Noël Pille

“Dilution”, A New Technology Used at the Pearl River Estuary Pipeline Installation Project

Abstract

This article explains a new technology, “dilution”, used for dredging and backfilling works during pipeline installation at the Pearl River Estuary.

Soil information for Arco China’s Yacheng 13-1 Gas Pipeline Installation Project across the Pearl River Estuary in the People’s Republic of China challenged the Contractors to develop new and innovative methods for the installation of the pipeline across the Urmston Road Channel. Over this last section of the 778 km pipeline from the Yacheng gas field offshore the island of Hainan to Hong Kong, the pipeline had to be installed on a firm and levelled seabed below a layer of soft to firm soil up to a depth of 20 m thick in some areas. This layer mainly consisted of previously dumped clay and silty marine deposits from many sources, including the new Chek Lap Kok Airport.

According to Hong Kong Authority requirements, only a limited amount of soil was allowed to be excavated from the trench by conventional methods and disposed of at approved dumping locations. As this quantity was far less than the amount of material required to excavate a conventional open trench, a new dredging technique was proposed by Jan De Nul N.V.’s Engineering Department and further developed in close cooperation with Arco China Inc. and Saipem-Emc J.V. The execution method proposed was based on “diluting” the cohesive materials in subsequent layers to such a reduced density and shear strength that the pipeline could be installed through the diluted medium to the specified design level at the bottom of the trench. Because of the dense and non-cohesive soils encountered in the deeper areas, a combination of dilution and traditional dredging methods were utilised to ultimately effect the installation of the pipeline.

The dilution works at Urmston Road were executed during September and October 1994 by the trailing suction hopper dredgers *J.F.J. De Nul* (11,750 m^3) and *Vasco da Gama* (10,000 m^3). These vessels were respectively the largest and third largest trailing hopper dredgers in the world and had been modified for the new technique. As a result of their size and capabilities, trench preparation could be executed over a minimum period of time at maximum efficiency.

After installation of the pipeline at Urmston Road, a rock bund has been installed by means of a large self-propelled splitbarge, providing stability for the pipeline and protection against anchors.

Outside Hong Kong, at the location of the Jiuzhou and Linding shipping channels in the People’s Republic of China, a three-layer engineered backfill has been applied, executed by means of a side stone dumping vessel. Works were executed by Jan De Nul N.V. for Arco China under a subcontract for Saipem-Emc J.V.

Mr Pille graduated as a Mechanical Engineer from the University of Ghent, Belgium in 1975 after which he joined the dredging department of Jan De Nul N.V. Since 1992 he has been Manager of the Offshore Works Department of its International Dredging Division. This department is involved with trenching and backfilling works for the installation of offshore pipelines, rock dumping and ballasting of offshore structures, shore approach dredging and landfalls, and other offshore industry works.

