# Productivity assessment of continuous flight auger piles

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Productivity assessment of Continuous Flight Auger (CFA) piles does not receive sufficient research attention although they are widely used in Egypt, and other countries in the world. In addition, it is important for construction equipment's owner to find equipment performance ratio to be able to estimate the budget cost for a given job inside the project. This paper focuses on describing the CFA pile installation features, exploring its construction phases, and determining the factors that affect on the productivity. The considered real data had been inquired from many existing pilling projects. This data will be utilized to estimate the factors that strongly affect on performance ratio of pile equipment and its influence weight.

خوازيق الحفر البريمى المستمر لم تصل للاهتمام الكافي بالرغم من استخدامها بنطاق واسع في مصر ودول كثيرة أخرى في العالم. بالإضافة إلى انه من المهم لأي صاحب معدة إنشاء تحديد معدل أداء هذه المعدة ليمكنه تقدير التكلفة المبدئية للعمل المطلوب في المشروع. ولهذا يركز هذا البحث على وصف طرق تنفيذ خوازيق الحفر البريمى المستمر وسرد العوامل المؤثرة على إنتاجياتها ويهدف هذا البحث بكونه امتداد لدراسة معدل أداء معدات الحفر البريمى المستمر. حيث تم أولا تجميع بيانات سابقة عن عدد كبير من المشروعات التي تم تنفيذها خصوصا في مجال الحفر البريمى المستمر وذلك لتحديد العوامل المؤثرة تأثير قوى على معدل أداء المعدة. وتم التوصل إلى العلاقة بين معدل أداء المعدة مع كل متغير.

**Keywords:** Concrete, Piles, Augers, Simulation, Productivity

## 1. Introduction

The Continuous Flight Auger (CFA) piles are appropriate for most ground conditions including soft rocks, but become particularly economical in non-cohesive soil such as sands, gravels, or silts where otherwise long casings or drilling would be required. For successful operation of rotary auger, the soil must be reasonably free of tree roots, cobbles, and boulders. This technique is available in various diameters 0.30, 0.45, 0.60, and 0.75 meter, and they can be constructed to depths in excess of 40.00 meter.

In general, the CFA piles are constructed by drilling a CFA auger into the ground and, on reaching the required depth, pumping concrete down the hollow stem as the auger is steadily withdrawn. During the auger withdrawal, which is not rotated, the auger passes through an auger cleaner that removes the spoil soil.

There were two methods for drilling holes: (a) rotary, auger, boring, or (b) conventional grabbing with a bucket. The selection of each type depends upon ground conditions, diameter, and depth of borehole required, and the cost and availability of the equipment [1].

CFA operation combines all main piling operations in a single process; it is able to achieve high drilling production rates. Since their introduction in the 1940s in North America, the CFA piles, also known as auger cast piles, have become increasingly popular, as they can be considerably cheaper than alternative pile types. It becomes the most common type of piles in Egypt.

Using CFA piles has many advantages as Low mobilization cost [2], Low noise and vibration [4], Auger protects the hole from caving [5], Grout is injected under pressure, so there is good soil bond and some soil compaction [7], and Used in a wide variety of soils [10]. However, CFA has many disadvantages as Sensitivity to operator performance [10], if equipment breaks down, pile is lost, Cannot be used with cobbles and boulders [6], and Poor and/or inconsistent quality and load carrying capacity [8].

## 2. Influencing factors

The following factors that impact pile construction productivity were identified: [6]: (a) Soil type (i.e. sand, clay, stiff clay, etc); (b) Efficiency of equipment operator; (c) Drill type and height of drilling tool (e.g., auger, bucket); (d) Method of soil removal, the size of hauling units, and space considerations at the construction site; (e) Pile axis adjustment (adjust the equipment above the pile axis location); (f) Weather conditions (Humidity, temperature, rain fall); (g) Concrete pouring method and efficiency; (h) Waiting time for other operations (i.e., pile axis allocation); (i) Job and management conditions; (j) Pile diameter; and length; and (k) Piling machine mechanical and drilling problems; Problems due to site restrictions and disposal of excavated soil. All these factors have greatly affected the production of CFA piles.

