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ORIGINAL ARTICLE

Cost analysis of continuous flight auger piles construction in Egypt

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Abstract Continuous Flight Auger (CFA) piling is widely used in the Egyptian construction industry. There is a dramatic fluctuation in pricing of executing this work package within short periods as a result of unsteady changes in supply-demand equilibrium. Consequently, there is an urgent need for the use of a scientific approach in estimating construction costs. Accordingly, it is crucial to consider the different cost elements of CFA piling construction as a step to reach an accurate and realistic cost estimate to be used by contractors in tendering. This research aims to study these cost elements based on an expert judgment, site observations and statistical analysis in order to develop an effective tool to estimate the total construction cost of the CFA piles in any future project. Expert survey was performed to draw detailed information to construct a cost breakdown structure (CBS) that was used as a basis for developing the proposed cost model. The developed cost model is then validated through the application on fifty two projects. Such projects were carefully selected in different sizes, purposes and locations. Then the collected data were exposed to statistical analysis techniques. An average percentage error of 4.1% was observed upon comparing the estimated costs with the actual costs of these projects. A sensitivity analysis was then performed to recognize the most effective cost factors. The developed recommended model was used by some experienced contractors in the Egyptian market who expressed their satisfaction with the model.

1. Introduction

A basic objective of construction equipment management was to accurately estimate the cost of construction operations to facilitate tendering, financing, funding and cost control of construction projects. The use of Continuous Flight Auger (CFA) piles is expanding in the Egyptian construction industry as it is the most appropriate for the different ground conditions with a variety of diameters and depths [10]. The prices of constructing CFA piles are dramatically changeable even by increase or decrease within short periods as a result of changes in the supply–demand equilibrium especially in the Egyptian market. The potential stability of the Egyptian market within the future years may affect this problem as the current status will not be accepted in a steady market. Meanwhile, there is insufficient research and industry attention to analyze and estimate the costs of CFA piles construction in the Egyptian operating conditions with unique marketplace

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Nomenclature

ABC	activity based costing
AC	actual cost
C	individual cost of an item or work package
CBS	cost breakdown structure
CC	construction cost
CCC	CFA cost calculator
CFA	continuous flight auger
DC	direct cost
d	daily wage rate of a human resource in pounds
EC	estimated cost
k	unit cost of a consumable (fuel, oil or grease)
L	lump sum amount of cost in pounds
n	number of project working days
Q	total quantity of piling in meter run
MS-Excel	microsoft excel software
PMIS	project management information system
R	daily consumption rate of a consumable (fuel, oil or grease)
SLD	straight line depreciation
TC	total cost
UML	unified modeling language
z	number of human resource peers for a specified job
4WTT	four wheel type tractor (Loader)
6WT	six wheeler truck
18WT	eighteen wheeler truck

factors [10]. The proposed research is an approach to study such a problem with an aim to reach a reliable solution.

2. Literature review

An estimate is an approximate prediction that provides information for decisions and is a substitute of actual measurement that is not economical or possible. It is accurate if it is close to the actual performance. The estimating job has been changing because of the increased complexity and size of construction projects [1]. The term estimate is a loose term in construction industry and its precise meaning is determined from the context in which it is used. It may refer to preliminary cost estimates, detailed cost estimates or quantities estimates [2].

