# ADAPTING LIFT-SLAB TECHNOLOGY TO CONSTRUCT SUBMERGED PILE CAPS

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**ABSTRACT:** Many techniques are used in practice to construct underwater foundations, including caissons and piled foundations. The main challenge of underwater construction is cutting off water seepage so as to always provide dry working conditions. Water seepage can be eliminated by continually pressurizing inside caissons and dewatering the intercepted space of sheet-pile cofferdams. Although these methods alleviate water seepage, they have negative aspects, including unhygienic working conditions and elevated costs. This paper presents a method to partly construct the submerged pile caps above water, sink to place, and complete work in totally dry working conditions. This method adapts the lift-slab technology to lower the pile cap to the underwater permanent position. Only activities necessary to make the pile cap monolithic with the pile group are achieved after the cap is lowered in secured dry working conditions. This method was used successfully in many bridges on the Nile River in Egypt during the last decade. The method is illustrated in this paper along with the problems encountered during construction. Finally, the method is evaluated and compared with other methods.



## INTRODUCTION

Methods used to construct underwater foundations include caissons and piled foundations with a pile cap. To construct pile caps under water, the use of cofferdams is essential to exclude water from the working area. Steel sheet piling is widely used for cofferdams because of its structural strength, watertightness given by its interlocking sections, and ability to be driven to deep penetration in most types of ground. The main drawbacks associated with using cofferdams are that (1) costs of cofferdams or other temporary work might greatly exceed the cost of the permanent foundation structures; and (2) security against blows or piping can be obtained only at a high cost.

Caissons are specially suited to work in deep waterways without the need for temporary works of sheet-piled cofferdams. The types of caissons include box, open, and pneumatic caissons. Box caissons can be founded on a prepared rock surface or piled raft. Open caissons are convenient for foundations in rivers and waterways where predominating soil can be readily excavated by grabbing from the open wells. Open caissons have the disadvantage that the process of grabbing underwater in loose and soft materials causes surging and inflow of material beneath the cutting edge, with consequent major subsidence of the ground around the caisson (Tomlinson 1987). Pneumatic caissons have the advantage that excavation can be carried out by hand in the dry working chamber. The pneumatic caissons avoid the loss of ground around the caisson. Moreover, the soil at foundation level can be directly inspected and tested; thus, the foundation concrete is placed under ideal conditions. The disadvantages include the requirement of more plant and labor, the slow sinking, and the unhygienic working conditions.

This paper introduces the Egyptian experience in adapting the lift-slab technology to construct submerged pile caps on the Nile River. Being submerged, these caps cause no obstruction to the vehicles moving through the river and thus provide a wide and clear waterway. Pile caps are constructed partly above water level, sunk to place, and monolithically completed with the pile group at the underwater permanent position. The novelty in the adapted lift-slab method is represented by the constructor-optional assembly and the use of a temporary construction system. The purpose was to work most of the time above water in dry and safe conditions, and eliminate the need for cofferdams. This method has already been used to construct pile caps along the Nile River in Egypt during the 1990s. Table 1 presents a list of bridges where this technology was used. The main objective of this paper is to document this experience so as to maintain awareness and share experience among constructors.

## METHOD OF CONSTRUCTION

The following steps describe the method of construction of a pile cap. This method was used in Egypt exclusively with steel-tube-cased auger-board piles and not with other pile types, since steel casing is vital for the system to work, as will be explained. Before any work on the cap takes place, preliminary work and checks need to be performed on the existing piles. This includes trimming tops of casings to provide equally protruding parts of about 50 cm above the highest water level, cleaning out the inside of casings down to the surface of pile concrete, and recording racked and bulged casings where bigger clearances must be provided between casings and pile caps to attain smooth sinking.

The preparation of the temporary system of casting and sinking the pile cap is initiated by filling in all casings with compacted sand to the level of 150 cm down the rim of casings. This sand layer is to support the subsequent concrete layer. According to the structural system of lifting and lowering the pile cap, piles that are selected for erecting the temporary frames of the system are located. In order to fix the temporary supporting frames of the system, plain concrete with formed 120-cm depth cylindrical grooves are poured in the casings as shown in Fig. 1. The diameter of the groove is designed to allow fitting in the leg of the supporting frame. The other casings are filled with compacted sand with 50-cm plain concrete topping.

The casings are ready at this stage to receive the temporary platform and pile cap formwork. Steel I-beams are stacked and welded to the casings to form the main girders of the temporary platform. Secondary beams are stacked perpendicular to the main girders as shown in Fig. 1. The bottom formwork is spread with holes along the casing vertical axes to allow erecting the supporting frames. The side formwork is erected to form the full horizontal and vertical dimensions of the pile cap as shown in Fig. 1. Cylindrical forms with open bottom and

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J. Constr. Eng. Manage., 2000, 126(2): 149-157

TABLE 1. List of Bridges over the Nile in Egypt and Their Records

| Number (1) | Bridge name (2) | Opening date (3) | Length (m) (4) | Width (m) (5) | Total number of spans (6) | Navigable span (maximum) (7) | Pile type (8) | Cost (£E) (9) |
|---|---|---|---|---|---|---|---|---|
| 1 | Rod El-Farag Bridge | 1990 | 500 | 36 | 9 | 130 | Rotary auger piling | —[a] |
| 2 | Luxor Bridge | 1997 | 744 | 22 | 18 | 84 | Rotary auger piling | 21,312,673[b] |
| 3 | El-Moneeb Bridge | 1998 | 1,700 | 42 | 26 | 150 | Rotary auger piling | —[a] |
| 4 | Mit Ghamr-Zifta Bridge | 1999 | 587 | 21 | 11 | 84 | Rotary auger piling | 14,725,450[b] |
| 5 | Sherbeen Bridge | 1999 | 880 | 21 | 23 | 90 | Rotary auger piling | 24,277,313[b] |

[a]No data available.
[b]Cost data obtained from George et al. (1996).



