CONSTRUCTION OF AMERIA CAISSON IN EGYPT

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ABSTRACT: The Ameria Tunnel Pumping Station (ATPS) is the main pumping station of the Greater Cairo Wastewater Project. The objective of ATPS is to lift the wastewater for a vertical distance of 32.0 m (from the collection tunnel at approximate mean sea level (MSL) of −14.0 m, to box culverts at ground level, +18.0 m MSL) to continue the flow under gravity to the final treatment plant. The ATPS contains eight huge centrifugal pumps, each with a lifting capacity of 3,600 L/s. It is considered one of the highly technological civil engineering works in Egypt, probably the largest installation of its kind in the world. This paper outlines the construction method used to carry out various work elements of such a large civil engineering project. The problems encountered during construction (mainly due to the soil structure and characteristics), and the solutions innovated for these problems are also presented. A call is made for extensive soil investigation to minimize uncertainty and problems during future underground constructions.

INTRODUCTION

In recent years, several projects using high technology were constructed in Egypt. One of these projects is the Caisson Construction of Ameria Tunnel Pump Station (ATPS).

Cairo's sewerage system was originally built according to a British design between 1910 and 1915 to serve a population of just under 1,000,000. This system is still in use today. In the late 1970s, a comprehensive maintenance and development plan was implemented, with the objective of building a system that would collect and treat the city's wastewater (Fig. 1).

This project is divided to two main parts: East and West bank schemes. The East scheme consists of the main collector sewer, a 16-km-long tunnel (4–5 m in diameter) that reaches to −14.50 mean sea level (MSL) at Ameria, the ATPS, a culvert conveyance system, and a wastewater treatment plant at El-Gabal El-Asfer. The total cost of the ATPS installation alone as let exceeds 60,000,000 Egyptian pounds (Amer 1992).

ATPS UNIT

Structure

The ATPS unit, as shown in Figs. 2 and 3, is a vast concrete cylinder, 50 m high, whose base rests 32 m below ground level. Its structure consists of two concentric wells, an inner dry well [1.4-m-thick reinforced concrete (RC) walls, with an outer diameter of 28 m, whose base rests at −14.5 MSL], surrounded by an outer wet well (2.5-m-thick RC walls, with an outer diameter of 45 m, whose base rests at −18.0 MSL). The wet well was constructed as an open caisson using an excavation and sinking technique. The dry well was constructed as a box caisson using a floating technique. The superstructure of the station building was constructed on top of the dry well. The fundamentals of the various techniques used were covered in detail by Tomlinson (1980), Yang (1965), and Whiet (1988).

Location and Site Constraints

The ATPS is located to the east of River Nile, some 300 m to the south of Ismailia Canal (Fig. 1). At this site, the ground-water table (GWT) is high (+12.00 MSL) and the soil, comprising 8 m of stiff clay followed by medium to coarse sand and gravel to below the foundation level, is highly permeable. The site was in close proximity to very old buildings with shallow foundations. Safety measures were required to protect these buildings during the construction works.

Another challenge was that the ATPS site formed a part of an existing wastewater pumping station. The operation of this pumping station was not to be interrupted by the construction method employed (Amer 1992).