There are many studies dedicated to cost estimates of construction equipment in general or especially CFA piling construction: Tumblin [2] defined "preliminary cost estimates" as quick estimates that may be needed to decide the availability of funds or to confirm the feasibility of a project, while "detailed cost estimates" is an accurate approach based on four categories of expenses: material, labor, equipment and subcontractors cost. The cost of materials and subcontractors are based on relatively fixed prices and can be accurately determined while the area of uncertainty lies in the selection of the proper unit cost and production rates of labor and equipment. Abdel-Razek and Mccaffer [3]: Performed several studies to determine residual variability within estimator calculations and developed simple computer models to calculate labor rate, plant rate, cost of materials, subcontractors cost and labor productivity. Peurifoy and Ledbetter [4]: Classified the total price of a construction operation into labor costs including salaries, transportation, insurance, taxes, training, recognition and rewards; material costs including purchasing, transportation, inspection and storage; equipment costs including ownership costs such as purchase, investment and storage of equipment in addition to equipment operating costs of consumables, minor and major maintenances plus construction overheads. Richardson [5]: Provided many approaches and templates to be used as a standard in estimating the construction costs but this was a general standard which needs some adjustment to work on CFA piles construction especially in the Egyptian operating conditions. Olwan [6]: Developed an integrated database and cost control system for construction projects based on labor/crew system, material system, equipment system, subcontractor system and overheads. Zayed [8]: An early approach to determine CFA costs but he claimed his failure to collect data from experts as they considered it confidential and not for public use. Therefore he considered material, equipment, labor and overheads as a basis for his estimate. This research was built on prices in USA and the approximate total cost for a pile ranged from 745 to 900 USD which cannot be applied in the Egyptian market not only due to different working conditions but also due to instability of currency exchange rates. Gabon [9]: Presented a study conducted to plan the construction of continuous flight auger operations using artificial neural network with cost time trade-offs to optimize the efficiency of such piling job. Fraig [11]: presented a simulation of CFA pile construction to assess productivity using time recording and activity sampling techniques to determine the amount of idle time and its effect on project objectives. Department of Defense, USA [12]: Developed a handbook for construction cost estimating that announced three main categories of construction cost: Direct costs that are attributed to a single task of construction work (labor, material, and equipment); Indirect costs that cannot be attributable to a single task of construction work (overheads, markup, bonds, taxes...etc.) and other costs (contingency reserves, testing, inspection and special requirements). Maowad [13]: Developed an integrated cost control system for construction costs using Unified Modeling Language (UML) with a case study applied on pump station projects in Egypt using artificial intelligence which could be applied on other construction jobs. A Guide to the Project Management Body of Knowledge [14]: The internationally recognized standard mentioned the sources of cost estimating procedures to be the following: expert judgment, historical data, regional and global markets and project management information system (PMIS). Bearing on the previous literature, it was clear that (1) some studies are missing vital cost elements, (2) most of them are covering cost estimates in general, (3) few approaches concentrated on piling costs with inaccurate results due to banned actual data by industry practitioners and (4) none of them studied the cost of CFA piles under the Egyptian working conditions which will be the main objective of this study.

3. Problem statement

The CFA pile construction is one of the complicated construction operations to plan, estimate or even execute because of the existence of many different resources (equipment, labor, materials and supplies) that commensurate in completing its deliverables. The clear problem lies in that industry practitioners deal with planning CFA construction jobs in a rough way due to lack of scientific estimating approaches and accordingly they face inaccurate results that could negatively affect their projects even by delays, funding problems and other risks. Therefore, it is essential to use an organized pattern for estimating CFA construction cost in Egypt instead of rough or analogous estimates; meanwhile, stakeholders need to precisely compute the total cost of such a construction operation for various objectives. They always claim, based on site visits and conversations, the too many detailed cost items and the problems in measuring each. A contractor needs to recognize the minimum achievable cost in order not to lose competition in tenders due to inaccurate rough estimates, while an owner needs to have an accurate independent cost estimate to be used as a benchmark to evaluate contractors' potential offers and to confirm the availability of funds to cover the project requirements.

4. Research objectives

The objective of this research was to construct a comprehensive Cost Breakdown Structure (CBS) for the elements that formulate the total cost of constructing CFA piles and developing a modulated approach that would be used to estimate the total and/or unit cost of constructing CFA piles which could be useful in preparing tenders, confirming the availability of financial funds or other benefits through planning, executing, monitoring and controlling processes during the project life cycle. It can be also extended to perform a sensitivity analysis to determine the most effective cost factors and their consequent effect on the construction cost upon increasing or decreasing. The model should be applied on real projects to measure its validity and draw a constructive feedback from stakeholders.

5. Research methodology

The proposed approach was planned to be achieved through the following procedure. First, Determining CFA cost elements using a "prompt list" questionnaire based on expert judgment interviews with project managers, consultants, cost estimators and site engineers. Second, Applying an "affinity diagramming" technique to classify the cost elements under their main suggested categories and developing a comprehensive cost breakdown structure (CBS) for CFA piles construction. Third, Determining the usage rates for consumable items along with depreciation values of equipment and human resource rates. Then, Developing a procedural cost estimating template that provides an evaluation of the total cost of CFA piling operation in any proposed project in a simple MS-Excel sheet. After that, Validating the model by comparing its results to actual costs of real projects to determine its accuracy. Finally, then Performing sensitivity analysis to study the effect of cost changes in main cost elements and their effect on total cost. The procedure for obtaining the ready model is shown in the methodology flowchart in Fig. 1.

6. Cost elements identification

A prompt list technique is developing a generic list based on expert judgment and guided by historical information of prior similar projects. This list is used to organize thoughts and draw more detailed items from practitioners as per [15]. The list is developed here based on two main cost categories: (1) direct costs and (2) indirect costs of CFA piles construction, where the direct costs are subdivided into five categories based on the main equipment used in CFA piles construction including piling rig, loader, pump, mixer/pan system and mini loader. The indirect costs are typically subdivided into site overheads and main office overheads. This list will be used later to compute the amount of Direct Cost (DC), Construction Cost (CC) and Total Cost (TC) for CFA construction where Direct Cost (DC) refers to costs that are directly attributable to the work in site (human resources, equipment, materials, supplies or services), Construction Cost (CC) refers to the summation of direct costs plus site overheads (Supervision, setup, security, catering, IT, risk reserves and others) and Total Cost (TC) is the entire cost of the construction operation including total direct and indirect costs (site and main office overheads). The list and its objective are then introduced to experts in order to suggest cost items under each category. The data collected from thirty-six experts with diverse project management, consultancy and site experiences are subjected to an affinity diagramming technique. The affinity diagramming is a mind mapping technique where all the collected data were put on the same map to recognize repeated items and re-order them in a final cost breakdown structure (CBS) that is supposed to include all cost factors of CFA piles construction as shown in Fig. 2. It is clear that the total cost is divided into two control accounts: direct and indirect cost; then, each of them is subdivided into work packages according to specialties ready to be solely analyzed for more accurate results.