There have been important studies aimed to:
(a) Designating a tool for adjusting the CFA pile productivity estimate through a Productivity Index (PI) [9],
(b) Assessing the CFA pile's cycle time, productivity, and cost using deterministic approach [9],
(c) Analyzing pile construction productivity factors [9-10], and
(d) Assessing productivity, cycle time, and cost using the regression analysis technique based upon most of the above factors [10].

A labor productivity model capable of quantifying the effect of varying labor production rates on the project's time and cost was developed [11].

Activity sampling techniques was applied on construction projects for the first time in Egypt. The productivity of bricklayers was measured and determined. The daily patterns for bricklayer's productivity during the hours of working day and during the days of the working weeks were determined [12].

The activity sampling technique on tiling operation was applied. The tiling operation productivity and allocated areas for productivity improvement [13] were measured.

The relationship between productivity and utilization was established. A formula was developed to measure utilization of resources and it was concluded that using this formula will improve the utilization of resources will lead to the improvement of productivity [14].

A developed formula was applied to measure and improve the utilization and productivity of three dredgers working on one of the largest construction project in Egypt [15].

The time study measurement technique was applied for the first time in Egypt to measure the productivity of reinforcement concrete operation on a large construction project. He reported an improvement of 35% on the formwork output and 11.30% on the reinforced concrete operation [16].

## 3. Construction process

The construction processes are summarized to the following phases, which will give a clear explanation for further suggestion:
First phase: Surveying works.

Second phase is the maneuvering the equipment to the position of pile axe. It begins when equipment has finished the last reinforcement of concrete pile and ends when equipment stands at a correct location.

Third phase is the setting the equipment to the correct point (vertically and horizontally). It begins as soon as equipment is located at correct position and ends when auger is centered at an exact point.

Fourth phase is the drilling downward into the soil for reaching the required length. The auger is used to excavate the hole with the proper diameter. When the CFA piles are formed, the hole in the ground does not need to be stable or stand open. The auger however should be kept full of soil, so that the surrounding soil will be supported. It begins after putting auger in exact point to rotate in soil and ends when auger arrives at a required length (foundation level)

Fifth phase is the concrete pouring: After the auger has reached full depth, the temporary closure plate below the central stem is to be pushed away by the concrete or mortar (grout). Usually the auger is for that purpose lifted without rotating and the start of concrete pumping should do the rest. It begins after auger arrives at foundation Level and ends when the auger moves up from the soil.

Sixth phase is the shaft formation. During the withdrawal of the auger, the concrete or mortar (grout) is pumped through the stem. This should be done with an overpressure in order to make sure that enough concrete is always supplied near the base, to compensate for the volume increase caused by the lifting of the auger.

Seventh phase is the installing steel reinforcement to concrete pile. Immediately upon completion of the pile shaft, the reinforcement cage is lowered down to its proper location and height. It begins as soon as concreting phase is finished and ends when the reinforced steel is put into the soil.

The first phase is done at the beginning of project and phases 2 to 7 are repeated in each cycle of pile construction.

## 4. Data acquisition

Current study collected data through proposed questionnaire, site visits, contractors, and consultants who are specialists in CFA pile construction. We asked to provide information about project identification, location, project description whether the project is residential, commercial, etc…, starting date, finishing date, number of piles, number of observed days, and number of non working days for each project. A questionnaire is prepared to be easy to understand in fields by site engineers. It inquires information about equipment, project, labors, piles, mixer, concrete, pump, and management. It is used to consider the parameters that affect pile equipment performance ratio.

Total numbers of selected construction projects were 40 projects. Total numbers of piles in all selected projects equals 5470 piles. The total number of observed days in all selected projects is 505 days.

All selected projects have some criteria that will be taken into consideration in this study: retaining vertical piles and foundation vertical piles, piles length ranged from 11.00 to 33.00 m, and piles diameter ranged from 0.40 to 0.60 m.