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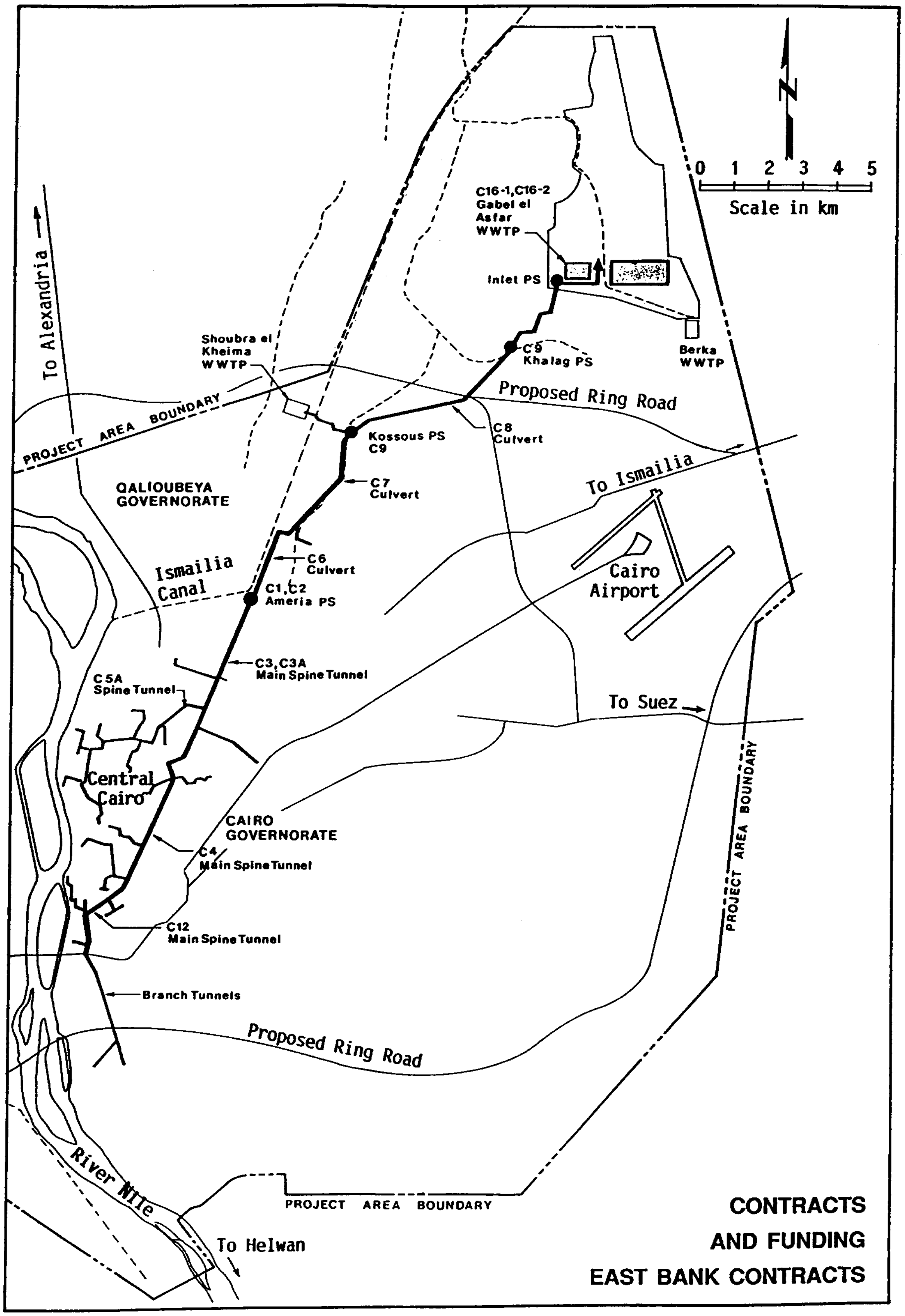

FIG. 1. East Bank Scheme and Ameria Contract

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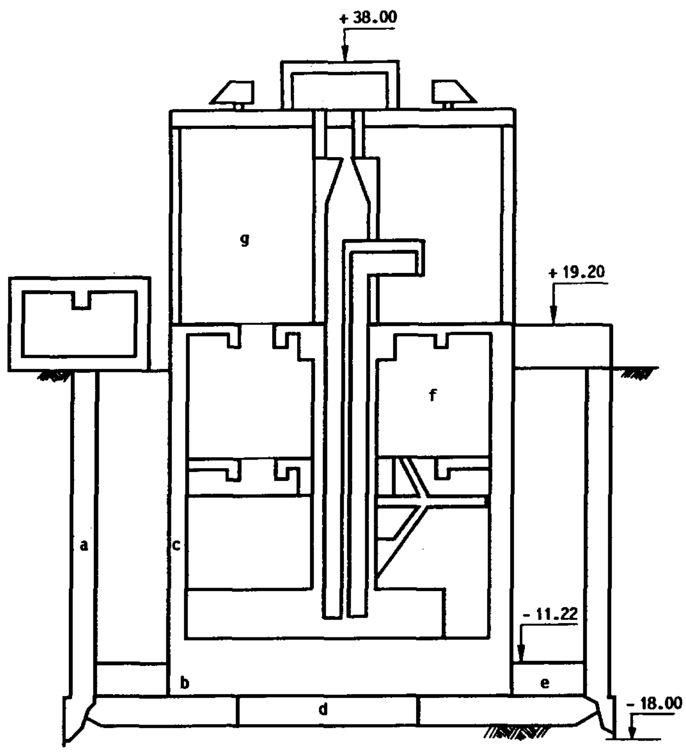

FIG. 2. Main Components of ATPS: (a) Outer Wall; (b) Dry-Well Base; (c) Dry-Well Wall; (d) Bottom Plug; (e) Permanent Base; (f) Pump Room; (g) Superstructure

Contract

The contract of ATPS was awarded through international tender. The term of reference suggested four different alternatives for the construction works: wet open caisson, compressed air caisson, diaphragm wall, and freezing. The contract was awarded to Christiani and Nielson/ Misr Concrete Joint Venture (C-MC), who proposed the wet open caisson method.