This cost breakdown structure along with its dictionary (shown in Table 1) which details the meaning of each cost item is sent back to thirty-six experts seeking their feedback. A total of thirty-one responses were received and there was a consensus about its usefulness and value. Accordingly, it was decided to develop a cost estimating template based on the agreement upon cost breakdown structure and the construction methodology explained by Aziz [7] and progressively elaborated by Elsamadony et al. [16] as follows.

1.1. Direct costs: It includes all costs that are directly attributable to the work of the main equipment used to construct CFA piles and are subdivided into the following: *(1.1.1) Rig Cost*: the main equipment that executes CFA piles by excavating the pile hole and concreting it simultaneously and its cost is the sum of transportation, fuel oil, grease, riggers, driver, rig captain, maintenance and depreciation costs, *(1.1.2) Loader Cost*: the main loader is a four wheel type tractor (4WTT) that is used to move heavy loads (gravel, sand, steel reinforcement…etc.) and performs secondary tasks to the augering process. Its cost is the sum of fuel, oil, grease, driver, maintenance and depreciation costs, *(1.1.3) Pump Cost*: a concrete pump is equipment used for transferring fresh concrete to fill the pile hole by means

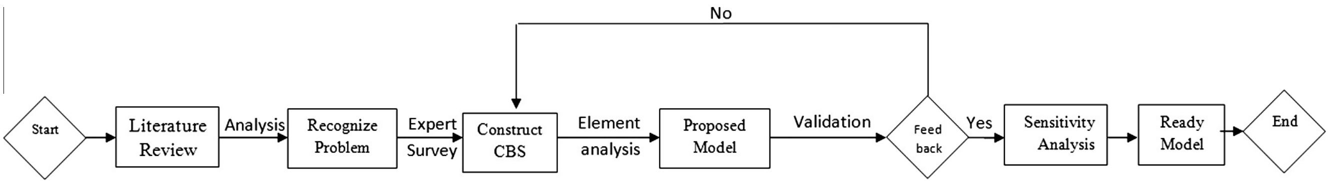


Figure 1 A flowchart describing the sequence of research steps to obtain the ready model.