## 5. Productivity factors

Many factors affect the performance of construction pile equipment. These factors were chosen according to proposed questionnaires and considering literature review.

### *5.1. Equipment*

Efficiency is the work ability of the equipment. It depends on maintenance, repair, lifetime, performance, etc. It was expressed as one of four choices: (Excellent - Good - Medium – Poor)

Equipment age is the difference between manufacturing year and observing date.

### *5.2. Labor*

Efficiency of equipment driver, which is the work ability of the driver, it was expressed as one of four choices: (Excellent - Good - Medium – Poor)

Efficiency of labor staff which is the work ability, it was expressed as one of four choices: (Excellent - Good - Medium - Poor).

### *5.3. Construction site*

Area of field is expressed in square meter.

Number of restrictions around field, which is the number of buildings beside the selected project, is expressed as one of four choices: (None, one, two, or three).

### *5.4. Soil profile*

Soil classification is expressed as one of three choices: strong, medium, or weak soil. Strong Soil includes (rock, stone, crushed stone, gravel, cemented sand, crushed cemented sand, stiff clay, stiff silty clay). Medium soil includes shells, crushed shells or bricks, loamy clay or sand, clayey or sandy loam, medium soft or medium clay, silty or medium soft silty or sandy or sandy silty clay, silty sand, clayey silty sand, clayey or coarse sand, silt, clayey or sandy or clayey sandy silt. Weak soil includes soft or very soft clay, soft or very soft sandy clay, soft or very soft silty Clay, soft or very soft sandy silty clay, fine, or medium fine sand).

Ground water level is measured from ground level.

*5.5. Piles*

Pile diameter, which is the total diameter of pile in (meter)

Total number of CFA piles.

Pile length, which is the total length of pile in (meter)

Piles orientation, which is the relative location between constructions, piles in the site; it was expressed as one of two choices: (straight in one line, random distribution).

*5.6. Mixer*

Mixer efficiency, which is the work ability of mixer, it was expressed as one of four choices: (Excellent - Good - Medium – Poor). It depends on maintenance, repair, lifetime, performance, etc.

*5.7. Concrete pumping*

Workability of concrete, which is expressed using the slump test for the fresh concrete in (cm)

Pump age is the difference between manufacturing year and observing year.

Efficiency, which is the workability of pump, it was expressed as one of four choices: (Excellent - Good - Medium - Poor). It depends on maintenance, repair, lifetime, performance, etc.

Distance between pump and equipment, which is the average distance between pump and equipment.

*5.8. Site management*

Construction specification and contract conditions, which it was divided into three categories: (loose, moderate, or restricted)

Management efficiency: that variable indicates how the manager managed the project and it is expressed as one of four choices: (excellent, good, medium, or poor). This indicator is determined by asking the project crew.

*5.9. Weather*

Temperature degree: [c]

## 6. Classification of productivity factors

The previous factors can be classified into two main groups according to their variation type.

*6.1. Descriptive*

These are the variables, which do not have measurable values (descriptive). They also vary in levels. They are (equipment efficiency, driver efficiency, labors efficiency, mixer efficiency, pump efficiency, management specification and conditions, management efficiency).

*6.2. Quantitative*

On the other hand, there are the measurable variables that have values for their variation. They are: (equipment age, area of field, number of restriction boundary, soil classification, ground water level, pile diameter, numbers of piles in project, pile length, piles coordination, workability of concrete, pump age, average distance between equipment and pump, temperature).

## 7. Data acquisition and processing

Table 1 shows sample of the recorded data of each element in every cycle. This table consists of project ID; date of collecting data, pile number, and (Total time, idle time) for maneuvering, setting, drilling, concreting, and reinforcement elements. The recorded idle time excluded the time break of labors.

Table 2 shows the data processing.

Column 1 includes the project identification number ID.

Column 2 includes the data date of collecting data.

Column 3 includes the number of constructed piles in this data.

