

## Chapter 67

### CONSTRUCTION OF EFFLUENT OUTFALL DIFFUSERS FOR THE BOSTON HARBOR PROJECT

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This paper deals with the construction of the Effluent Outfall Diffusers which form part of the outfall for the Deer Island sewage project. The work was executed 15 km out to sea in Massachusetts Bay and required the drilling, installation, grouting and accurate determination of the actual position of 55 riser shafts in 33.5 m deep water.

The contractor's approach to the installation of the diffusers required the design and manufacture of many special pieces of equipment and the purchase of some major standard equipment.

The selection of the right drilling method and the right drilling equipment played a major role in the success of the project and the paper discusses these in the context of the overall working method.

#### INTRODUCTION

The Boston Harbor project is a wastewater treatment project undertaken by the Massachusetts Water Resources Authority (MWRA) under a Federal court order, which found wastewater discharges to Boston Harbor to be in violation of the Federal Clean Water Act of 1972.

The main part of the overall project consisting of a \$6.1 billion, 11-year effort, is comprised of the new primary and secondary waste water treatment plant at Deer Island, designed for a total capacity of 57.2 m<sup>3</sup>/s. In addition to the plant, new tunnels and headworks are being built to transport raw sewage from the metropolitan Boston area to the plant, as well as numerous ancillary facilities.

Treated sewage or effluent will be discharged through a 7.4 m (finished) I.D. tunnel, drilled approximately 15.1 km offshore by Tunnel Boring Machine (TBM) excavation. This project is currently under construction. (Figure 1 and 2)

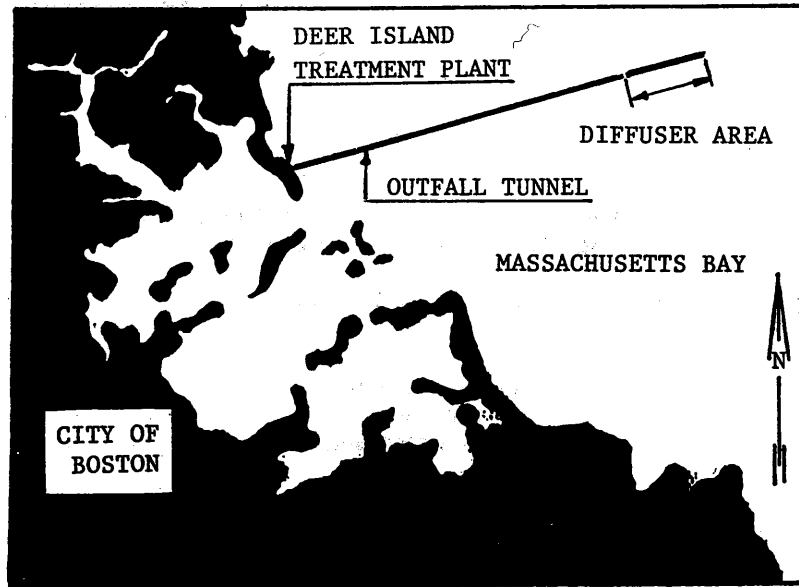


FIG 1 - KEY PLAN

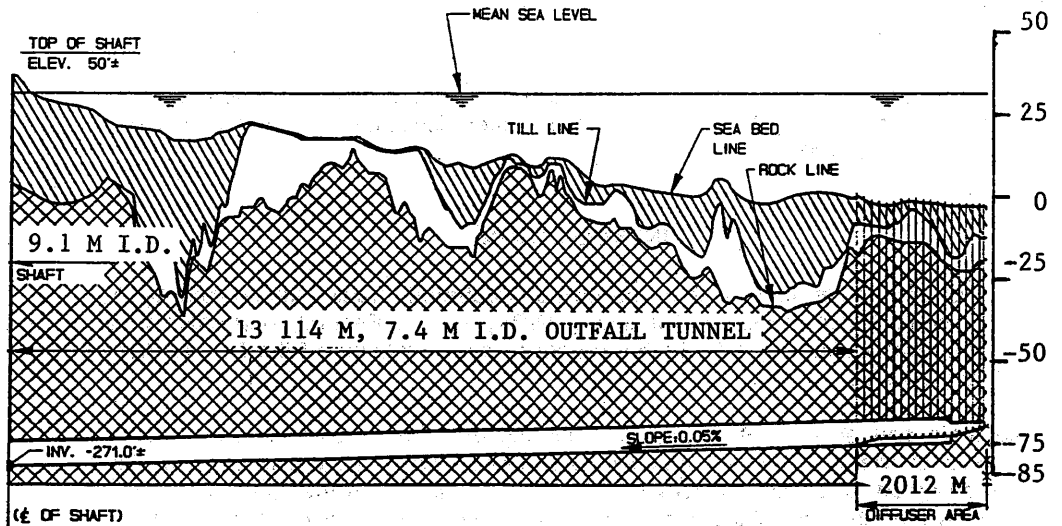


FIG 2 - OUTFALL PROFILE

The effluent discharge will take place over the last 2.0 km through lateral offtakes from the tunnel through the risers into the diffuser heads, which are located just above seabed level. (Figure 3)

The contract for the construction of the effluent outfall diffusers was awarded after a competitive bid in August 1990 by the MWRA to Cashman/Interbeton (CMIB Joint Venture). The contract amount was \$77 million and the project was to be completed in June 1993. However, the work was completed ahead of schedule, in November 1992.