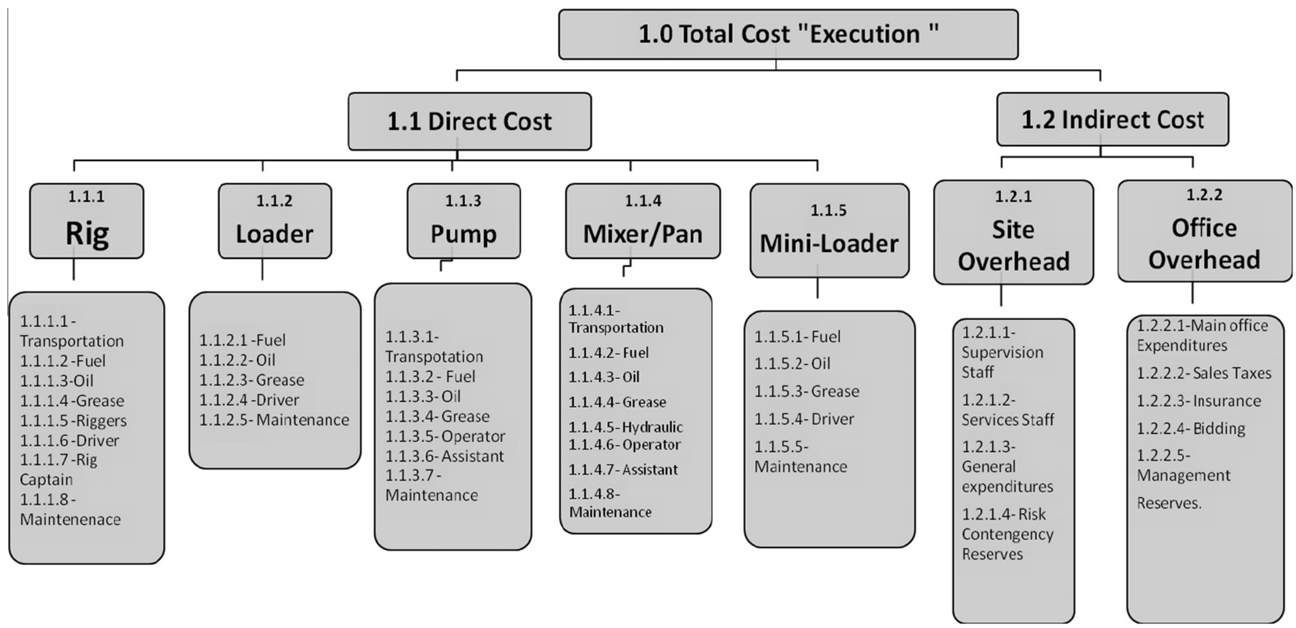


Figure 2 A comprehensive cost breakdown structure of CFA piles construction.

of successive pumping and its cost is the sum of transportation, fuel, oil, grease, operator, assistant, maintenance and depreciation costs, *(1.1.4) Mixer/Pan Cost*: a concrete mixer is equipment used for mixing concrete ingredients mechanically in site to fill the pan which acts as a concrete storage to be ready to feed the pump with the required volume of concrete based on pile design; their cost is the sum of transportation, fuel, oil, grease, operator, assistant, maintenance and depreciation costs and *(1.1.5) Mini Loader Cost*: a mini loader is relatively new equipment used mainly to charge the mixer with concrete ingredients and to carry minor loads; its cost is the sum of fuel, oil, grease, driver, maintenance and depreciation costs.

1.2. Indirect costs: It includes the costs related to general cost or an overhead even in site or main office of the performing organization and it was subdivided into the following cost items: *(1.2.1) Site Overhead Cost*: includes the general expenditures in the construction site before and during the performance period which cannot be allocated to a certain control account, its cost is the sum of the following: supervision, services, security, general expenditures, risk contingency reserves and other costs and *(1.2.1) Main Office Overhead Cost*: includes the costs related to the main office of the performing organization and is mainly calculated by activity based costing (ABC) technique and is determined by the senior management with no input or control from the project team. It may include but are not limited to the following: taxes, insurance, salaries, bidding, management reserves and total investment cost.

7. Cost elements categorizing

The equipment cost, based on literature reviews and the collected expert inputs, fills in the following main cost categories: (1) *Transportation cost*: the cost of transporting equipment to the proposed site from a predecessor site or elsewhere. It can be applied on the main rig using a hired eighteen wheeler truck (18WT) or using a six wheeler truck (6WT) for the pump, mixer and pan. Meanwhile, other equipment can be self transported such as main loader and mini loader, (2) *Consumables cost*: the cost of materials and chemical supplies that are consumed by operating the equipment such as fuel, oil and grease. These cost items can be applied to all equipments even considering the various consumption rates and types of consumables, (3) *Labor cost*: refers to the cost of equipment drivers, operators, assistants, riggers and the rig captain. It includes daily rates, catering, motivation and bonus structure based on productivity metrics. The supervision and services staff are excluded as they will be included in other cost item(s), (4) *Maintenance cost*: it the total cost of equipment regular maintenance during the project performance period by an authorized service center or retailer. It can be obtained using the time ratio of the performance period to the whole year and (5) *Depreciation cost*: calculated as the decrease in equipment book value using straight line depreciation (SLD) method during the project performance period and can also be calculated using the time ratio of the performance period to the whole year.

Table 1 Cost breakdown dictionary for CFA construction.

ID	Cost element	No.	Cost item	Unit of measure
A. Control Account: Direct Costs				
1.1.1	RIG	1	Transportation	*Lump sum*
		2	Fuel	*Liter/day*
		3	Oil	*Liter/day*
		4	Grease	*kg/day*
		5	Riggers	*Working day*
		6	Driver	*Working day*
		7	Rig captain	*Working day*
		8	Maintenance	*Lump sum*
		9	Depreciation	*Lump sum*
1.1.2	LOADER	1	Fuel	*Liter/day*
		2	Oil	*Liter/day*
		3	Grease	*kg/day*
		4	Driver	*Working day*
		5	Maintenance	*Lump sum*
		6	Depreciation	*Lump sum*
1.1.3	PUMP	1	Transportation	*Lump sum*
		2	Fuel	*Liter/day*
		3	Oil	*Liter/day*
		4	Grease	*kg/day*
		5	Operator	*Working day*
		6	Assistant	*Working day*
		7	Maintenance	*Lump sum*
		8	Depreciation	*Lump sum*
1.1.4	Mixer/pan	1	Transportation	*Lump sum*
		2	Fuel	*Liter/day*
		3	Oil	*Liter/day*
		4	Grease	*kg/day*
		5	Operator	*Working days*
		6	Assistants	*Working days*
		7	Maintenance	*Lump sum*
		8	Depreciation	*Lump sum*
1.1.5	Mini loader	1	Fuel	*Liter/day*
		2	Oil	*Liter/day*
		3	Grease	*kg/day*
		4	Driver	*Working day*
		5	Maintenance	*Lump sum*
		6	Depreciation	*Lump sum*
B. Control Account: Indirect Costs				
1.2.1	Supervision staff	1		
		1a	Project manager	*Monthly salary*
		1b	Site engineer	*Monthly salary*
		1c	Supervisor	*Monthly salary*
		2		
Site overheads	Services staff	2a	Surveyor	*Monthly salary*
		2b	Mechanic	*Monthly salary*
		2c	Security	*Monthly salary*
		2d	Purchaser	*Monthly salary*
		3	General expenditures	*Lump sum*
		4	Risk contingency reserve	*Lump sum (based on risk assessment)*
1.2.2		1	Main office	*A percentage based on activity based costing*
		2	Sales tax	*and is determined by higher management*
		3	Insurance	
Office overheads		4	Bidding expenses	
		5	Management reserves	
		6	Total investment costs	*Based on the annual governmental bank interest rate*

