

CHAPTER 204

SUBMARINE SIPHONS FOR ATHENS SEWERAGE SYSTEM

Y. Eisenberg, M.ASCE
Th. C. Gofas, M.ASCE
R. A. Fasano, M.ASCE
F. S. Hindes

ABSTRACT

The submarine siphons with an overall length of almost 1300 meters and an ultimate capacity of 27 cubic meters (m^3) per second (about 600 million gallons per day) will be a major element of the new wastewater conveyance and treatment system presently under construction in Athen, Greece. This will help alleviate the present condition where an average of more than 6 m^3 per second (130 million gallons per day) of untreated domestic and industrial wastewater are discharged into the sea near Athens. Construction of the submarine siphon pipes started in late 1984 and was completed in early 1987.

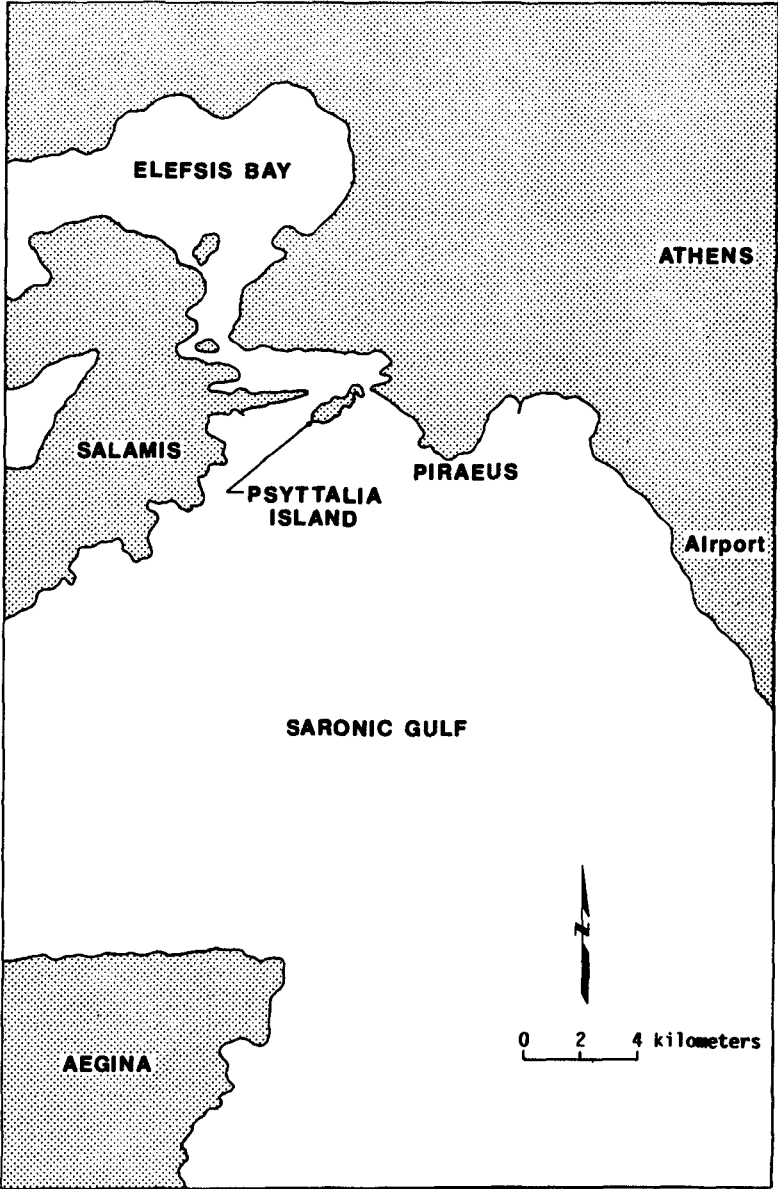
Description of the data collection for and the design, manufacture and construction of these submarine siphons are presented in this paper.

INTRODUCTION

In 1983, the Greek Government undertook a \$100 million program dealing with the collection, transportation, treatment, and disposal of sewage of the greater Athens area serving a population of over three million people. The program involves the collection of sewage from the mainland and its transportation to the small island of Psyttalia through two 1300 meter long submarine siphon pipelines with an inside diameter of 2.8 meters. A treatment plant on Psyttalia will process the sewage prior to its ultimate disposal through a 1600 meter long diffuser outfall into the 60 meter deep water of the Gulf of Saronikos.