The main piece of equipment utilized for the installation of the diffusers was the jack-up barge IB-909, a self-elevating platform. Dredging and stone placing was done by the crane barge, John Lyons II.

#### WORK ENVIRONMENT

The project site, approximately 15 km east of Boston in Massachusetts Bay is exposed to the sometimes hostile weather and ocean conditions prevailing in this area. In anticipation of these conditions the construction of the diffusers was scheduled during workable time periods of 1991 and 1992, i.e. from April through November. During these seasons, work offshore continued 6 days a week, 24 hours a day. Personnel were transported from shore to the jack-up barge by helicopter. Materials were supplied by barges from a staging area located at East Boston.

The water depth at the project site was approximately 33.5 m and the jack-up barge was equipped with legs long enough to allow for anticipated leg penetration and to ensure a safe deck elevation above sea surface.

While on site, the weather and sea state conditions were generally as expected. However, work was disrupted by hurricane "Bob" in August 1991, and again by the "No name storm" in October 1991.

#### SUBSURFACE CONDITIONS

Since the construction of the diffusers involved large diameter drilling through a total of approximately 4200 m of sediment and rock, knowledge of the site geology was of great importance.

The principal rock formation along the diffuser alignment is Cambridge Argillite, a slightly metamorphosed mudstone or siltstone, with an average compressive strength of 105 MPa. The rock was known to have numerous discontinuities, folded bedding and faulting. Core drillings of the bedrock, obtained during a prior geotechnical exploration program were examined during bid preparation. The rock typically appeared to be uniform and had high average Rock Quality Designation (RQD) values.

Due to the generally stable nature of the underlying bedrock, no collapsed holes were experienced during or after drilling.

Above the bedrock the stratigraphy is comprised of recent sediments, holocene marine clays and pleistocene tills. During construction the total thickness of these sediments appeared to vary between 6.0 to 21.0 m. The individual strata could not readily be discerned during drilling.

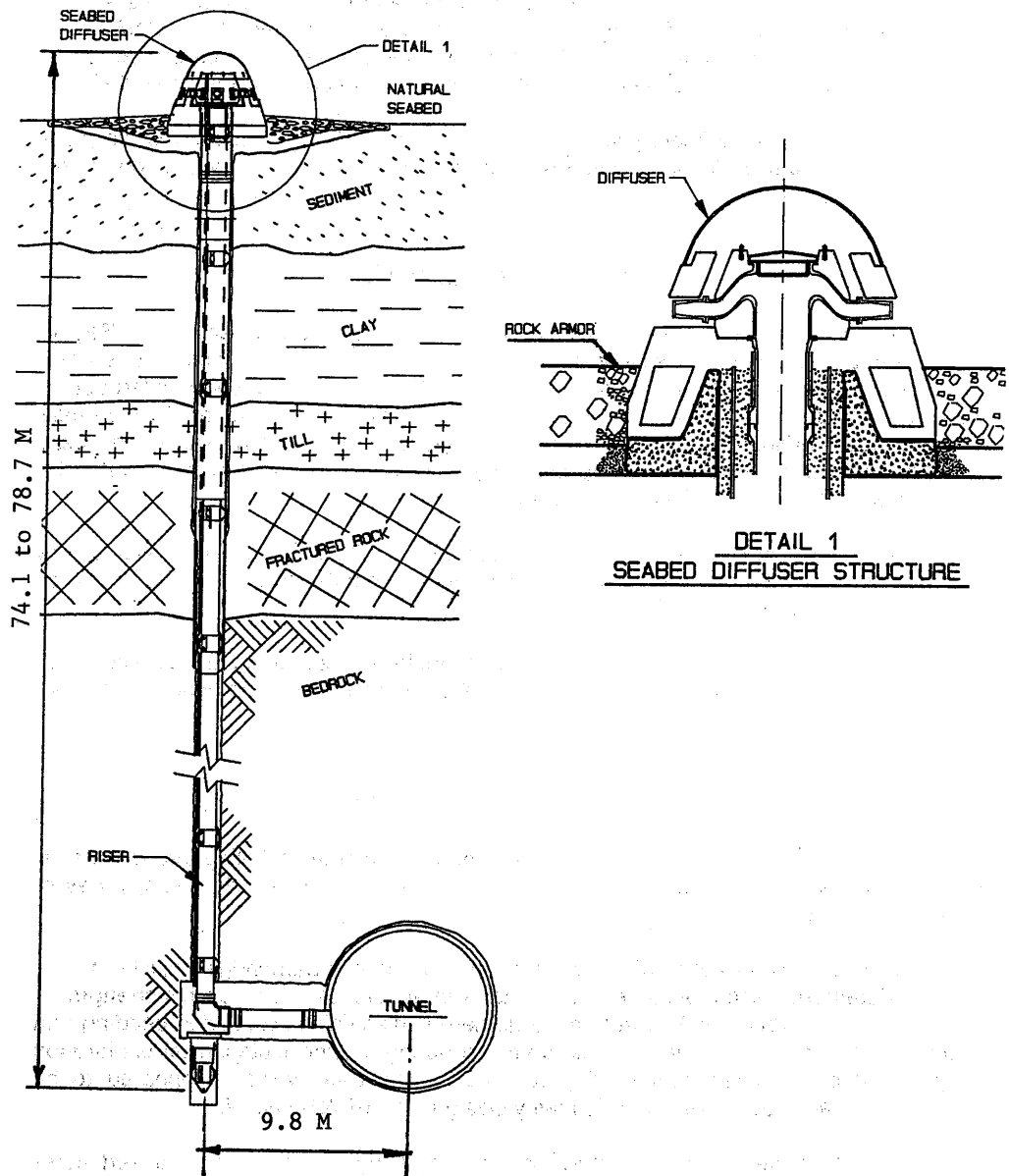


FIG 3 - DIFFUSER WITH TUNNEL CONNECTION

## MOBILIZATION

The time period between contract award in August 1990 and actual start of activities offshore in April 1991 was utilized by Cashman/Interbeton to prepare for continuous operations. Time and financial restraints would not permit undue experimenting once on site. Following were the main activities which took place:

### Procurement of permanent materials

Due to their unique character, as well as 100 year design life, the permanent risers and diffuser structures feature various complex and unusual materials, subject to high quality requirements. The main items being:

Fiberglass reinforced plastic (FRP) pipes. These heavy wall thickness pipes, which form the inner lining of the risers, are spirally wound and measure 12.0 m long by 0.76 m I.D. During flexural testing, each pipe was monitored for acoustical emissions.

Fiberglass reinforced plastic (FRP) manifolds. These components were located on top of each riser and formed the inner liner of the diffuser head. They include 8 port arms for the uniform dispersment of effluent at the ocean bed level. The FRP manifolds were fabricated of hand-laid fiberglass and concrete encased. Each was hydrostatically tested, while simultaneously being monitored for acoustical emissions.

Cast nylon nozzles and port caps. These units are attached to each manifold port arm and, they vary in diameter according to their location along the diffuser line. The port caps effectively seal the riser/diffuser assembly and will not be removed until commissioning of the outfall.

Cast steel clamps. These clamps, which weigh 545 kg per set, provide the connection for the FRP pipes.

Precast concrete diffuser head. These units comprise the concrete encased manifolds, mentioned above, the concrete base and the ringwall. This unit formed the protection at seabed level of the diffuser. The outer surface of the precast components are provided with a 3.2 mm polyurethane coating, which serve to provide additional mechanical protection to the installed diffuser. The total weight was 54 tonnes.

High density polyethylene domes. These units, located on top of the ringwall are designed to Deflect dragging wires, anchors, etc. for protection of the diffuser head. They were rotationally molded, using the cross-linked HDPE process.

Inconel™ (and high-grade stainless steel.) Inconel, a high nickel alloy is used in various connections, fittings, inserts, etc. Most of these parts are machined or fabricated assemblies and have been designed to provide highly corrosion resistant connections to the diffuser head components.

Various custom fabricated mild steel components Although most of these items performed a temporary function in the construction of the diffusers, they were manufactured under the same rigorous quality control standards as permanent materials and required the construction manager's review and approval.

Production of permanent materials was all done under purchase agreement by highly specialized companies throughout the U.S.A. as well as Australia, in case of the steel clamps. All materials were delivered at the staging area in East Boston where they were assembled in three sections (diffuser head and two riser sections) prior to shipment offshore for installation.

#### **Mobilization of equipment**

IB-909 The jack-up barge, IB-909, as the main piece of equipment utilized for drilling and riser installation and was mobilized from Singapore. On arrival in Boston, it was equipped with a Manitowoc 4100 S3 ringer crane with a 54.8 m boom. Its pontoon shaped hull measured 43.0 m x 30.0 m x 4.20 m, and had a carrying capacity of 3200 tons when jacked up. The 4 legs were extended to an overall length of 70.0 m. The jacking up system consisted of hydraulic driven rams with holding and working pins. Compressed air for drilling was provided by 4 compressors.

Electric power for the jack-up barge operation and drilling was provided by 3 synchronized 150 generators. Four submersible pumps were installed to provide a continuous head of water pressure in the drill casing to prevent hole collapse. For the specific purpose of casing-top drilling and riser positioning and installation the barge was equipped with 2 custom engineered templates, one to port and one to starboard side of the barge which could slide along a bullrail fixed to the barge deck. Each template was provided with a gate, which in turn could slide laterally to the barge for positioning purposes. The barge was equipped with a 6-point mooring system, used during repositioning of the barge.

In addition to the primary systems, the jack-up barge was fitted with a heli-deck, a 20 tonne hydraulic service crane, extensive diving and navigation equipment, and various storage compartments.

The advantages of a jack-up barge for this type operation are that it provides a stable platform relative to the seabed, and facilitates an accurate and safe riser installation. Virtually no shutdowns due to adverse weather and sea state conditions were encountered.

An added advantage of the specific jack-up barge selected was the hull size (beam 30.0 m). This allowed simultaneous work at two riser locations at each set-up. (The risers were located at 37.8 m centers). Figure 4 shows a view of bow side of the IB-909 while at a typical set-up. Figure 5 shows a picture of the IB-909 in operation.

Drilling Rigs For the actual drilling of the riser hole, 2 new Wirth B818/2500/300 casing top drilling rigs were purchased along with bottom hole assemblies containing weight cans and centralizers. Drill bits measuring 1.70 m and 1.35 m diameter were provided for the upper and lower portion of the drilled hole respectively. Both tooth cutters (for drilling through upper overburden) and disk cutters (for drilling through lower rock) were provided.