Table 2 Calculation equations of CFA cost items.

Item ID	Item	Equation	Meanings
1.1	Direct costs		
1.1.1	Rig costs		
1.1.1.1	*Rig transportation*	$C_1 = L_1$	• C_1: cost of rig transportation • L_1: rig transportation fee (lump sum)
1.1.1.2	*Rig fuel*	$C_2 = k_1 * n * R_1$	• C_2: Cost of rig fuel • k_1: Unit cost of rig fuel (EGP/liter) • n: Work period (days) • R_1: Rig fuel consumption rate (liter/day)
1.1.1.3	*Rig oil*	$C_3 = k_2 * n * R_2$	• C_3: Cost of rig oil • k_2: Unit cost of rig oil (EGP/liter) • n: Work period (days) • R_2: Rig oil consumption rate (liter/day)
1.1.1.4	*Rig grease*	$C_4 = k_3 * n * R_3$	• C_4: Cost of rig grease • k_3: Unit cost of rig grease (EGP/kg) • n: Work period (days) • R_3: Rig grease consumption rate (kg/day)
1.1.1.5	*Riggers*	$C_5 = n * z_1 * d_1$	• C_5: Cost of riggers • n: Work period (days) • z_1: Number of riggers • d_1: Daily rate of a rigger (EGP/day)
1.1.1.6	*Rig driver(s)*	$C_6 = n * z_2 * d_2$	• C_6: Cost of rig driver(s) • n: Work period (days) • z_2: Number of driver(s) • d_2: Daily rate of a rig driver (EGP/day)
1.1.1.7	*Rig captain*	$C_7 = n * z_3 * d_3$	• C_7: Cost of rig captain(s) • n: Work period (days) • z_3: Number of rig captain(s) • d_3: Daily rate of a rig captain (EGP/day)
1.1.1.8	*Rig maintenance*	$C_8 = L_2$	• C_8: cost of rig maintenance • L_2: rig maintenance fee (lump sum by experts)
1.1.1.9	*Rig depreciation*	$C_9 = L_3$	• C_9: cost of rig depreciation • L_3: rig depreciation cost (lump sum by S.L.D.)
1.1.2	Loader		
1.1.2.1	*Loader fuel*	$C_{10} = k_4 * n * R_4$	• C_{10}: Cost of loader fuel • k_4: Unit cost of loader fuel (EGP/liter) • n: Work period (days)R_4: Loader fuel consumption rate (liter/day)
1.1.2.2	*Loader oil*	$C_{11} = k_5 * n * R_5$	• C_{11}: Cost of loader oil • k_5: Unit cost of loader oil (EGP/liter) • n: Work period (days) • R_5: Loader oil consumption rate (liter/day)
1.1.2.3	*Loader grease*	$C_{12} = k_6 * n * R_6$	• C_{12}: Cost of loader grease • k_6: Unit cost of loader grease (EGP/kg) • n: Work period (days) • R_6: Loader grease consumption rate (kg/day)
1.1.2.4	*Loader driver*	$C_{13} = n * z_4 * d_4$	• C_{13}: Cost of loader driver(s) • n: Work period (days) • z_4: Number of loader driver(s) • d_4: Daily rate of a loader driver (EGP/day)
1.1.2.5	*Loader maintenance*	$C_{14} = L_4$	• C_{14}: cost of loader maintenance • L_4: Loader maintenance fee (lump sum by experts)
1.1.2.6	*Loader depreciation*	$C_{15} = L_5$	• C_{15}: cost of loader depreciation • L_{15}: Loader depreciation cost (lump sum by S.L.D.)
1.1.3	PUMP		
1.1.3.1	*Pump transportation*	$C_{16} = L_6$	• C_{16}: cost of pump transportation • L_6: pump transportation fee (lump sum)
1.1.3.2	*Pump fuel*	$C_{17} = k_7 * n * R_7$	• C_{17}: Cost of pump fuel • k_7: Unit cost of pump fuel (EGP/liter) • n: Work period (days) • R_7: Pump fuel consumption rate (liter/day)
1.1.3.3	*Pump oil*	$C_{18} = k_8 * n * R_8$	• C_{18}: Cost of pump oil • k_8: Unit cost of pump oil (EGP/liter) • n: Work period (days)