Noël Pille

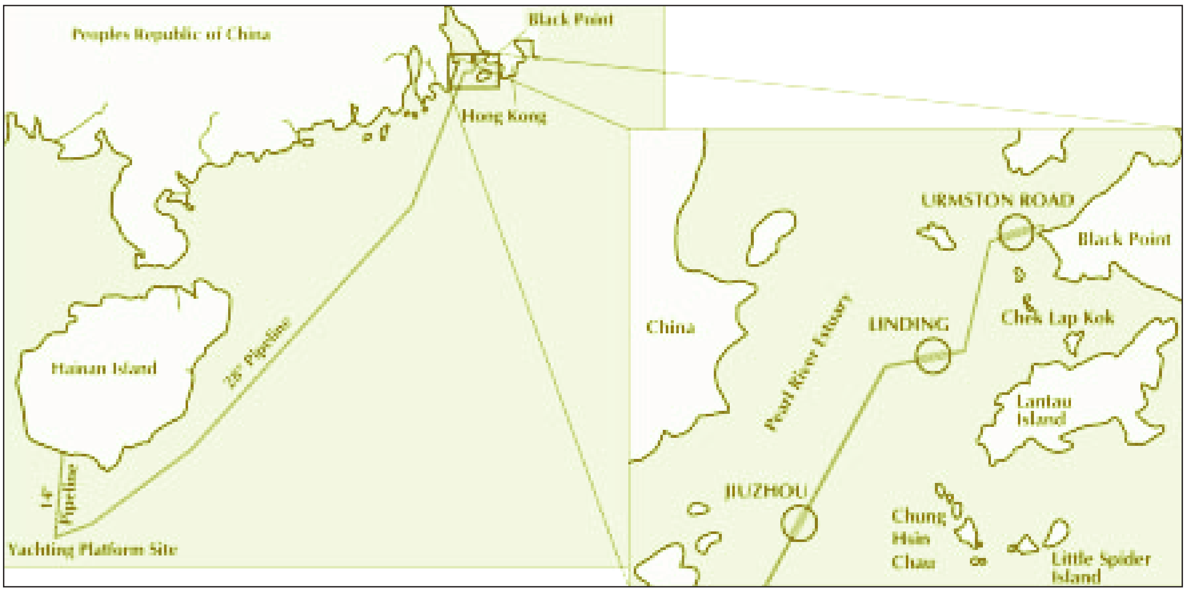


Figure 1. The Yacheng 13-1 Pipeline Installation Project from the Yacheng gas field offshore the island of Hainan to the Black Point Power Station at Hong Kong.

Introduction

Gas transportation from the Yacheng 13-1 gas fields offshore the island of Hainan in the People's Republic of China to the Black Point Power Station at Hong Kong required the installation of 778 km of 28" pipeline in the South China Sea. Over the last 71 km, the pipeline had to cross the Urmston Road, Linding and Jiuzhou shipping channels in the Pearl River Estuary (Figure 1).
For the crossing at the Urmston Road Channel, the pipeline had to be installed on a firm and levelled seabed below a layer of soft materials of up to 20 m in thickness at certain locations. This required a new and innovative method to be used as dredging by conventional methods and disposal at approved dumping locations was limited by Authority restrictions.
After installation in this section, the pipeline had to be protected by a rock bund providing 3.5 m cover above the pipeline and with top of backfill materials always remaining -21.5 HKPD over the central section. Across the Linding and Jiuzhou channels, a trench had to be predredged in order to install the pipeline below minimum future draught requirements, and an engineered backfill had to be provided for sufficient stability of the pipeline and an adequate protection against shipping anchors.

New Dredging Technology for Seabed Preparation at the Urmston Road Crossing by Means of "Dilution"

The 28" pipeline was required to be installed across Urmston Road which lies within Hong Kong's Outer Deep Bay dumping area on the border between the Chinese and Hong Kong territorial waters.

The pit at Urmston Road was formed by dredging methods for reclamation purposes, extraction being completed in 1991. The dredged seabed at that time was alluvial, with the marine deposits having been removed prior to the extraction of sand. As such, the firm seabed in the pit was known to be changing rapidly, due to the erratic shape of the earlier dredged bottom. Since 1991, a variety of materials had been dumped in the pit, largely comprising clayey and silty marine deposits dredged by clam-shell and other methods (Figure 2).

The sources included materials from the new Chek Lap Kok airport works and other nearby and more distant projects in Hong Kong, and from the People's Republic of China. In the western half of the channel, the thickness of the layer of dumped mud and very soft to firm clay varied from 10 m to over 25 m. The density of these materials was up to 1.7 T/m^3 with a shear strength above 1 kPA.

This posed two major limitations on pipeline installation. Firstly the highly irregular alluvium profile was unacceptable from a pipeline stress point of view, and secondly the varied soil properties could not be penetrated by the pipeline during installation in order to reach its specified design level. Because there was limited soil information available across Urmston Road a detailed geotechnical and geophysical survey was undertaken to finalise the pipeline installation scope of work. From the final report, the optimum profile was analysed, seabed preparation methodology developed and installation procedures prepared.