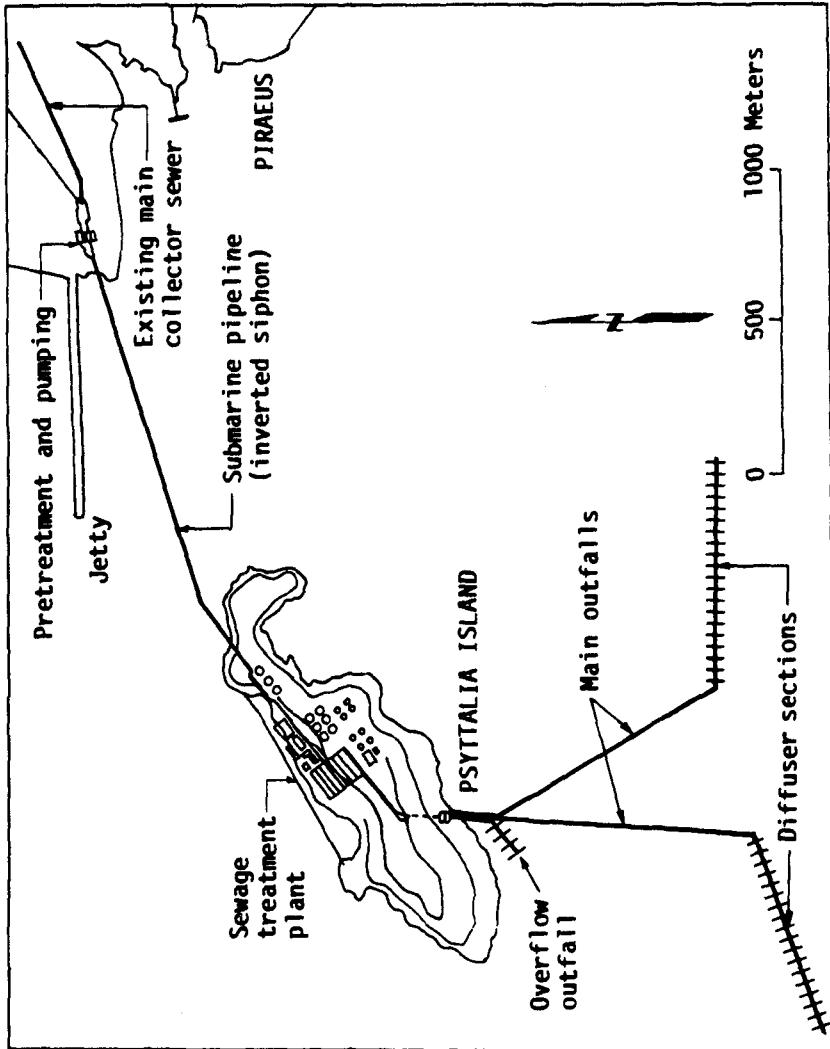
The submarine siphon pipelines, whose design and construction are described in this paper, have a hydraulic design capacity of 27 cubic meters per second (about 600 million gallons per day). They traverse a shipping channel carrying heavy traffic to Elefsis Bay near Piraeus Harbor (see figure 1 - Vicinity Map and figure 2 - Project Site) through a troublesome layer of sludge created by previous sewage dumping and are placed in a protective trench at depths reaching almost 50 meters below sea level (see figure 3).

Y.Eisenberg, Parsons Brinckerhoff, San Francisco, California, U.S.A.
Th.C.Gofas, Th. Gofas and Partners Ltd., Athens, Greece
R.A.Fasano, AWD Technologies, Wayne, New Jersey, U.S.A.
(formerly with Woodward-Clyde Consultants, Wayne, NJ, U.S.A.)
F.S.Hindes, Lafayette, California U.S.A.