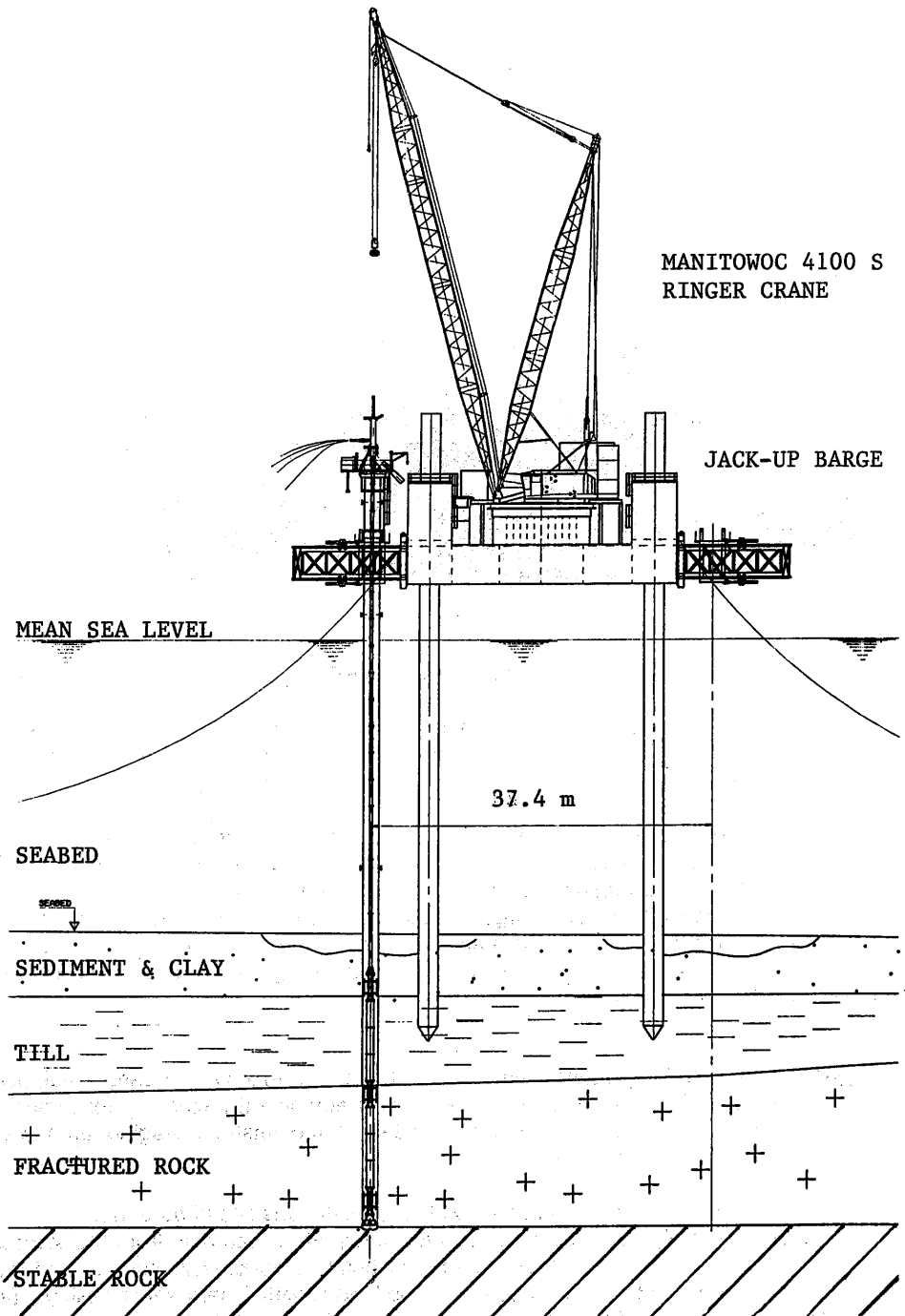


FIG 4 - TYPICAL SET-UP JACK-UP BARGE  
DURING FIRST PHASE DRILLING

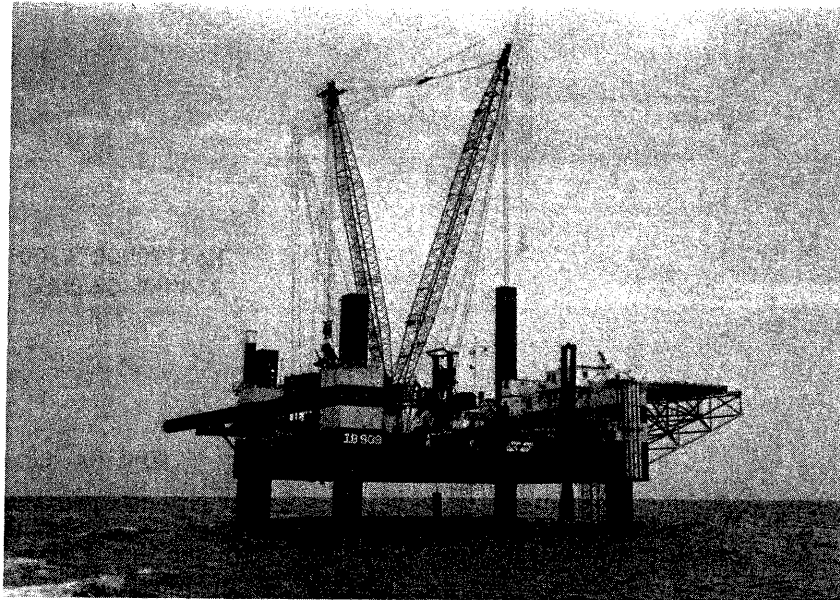


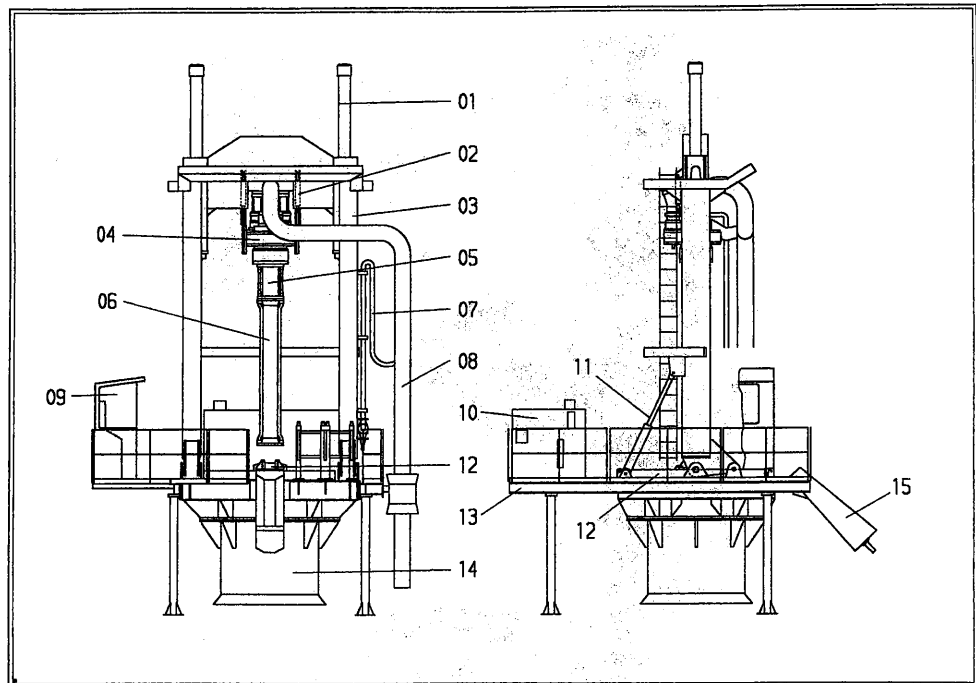
FIG 5 - JACK-UP BARGE IN POSITION

An adequate number of drill strings, each measuring 3.0 m by 0.3 m I.D. were purchased with the drill. For a drawing and specification of the Wirth drilling rig refer to Figures 6. A photograph of the drilling rig in operation is shown in Figure 7.

**Dredge** The dredge John Lyons II, a floating crane barge equipped with a track mounted 2400 Lima crane was outfitted for use offshore as a clamshell dredge. The rig was primarily used for dredging the riser holes and backfilling with sand and rock following the riser installation. The barge measured 46 m x 16.7 m x 3.0 m. The crane was equipped with a 7.5 m<sup>3</sup> dredging bucket and a 3.4 m<sup>3</sup> material handling bucket. Diving facilities as well as precise navigation positioning and bathymetric survey equipment were also on board.

**Grout barge.** The floating grouting plant consisted of a 58.0 m x 17.0 m barge equipped with a 10 bulk tanks, 2 water tanks and various other equipment necessary for offshore grouting operations. The bulk tanks were loaded at the onshore staging area with preblended dry groutmix.