Column 4 includes actual pile time that is equal to the summation of total times for each cycle that consists of five elements that given in table 1.

Column 5 includes the summation of all idle times for each cycle that consists of five elements that given in table 1.

Column 6 includes ideal pile time, which was found by subtracting summation of idle times from actual pile time, which was made in each cycle [Column 4– Column 5].

Column 7 includes the minus mean ideal pile time, which was found by subtracting mean ideal pile time from ideal pile time, which was made in each cycle [Column 6– T/N], Where T = the summation of ideal piles times per day{summation of Column 6] in processing sheet, and N = total number of piles per day.

Column 8 includes the minus mean actual pile time, which was found by subtracting mean ideal pile time from actual pile time, which was made in each cycle, [Column 4– T/N].

## 8. Project analysis sheet

Table 3 gives a full summary of the data analysis of all recourses in the previously selected project. The data are ranked in designed table as follows:

Column 1 includes the project identification ID.

Column 2 includes the type of equipment and its model.

Column 3 includes the calendar data date of observation.

Column 4 includes total number of piles per day.

Column 5 includes mean of actual pile time for each day = Tt/N, Where Tt = the summation of actual piles times per day [summation of Column 4] in processing sheet.

Column 6 includes mean ideal pile time for each day = T/N.

Column 7 includes actual productivity calculated from the following formula:

Actual Productivity = 1/ mean actual pile time = X1 units / hr.

Column 8 includes ideal productivity calculated from the following formula:

Ideal Productivity = 1/ mean ideal pile time = X units / hr.

Column 9 includes performance ratio, which is the ratio between Actual and Ideal productivity where Performance Ratio = X1/X.

## 9. Statistical analysis

Statistical analysis has been performed by using the regression technique between equipment performance ratio and all the variables. The benefits of the correlation here are to measure the strength degree of the relationship between equipment performance ratio and quantitative variables.

Correlation coefficient indicates what will be done when the variable changes in equipment performance ratio.

If Correlation coefficient indicates a positive sign, it means direct proportion.

If Correlation coefficient indicates a negative sign, it means inverse proportion.

If Correlation coefficient is more than or equal to 0.80, it means there is a strong correlation between equipment performance ratio and the studied variable.

If Correlation coefficient is less than 0.8, it means there is a weak correlation between equipment performance ratio and the studied variable.

By the aids of statistics software, that gives the correlation between PR and each factor. For example, it was found the coefficient between PR and pile diameter is 0.748. It means weak correlation with direct proportion. It was found the coefficient between production rate, PR, and square pile diameter is 0.837. It means strong correlation with direct proportion.

The relationships were presented in table 4 to clarify the effect of the considered factors on the equipment performance ratio.

## 10. Proposed model

The proposed model for estimating ideal production rate was designed with the aids of Monte Carlo simulation modeling. The actual total time to complete this project can be predicted. The proposed model has four cycles; these cycles were integrated together to give the production system network. These cycles can be summarized as follows: (a) $1^{st}$ cycle indicates the concrete mixing cycle, (b) $2^{nd}$ cycle includes the concrete pumping cycle, (c) $3^{rd}$ cycle expresses the equipment pilling cycle, and (d) $4^{th}$ cycle refers to the reinforcement cycle.

Fig. 1 shows the used model network, all data, requirements, codes, and cycles. Each cycle gives a production process for an exact operation. These cycles are integrated together to give the production system network. This system can be repeated many times as the user needs. The number of repeating is equal to the number of piles in the site, which can be controlled by using a counter inside the production system network.

*10.1. First cycle*

The first cycle belongs to mixing the concrete in the field, which consists of seven elements. (i.e. five Queues, one Combi, one Normal).

Queue number (101) is responsible for sending sand to the first cycle. Queue number (102) is responsible for sending gravel to the first cycle. Queue number (103) is responsible for sending cement to the first cycle. Queue number (104) is responsible for sending water and admixture to the first cycle. Queue number (105) is responsible for sending one mixer to make ready fresh concrete in the first cycle.

