crossing. Window of suction pipe of Lelystad.

were minimised, and the pipeline could have been returned to service as quickly as possible.

The procedures also placed restrictions on the movement of vessels and required that the suction heads of the dredger were always at surface when crossing the gas pipeline (Figure 7). After the pipe bridge had been installed and the procedures agreed, dredging to remove the 30,000 m^3 of material underneath and close to the pipeline could begin.

The dredging of this gas line crossing section had originally been planned for an underwater, remotely controlled vehicle carrying a jet pump. Unfortunately, production targets could not be met and the work method was changed to two cutter FLYGT pumps mounted on a vertical steel tube, supported by a crane aboard the pontoon *Kutxa.* High pressure water jets were also mounted around the pumps to help dislodge material around the pumps. Figure 8 shows the dredging system used at the gas line crossing.

Because of the nature of the sandy clay encountered, excavation slopes were steep (approximately 1:1). This had the advantage of reducing the overall amount of material to dredge, but as the material was not free running towards the pump and cutters, every part of the required trench area had to be thoroughly covered by the cutters. Figure 9 shows the trench cross-section near the gas line. It makes clear just how steep the trench slopes were.

Survey was carried out by survey launch, supported by divers when necessary. The divers were also required to manually remove the small amount of material lying directly underneath the pipe bridge.

Trench Section 1: Cofferdam to 15 m Water Depth

This section of trench was dredged by the cutter dredger *Rozenburg* on a box cut of 40 m width. The bottom width required before pipe pulling was 10 m. As the prevailing wind direction is from the northwest, and because of a slight coastal drift and the close proximity to shore and the surf zone, a small amount of trench maintenance was expected. In the event however, no maintenance dredging was required. Dredged material was dumped via a floating pipeline 450 m to the south of the trench.

Trench Sections 2 and 4: 15 m Water Depth to Gas Crossing, Gas Crossing to End of Trench

These sections were dredged by the hopper dredger *Lelystad.* Bottom width was set at 15 m while the side slopes were expected to be stable with slopes of 1:4. Dredge tolerances were determined by the pipe, with computer analysis on site to verify that the profile was acceptable. Tolerances were typically plus 10 cm to minus 40 cm per cross-section.

Difficulties encountered in the dredging of section 4 of the main trench included the material being very soft, the requirement for very tight tolerances at great depths, and being restricted to dredge without overflow. Overcoming these difficulties required a great deal of skill and attention.

A difficulty encountered in dredging section 2 was the presence of a “hard spot” in the trench at CH 480 (Figure 10). The difficulty with dredging such hard spots is that the suction head follows the path of least resistance, and the danger arises of overdredging one side of the trench and leaving the other side high. This again calls for experience and skill from the crew and the dredging engineer on the bridge.