**Material transport barge** A transport barge with overall dimensions of 55.0 m x 13.7 m equipped with pipe cradles, was used for transport of materials from the staging area in East Boston to the offshore site. As the installation works were carried out for 2 risers simultaneously, the transport barge could be loaded with 2 permanent casings, (4) 36.5 m long FRP-sections, (2) complete diffuser assemblies and (2) temporary casings. Additionally miscellaneous other items could be transported at the same time.



Drawing legend

Pile top drilling rig  
WIRTH PBA 818/2500/300

- 01 advance cylinder
- 02 power swivel tilting cylinder
- 03 drilling mast
- 04 power swivel
- 05 drill-pipe sub
- 06 drill-pipe
- 07 air supply line
- 08 discharge hose
- 09 control desk
- 10 hydraulic power pack
- 11 mast tilting cylinder
- 12 retaining device
- 13 working platform
- 14 clamping device
- 15 pipe rack

Technical Data

Manufacturer:	WIRTH GmbH
Type:	PBA 818/2500/300
Dimensions:	
Length:	7,5 m
Width:	6,65 m
Height:	11,2 m
Travel length of the power swivel:	3,2 m
Drilling thrust, max:	800 kN
Vertical load capability of the retaining device:	900 kN
Drill pipe length, max.:	3000 mm
Drill pipe diameter:	300 mm
Drilling diameter, max.:	
Clearance retaining device:	2500 mm
Speed, power swivel:	6.5-18/23-64 RPM
max. Torque, power swivel:	180 kNm
Hydraulic power pack:	N = 160 kW