VICINITY MAP

Figure 1



SITE PLAN

Figure 2

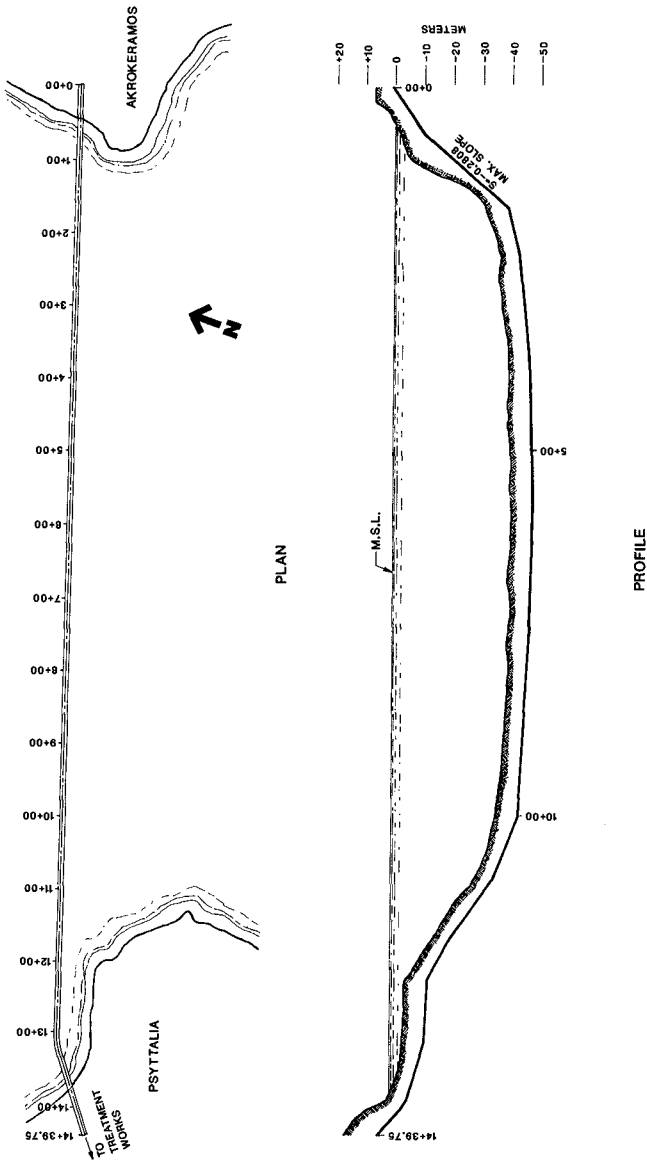


Figure 3

DATA COLLECTION

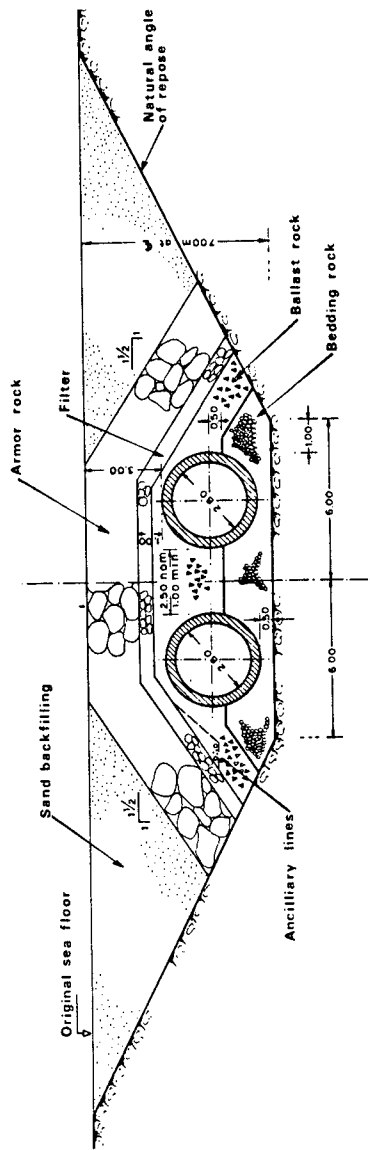
The geotechnical conditions along the route of the pipeline were investigated by a combination of borings, probes, and marine geophysics.

A total of 14 borings were made at 100 meter intervals to depths of approximately 15 meters below the sea bottom. The borings were supplemented by a total of 30 probes driven to "firm" conditions below the sea bottom. The purpose of the probes was to provide additional information on the depth, extent, and consistency of the sewage sludge discharged into the sea from the main interceptor sewer, and the thickness of loose natural sediments lying on the sea bottom.