This seabed preparation method required the utilisation of two 10,000 m^3 trailing suction hopper dredgers.

Modification of one of the 10,000 m^3 TSHD’s was made to allow high capacity water injection, via the suction pipe, into the mud medium thus reducing its in-situ density.

To assess the effectiveness of the proposed dilution operations, extensive trials were undertaken. These trials showed that sufficient reduction of soil shear strength to allow penetration of a test pipe could not be achieved by controlled pumping of water at varying layer depths only. However, as already proposed in the installation procedures as an alternative method, it appeared that optimum effectiveness could be achieved by dredging pre-determined box-cut layers with one suction pipe and simultaneously discharging through the opposite suction pipe into the trench at the top of the nominated layer after adding water through one of the dredge pumps, thus reducing its in-situ shear strength and achieving a returning target density of 1.35 tons/m^3.

Although the initial field trials of the dilution technique were proven to be successful, the presence of pockets of consolidated clay and granular seabed material necessitated, particularly in the deeper sections, the use of traditional dredging techniques. As part of the lighter components of the diluted soil was washed downstream by the river currents and the sand settled to the bottom, dilution was no longer effective by the time three quarters of the required depth was achieved, and conventional dredging techniques then had to be used to reach the design depth.

At these depths, in-situ trench materials were disposed of at agreed dumping grounds together with diluted soils which were loaded on top of the granular materials until overflow level was reached. As slope stability had been based on the presence of diluted material in the trench profile, dredging as a result of slope instability had to be continued at some locations in order to achieve the target design level for pipeline installation.

By the combined result of these dilution and dredging operations, a mainly open trench was created into which the pipeline was ultimately installed. The as laid survey was performed in early October, directly upon completion of pipelay operations. It revealed that slope failures had occurred between dredging and pipelaying in the deepest portion of the trench. However, a subsequent soil investigation revealed the soil to have a higher sand content than before and now provided a suitable foundation for the pipeline.

Principles of the new dredging technique by means of dilution

(i) Diluting of the trench materials is executed in accordance with detailed procedures based on the working principles of a trailing hopper dredger. The works are executed in successive layers of up to 2.0 m in thick-

Figure 3. Principle of trench dilution (cross profile).

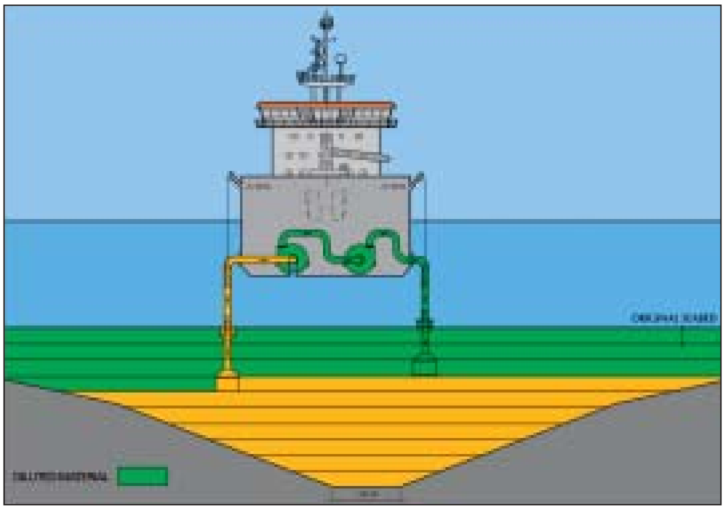


Figure 2. Geotechnical profile at the Urmston Road crossing.