FIG 6 - DETAILS DRILLING RIG

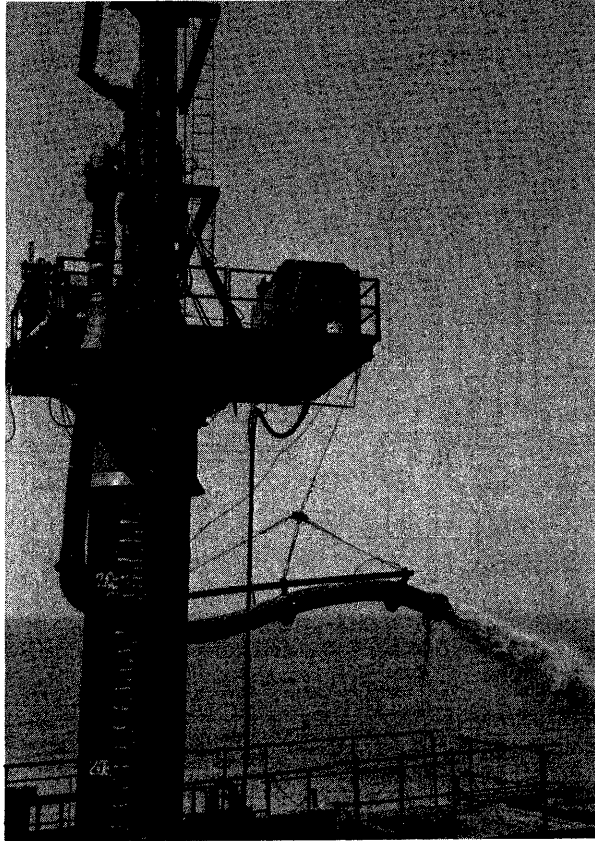


FIG 7 - DRILLING IN PROGRESS

Sand/stone barges Several barges of various dimensions were used to transport filter sand and/or rock from Gloucester, MA to the offshore site.

Utility vessel A 800 hp, 100 ft long steel hulled utility vessel was used during the 1991 offshore season for occasional crew transport, site assistance and supply.

Dive vessel A 1200 hp, 120 ft long steel hulled utility vessel was used during the 1992 offshore season as a diving vessel. For this purpose it was equipped with a Del Norte microwave positioning system, full diving equipment and 2-diving chambers for back to back diving.

Tugboats/crew boats Tugs and miscellaneous crew boats were rented on an as needed basis.

Other equipment The onshore staging at East Boston was the site for the grout blending plant. Basic components like cement, sand and slag were delivered in bulk. Preblended dry groutmix was stored in bulk holding tanks, from where it was transferred to the grout barge storage tanks.

A Manitowoc 4000 crawler crane and a travel lift were used for assembly of the major riser and diffuser components.

Offshore transportation for most personnel was carried out from a pickup area on Long Island by a Twin star AS 355 helicopter.

### **Engineering**

Due to the unconventional nature of this project a considerable effort was given to work preparation and engineering during the mobilization phase. The main activities are described below.

Work method. Given that the contract specifications contained specific parameters regarding the allowable method of construction, deciding on the final work method and reaching a consensus among all parties involved, required extensive coordination with the Construction Manager.

Engineering and design of various construction aids such as the appurtenances to the jack-up barge, templates, gates, support frame for diffuser etc. Also developing specific lifting devices and frames for the handling of steel casings, FRP pipe assemblies and diffuser heads.

Installation manual. Developing a "step by step" installation manual covering both the assembly and the offshore operations. This manual, which incorporated very strict quality control procedures, was considered of extreme importance. Field errors could give rise to physically hazardous conditions as well as cause the loss of expensive permanent materials during construction. Also, these errors would potentially be very difficult and expensive to correct at a later date, and clearly possessed to capacity to seriously delay the overall project schedule. Finally, deviation from strict installation procedures could ultimately cause the riser to leak.

Subcontracts. In cooperation with specialty subcontractors, procedures were established for grouting, survey and diving. These aspects of the project are further elaborated on in the installation section of this paper.

Safety. Procedures were developed to suit the nature and location of the project. Training on safety rules and procedures was mandatory for all personnel prior to offshore activities.

## **INSTALLATION**

The emphasis in this section given the purpose of this paper, is placed on the actual installation of the diffusers offshore. The activities of the dredge, prior to and after installation, are not addressed in detail.

What follows is the chronological sequence of events which took place during installation of a riser. While in practice activities were ongoing at 2 riser locations at the same time, the description below reflects the activities at one riser only.

### General

The chosen work method for drilling and installing the risers allowed maintaining contact with the hole from jack-up barge level at all times. This avoided major diving and underwater survey work. Diving was limited, and remote operated vehicles (R.O.V's) were deployed as much as possible to carry out underwater inspections and video recording during crucial construction phases.

### Jack-up barge positioning

Using a gyro compass and microfix positioning system, the jack-up barge was placed in position by its mooring system and jacked up. Deck level was then established to serve as a reference for permanent construction.

### Installation of temporary casing "A"

After a position check of a reference point on deck by tellurometer (a high precision microwave system), the template and gate were moved to the required position, i.e. the theoretical coordinates of the riser center.

A temporary steel casing ("A" I.D. 1.76 m, length approximately 60.0 m) was pitched vertically in the template until it was supported by the seabed. The purpose of this casing was to provide a support for the drilling machine and function as a sediment sleeve to retain the upper unstable layers.

### Drilling first phase

The purpose of this phase was to drill a hole through overburden approximately 3.0 m into stable rock. This permitted installation of the permanent steel casing.