Table 2 (*continued*)

Item ID	Item	Equation	Meanings
			• R_8: Pump oil consumption rate (liter/day)
1.1.3.4	*Pump grease*	$C_{19} = k_9 * n * R_9$	• C_{19}: Cost of pump grease • k_9: Unit cost of pump grease (EGP/kg) • n: Work period (days) • R_9: Pump grease consumption rate (kg/day)
1.1.3.5	*Pump operator*	$C_{20} = n * z_5 * d_5$	• C_{20}: Cost of pump operator(s) • n: Work period (days) • z_5: Number of pump operator(s) • d_5: Daily rate of a pump operator (EGP/day)
1.1.3.6	*Pump assistant (s)*	$C_{21} = n * z_6 * d_6$	• C_{21}: Cost of pump assistant(s) • n: Work period (days) • z_6: Number of pump assistant(s) • d_6: Daily rate of a pump assistant (EGP/day)
1.1.3.7	*Pump maintenance*	$C_{22} = L_7$	• C_{22}: cost of pump maintenance • L_7: Pump maintenance fee (lump sum by experts)
1.1.3.8	*Pump depreciation*	$C_{23} = L_8$	• C_{23}: cost of pump depreciation • L_8: Pump depreciation (lump sum by S.L.D.)
1.1.4	Mixer/pan		
1.1.4.1	*Mixer-pan transportation*	$C_{24} = L_9$	• C_{24}: cost of mixer/pan transportation • L_9: Mixer/pan transportation fee (lump sum)
1.1.4.2	*Mixer-pan fuel*	$C_{25} = k_{10} * n * R_{10}$	• C_{25}: Cost of mixer/pan fuel • k_{10}: Unit cost of mixer/pan fuel (EGP/liter) • n: Work period (days) • R_{10}: Mixer/Pan fuel consumption rate (liter/day)
1.1.4.3	*Mixer-pan oil*	$C_{26} = k_{11} * n * R_{11}$	• C_{26}: Cost of mixer/pan oil • k_{11}: Unit cost of mixer/pan oil (EGP/liter) • n: Work period (days) • R_{11}: Mixer/pan oil consumption rate (liter/day)
1.1.4.4	*Mixer-pan grease*	$C_{27} = k_{12} * n * R_{12}$	• C_{27}: Cost of mixer/pan grease • k_{12}: Unit cost of mixer/pan grease (EGP/kg) • n: Work period (days) • R_{12}: Mixer/pan grease consumption rate (kg/day)
1.1.4.5	*Mixer-pan operators*	$C_{28} = n * z_7 * d_7$	• C_{28}: Cost of mixer/pan operators • n: Work period (days) • z_7: Number of mixer/pan operators • d_7: Daily rate of a mixer/pan operator (EGP/day)
1.1.4.6	*Mixer-pan assistants*	$C_{29} = n * z_8 * d_8$	• C_{29}: Cost of mixer/pan assistants • n: Work period (days) • z_8: Number of mixer/pan assistants • d_8: Daily rate of a mixer/pan assistant (EGP/day)
1.1.4.7	*Mixer-pan maintenance*	$C_{30} = L_{10}$	• C_{30}: cost of mixer/pan maintenance • L_{10}: Mixer/pan maintenance fee (lump sum by experts)
1.1.4.8	*Mixer-pan depreciation*	$C_{31} = L_{11}$	• C_{31}: cost of mixer/pan depreciation • L_{11}: Pump depreciation cost (lump sum by S.L.D.)
1.1.5	Mini loader		
1.1.5.1	*Mini loader fuel*	$C_{32} = k_{13} * n * R_{13}$	• C_{32}: Cost of mini loader fuel • k_{13}: Unit cost of mini loader fuel (EGP/liter) • n: Work period (days) • R_{13}: Mini loader fuel consumption rate (liter/day)
1.1.5.2	*Mini loader oil*	$C_{33} = k_{14} * n * R_{14}$	• C_{33}: Cost of mini loader oil • k_{14}: Unit cost of mini loader oil (EGP/liter) • n: Work period (days) • R_{14}: Mini loader oil consumption rate (liter/day)
1.1.5.3	*Mini loader grease*	$C_{34} = k_{15} * n * R_{15}$	• C_{34}: Cost of mini loader grease • k_{15}: Unit cost of mini loader grease (EGP/kg) • n: Work period (days) • R_{15}: Mini loader grease consumption rate (kg/day)
1.1.5.4	*Mini loader driver*	$C_{35} = n * z_9 * d_9$	• C_{35}: Cost of mini loader driver(s) • n: Work period (days) • z_9: Number of mini loader driver(s) • d_9: Daily rate of a mini loader driver (EGP/day)
1.1.5.5	*Mini loader*	$C_{36} = L_{12}$	• C_{36}: cost of mini loader maintenance