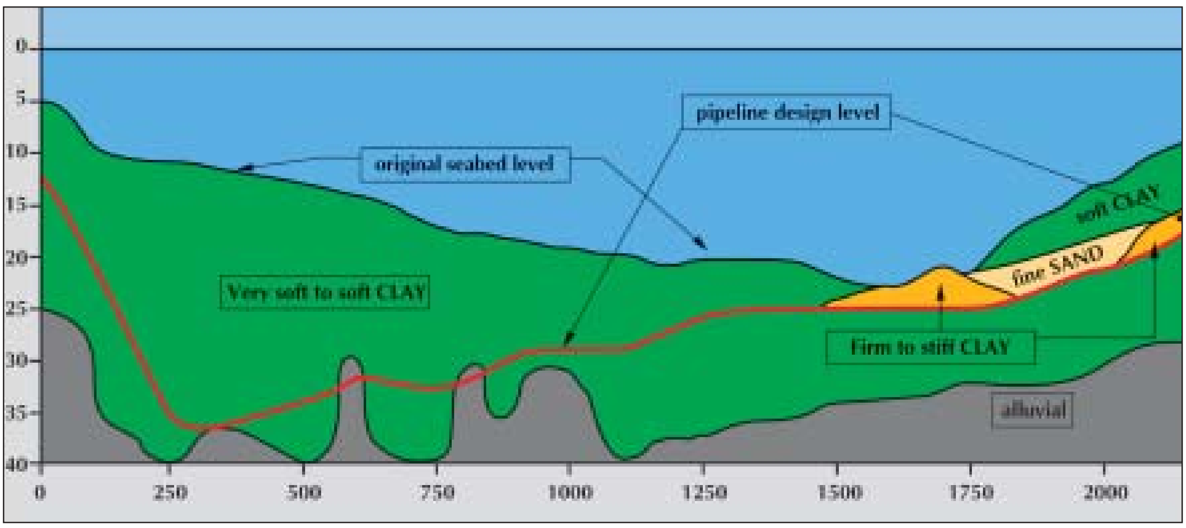


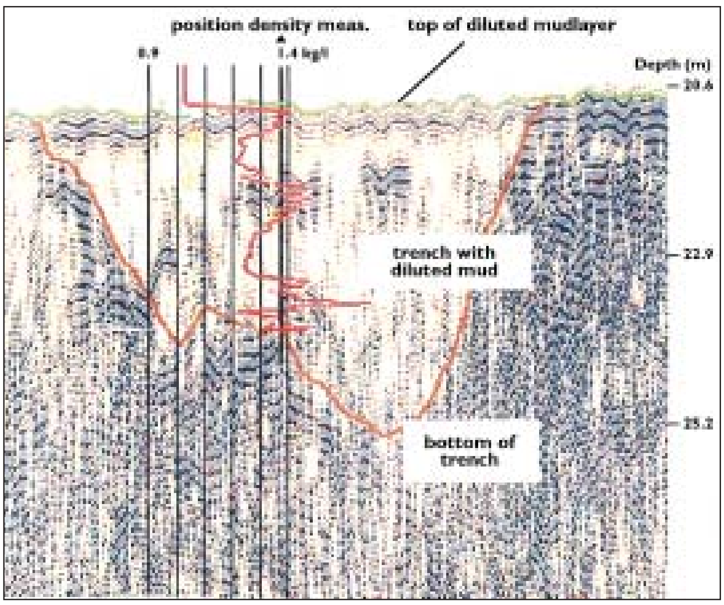
Figure 4. Principles of trench preparation by means of dilution by using a larger trailing hopper dredger.

Figure 5. The J.F.J. De Nul, one of the largest trailing suction hopper dredgers in the world, was modified for the new technique of dilution.

ness where boxcuts over the width of the draghead are removed (Figure 3).
In this respect, the trailing hopper dredger sails parallel tracks at a speed of around 1 knot at average 3.5 m interspacings whilst diluting each layer (Figure 4).
In case of limited draghead penetration as a result of more cohesive soils, the height of the box has to be reduced.

(ii) The in-situ density and shear strength of the trench materials are reduced by dredging each box measuring 2.0 m x 3.5 m with one of the suction pipes. Before the entrance of the mixture in the suction pump, a quantity of water is added by controlled setting of one or more inlet valves. The outgoing density is measured by the radioactive measuring devices at the outlet of the pump.

Figure 6. Digital record of cross-section of trench during the beginning of the dilution works.