CONSTRUCTION METHOD

An excavation and sinking technique was used in which the caisson was built on the surface. Excavation within the caisson allowed the caisson to sink to its final elevation. Excavation proceeded while allowing the water level within the caisson to remain at its static level in the existence of ground water.

Caisson Sinking

The sinking of ATPS caisson was performed using a combination of the following techniques:

- Sinking under the weight of the caisson walls
- Using a cutting shoe under the wall to reduce the contact area between the wall and the soil, which increases the stress on the soil
- Excavating the soil beside the cutting shoe to allow the soil beneath to fall towards the excavated holes
- Reducing the skin friction on the wall to reduce the resistance to caisson sinking

The construction method used involved three main operations: (1) Removal of material from within the caisson; (2) ground control; and (3) vertical construction of caisson body (Amer 1992).

Removal of Material from within Caisson

General excavation of the soil, taking a profile suitable for constructing the caisson, was performed using a heavy excavator to excavate the soil from +17.00 to +9.00 MSL (Fig. 4). Hand excavation was performed to produce the required horizontal and vertical profiles.

A 3.0-m-deep cutting shoe for the outer caisson wall was constructed to facilitate the caisson sinking. First, the toe (the lowest part of the cutting shoe) was assembled and welded on a temporary unreinforced concrete support using 16 pieces of steel plates. The cutting shoe was then constructed of reinforced concrete, poured in three lifts using special steel shutters (Fig. 4).

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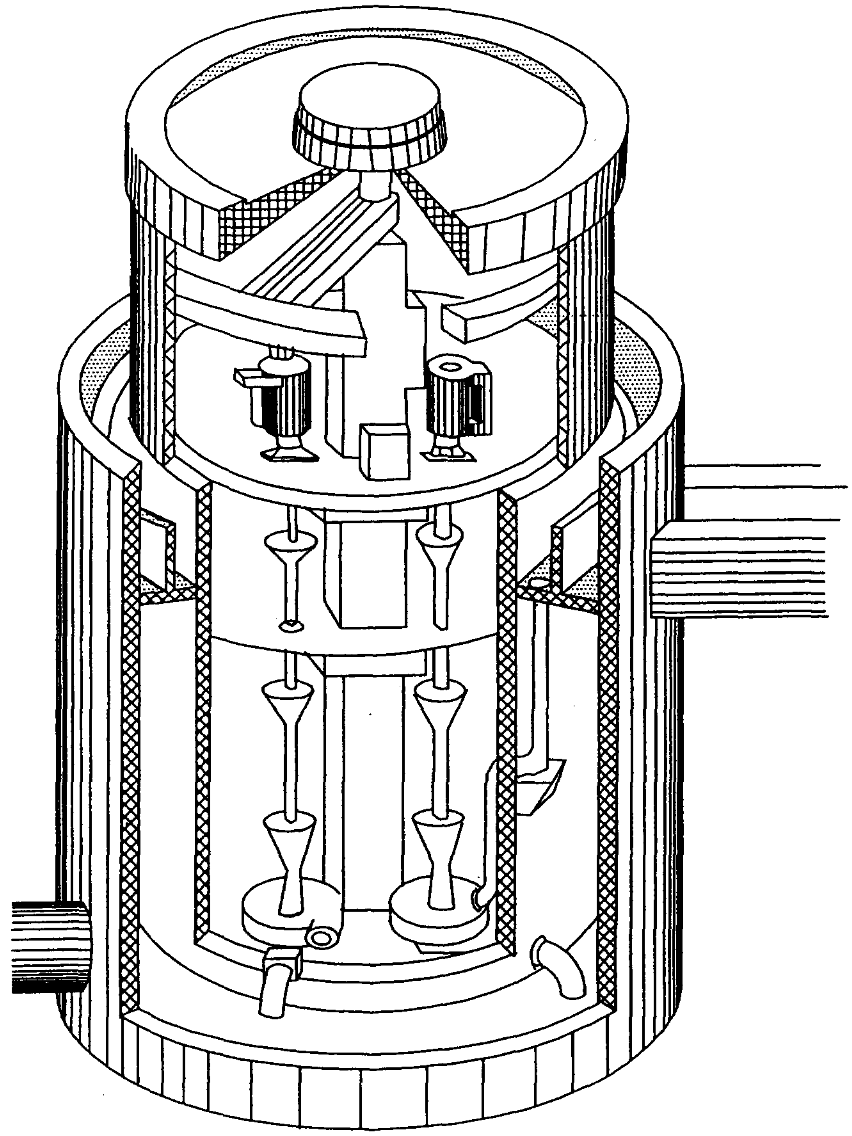