After clamping the Wirth drilling machine on top of casing "A", placing the bottom hole assembly equipped with a 1.70 m diameter drill bit into the casing, and adding a sufficient number of drill strings, drilling commenced. See Figure 8 for photo of the bottom hole assembly. Air was injected into the drill string, and through the process of reverse circulation, drill spoil was airlifted to the surface and sidecast into the sea.

The drilled depth at this stage was developed by experience. The minimum length of the permanent casing was 15.2 m as required by the specifications. While drilling had to continue 3.0 m into stable rock, it was difficult to determine where stable rock began during drilling. As experience was gained, predictions could be made and drilling usually continued to suit a predetermined length of permanent casing. This length varied between 15.2 m and 27.4 m depending on the anticipated depth of stable rock. After drilling to the anticipated depth and retrieving of the drill, the hole was inspected using an underwater camera and the exact drilled depth established.

The progress statistics for the 1.70 m diameter hole drilling are: (for 55 risers)

total hours drilled	:1450
total depth drilled	:997 m
average drilling speed	:0.69 m/h
highest average drilling speed	:(riser no. 15) 2.43 m/h
lowest average drilling speed	:(riser no. 44) 0.23 m/h

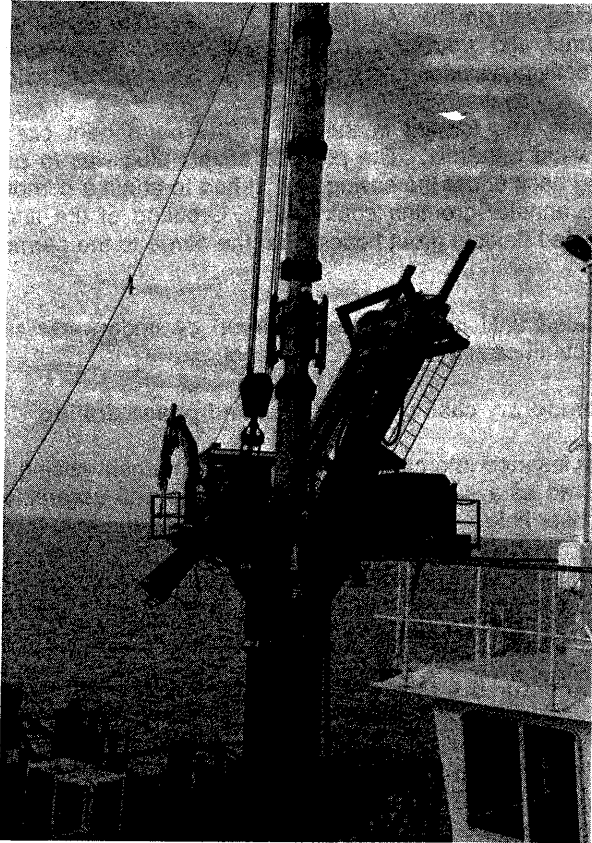


FIG 8 - LOWERING OF BOTTOM HOLE ASSEMBLY

#### **Installation and grouting of permanent casing**

This casing, once installed, served as a permanent retaining sleeve of the unstable seabed sediments. It also served as the support of the riser/diffuser assembly immediately following installation. As such, the top level of the permanent casing was of utmost importance for the final diffuser level relative to existing seabed, which was tied to strict design tolerances.

The permanent casing consisted of a ASTM A-36 steel casing, straight seam welded, outside diameter 1.55 m, wall thickness 38.1 mm fabricated in various lengths from 15.2 to 27.4 m. The top was provided with an internal recess to allow latch-in of the diffuser head. Both inside and outside of the casing were coated with a polyurethane coating. Four external extractable grout pipes measuring 44 mm I.D. were equally spaced around the circumference of casing.

Using a special lifting device, which could be remotely released, the permanent casing was carefully lowered into casing "A" and down into the drilled hole. After a final check of the top level the casing, grouting commenced.

The grouting was done from a floating grout barge fully equipped with bulk storage, mixing and pumping equipment. All essential criteria of the grouting process, such as flow rates, pressures, and grout temperatures, were controlled by automated monitoring equipment. This activity was done by a specialty grouting subcontractor.

First a grout plug was formed in the toe of the permanent casing, using a rapid hardening underwater groutmix. The purpose of this plug was to prevent the annular grout from flowing back under the casing toe. It had to attain a compressive strength of 1.41 MPa before annular grouting could start. Grouting of the annulus started after divers had connected flexible grout hoses from the barge to the permanent casing grout pipes.

Grouting continued until returns were observed by underwater camera through an observation hole cut in casing "A" at dredged level.

#### **Installation of temporary casing "B" and second phase drilling**

This casing was inserted into casing "A" and the permanent casing, and rested on the grout plug. It served as a guide and centralizer to the drill assembly while drilling the remainder of the riser hole.

Since this configuration of concentric casings required very tight tolerances with regard to straightness and out of roundness, all casings were fabricated to tolerances stricter than API 2B to prevent jamming.

The casing "B" measured 1.41 m I.D. and had a length which varied from 27.0 m to 38.0 m.

Once installed, the top was located 5.0 to 10.0 m above the top of permanent casing and a funnel shaped ring welded to the top acted as a guide for the drill assembly when lowering it into the hole.

A remotely operated hoisting device was again used for placing and later retrieving of the casing.

The drill bottom hole assembly of 1.35 m nominal diameter was then inserted, drill strings added and drilling resumed as described before. Drilling depth was monitored, and drilling would continue to 0.60 to 0.90 m below the projected toe level of the installed riser.