Combi number (201) is responsible for the time of one cycle of mixing concrete in the first cycle.

Normal number (202) is responsible for the time of one cycle of dumping concrete into the standby pan in the first cycle. This normal node is the last element in the first cycle.

*10.2. Second cycle*

The second cycle belongs to pumping concrete from standby pan to the CFA pilling equipment, which consists of four elements (i.e. two Queues, one Combi, and one Consolidation).

Queue number (106) is responsible for giving ready fresh concrete to the second cycle. One pulse inside Queue number (106) was generated into eleven small pulses because a pulse from Normal number (202) equal 0.50 m3 concrete (one cycle of concrete mixer), and a pulse inside Queue number (106) must equal 0.045 m3 concrete (one cycle of concrete pump). The number of recourses inside Queue number (106) must equal zero at the beginning of the program, and it will store a resource unit by receiving a pulse from the previous Normal element (202) when it finishes its task. Queue number (107) is responsible for sending one pump to supply ready fresh concrete to the CFA pilling equipment.

Combi number (203) is responsible for the time of one cycle of pumping concrete in the second cycle.

Consolidation number (300) is responsible for consolidating the small pulses into (N); Where N is the required number of pumping cycles to pour one pile with ready fresh concrete. This consolidation node is the last element in the second cycle.

*10.3. Third cycle*

The third cycle belongs to the pilling construction system of CFA equipment, which consists of ten elements (i.e. four Queues, two Combis, three Normals, one Counter).

Queue number (108) is responsible for locating the correct position of the pile in the third cycle. The number of recourses inside Queue number (108) must equal (N) at the beginning of the program. Queue number (109) is responsible for sending a CFA equipment to make its work tasks in the third cycle. Queue number (110) is responsible for making a pile hole to pour ready fresh concrete in the third cycle. The number of recourses inside Queue number (110) must equal zero at the beginning of the program, and it will store a resource unit by receiving a pulse from the previous Normal element (206) when it finishes its task. Queue number (111) is responsible for sending ready fresh concrete to pour one pile in third cycle. The number of recourses inside Queue number (111) must equal zero at the beginning of the program, and it will store a resource unit by receiving a pulse from the previous Consolidation element (300) when it finishes preparing the pile volume of concrete.

Combi number (204) is responsible for the time of one cycle of maneuvering the CFA equipment in the third cycle.

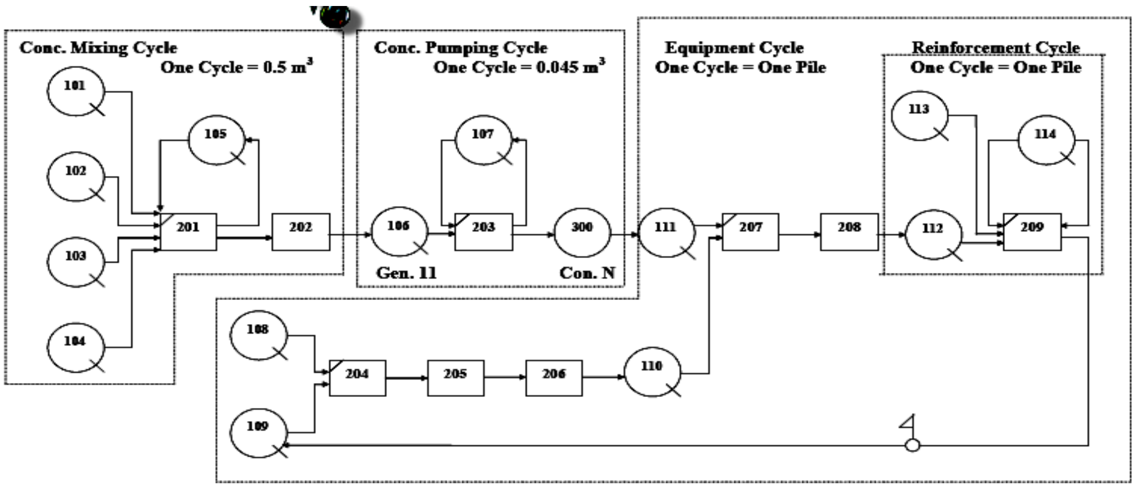


Fig. 1. Simulation sequence for production process system network.