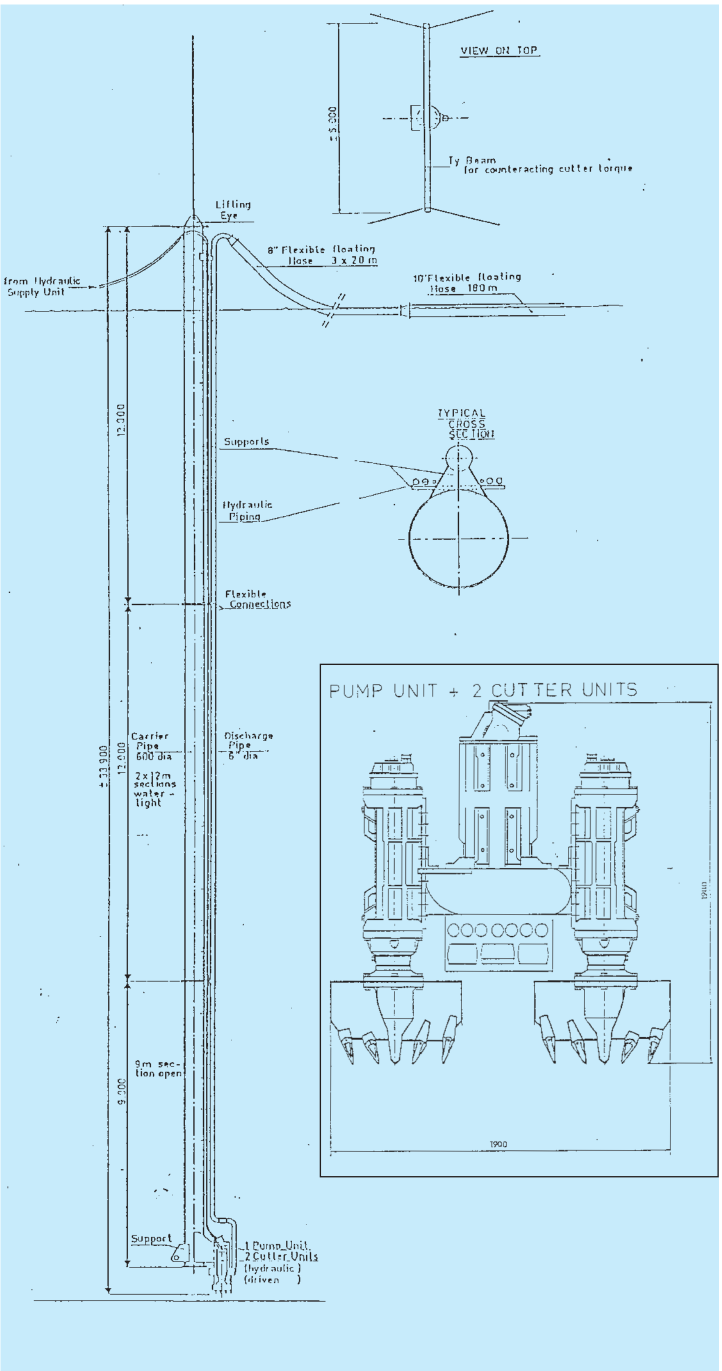


Figure 8. General arrangement of the steel pump; insert: one pump unit and two cutter units, hydraulic driven.

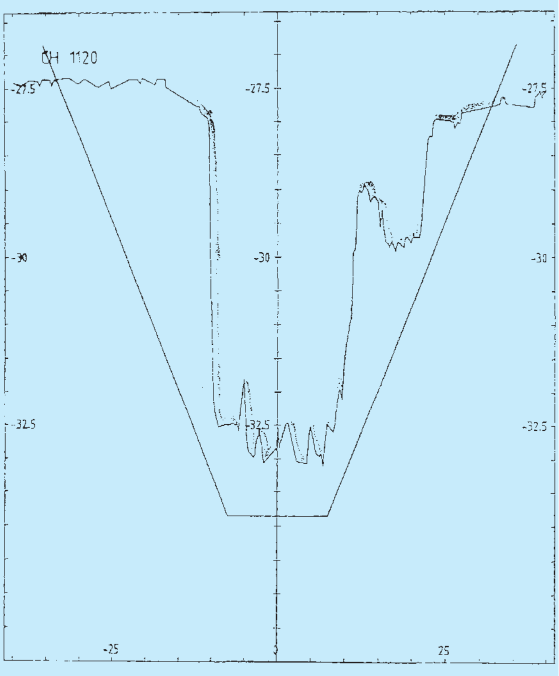


Figure 9. CH 1120 cross-section. Progress bridge 19 November 1994.

PIPE PULL

When dredging of the trench was complete and accepted by the client, the outfall could be pulled out. The pull out went very smoothly, with the outfall being pulled into the trench using the *Taklift 8* pull barge with an installed winch capacity of 600 tonne reacting against four huge anchors placed further offshore (13 Tonne Stevpris type). One 117 metre string was fully welded, wrapped, concrete coated and pulled out every 24 hours (Figure 11).

The pull barge was initially anchored 1.5 km offshore with the pull pennant passing underneath the gas line only 400 m away. Considerable detailed engineering and monitoring was required to ensure that the pull wires did not lift off close to the gas line, threatening contact with it.

During the pull, continuous survey was carried out to determine that the pipe was following the correct profile and monitoring the cable touchdown point. Installation of the diffusers, traditionally a very weather-sensitive and timeconsuming activity also went very smoothly. All 15 diffusers were installed within 30 hours. This is all the more remarkable considering that this was carried out by divers in 50 metre water depth with one metre visibility. The diffusers were installed using the deck crane aboard the pull barge.