The progress statistics for the 1.35 m diameter hole drilling are: (for 55 risers)

total hours drilled	:2879
total depth drilled	:3046
average drilling speed	:1.05 m/h
highest average drilling speed	:1.85 m/h
lowest average drilling speed	:0.60 m/h

#### **Down the hole survey**

The contract specifications allowed a 1 degree out of vertical for the final drilled hole. To determine conformity with this requirement a down-the-hole survey was carried out to accurately establish the position of the riser hole toe and the top of permanent casing elevation.

At this time a reference point on deck was accurately determined by Global Positioning System (GPS) and these coordinates were related to the top of permanent casing. The actual down the hole survey was carried out by Surface Reading Gyroscope (SRG). This tool which fits into the center of the drill string, was gradually lowered into the hole, while readings were taken to determine both the inclination and the directional bearing (azimuth) of the drilled hole. The SRG observation was double checked by means of an inverted plumb bob. In all cases the drilled holes were within the specified tolerances, with 75% of the holes within 0.5 degree inclination.

#### **Riser installation**

After removal of the drill assembly and the "B" casing, the lower half of the pre-assembled FRP riser pipe was lowered into casing "A".

The specifications required that each riser be filled with fresh water containing dye. The purpose of this colored water was to serve as an indicator to facilitate future tapping from the outfall tunnel into the riser. Further the weight of this water provided the negative buoyancy to allow lowering the riser assembly.

Prior to securing the bottom half of the riser at deck level, the casing "A" would be cut off by divers at a level below the top of permanent casing and removed. This permitted attachment the upper half of the riser pipe and subsequent lowering of the complete riser pipe into the hole. Since water tightness was of extreme importance, each connection of the riser pipe sections was thoroughly checked.

During riser installation, a temporary support frame for the diffuser head was brought into position, the connection made with the riser pipe, grout pipes connected, and more colored water added. The entire assembly was lowered into the drilled hole until the latching mechanism, which was fixed to the underside of the diffuser head, latched into the permanent casing. This lowering process was carefully monitored underwater by a R.O.V. To assure that the complete assembly was properly latched to the casing, an amount of upward force was exerted on the assembly. Also at this time, a diver's gauge incorporated in one of the portcaps was read to ascertain if any leakage of seawater into the riser had taken place. Reference is made to Figure 9 for a photo of a diffuser prior to installation.

#### **Grouting of riser**

Once proper installation of the diffuser was confirmed, grouting of the riser annulus around the FRP pipe started.

Grouting took place through a 89 mm diameter pipes, externally fitted along the side of the riser pipe. A remedial grout line was provided in case of serious disruption of the grouting procedure.

Grouting continued until returns were sighted at an overflow hole at the diffuser base. The density of grout placed under the diffuser was monitored by a nuclear density gauge. The minimum density that had to be obtained was 1920 kg/m<sup>3</sup>.

#### **Completion of diffuser location**

After completion of installation the jack-up barge was relocated 76.0 m along the outfall alignment and set-up to start work for the next two diffusers.

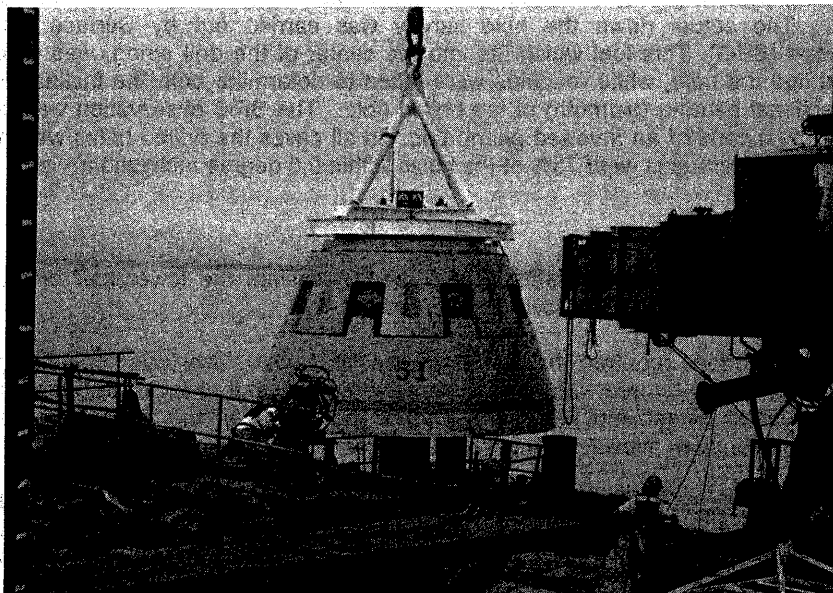


FIG 9 - DIFFUSER READY FOR LOWERING

The dredge barge was utilized to complete the final work at each location. This involved grouting the diffuser base, (the space between the underside of the diffuser head and the dredged hole) using a nylon fabric skirt to retain the grout. The dredged hole around the risers, measuring about 21.0 m in diameter, was then filled with a sand gravel filter and covered with rock armor. Finally, the HDPEX dome was placed to complete each diffuser.

#### PROGRESS

A total of 253 work days were spent on the diffuser installation only. This time period can be broken down to groups of activities as follows:

install casing "A", drill 1.70 m diameter hole	:75 days
install and grout permanent casing	:42 days
drill 1.35 m diameter hole and survey	:97 days
install diffuser	:39 days