Marine geophysical methods included bathymetric surveys and an attempt at sub-bottom profiling. The bathymetric surveys, combined with depth measurements from the borings and probes, were sufficient to map the surface of the sea bottom in an approximately 500 meter wide corridor along the route of the pipeline. Sub-bottom profiling was not successful over most of the alignment due to the presence of methane gas bubbles in the sewage sludge. The gas bubbles tended to cause absorption of the acoustic energy of the signal, rather than having it reflected back to the sensor by successive harder layers below. The results of the geotechnical investigation indicated that the sewage sludge covered the sea bottom over approximately two-thirds of the pipeline route from the discharge of the interceptor sewer on the east side of the channel to near the end of a jetty on the north side of the channel. The sludge varied in consistency from very loose or "liquid" near the surface to medium stiff at its deepest point. The gain in consistency with depth is attributed to consolidation of the lower, older portions of the sludge under the weight of more recently deposited sludge near the surface. The thickness of sludge varied from 0 near the edges of the deposit to approximately 6 meters near the center of the deposit.

The natural sea bottom consists of loose to medium dense marine sand with a high silt and clay content. The sand exhibited some natural cementation which varied in location and depth. The thickness of the sand varied from 0 near the shorelines to greater than 15 meters near the center of the channel.

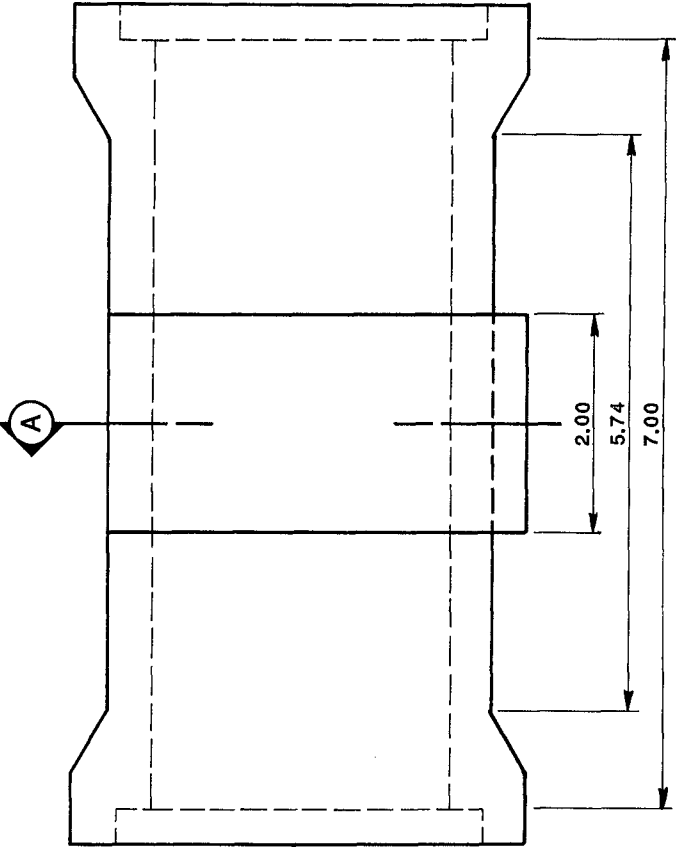
Beneath the marine sand is rock which is classified as Neogene limestone. Based on inspection of cones and observations of outcrops of rock on the mainland and on Psyttalia Island, the rock is characterized by the presence of solution cells and cavities. Some of the smaller cells are filled with calcite. As observed on land, the dimensions of cavities vary from 1 to 2 cm up to a few meters. The formation of these cavities is attributed to the existence of joints and faults in the limestone and to solution activity. It was the presence of these cavities which lead to the decision to transport the sewerage from the mainland to Psyttalia Island via siphon pipes laid in a trench in the sea bottom, rather than via a sewer tunnel in rock beneath the sea bottom.



- Bedding rock : 9 to 60 mm
- Ballast rock : 90 to 240 mm
- Filter : 150 to 250 kg
- Armor rock : 1.5 to 2.5 tonnes