Normal number (205) is responsible for the time of one cycle of setting the CFA equipment in the exact position in the third cycle. Normal number (206) is responsible for the time of one cycle of drilling the soil with the CFA equipment in the third cycle. Combi number (207) is responsible for the time of one cycle of pouring ready fresh concrete in the pile hole in third cycle. Normal number (208) is responsible for the time of one cycle of moving the CFA equipment from its position to another position to put the steel reinforcement in fresh concrete pile in the third cycle.

Counter element is responsible for counting the total number of cycles that will be done per day in the field in the third cycle. This counter is the last element in the third cycle.

*10.4. Fourth cycle*

The fourth cycle is related to installing the steel reinforcement in fresh concrete pile. This cycle is integrated strongly with the third cycle. It can be said that the fourth cycle is a complement of the third cycle. This cycle consists of four elements (i.e. three Queues, one Combi).

Queue number (112) is responsible for sending one poured pile with fresh concrete to the fourth cycle. The number of recourses inside Queue number (112) must equal zero at the beginning of the program, and it will store a resource unit by receiving a pulse from the previous Normal element (208) when it finishes its task. Queue number (113) is responsible for sending steel reinforcement to poured pile in the fourth cycle. The number of recourses inside Queue number (113) must equal (N) at the beginning of the program. Queue number (114) is responsible for sending one vibrator to install steel reinforcement into poured pile in the fourth cycle.

Combi number (209) is responsible for the time of one cycle of installing steel reinforcement in the fourth cycle. This Combi is the last element in fourth cycle.

## 11. Conclusions

It was found that there were twenty variables affecting the equipment performance ratio; these variables are: equipment efficiency, equipment age, driver efficiency, labors efficiency, area of field, number of restriction boundary, soil classification, ground water level, pile diameter, number of piles, pile length, piles coordination, mixer efficiency, workability of concrete, pump age, pump efficiency, average distance between equipment and pump, project specification and conditions, and management efficiency, and climate temperature. Best operating conditions means best performance ratio for the equipment. The values of every variable were studied carefully with the performance ratio.

Table 1
Recorded sheet of time observation

| Recorded sheet | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Planning unit: Second | | | | | | | | | | | | |
| ID | Data date | Pile No. | Construction process | | | | | | | | | |
| | | | Maneuvering | | Setting | | Drilling | | Concreting | | Reinforcement | |
| | | | Total | Idle | Total | Idle | Total | Idle | Total | Idle | Total | Idle |
| 1 | 13/10/2002 | 1 | 136 | 0 | 68 | 0 | 562 | 157 | 431 | 0 | 974 | 580 |
| | | 2 | 192 | 77 | 95 | 0 | 518 | 0 | 519 | 134 | 353 | 0 |
| | | 3 | 172 | 0 | 81 | 0 | 642 | 191 | 380 | 0 | 359 | 0 |
| | | 4 | 140 | 0 | 70 | 0 | 470 | 0 | 445 | 0 | 506 | 102 |
| | | 5 | 122 | 0 | 85 | 0 | 657 | 180 | 462 | 60 | 876 | 552 |

Table 2
Data processing sheet

| Data processing | | | | | | | |
|---|---|---|---|---|---|---|---|
| Planning unit: second | | | | | | | |
| ID (1) | Data date (2) | Pile no (3) | Actual pile time (sec) (4) | Sum (idles) (5) | Ideal pile time (sec) (6) | Minus mean ideal pile time (sec) (7) | Minus mean actual pile time (sec) (8) |
| 1 | 13/10/2002 | 1 | 2171 | 737 | 1434 | 22 | 715 |
| | | 2 | 1677 | 211 | 1466 | 10 | 221 |
| | | 3 | 1634 | 191 | 1443 | 13 | 178 |
| | | 4 | 1631 | 102 | 1529 | 73 | 175 |
| | | 5 | 2202 | 792 | 1410 | 46 | 746 |
| Summation | | | 9315 | 2033 | 7282 | 164 | 2035 |