(iii) After passing the pump, the diluted mixture is pumped down to the trench by means of the other suction pipe, which is, for this purpose, serving as a fallpipe. The draghead of the suction pipe acts as diffuserhead and is positioned at a depth approx. 2 m higher than the nominated suction level.

Choice of equipment and required modifications
The dilution works at the Urmston Road crossing were executed by means of Jan De Nul's trailing suction hopper dredgers *J.F.J. De Nul* (11,750 m^3) and *Vasco Da Gama* (10,000 m^3) (Figure 5). The following modifications had been executed prior to start of the works:

- Pumproom alteration for the outlet of the starboard pump to be connected to the inlet of the port suction pipe.
- Port suction pipe adapted for reverse flow.
- Setting devices on water inlet valves for control of outgoing mixture density.
- Positioning and tracking displays and logging with hard copies to be provided if required.
- Draghead position systems installed.

Survey and monitoring
Particular survey and testing methods have been developed in order to enable monitoring of the works during the progress of dilution (Figure 6).
(i) Density measurements were carried out in the diluted layers by means of the STEMA density probe launched from the survey vessel.

(ii) The draghead position monitoring system installed on the dredgers provided online information of the dredge levels reached, and a longitudinal draghead survey could be added to the daily report.

(iii) "Pipe dunking" tests provided information on the actual diluted levels reached. The pipe dunking was executed by lowering a sealed air filled 12.2 m long section of the concrete coated 28" gas pipe by means

Figure 7. Installation of rockbund at Urmston Road by means of the 2000 m3 self-propelled splitbarge Verrazzano.

of the dredger’s deckcrane whilst the vessel remained on position during slack tide. The reading of the underwater weight of the pipe section (both ends closed) relative to the levels reached, provided information about to what anticipated levels the pipeline would sink during installation from the laybarge.
After the initial phase, a scaled 1m long model of the 28” coated pipe handled from the survey vessel has been provided by Main Contractor in order to save time for the dredgers.

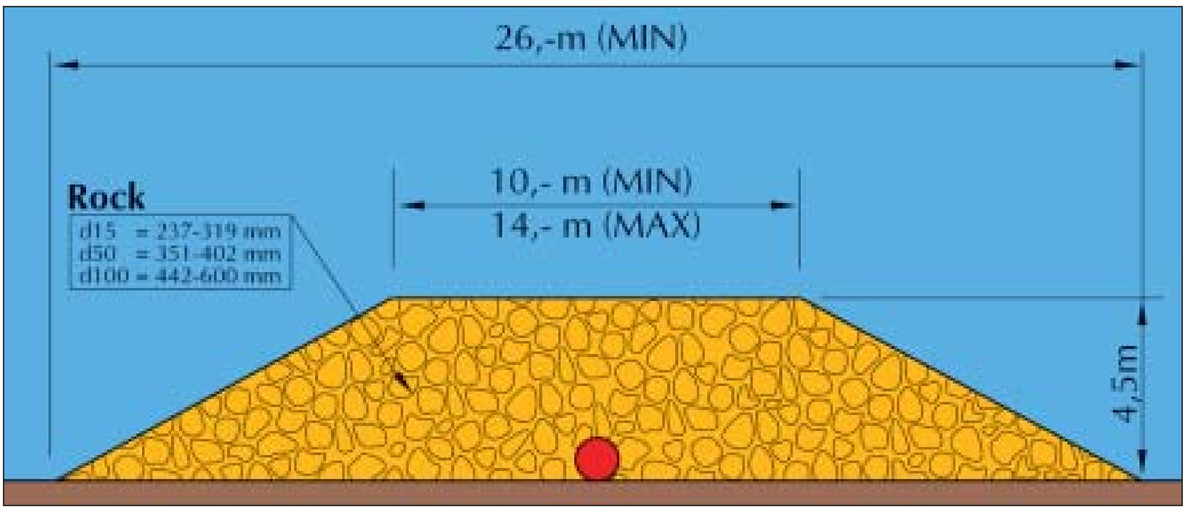
Installation of the Rock Bund for Pipeline Protection at the Urmston Road Crossing

After completion of the dredging and dilution works and successful pipeline installation at Urmston Road, the pipeline had to be protected by a rock bund providing 3.5 m cover above the pipeline, and with top of backfill materials always remaining below -21.5 HKPD over the central section.