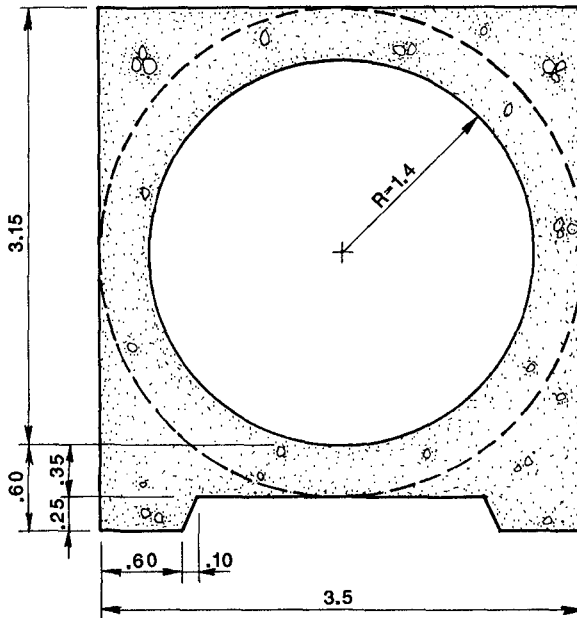
Figure 5

BACKFILL DIAGRAM



DOUBLE BELL PIPE AT STATION 5+43

Figure 6



(A) SECTION OF DOUBLE BELL PIPE

Figure 7

PIPE MANUFACTURE (See Figures 8, 9, 10 & 11)

The 8-meter lengths of pipe were cast at the jobsite. PIPE, Inc. of Tacoma, Washington, were retained as consultants to the Contractor and were vital in minimizing the problems that did occur. Casting large Reinforced Concrete Pipe is a much more sophisticated operation with unique skills than would appear on the surface to the uninitiated.

The pipe was cast-in-place vertically with the raised bell down. Three sets of forms were fabricated locally with some of the problems which should be expected. The tolerances on the bell and spigot

machined rings are critical in order to have interchangeability between pipe cast in different forms with the very close dimensional clearances in the joint design.

The double reinforcing cages were fabricated at the jobsite using PIPE's imported machine, which they had used on San Francisco's Southwest Ocean Outfall Project.

The spigot is the "tenderest" part of the pipe, and any spalling or cracking of the front edge usually results in a test failure at installation, which is a costly expense to the Contractor. Unfortunately, due to the nature of the spigot being cast up, this concrete has the least consolidation, most segregation, air entrapment and laitence formation requiring extraordinary care in concrete placement, vibration and finishing. Unfortunately, this lesson is not appreciated until major problems are encountered with the laying, at which time a considerable amount of defective pipe has already been cast.

Another problem arose when the too-small crane used to strip the too-tight fitting and untrue interior form would rock back and forth as the form would break loose and then stick, resulting in a non-vertical pull on the form, which in turn had a prying effect on the spigot end, invariably resulting in spalling the spigot. The result was that every pipe spigot had to be patched. The O-ring grooves required extensive finishing work ending up with every spigot epoxy-coated to provide the necessary crack-free, smooth, uniform surface and uniform groove depth which varied due to lack of attention in maintaining the forms.

Every pipe was internally hydrostatically tested, revealing very few cracks and giving a good check on the sealing configuration of the spigot. Additionally, after months of unexplained joint test failures during field installation, each pipe was joined with what was going to be its mate, and the joint was hydrostatically tested in the yard before being sent out for installation.

The epoxy painting of the interior and exterior was an unusual requirement and made for a very high-quality finish, which should more than pay for itself in increased longevity and flow characteristics. A side benefit was that the light sandblast prior to application of the paint revealed many air-entrapped pockets under the grout surface, particularly on the interior of the pipe, including high porosity conditions at the rebar chairs. These areas were epoxy patched before painting.

The concrete was batched on the job into ready mix trucks and then craned into place. As the local aggregates are not high strength, the Contractor elected to use generous proportions of cement, resulting in exceedingly high compressive strengths. The Greek Ministry of Public Works maintained a complete and competent inspection force at the jobsite.



PIPE PLANT

Figure 8



PIPE SPIGOT DETAILS

Figure 9

**DOUBLE BELL SECTION**

Figure 10

**COAL-TAR EPOXY FINISH ON PIPE**

Figure 11

CONSTRUCTION

The construction of the submarine siphon described below was divided into the following components:

1. Excavation
2. Pipe Laying and Bedding
3. Rock Backfill
4. Surveying
5. Utility Line Installation
6. Final System Leakage Tests

1. Excavation (See Figure 12)

The trench was dredged in its entirety using three 2400 Lima barge-mounted cranes clamming into small dump scows (i.e., 250 m³) and disposing of the material a short distance away.