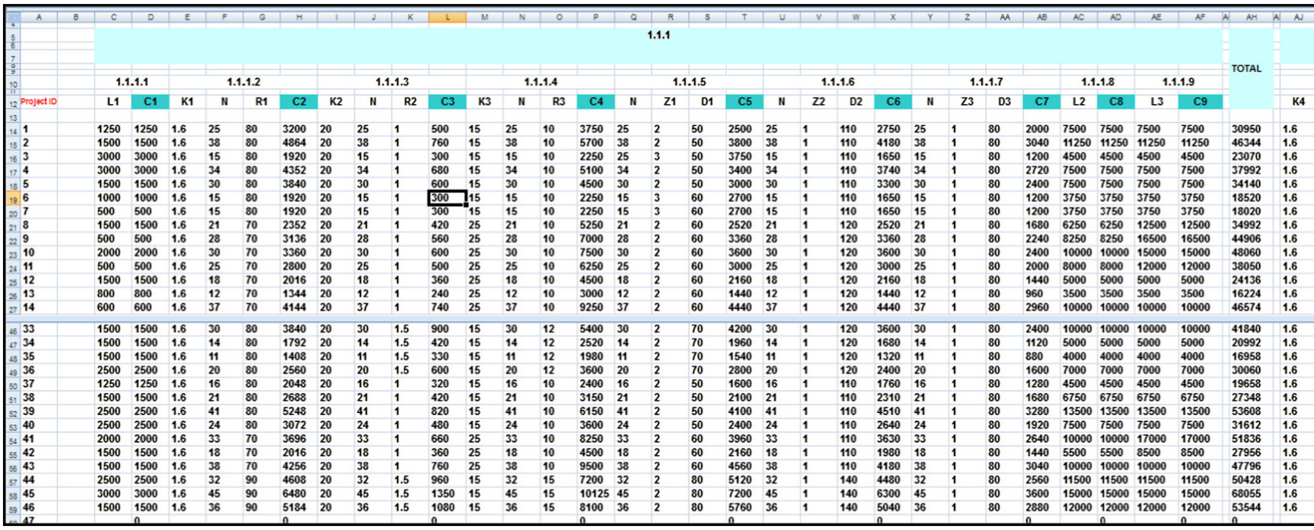
(*continued on next page*)

Table 2 (*continued*)

Item ID	Item	Equation	Meanings
	maintenance		• L_{12}: Mini Loader maintenance fee (lump sum by experts)
1.1.5.6	*Mini loader depreciation*	$C_{37} = L_{13}$	• C_{37}: cost of mini loader depreciation • L_{13}: Mini loader depreciation cost (lump sum by S.L.D.)
1.2	Indirect costs		
1.2.1	Site overheads		
1.2.1.1	*Supervision staff*		
1.2.1.1a	Project manager	$C_{38} = n * z_{10} * d_{10}$	• C_{38}: Cost of a Project Manager • n: Work period (days) • z_{10}: Number of Project Managers • d_{10}: Daily rate of a Project Manager*(based on monthly salary plus bonus structure)*
1.2.1.1b	Site engineer(s)	$C_{39} = n * z_{11} * d_{11}$	• C_{39}: Cost of site engineers • n: Work period (days) • z_{11}: Number of site engineers • d_{11}: Daily rate of a site engineer*(based on monthly salary plus bonus structure)*
1.2.1.1c	Supervisor(s)	$C_{40} = n * z_{12} * d_{12}$	• C_{40}: Cost of supervisors • n: Work period (days) • z_{12}: Number of supervisors • d_{12}: Daily rate of a supervisor*(based on monthly salary plus bonus structure)*
1.2.1.2	*Services staff*		
1.2.1.2a	Surveyor	$C_{41} = n * z_{13} * d_{13}$	• C_{41}: Cost of Surveyor(s) • n: Work period (days) • z_{13}: Number of surveyors • d_{13}: Daily rate of a surveyor*(based on monthly salary plus bonus structure)*
1.2.1.2b	Mechanic	$C_{42} = n * z_{14} * d_{14}$	• C_{42}: Cost of Mechanics(s) • n: Work period (days) • z_{14}: Number of mechanics • d_{14}: Daily rate of a mechanic*(based on monthly salary plus bonus structure)*
1.2.1.2c	Security	$C_{43} = n * z_{15} * d_{15}$	• C_{43}: Cost of Security Guards • n: Work period (days) • z_{15}: Number of security guards • d_{15}: Daily rate of a security guard*(based on monthly salary plus bonus structure)*
1.2.1.2d	Purchaser(S)	$C_{44} = n * z_{16} * d_{16}$	• C_{44}: Cost of Purchaser(s) • n: Work period (days) • z_{16}: Number of purchasers • d_{16}: Daily rate of a purchaser*(based on monthly salary plus bonus structure)*
1.2.1.3	*General expenditures*		
1.2.1.3a	Cost of quality	$C_{45} = L_{14}$	• C_{45}: cost of quality • L_{14}: Lump sum of total costs of quality*(based on expert estimates and project needs)*
1.2.1.3b	Miscellaneous	$C_{46} = L_{15}$	• C_{46}: Miscellaneous costs • L_{15}: Lump sum of total extra costs in site*(a percentage or fixed number estimated by the Project Manager based on project requirements to cover unknown risks and other items)*
1.2.1.3	*Risk reserves*	$C_{47} = L_{16}$	• C_{47}: Risk reserve costs • L_{15}: Lump sum of total risk responses costs*(a percentage or fixed number estimated by the Project Manager based on complete risk assessments)*
1.2.2	Office overheads	$C_{48} = L_{17}$	*A percentage based on activity based costing and is determined by the company's higher management*