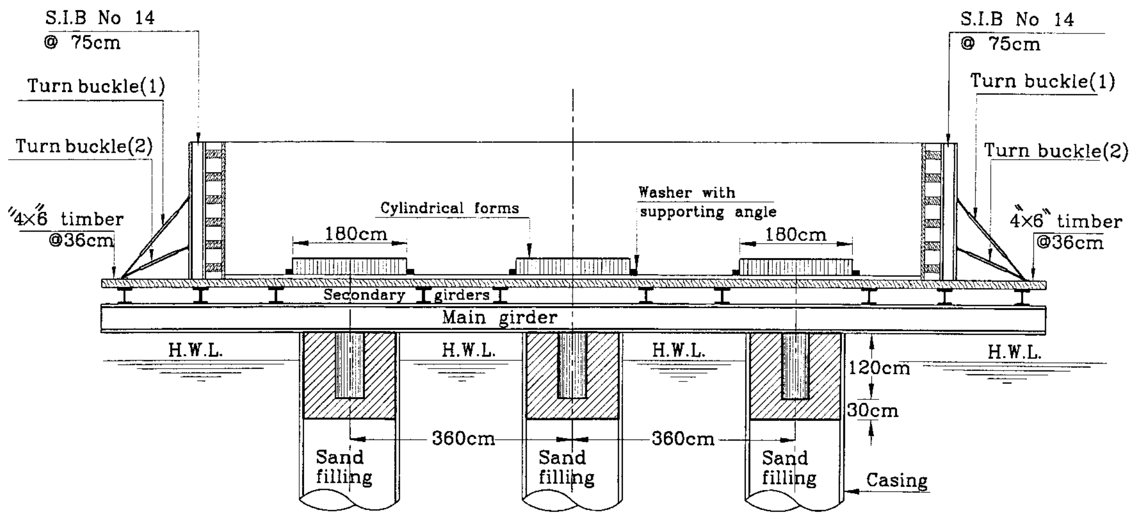


FIG. 1. Preparation of Temporary System of Casting and Sinking the Pile Cap

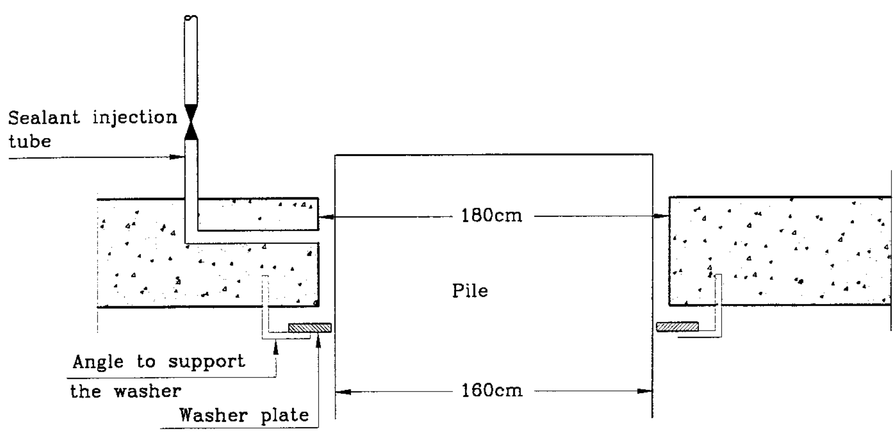


FIG. 2. Details of Sealing System of Space between Pile Casing and Pile Cap

top are formed to intercept holes above the casings. The height of these forms is the same as the height of the cap bottom to be poured at this temporary position, and approximately equals the thickness of the bottom reinforcement of the cap plus top and bottom concrete covers. The diameter of the cylindrical form is 20 cm longer than the diameter of the casing to form about 10 cm of clearance around the casing. This makes up the total diameter of the cylindrical forms, about 180 cm, as shown in Fig. 1. The clearance should be increased adequately for raked casings to allow smooth sinking. The cylindrical forms are erected coaxially with the casings. A 6-mm-thick washer, which will be needed later to capture the sealant necessary to seal the space between the casing and the pile cap, is hung on a supporting angle. This circular supporting angle is to be installed in the bottom formwork at this stage to form the section shown in Fig. 2.

Temporary supporting frames are inserted in the grooves of the casings, the verticality is adjusted, and the frames are fixed by pouring plain concrete around the legs. The supporting frame is composed of a prop that supports two perpendicular I-beams. Concurrent with erecting frames, the steel reinforcement of the bottom and sides of the pile cap is fixed in place as shown in Fig. 3. The anchorage system is embedded around each cylindrical form right below the spots of the mounted jacks as shown in Fig. 4. In addition, tubes that will be used later to inject sealant are installed properly around the cylindrical forms as shown in Fig. 2. The reinforcement of the remaining part of the cap that is to be completed before sinking is fixed in place as shown in Fig. 3. Pouring the concrete of that remaining part of the cap will leave out circular working rooms above each pile, as will be illustrated in the following steps.