FIG. 3. Isometry of ATPS

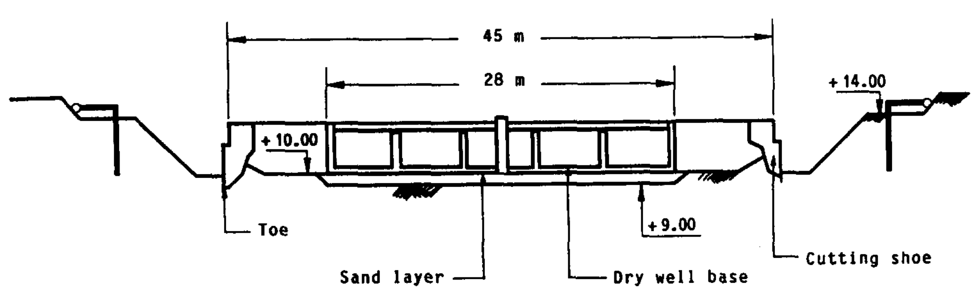

FIG. 4. Casting of Cutting Shoe and Dry-Well Base

The caisson dry-well base was constructed as a raft foundation on a sand layer 1.0 m in thickness (Fig. 4). The top of the dry-well base was covered by a plate of wood and used as a working platform (pontoon) for excavation equipment and divers (Fig. 5). The material inside the caisson was excavated using two sand jet pumps (submerged dredging pumps) fixed to an arm moving radially and laterally on a railway on the pontoon. This allowed the pumps to sweep the bottom of the caisson under the caisson wet well. The material excavated was pumped to settling ponds outside the wet well, from where it was removed by trucks. Meanwhile, the water being pumped out was circulated back into the wet well to maintain the water table at the required level.

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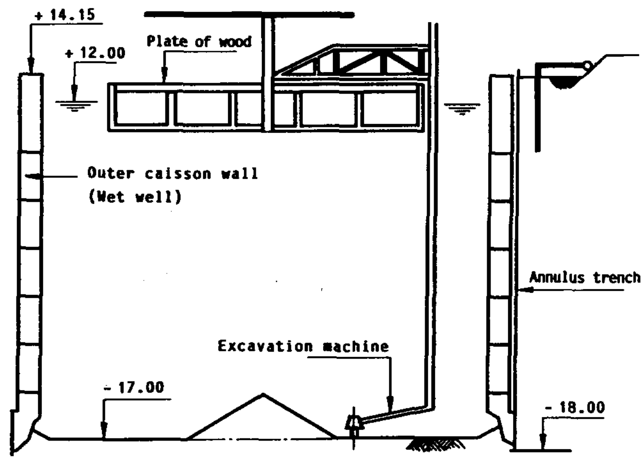

FIG. 5. Caisson Sinking and Wet Excavation

Control of Caisson Sinking

The caisson sinking to its final elevation was controlled by: (1) Monitoring the water table inside and outside the caisson; and (2) controlling the location of the wet excavation.

The measurements of water level were made using Kint instruments. The water level inside the caisson was kept higher than the GWT outside the caisson by a small value (about 0.30 m) to prevent water seepage and maintain the desired sinking rate. If the inside water level was lower than the GWT, seepage under the caisson shoe from outside to inside would induce dangerous effects such as flow of bentonite (used as lubricant) from the outside walls to inside the caisson. This action would increase the skin friction and reduce the sinking rate and/or flow of GWT. Besides, the flow of fine particle into the caisson would affect the surrounding structures. On the other hand, if the inside water level was higher than the GWT by a large value, the seepage would be from inside to outside, leading to the stabilization of the sand against the shoe, which would also reduce the sinking rate.

The location of the wet excavation was controlled by investigating the profile of soil after excavation. Three methods were used: sonar instrument, divers, and surveying works.