Table 3
Project analysis sheet

| ID (1) | Type (2) | Date (3) | No. Of piles (4) | Act. pile time (5) | Ideal pile time (6) | Actual productivity (7) | Ideal productivity (8) | Performance ratio (9) |
|---|---|---|---|---|---|---|---|---|
| 1 | SoilMec CM 48 | 12/10/2002 | 13 | 1588 | 1409 | 2.3 | 2.6 | 0.88 |
| | | **13/10/2002** | **5** | **1863** | **1456** | **1.9** | **2.5** | **0.76** |
| | | 14/10/2002 | 5 | 1772 | 1426 | 2 | 2.5 | 0.80 |
| | | 15/10/2002 | 6 | 1533 | 1281 | 2.3 | 2.8 | 0.82 |
| | | 16/10/2002 | 11 | 1535 | 1373 | 2.3 | 2.6 | 0.88 |
| | | 17/10/2002 | 10 | 1720 | 1452 | 2.1 | 2.5 | 0.84 |

Table 4
Relations between equipment performance ratio with individual variable

| | Factor | Level | Performance Ratio |
|---|---|---|---|
| Equipment | Efficiency | Excellent | 86.61% |
| | | Good | 84.89% |
| | | Medium | 82.00% |
| | Age | Up to 5 years | 86.15% |
| | | 5 – 10 years | 84.75% |
| | | 10 – 20 years | 83.31% |
| Labor | Equipment driver efficiency | Excellent | 86.26% |
| | | Good | 84.49% |
| | | Medium | 80.62% |
| | Labor efficiency | Excellent | 87.06% |
| | | Good | 85.14% |
| | | Medium | 84.00% |
| Construction site | Area | Less than 250 $m^2$ | 85.27% |
| | | 250 – 500 $m^2$ | 84.90% |
| | | 500 – 1000 $m^2$ | 85.04% |
| | Number of restriction boundary | None | 88.00% |
| | | One | 87.73% |
| | | Two | 86.11% |
| | | Three | 85.26% |
| Soil profile | Classification | Strong | 73.11% |
| | | Medium | 85.17% |
| | | Weak | 86.00% |
| | ground water level | Less than 1.0 m | 84.76% |
| | | 1.0 – 2.0 m | 84.87% |
| | | 2.0 – 4.0 m | 84.98% |
| | | 4.0 – 8.0 m | 85.00% |
| Piles | Diameter | 0.4 m | 82.57% |
| | | 0.5 m | 85.87% |
| | | 0.6 m | 87.37% |
| | Required number | Less than 100 | 84.90% |
| | | 100 – 200 | 84.91% |
| | | 200 – 400 | 84.92% |
| | | 400 – 800 | 95.94% |
| | Length | Less than 12.00 m | 78.59% |
| | | 12.00 – 20.00 m | 85.29% |
| | | 20.00 – 33.00 m | 90.17% |
| | Coordination | Linear | 86.49% |
| | | Random | 85.00% |
| Mixer | Efficiency | Excellent | 87.33% |
| | | Good | 83.81% |
| | | Medium | 82.41% |
| Concrete pump | Concrete workability | Less than 16 cm | 84.70% |
| | | 16 – 18 cm | 85.00% |
| | | 18 – 20 cm | 85.60% |
| | | More than 20 cm | 84.85% |
| | Age | Less than 4 years | 85.61% |
| | | 4 – 8 years | 83.00% |
| | | 8 – 16 years | 77.31% |
| | Efficiency | Excellent | 85.92% |
| | | Good | 84.80% |
| | | Medium | 84.66% |
| | | Poor | 83.00% |
| | Distance | Less than 10 m | 85.19% |
| | | 10 – 20 m | 85.10% |
| | | More than 20 m | 85.07% |
| Management | Specification and conditions | Loose | 86.02% |
| | | Moderate | 84.82% |
| | | Restricted | 83.00% |
| | Efficiency | Excellent | 87.34% |
| | | Good | 85.72% |
| | | Medium | 84.65% |
| | | Poor | 82.47% |
| Weather | Temperature | Less than 20 c | 89.13% |
| | | 20 – 30 c | 86.23% |
| | | More than 30 c | 81.33% |