J. Constr. Eng. Manage., 2000, 126(2): 149-157

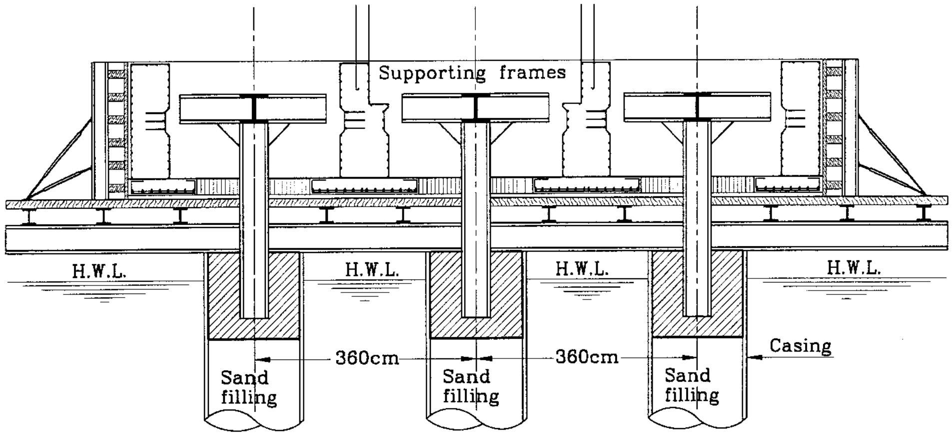


**FIG. 3. Erecting Frames and Fixing Steel Reinforcement of Bottom and Sides of Pile Cap**

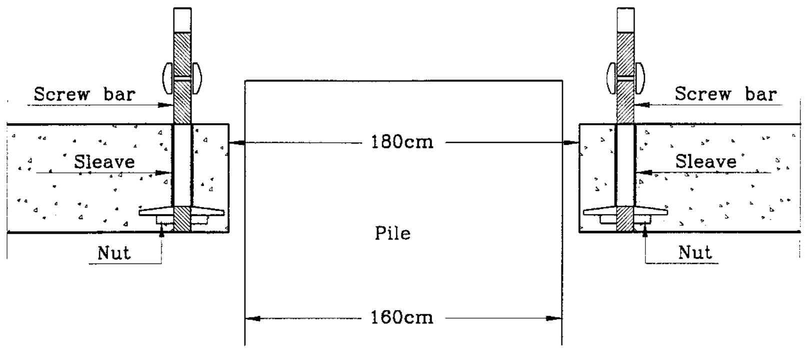


**FIG. 4. Details of Anchorage of Screw Bars to Bottom of Pile Cap**

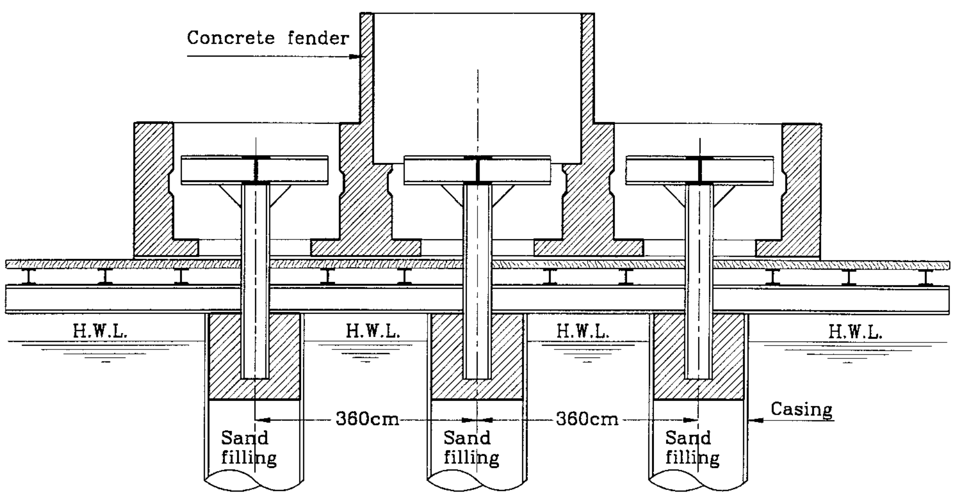


**FIG. 5. Pouring the Bottom, Forming Working Rooms, and Pouring around Working Rooms**



The work is ready at this stage to start casting the bottom of the pile cap. Concrete is poured in the space between the cylindrical forms with depth equal to the depth of the cylindrical forms. Care is taken to have leveled-surface concrete, especially at the area of 20-cm width around the rim of the cylindrical forms, where steel forms will be rested later and even contact surfaces are needed. After the concrete sets, the cylindrical forms are dismantled. At this stage, other vertically segmented cylindrical steel forms are used to form working rooms of height equal to the full height of the pile cap, and diameter of about 250 cm. These working rooms are located above and coaxial to the casings. The space between the steel forms will be poured before sinking starts to increase the weight of the cap and insure adequate rigidity. The steel forms are vertically segmented to enable stripping off from inside the working rooms after the concrete sets. The cylindrical forms are assembled and rested on the concrete. Interface openings between the steel forms and concrete are caulked by grouting with cement slurry. The reinforcement of the space between the working rooms is completed. At the level of middle-layer reinforcement of the cap, extended reinforcements are left to provide the lap with the reinforcement that will be fixed later in the space of the working rooms. In addition, the reinforcements of the concrete fender of the column are fixed in place.