The sonar instrument was used to determine the soil profiles of the different areas under the caisson. These profiles were analyzed to determine to which area excavation should proceed.

An additional method utilized divers who descended to the bottom of the caisson and measured the distance between the cutting shoe and the soil. This information enabled them to determine the location and the level of excavation, graphically display a section of the soil, provide a description of the soil, and take a sample for laboratory analysis.

A rope and a weight were used to determine the depth and the location of the caisson wall. The section of soil under water could then be drawn to show the level of excavation reached. The curves drawn were then combined with the sonar profiles to determine the location of required excavation. A diver equipped with jetting equipment assisted final excavation and leveling of the bottom of the excavation.

Ground Control

Ground control was used to stabilize the soil during the caisson sinking. Partial dewatering and bentonite slurry were used as means of ground control.

A temporary dewatering system was installed around the caisson perimeter to reduce the GWT from +12.00 to +9.00 MSL to enable further excavation in free air.

A bentonite slurry was injected into the 200-mm annulus trench formed by the cutting shoe in the outside walls of the caisson (Fig. 5). This reduced the friction between the caisson and the soil, as well as supported the sides of the annulus space during the caisson sinking.

Vertical Construction of Caisson Body

The caisson body was vertically constructed concurrent with the excavation and caisson sinking. The 2.5-m-thick perimeter wall of the caisson was cast using special steel shutters in approximately 3.0-m lifts, continuously adding weight to the structure.

When the caisson was sunk to its final elevation, the bentonite slurry used for ground control was replaced by a sand/cement grout. High slump concrete was then poured into the annulus trench through a tremie pipe reaching to the bottom of the excavation. As concreting continued, the bentonite slurry was displaced upwards and removed from the trench until concreting was completed. This increased the skin friction between the caisson and the soil, leading to stopping the caisson sinking.

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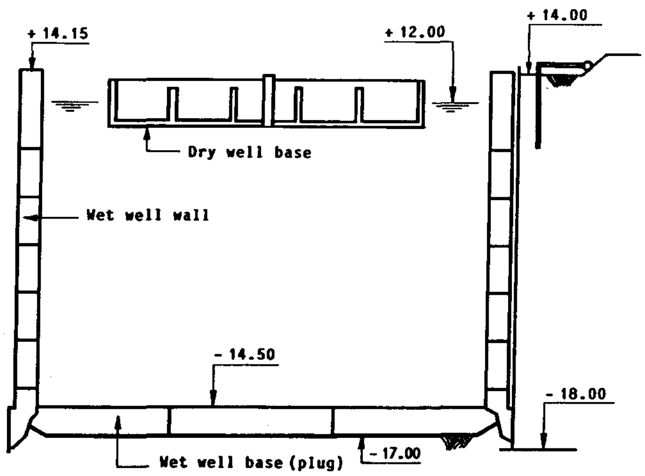

FIG. 6. Casting of Underwater Concrete Plug

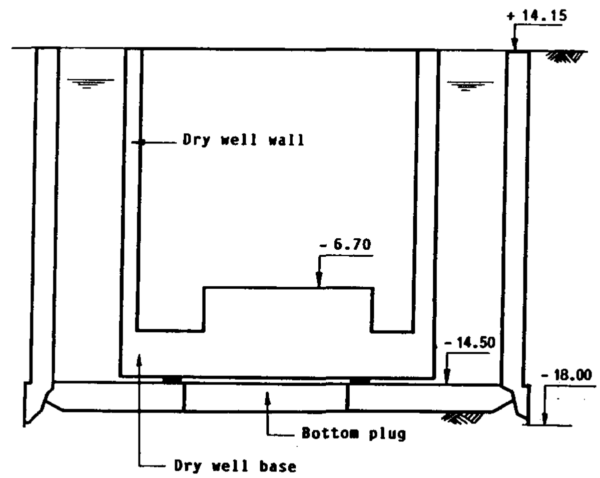

FIG. 7. Casting of Dry-Well Walls

The bottom of the excavation was sealed with a concrete plug cast under water (Fig. 6). The bottom area was divided into two portions: the central portion and the perimeter portion. The central portion was constructed of unreinforced concrete, and the perimeter portion, exposed to a higher uplift pressure, was constructed of reinforced concrete. The concrete was placed using a tremie pipe, with the assistance of the sonar instrument and divers. The flow characteristics and resistance to segregation for the underwater concrete were improved by using hydrocrete additive.