The results of the study were as follows: The excellent equipment efficiency yields an average performance ratio of 86.61%. The Excellent efficiency of equipment driver yields an average performance ratio of 86.26%. The excellent efficiency of labor yields an average ratio 87.06%. The strong soil classification yields an average performance ratio equal to 73.11%. The excellent mixer efficiency yields an average performance ratio equal to 87.33%. The excellent pump efficiency yields an average performance ratio equal to 85.92%.

The area of the site, site management efficiency and restricted project specification is considerable has no affect on performance ratio.

**References**


[1] F. Harris, Ground Engineering Equipment and Methods, McGraw-Hill, New York (1983).

[2] Web-1. http://www. geoforum. com/ info/ pileinfo/ view. asp? ID58 (2004).

[3] Web-2 http://www. fps. org. uk/ Position% 20 Papers 20 and % 20 Documents/ aquifers. htm (2004).

[4] Web-3, http://sbe. napier. ac. uk/ projects/piledesign/guide/ chapter8.htm (April 23, 2004).

[5] Web-4, www. Simplex-Foundations. co. uk, April 23 (2004).

[6] R.L. Peurifoy, W.L. Ledbetter and C.J. Schexnayder, Construction, Planning, Equipment, and Methods, 6th Ed., McGraw-Hill, New York (2002).

[7] Web-5 (2004), http://www. pennine-group. co. uk/cfa-pilling-continuous-flight-augerpiling. Html, April 23 (2004).

[8] Web-6, http://www. franki. co. za/cfa. html, April 23 (2004).

[9] T.M. Zayed and D.W. Halpin, "Process Versus Data Oriented Techniques in Pile Construction Productivity Assessment", J. Constr. Eng. Manage, Vol. 130 (4) pp. 490–499 (2004).

[10] T.M. Zayed and D.W. Halpin, "Productivity and Cost Regression Models for pile Construction", J. Constr. Eng. Manage, Vol. 131 (7), pp. 779–789 (2005).

[11] R.H. Abdel-Razek and R. McCaffer, "Evaluating Variability in Labour Productivity" Proceedings of the 3rd International Symposium, International Project Management Association, Cairo (1990).

[12] R.H. Abdel-Razek, A. Hosny and H. Alaraby, "Improving Bricklayers' Productivity", Proceeding of the first Alexandria Conference on Structural and Geotechnical Engineering, Alexandria, Egypt, Dec. (1990).

[13] A. Hosny, R.H. Abdel-Razek and N. El Yamani, "Improving Productivity of Tiling Operations: A Case Study", Proceedings of the International Colloquium on Structural Engineering, Ain Shams University, Egyptian Society of Engineers and Canadian Society for Civil Engineering, Cairo, Egypt, Apr. (1992).

[14] R.H. Abdel-Razek, "Resource Utilization: Evaluation and Improvement", Proceeding of the fourth Arab Structural Engineering Conference, Cairo University, Egypt, Nov. (1991-a).

[15] R.H. Abdel-Razek, "Measuring Construction Equipment Utilization: A Case Study", Proceeding of the Fourth Arab Structural Engineering Conference, Cairo University, Egypt, Nov. (1991-b).

[16] R.H. Abdel-Razek, "Measuring and Improving Construction Productivity Using Work Measurement Techniques: A case study", Proceeding of the International Colloquium on Structural Engineering, Ain Shams University, Egyptian Society of Engineers and Canadian Society for Civil Engineering, Cairo, Egypt, Apr. (1992).


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