BACKFILLING

After the pipe and diffusers had been installed and approved, backfilling could begin. Unfortunately, the quantity of sand available in the contractual sand bor-

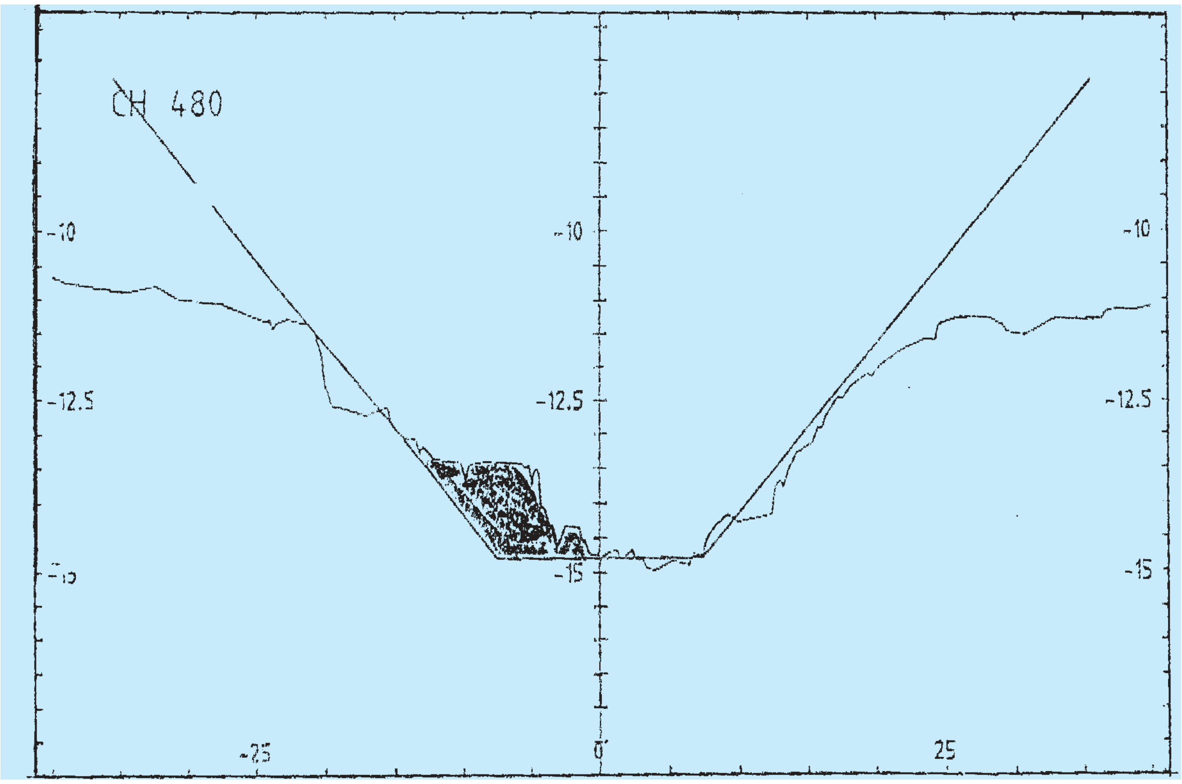


Figure 10. CH 480 cross-section. Preliminary outsurvey Kp 60-500, 15 November 1994, showing "hard spot".

row area was very limited and alternative borrow areas had to be located. The alternative sand source provided material of the grading shown in Figure 12.

Backfilling was done in two parts because of the draft restrictions of the suction hopper dredger *Poseidon* mobilised to backfill the trench. The first section was from the beach cofferdam to CH 400, and the second from CH 400 offshore.

The shallower section was backfilled using the pontoon *Kutxa* supporting a T-shaped fall-pipe which, when connected with the *Poseidon* via a floating pipeline, allowed discharge of the 3000 m^3 load over the outfall.

The offshore section was backfilled by the hopper dredger directly. This was done by pumping the hopper contents down one of the suction pipes and allowing it to discharge 5 to 10 m above the outfall.

Unfortunately, because of the fine content of the backfill material and cross-currents, there was a significant loss of backfill material.

Figure 11. In the foreground, the pipeline is awaiting the pull. In the background is the pull barge and the pontoon dredging underneath the gas line. In the middle ground is a sewer diversion pipe crossing the pipe trench.