At this stage, all the casting works are completed before the sinking process as shown in Fig. 5. The intercepted space between working rooms is cast and its surface is leveled. After



J. Constr. Eng. Manage., 2000, 126(2): 149-157

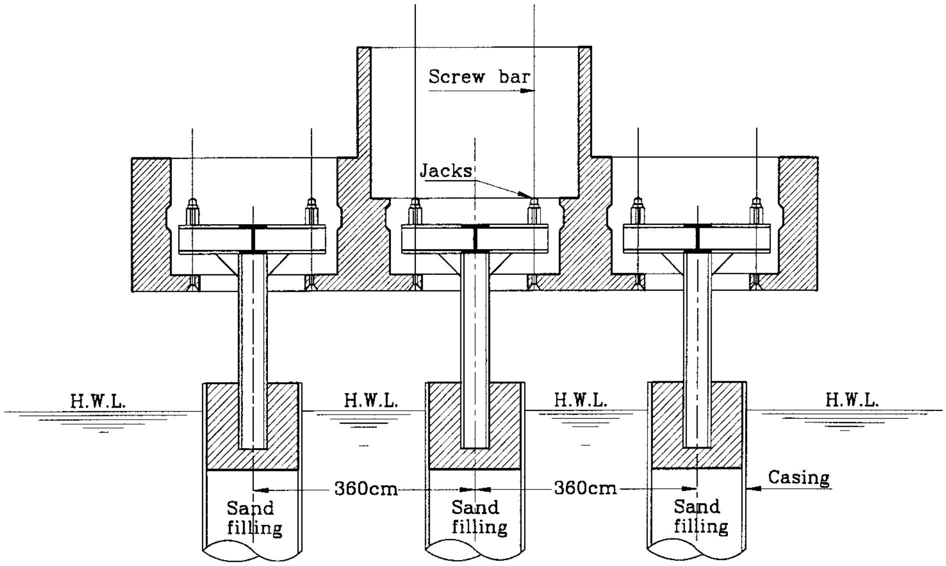


**FIG. 6. Lifting the Pile Cap, Stripping off Side and Bottom Formwork, and Taking Apart the Temporary Platform**

setting, the cylindrical steel forms are stripped off. Subsequently, the concrete fender carpentry work is completed, the steel reinforcement that was initiated before is completed, and concrete is cast. After setting, the forms of the fender are stripped off as well as the side forms of the pile cap, as shown in Fig. 5. Any insulation work for the pile cap and fender is performed at this stage.

At this stage, the pile cap is ready to install the lifting equipment. Extension screw bars are anchored to the screw bars that pass through the previously poured bottom layer of the cap as shown in Fig. 4. Hydraulic jacks are mounted on the temporary supporting frame and attached to the corresponding screw bars. Connections between the jacks and hydraulic pumps are installed. A control system is installed between the hydraulic pump and jacks to provide synchronized lifting or lowering with the same rate. At this stage, extension hoses that will be used later to inject sealant are attached to the orifice of the injection system.

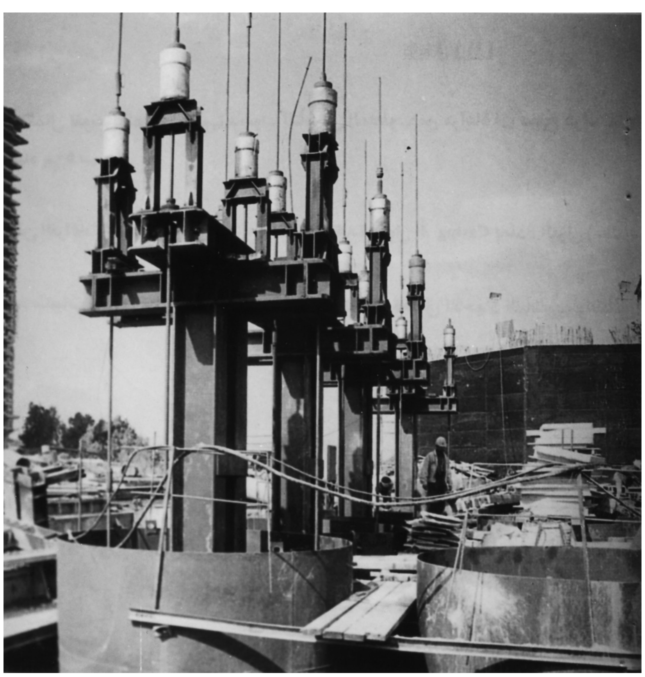

**FIG. 7. Jacks Are Mounted on Steel Frames**

All the precaution and safety measures are taken at this stage to start lifting the pile cap. The jacks are operated to lift the cap about 50 cm. Then the temporary platform is taken apart and the bottom formwork of the pile cap is stripped off. At this stage, the pile cap is completely suspended on the supporting frames as shown in Fig. 6.

Lifting equipment includes four basic components: the jacks, hydraulic connectors, power unit, and automatic electrical control unit. The lift slab jack features hydraulic operation and electrical synchronization. The hydraulic connector unit controls the lift slab jacks. The power unit provides hydraulic power to operate the systems. The automatic electrical control unit synchronizes and controls the hydraulic connector unit. Figs. 7 and 8 show the arrangement of the lifting equipment during the construction process.

The sinking process is started by lowering the pile cap slowly until the top of the pile cap is about 50 cm above the water surface. Extensions to working rooms are made using cylindrical steel tubes. These tubes are built of segments up to a suitable height, and are welded to each other carefully to insure watertightness. All vertical tubes are braced together to avoid the destructive effect of any lateral forces. To insure a water tight interface and provide fixation at the bottom of the steel tubes, a 15-cm concrete layer is poured all over the intercepted area between the steel tubes.