During the approx. 3 months execution period of these backfilling works, the trench profile remained remarkably stable. In view of the thickness and width of the rock bund to be installed within the central part of the Urmston Road section, the works have been executed by means of Jan De Nul’s large self-propelled seagoing splitbarge *Verrazzano* (Figure 7). The self-propelled splitbarge positioned longitudinally above the pipeline at slack tide by means of its twin rudder propellors and bow thruster. The load of the vessel, approx. 2400 tons of rock, was such that an average of three dumps was necessary in order to build up the theoretical profile.

In order to stabilise the pipeline as quickly as possible, the pipeline was pinned first by means of intermediate dumps of 50 m long every 100 m. Subsequent in-between dumps completed the first layer, and afterwards the second and the third layer were installed in accordance with the dumping sequence of the procedures. Defined “windows” were left open and continuously surveyed to monitor the position of the pipeline. These survey data were utilised by Saipem-Emc JV and Arco to determine and optimise the dumping sequence (Figure 8).
Intermediate and final surveys were executed after each dump by means of bathymetric and seismic surveys (Figure 9).
Considering the method adopted, installation of rock armour materials for this kind of dumping profile by means of a splitbarge proved to give acceptable results at lower costs than in the case of using a side dumping

Figure 8. Cross-section of rockbund at Urmston Road.



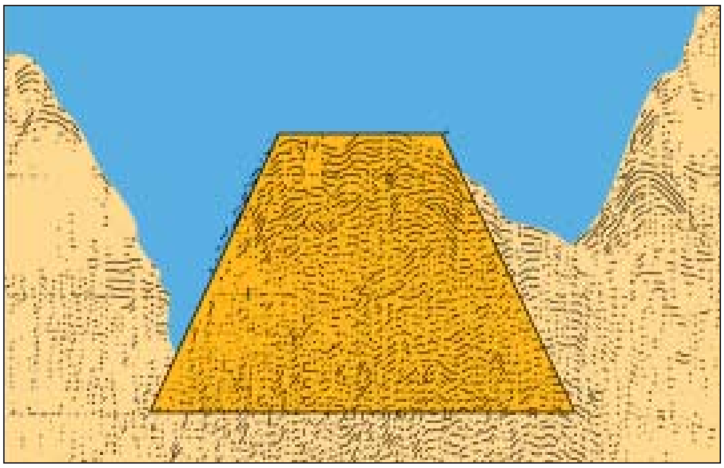


Figure 9. Seismic survey results of the as-dumped profiles.

vessel. In total, over 350,000 tons of rock have been installed by this method, providing protection for the pipeline against 27.5 tons stockless anchors over a section of 2180 m.

Backfilling at the Jiuzhou and Linding Shipping Channels

At the location of the Jiuzhou and Linding channels in the territorial sea of the People's Republic of China, a conventional design of a pre-dredged open trench with engineered backfill has been applied (Figure 10). Taking into account the fine bottom material, and in accordance with filter rules, a three-layer backfill design has been adopted providing a cover of 2 m above the top of pipe (Figure 11).