The first order of business was to remove the sewer sludge which overlay a third of the alignment on the mainland side and varied up to 7 meters in thickness. This material was the deposited result of the many, many years of discharge of Athen's raw sewage at the shoreline adjacent to the project and was only diverted 100 meters away for the convenience of construction. The material consisted of very low shear strength "black mud" and posed no problem in excavation other than its odorous nature. However, due to the long delay (1-½ years) between the initial excavation and pipe placement in the excavated trench, the sludge crept back into the trench, which required extensive clean up before pipe installation and again before cover rock placement.

The 7-meter deep trench in the seabed was founded generally in hard clayey sand, posing considerable problems for the Contractor. One-half of the material lies below a 40-meter depth and almost three-quarters below 30 meters.

The dredging was conducted in two shifts, six days a week, and the average production was in the range of 250-300 m³ per dredge per shift.

Rock was encountered on both ends of the alignment, and after unsuccessful attempts at drilling and shooting, the rock was removed using chiseling and scraping with the buckets.

Upon experiencing the hardness of the seabed material, the Contractor elected to help offset the adversities by excavating the trench to the minimum width (12 meter) with the side slopes standing competently at near vertical. This, of course, minimized the quantity of material to be excavated and the quantity of manufactured rock backfill to be produced and placed. The minimum width combined with the vertical side slopes did cause some difficulty in trying to maintain adequate clearances for the pipe laying, as one can imagine the difficulties in trying to clam a 12 meter-wide groove 40 plus meters below you in the blind!

In total, the excavation of the 7 meter deep trench entailed the removal of 125,000 m³ of sludge overburden in addition to 200,000 m³ of other material.



PIPE TRENCH EXCAVATION

Figure 12

2. Pipe Laying and Bedding (See Figures 13, 14, 15, 16 & 17)

The pipe was lowered into the trench, mated with the previously laid joint and held in alignment while being bedded in the conventional manner using a "Horse" (see Figure 14). This device is like a four-legged table under which the pipe is strapped, and, once set on the trench bottom, is independent of the barge-mounted 4600 Ringer lowering crane above. The four legs telescope independently such that grade and slope can be controlled. The pipe is fastened to a carriage within the "table", allowing for longitudinal (2 meters) translation for joining and independent transverse movement (± 1 meter) of either end of the pipe for alignment. The hydraulic controls for these movements are all on the surface and directed via communication link from a diver on the bottom. The station positioning of the "Horse" during lowering and setdown was controlled by an inhaul winch on the beach. The cable was marked at 8-meter intervals, which allowed the "Horse" to be positioned at just the right place so as not to set on the previously laid pipe nor too far away to be "out-of-stroke" for joining. The inhaul winch also held the "Horse" from sliding down the 25% slopes on the shore ends of the alignment.

As there was no visibility on the bottom due to the existing sewage discharge and/or silt from the bedding operation, all pipe laying and jointing was done "in-the-dark" by feel.

The dual pipelines were laid concurrently with the joints of one line, staggered a half-length (4 meters) from the adjacent line in order to give the maximum clearance at the raised bells. The narrowness of the trench gave surprisingly few problems to the laying operation, and, in fact, forced the Contractor down the "straight and narrow" such that he didn't get into any steering/gap tolerance problems.

The bedding was accomplished by bringing an anchored gravel barge with a long tremie pipe over the top of the "Horse" once the pipe was joined. A 1-½ m³ rubber-tired loader would dump gravel into an overboard hopper which fed the tremie pipe. The tremie was "spotted" over the centerline of the pipe and gravel was fed down bedding the leading end of the previously placed pipe and about ¾ of the one being laid and held in position by the "Horse". Transport of the gravel under the bottom of the pipe was aided by divers using a hand-held water jet and later by a jetting system plumbed into the "Horse" itself. The water was provided by a small diesel-powered jet pump on board the derrick barge.

Adequate placement and consolidation of the bedding under the barrel of the pipe is always one of the more controversial aspects of pipe laying, and this job was no exception. If the bedding is not adequately placed and consolidated under the pipe, voids can exist which may cause differential settlement when the pipe is covered with rock, resulting in the joints articulating.

3. Rock Backfill

The remainder of the ballast rock, that above the springline and covering the pipe, was placed similarly to the bedding portion by tremie pipe fed by a front end loader on the rock barge. The section was controlled by leadline sounding and later proofed with fathometer readings. Low spots were later supplemented with rock placed with a clamshell derrick.