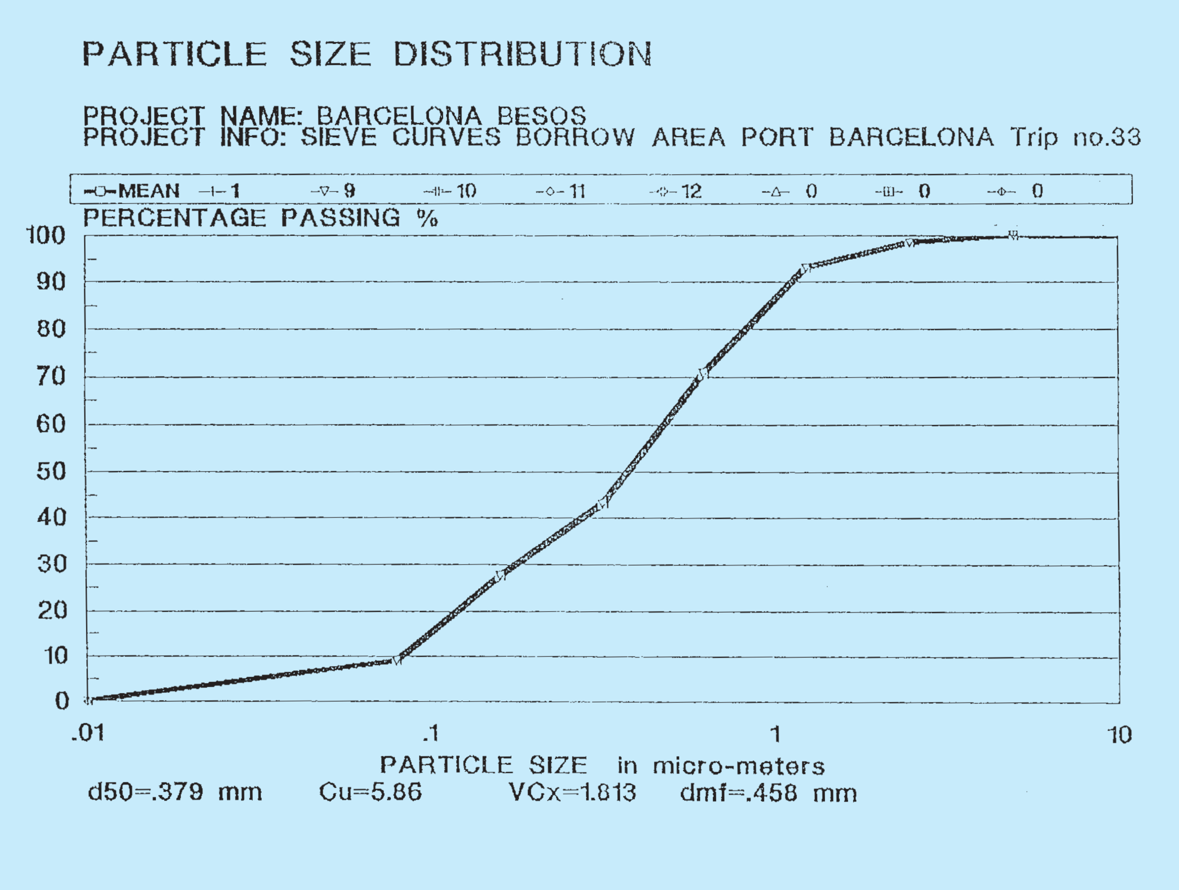


Figure 12. Particle size distribution of sand for backfilling.

SURVEY

The key to the successful accurate dredging of the trench was survey. The control system for the survey comprised two DGPS reference stations, seven microfix stations and an automatic tide gauge. Survey stations were installed on the survey launch *La Restinga,* crane pontoon *Kutxa,* suction hoppers *Poseidon* and *Lelystad* and the cutter dredger *Rozenburg*. In the later stages, a station was set up on the pull barge *Taklift 8* and another on the anchor handling tug *Smit Lloyd 31*.

Conclusion

The dredging activities necessary to ensure the successful construction of the new longer outfall at Besòs in Barcelona were defined by several strict requirements. For instance, dredging activities were not allowed to cause turbulence which would disturb beaches during holiday seasons. Therefore work took place during restricted periods (spring and autumn) and suction hopper dredgers had to work mostly without overflow.

In addition, utmost care was needed to cross a high pressure operational gas pipeline. This included devising contingency plans which had to be approved by Gas Natural SA. Movement of vessels was restricted and contingency plans required that suction heads were always on the surface when crossing the gas line.

Although modern engineering works are increasingly dominated by highly sophisticated technical systems, the type of precision involved in this project also relied heavily upon the close cooperation of a large number of individuals. The collective skills of the crew, the engineers and the divers allowed for the successful completion of this a significant contract within a limited time span.