The sinking process proceeds until the bottom of the pile

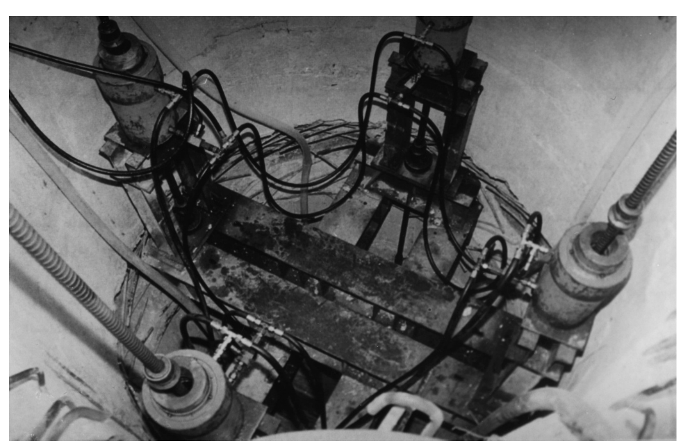

**FIG. 8. Jacks and Hydraulic Connections inside Working Rooms**



J. Constr. Eng. Manage., 2000, 126(2): 149-157

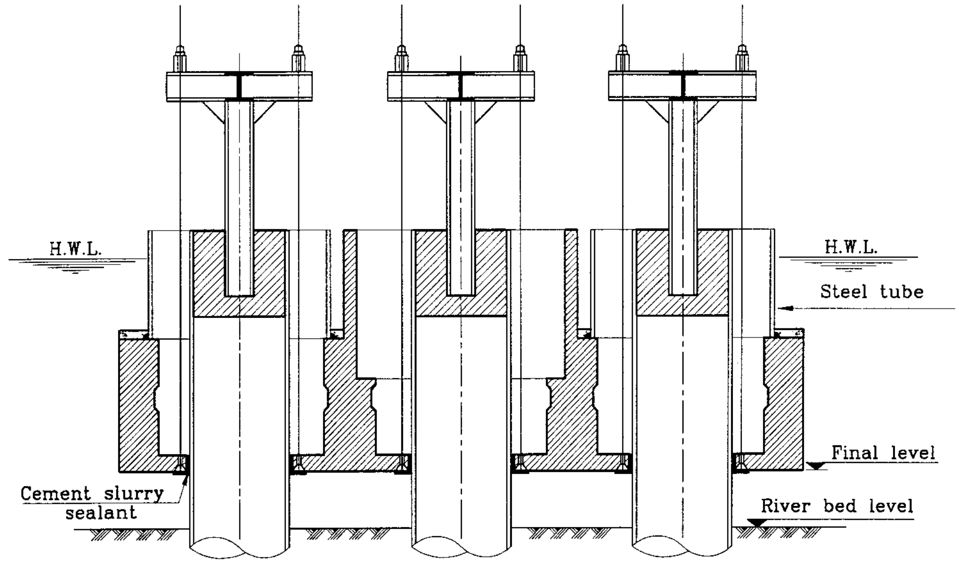


FIG. 9. Sinking the Pile Cap to Permanent Position

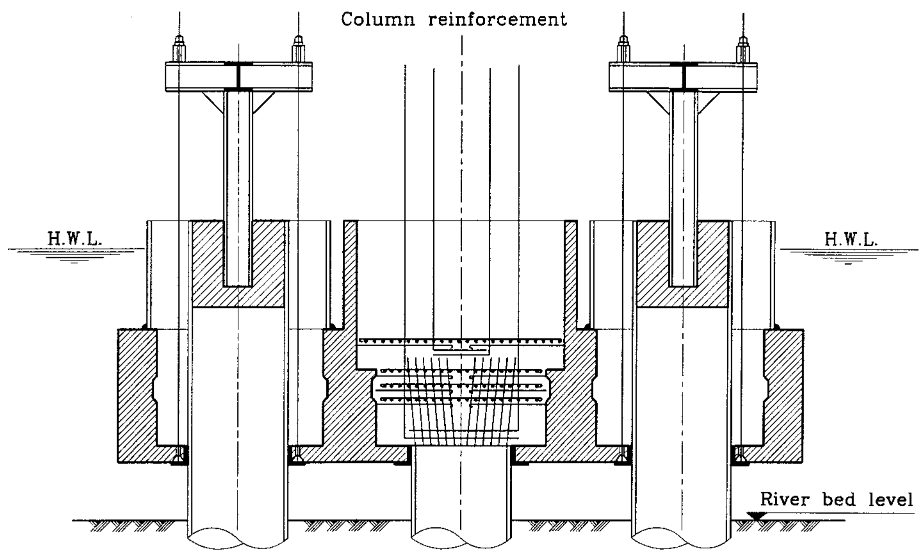


FIG. 10. Pouring of Some Pile Caps Monolithically with Pile Cap

cap reaches the final level as shown in Fig. 9. The cement-slurry sealant is injected through extension hoses around the casings. Then the water inside the working room is pumped out. Any leakage through the cement-slurry sealant is carefully treated to ensure dry working conditions.

At this stage, the construction works proceed at the permanent position of the cap. Starting with piles without supporting frames, the steel casing and concrete are removed down to the surface of the cap bottom layer. The protruding steel bars of the piles are cleaned. The concrete surface of the working rooms is roughened to ensure enough cohesion and bond. The lap bars of reinforcement of the middle layer are uncovered, stretched, and cleaned. Extra horizontal reinforcement and the column reinforcement are fixed in place according to drawings. Then these working rooms are filled with concrete.

For piles with supporting frames, the supporting frames are dismantled. The work of the previous step is repeated, but at stages, to ensure safe transmission of the cap load to the piles. First, the working room inside the fender is prepared with reinforcement of the column as shown in Fig. 10. Subsequently, the work at the other working rooms proceeds until the whole pile cap is completed.

The last stage is to erect the carpentry of the column, fix reinforcement, and pour concrete as shown in Fig. 11. Figs. 12–16 outline the overall construction sequence of a nine-pile supported pile cap. It is to be noted in these sketches that nine steel frames were used.

## PROBLEMS ENCOUNTERED

The leakage through the cement-slurry sealant represents a common problem encountered during the construction of the pile caps using the adapted lift-slab technology. This problem was treated by repeating the injection process to attain complete watertightness.