After completion of the wet well and removal of the dewatering system, the dry well was constructed and sunk to its final elevation while it was floating inside the wet well (Figs. 6 and 7). During that stage, the stability of the dry well was strictly controlled by pouring its wall lifts and filing the cells of its raft with water in a symmetrical pattern. This ensured that the dry well floated horizontally as well as prevented any water movement, which might produce tilt angles and overturning couples.

By lowering the water table in the wet well by approximately 2 m, the dry well structure could be accurately placed on three leveled pads on the bottom plug (Fig. 7). The gap under the bottom slab was grouted through pipes in the slab. When the lift shaft and floor at level +7.7 MSL had been constructed, additional weight was added to the well structure in the form of water ballast. The water was pumped from the wet-well structure, which could be completely dewatered when the dry well was ballasted to level +11.5 MSL.

The dry well and the wet well were connected together using reinforced-concrete joints with CCL screwed cuplers (a method of joining high-yield ribbed reinforcing bars end-to-end with interconnecting threaded studs). The completed joint met the ultimate strength of the bar as defined in the British Standards (either BS 449 or BS 4461, referring to hot rolled and cold worked steel bars, respectively).

The pump room was finally constructed, and the caisson was ready for constructing the superstructure (Fig. 2).

CONSTRUCTION PROBLEMS

During the construction operations, two main problems were encountered, related to the bentonite annulus and the excavation techniques. To overcome these problems, some modifications of the used techniques were made.

The bentonite annulus was used to reduce the skin friction between the soil and caisson wall. It was planned to be 0.15 m in width and divided into eight parts filled successively with bentonite and sand. This was made to control the caisson sinking and stop it when it moved down rapidly, by filling the bentonite part with sand. This was due to the wrong soil investigation, which indicated that the caisson would be sinking quickly and need a means to stop it, but this did not occur. After ground losses occurred the annulus collapsed, leading to increasing the skin friction, thus reducing the sinking rate.

At the beginning of this problem, the Colecrete drilling technique was used to reconstruct the annulus with the same width. But as the work progressed, the problem appeared again and again. So, the annulus was redesigned with an increased width of 1.0 m, and was constructed using a grabbing machine. This process was completed in about nine weeks, working six days per week, on a 24-hour double shift system.

The dredging pump, used in excavation, broke many times. Its operation was influenced by the solid particles content (a maximum of 10% solid content was specified). The solid content

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changed from a soil layer to another, which caused the piping system to be blocked many times. The solutions innovated for this problem were as follows:

1. Attach a clay cutter to the dredging pump in order to excavate clay with high efficiency.
2. Use horizontal and vertical water jets and air lifts to excavate beside the cutting shoe to help the sinking.
3. Use a grabbing machine attached to a winch moving on a railway over the caisson wall. By the aid of the winch, the grabbing machine was capable of excavating inside and outside the caisson wall.

The planned rate of caisson sinking was about 1.65 m/month (28-m down movement in about 17 months, from November 1985 to April 1987). The problems encountered have delayed the caisson sinking by about 14 months (about 82%), ending in May 1988, with an average actual sinking rate of only 0.90 m/month (Amer 1992).

CONCLUSION

The construction of ATPS caisson is considered one of the most highly technological civil engineering works in Egypt. In the method of construction used, many arrangements were made to cope with the different constraints at the ATPS site. The most important arrangements include: (1) Dewatering System for excavation in dry condition; (2) submerged pumps for underwater excavation; (3) sonar instrument for controlling the location of wet excavation; (4) Kint instrument for measuring the water level inside and outside the caisson; and (5) CCL screwed couplers for joining the dry and wet wells.

The soil structure and characteristics were found to be the major causes of uncertainty and problems during the construction of ATPS. Therefore, extensive soil investigation is very essential to minimize uncertainty and problems during future underground constructions.

APPENDIX. REFERENCES

Amer, M. I. (1992). "Caisson construction in Ameria Tunnel Pumping Station," MSc thesis, Fac. of Engrg., Zagazig Univ., Zagazig, Egypt.

Tomlinson, M. J. (1980). *Foundation design and construction*, 4th Ed., Pitman Press, New York, N.Y.

Whiet, R. E. (1968). *Caisson and cofferdam*. Found. Engrg., McGraw-Hill Book Co., New York, N.Y.

Yang, N. C. (1965). "Condition of large caisson during construction." *Highway Res. No. 74*, Highway Research Board, Washington, D.C., 68–82.

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