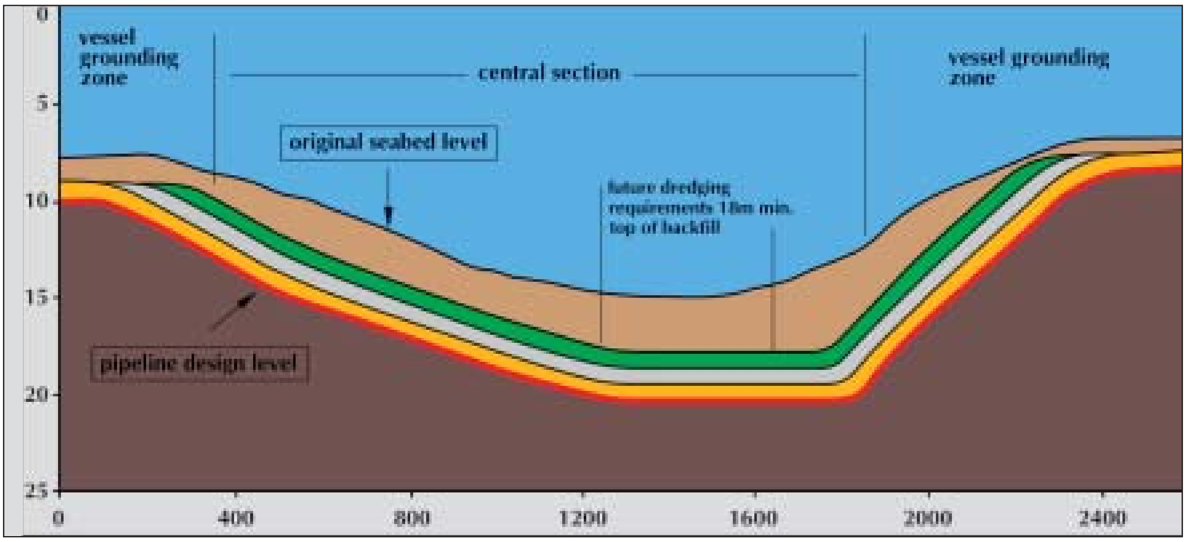
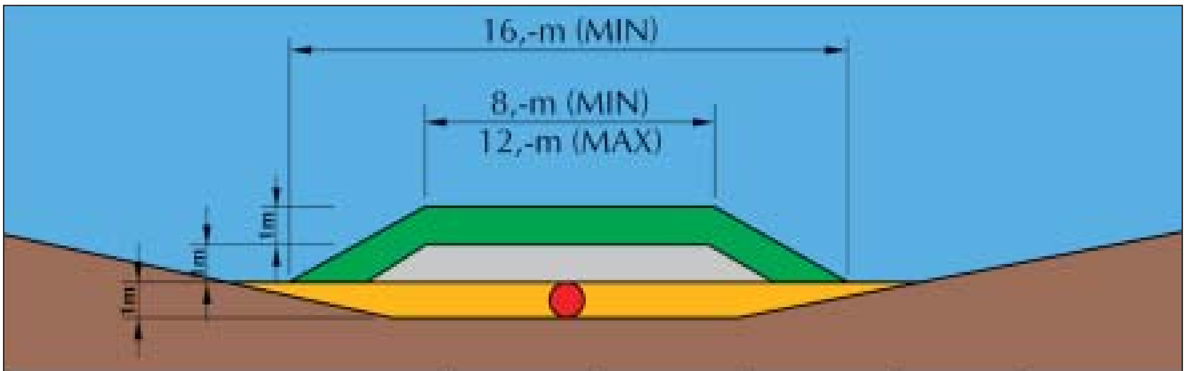


Figure 10. Longitudinal backfilling profile at Linding channel.

Figure 11. Cross-section of Linding channel.



	thickness	d15	d50	d85	d100
BASE LAYER	1m	1mm	2mm	4mm	-
INTERMEDIATE LAYER	1m	10mm	20mm	35mm	-
ROCK ARMOUR LAYER	1m	102/136mm	150/172 mm	-	189/256mm