## EVALUATING THE NEW METHOD

In the following paragraphs, the merits of the new method are discussed based on the basics of construction management, namely, cost, schedule, quality, and safety.

### Cost

The cost in Egyptian pounds (£E) of constructing the pile cap using the method introduced in this paper is compared



J. Constr. Eng. Manage., 2000, 126(2): 149-157

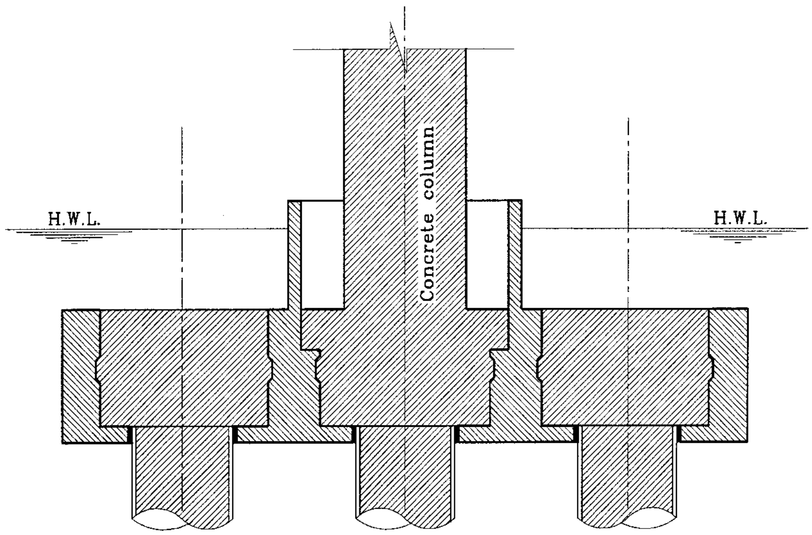


FIG. 11. Pile Cap after Pouring the Rest of Pile Caps

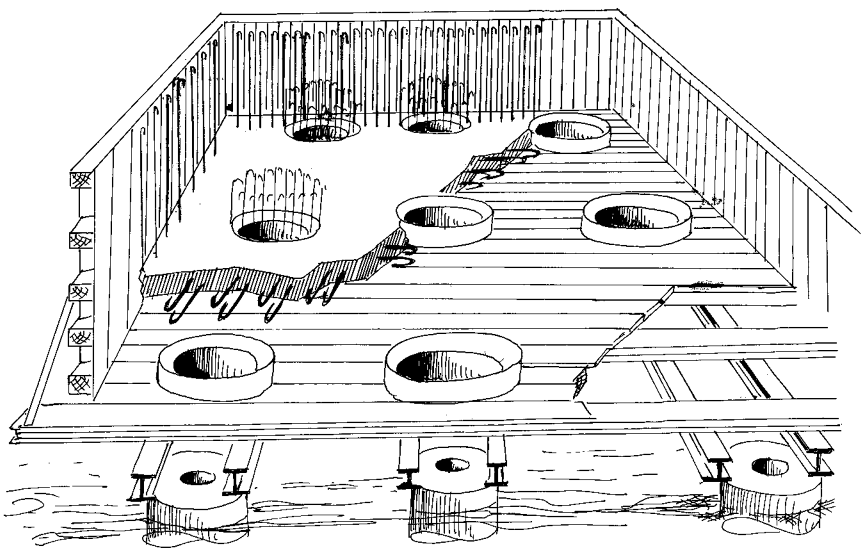

FIG. 12. Pouring the Bottom of Pile Cap

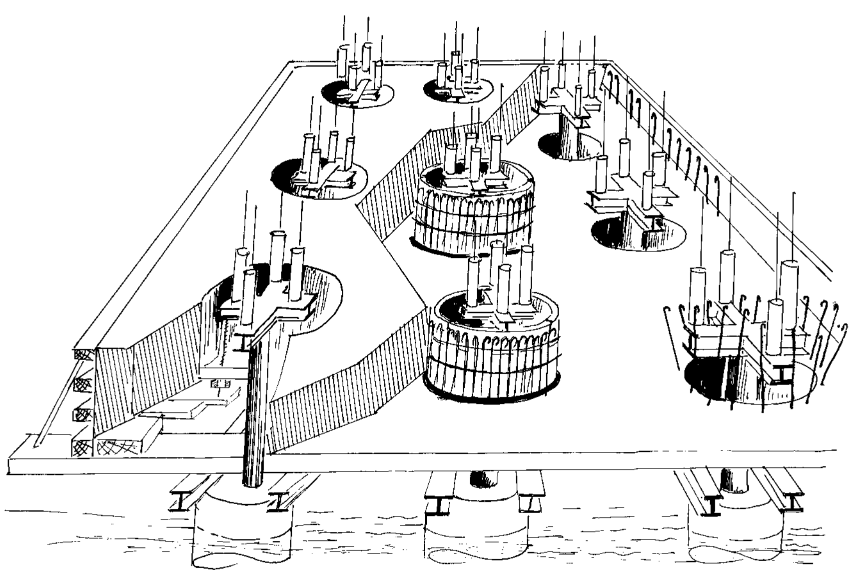

FIG. 13. Stages of Finishing the Pile Cap to Make It Ready for Lifting



J. Constr. Eng. Manage., 2000, 126(2): 149-157

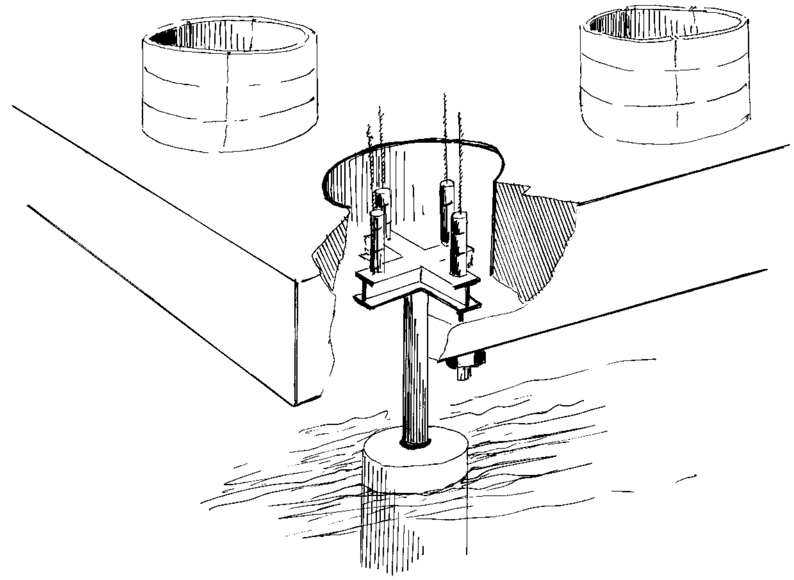

**FIG. 14. Lifting the Pile Cap and Removing Formworks and Temporary Platform**

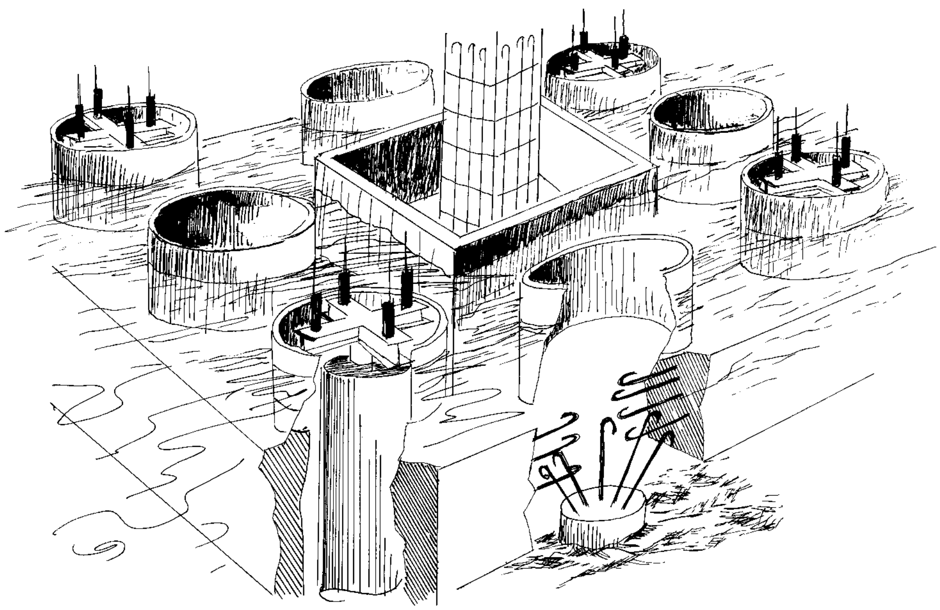

**FIG. 15. Sinking Pile Cap to Permanent Position and Pouring Same Piles Monolithically with Pile Cap**

with the cost of constructing the pile cap directly in place using sheet-pile cofferdams. The cost of the sheet-pile method, compiled by Ali (1994), is as follows:

1. Sheet pile depreciation (four uses) = 500 £E/m$^3$
2. Driving and extracting sheet piles = 500 £E/m$^3$