The ½-meter cover of filter rock was placed using the "bombing" method -- discharged from a split-hull dump scow. In the deep water this method worked fairly satisfactorily, as the material has a chance to disperse on the way down. However, the material, if discharged too rapidly, will have a tendency to "blow away" from the center of impact leaving highs on the edges and lows in the middle.

The armor rock was very laboriously placed using the 2400 Lima clamshell rigs -- up to four rigs operating at a time, which in the end ran the rock quarry dry.

In total, the backfill operation entailed the placement of 30,000 m³ of ballast, 10,000 m³ of filter material and 40,000 m³ of armor rock.

**PIPE CARRIER**

Figure 13

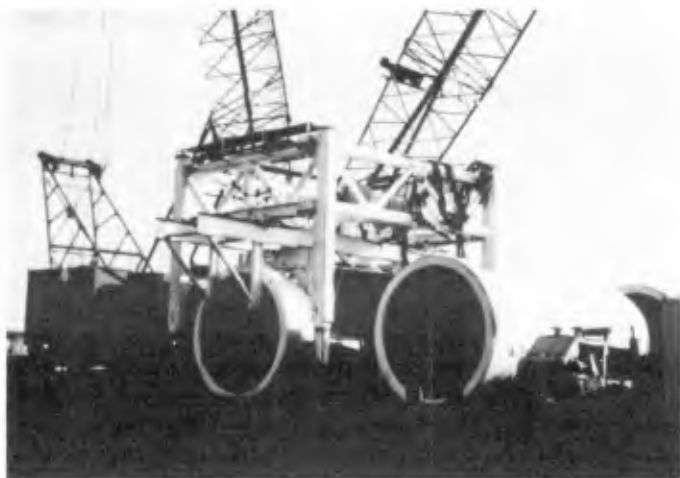
**PIPE LAYING "HORSE"**

Figure 14



PIPE LAYING BARGE

Figure 15



BACKFILL BARGE

Figure 16



ON-SHORE TERMINUS
OF SIPHON PIPES

Figure 17

4. Surveying

Alignment for all the operations was controlled by normal vertical-fan shore mounted lasers. As almost all of the marine work was on a tangent, this system worked satisfactorily.

Grade was controlled strictly by manual tide gages. The tide gages (floats) were housed in stilling wells which negated the influence of the short period waves (chop). The grade on the pipe laying was similarly monitored by attaching a floating tide gage, also in a stilling well, by cable to the center of the frame on the leading end of the pipe. Given the low tidal currents in the area, this tensioned leg gage also served for monitoring the transverse position of the pipe.

Due to the steep-sidedness of the trench excavation, meaningful fathometer readings were unobtainable so lead line soundings were used for the dredging cross-sectioning.

5. Utility Line Installation

A multi-utility line bundle consisting of one 12" water line, one 6" gas line, two fiber optic cables and one electrical power line was placed in the trench. The water line and gas line were cement-coated at the jobsite to provide proper ballast for the pull. The bundle was prefabricated into 100-meter lengths with a continuous timber plant bottom. The bundle was pulled across the 1400 meters by a winch placed on the opposite shore. The electric cable required one mid-pull splice, which required a two-day delay in the pull.

6. Final System Leakage Tests

Both siphons successfully passed the system-wide leakage tests which were completed in May 1987. No pipe evacuation tests were carried out as of the writing of this paper (June 1988). They are presently scheduled to take place during the summer of 1988.

ACKNOWLEDGEMENTS

The Owner of the facility is "The Special Service for the Sewerage and Sewage Treatment Authority of Greater Athens" (E.Y.D.E.) of the Greek Ministry of Environment, Regional Planning and Public Works. Consultants to E.Y.D.E. is a Joint-Venture of Th. Gofas and Partners, Athens, Greece; Haiste International, Leeds, U.K. and Woodward-Clyde Consultants, San Francisco, California, U.S.A. Parsons Brinckerhoff, San Francisco, California, U.S.A. is under subcontract to Woodward-Clyde Consultants.

The Contractor was a Joint-Venture of Athena Hellenic Engineering, Industrial and Touristic Co. S.A., Athens, Greece, and Raymond International, Houston, Texas, U.S.A.

REFERENCES

Theofanis C. Gofas, Yiannis Tselentis, Hugh A. Allan, Ralph A. Fasano, Yair Eisenberg and Donald D. Treadwall. Athens Siphon and Outfall - Coastal Zone '87, ASCE, Seattle, Washington, U.S.A., May 1987.