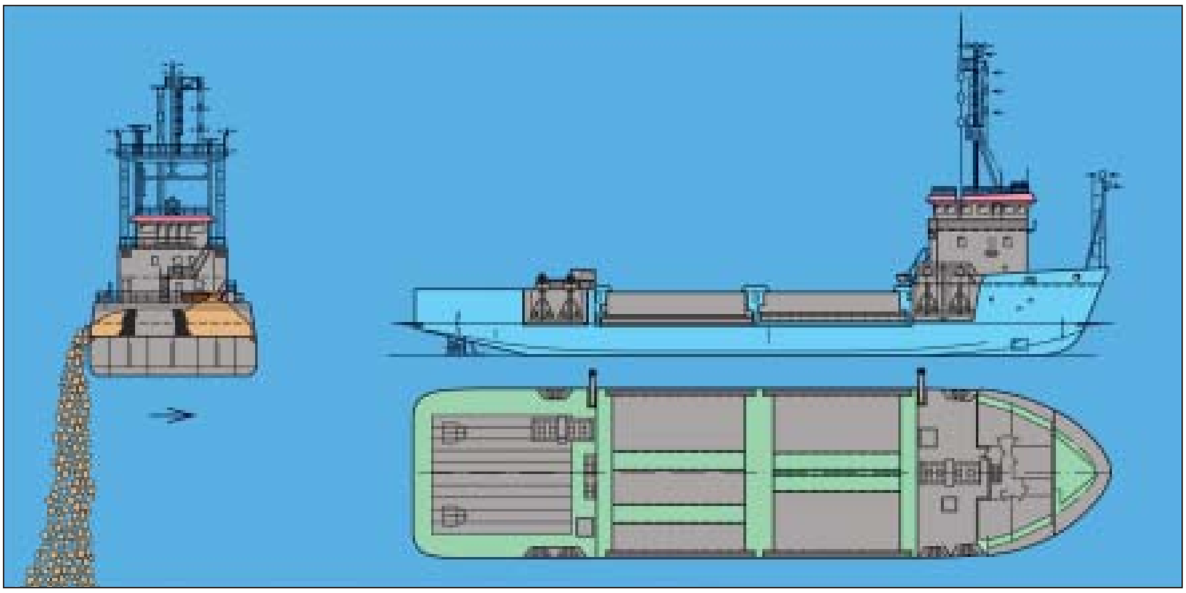


Figure 12. Installation of backfill materials by means of side-dumping vessel.

As such, sufficient stability for the pipeline and protection against a possible impact of 13.5 ton stockless anchors have been provided for.

In order to provide accurate installation of all three layers in these channels, the rock material has been placed by controlled sideward disposal by means of a side dumping vessel (Figure 12).

The side dumping vessel allows accurate placing of pre-defined quantities of backfill material at pre-defined locations. Up to 2000 tons of backfill materials are loaded on the four cargo decks. On arrival above the dumping location, the vessel positions itself parallel above the pipeline, and installs each layer to the specified thickness and width by means of controlled sidewards dumping.

During the dumping sequence, the vessel moves sidewards in a controlled manner on its dynamic positioning system using its twin rudder propellors and bow thruster. The dumping rate can be controlled by adjusting the speed of the hydraulic rams on the slide scrapers. By means of a combination of the dumping rate and the speed of sidewards movement, any profile of uniform or linear increasing or decreasing thickness can be achieved. The rock was supplied by Pioneer Quarries Ltd. from local quarries located at Chung Hsin Chau and Little Spider Island in the People's Republic of China.

Conclusions

As a result of particular circumstances and requirements for the installation of the last 71 km of the 28" Yacheng 13-1 pipeline across the Pearl River Estuary, new and cost effective dredging and backfilling techniques have been developed.

Seabed preparation for installation of the pipeline on firm seabed below cohesive and non-cohesive soils has been applied by means of the newly developed "dilution" principle executed with high capacity trailing hopper dredgers in combination with conventional dredging techniques.

Detailed procedures have been prepared for execution of the works in accordance with these new principles.

Particular testing methods have been developed in order to enable monitoring of the dilution and dredging works.

A rockbund has been installed within acceptable tolerances by means of controlled bulk dumping by means of a large self-propelled seagoing splitbarge.

A conventional three layer engineered backfill has been applied at the Jiuzhou and Linding Shipping Channels in the People's Republic of China.