3. Depreciation of supporting and bracing formwork elements (four uses) = 25 £E/m$^3$
4. Dewatering inside sheet piles = 150 £E/m$^3$
5. Excavating the river bed using floating excavator = 80 £E/m$^3$
6. Floating hoist for installments = 35 £E/m$^3$
7. Welding operations = 7.5 £E/m$^3$
8. Workers = 5 £E/m$^3$
9. Supervision and specialized labor = 20 £E/m$^3$
10. Demolishing pile heads = 18 £E/m$^3$
11. Formwork for pile cap = 8 £E/m$^3$
12. Labor costs of pile cap = 2.5 £E/m$^3$
13. Costs of boat and work platforms = 15 £E/m$^3$
14. Equipment operators = 10 £E/m$^3$
15. Costs of concrete material = 400 £E/m$^3$

Total cost of a cubic meter of the pile cap is 1,776 £E/m$^3$ ($522 at the 1994 rate of currency exchange).

The cost of the new method was compiled by Ali (1994) as follows:

1. Costs of sinking and underwater sealing = 450 £E/m$^3$
2. Floating hoist = 15 £E/m$^3$
3. Excavating the river bed = 15 £E/m$^3$
4. Manufacturing costs of supporting frames and washers = 12 £E/m$^3$
5. Steel cylindrical forms for forming working rooms = 15 £E/m$^3$
6. Demolishing heads of piles = 10 £E/m$^3$
7. Platforms, bottom and side forms = 18 £E/m$^3$
8. Welding works = 3 £E/m$^3$
9. Costs of concrete material = 400 £E/m$^3$

Total cost of a cubic meter of the pile cap is 938 £E/m$^3$ ($276).



J. Constr. Eng. Manage., 2000, 126(2): 149-157

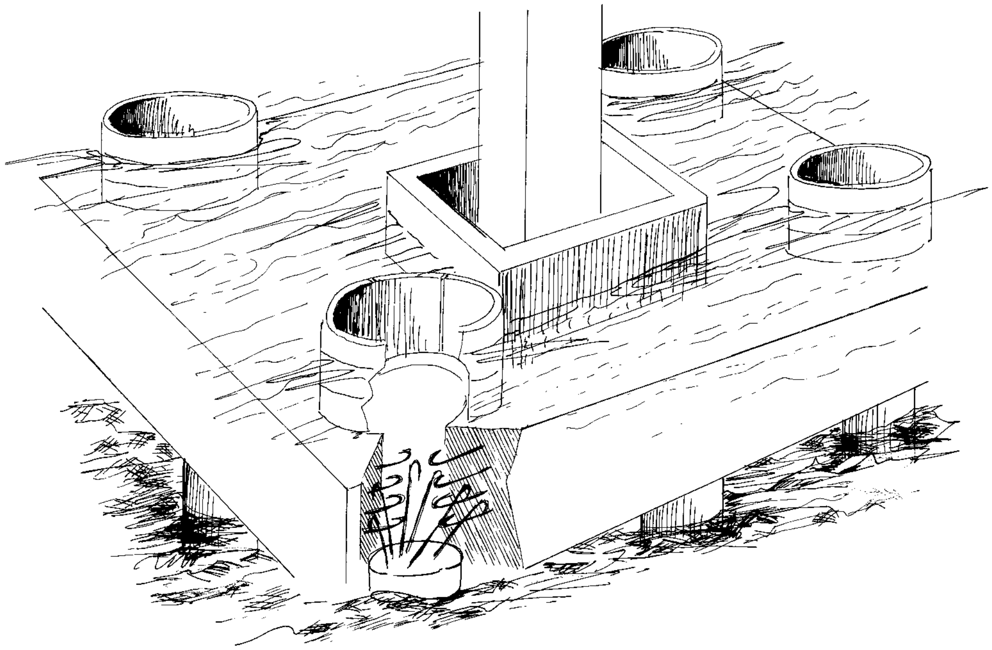

FIG. 16. Pouring the Rest of Piles Monolithically with Pile Cap

Ali (1994) exclusively considered the costs of constructing the pile cap and did not include costs associated with the construction of the piles. Material costs of steel-tube pipe casing were dropped from the cost analysis presented by Ali, probably because this cost element differs from one project to another according to the depth of the water. However, for fair cost comparisons, all the relevant costs of the piles and pile cap of the particular project must be included. It is to be noted that this method is labor intensive; thus, even if the above cost analysis shows lower cost in the Egyptian experience, the method could be costly in other countries where labor is more expensive.

## Schedule

Ali (1994) reported that constructing pile caps using the adapted lift-slab technology consumes about one-third of the duration required to implement using sheet-pile cofferdams.

## Quality

Construction activities are performed easily and inspected thoroughly when work is above water. Dry working conditions facilitate manufacturing rigid and stable forms with accurate measurements. Inspection can be performed easily since the pile cap is always accessible.

## Safety

Safety is greatly enhanced by transferring deep work above water. However, care must be taken to properly design the temporary structures, including the steel casings platform and supporting frames, to support the vertical pile-cap weight, and lateral forces due to weather and wave conditions. In addition, the attachments between the screw bars and the partially constructed pile cap should be given special care as far as design and construction are concerned to avoid dislocation or damage at the worst loading case. Precautions must be made to secure safe, smooth sinking, and safe transmission of the weight of the pile cap to the piles.

## Other Issues

1. Dewatering the river bed in the case of using cofferdams does not necessarily guarantee dry soil for supporting the loads of the pile cap.
2. It is easy to insulate the bottom of the pile cap and strip off the bottom formwork and platform when using the new method.
3. Working with cofferdams necessitates importing sheet piles, which are not locally available, thus requiring hard currency.
4. Using the adapted technology over and over potentially reduces the initial costs of building the supporting frames.
5. Resorting to cofferdams, weather and wave conditions could be so strong as to wreck the construction plant and partly completed work, or at least cause long interruptions. This method limits the time the work is at the mercy of weather conditions exclusively to the time of sinking the cap.

As shown before, the new method improves constructability of the pile cap by moving the majority of the construction activities to safer and more accessible places; using temporary construction systems represented by the platforms and supporting frames; and following constructor-optional assembly represented by assembling the partially completed cap with the piles. According to the classifications of O'Connor and Davis (1988) for circumstantial prompters of construction innovation, the main prompter to adapt this technology is the ''work-around'' solutions to potential field operations. As the term implies, this technology allows one to avoid harsh working conditions in favor of better ones. The second prompter is the ''risk-management'' solutions, since risk of working in unsound soil conditions and deep places is totally avoided.

## CONCLUSIONS

This paper presents a new method for constructing submerged pile caps above water. This method adapts the widely spread lift-slab technology. Temporary platforms are used to pour most of the pile cap above water. Only the parts of the



J. Constr. Eng. Manage., 2000, 126(2): 149-157

cap that need to be poured monolithically with the piles are left to be carried out under water. The subsequent stages involve sinking the pile cap to the underwater permanent position, and pouring the connections between the piles and cap in dry conditions. The main objective is to avoid risk and the problems of working in deep and wet places. This method was successfully used in several bridges along the Nile River in Egypt for about one decade. Compared with the traditional piled foundations with sheet-pile cofferdams, the new method features about half the cost and a construction progress rate three times higher under the conditions prevailing in Egypt.

## ACKNOWLEDGMENT

This method was used in Egypt for the first time to construct the foundations of Rod-Elfarag bridge across the Nile in 1988, constructed by the Arab Contractors (Osman Ahmed Osman & Co.). This technology was implemented under the supervision of Arab Consultants (Moharam/Bakhoum).

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J. Constr. Eng. Manage., 2000, 126(2): 149-157