8. Cost elements measurement

Each cost item was individually computed through a single equation (as shown and explained in Table 2). These equations will be applied to the proposed estimating template and accordingly the cost items will be aggregated to determine the total construction cost for a proposed CFA pile construction operation. Equations vary according to the type of cost item being calculated. For example, the calculation of consumable cost is obtained by multiplying the number of working days (n) by the daily consumption rate (R) by the unit cost of such a consumable (k), the calculation of a human resource daily rate is obtained by multiplying the number of working days (n) by the number of human resource peers (z) by the monetary daily rate of such a human resource (d) and other cost items are measured in lump sum (L). The project duration (n), which is a main input in calculating costs of CFA construction, was previously calculated using a mathematical model for determining CFA construction duration developed by Hosny et al. [17] as a predecessor approach of CFA construction management.



	1.1.1.1		1.1.1.2				1.1.1.3				1.1.1.4				1.1.1.5				1.1.1.6				1.1.1.7				1.1.1.8		1.1.1.9		TOTAL		
Project ID	L1	C1	K1	N	R1	C2	K2	N	R2	C3	K3	N	R3	C4	N	Z1	D1	C5	N	Z2	D2	C6	N	Z3	D3	C7	L2	C8	L3	C9		K4	
1	1250	1250	1.6	25	80	3200	20	25	1	500	15	25	10	3750	25	2	50	2500	25	1	110	2750	25	1	80	2000	7500	7500	7500	7500	30950	1.6	2
2	1500	1500	1.6	38	80	4864	20	38	1	760	15	38	10	5700	38	2	50	3800	38	1	110	4180	38	1	80	3040	11250	11250	11250	11250	46344	1.6	3
3	3000	3000	1.6	15	80	1920	20	15	1	300	15	15	10	2250	25	3	50	3750	15	1	110	1650	15	1	80	1200	4500	4500	4500	4500	23070	1.6	1
4	3000	3000	1.6	34	80	4352	20	34	1	680	15	34	10	5100	34	2	50	3400	34	1	110	3740	34	1	80	2720	7500	7500	7500	7500	37992	1.6	3
5	1500	1500	1.6	30	80	3840	20	30	1	600	15	30	10	4500	30	2	50	3000	30	1	110	3300	30	1	80	2400	7500	7500	7500	7500	34140	1.6	3
6	1000	1000	1.6	15	80	1920	20	15	1	300	15	15	10	2250	15	3	60	2700	15	1	110	1650	15	1	80	1200	3750	3750	3750	3750	18520	1.6	1
7	500	500	1.6	15	80	1920	20	15	1	300	15	15	10	2250	15	3	60	2700	15	1	110	1650	15	1	80	1200	3750	3750	3750	3750	18020	1.6	1
8	1500	1500	1.6	21	70	2352	20	21	1	420	25	21	10	5250	21	2	60	2520	21	1	120	2520	21	1	80	1680	6250	6250	12500	12500	34992	1.6	2
9	500	500	1.6	28	70	3136	20	28	1	560	25	28	10	7000	28	2	60	3360	28	1	120	3360	28	1	80	2240	8250	8250	16500	16500	44906	1.6	2
10	2000	2000	1.6	30	70	3360	20	30	1	600	25	30	10	7500	30	2	60	3600	30	1	120	3600	30	1	80	2400	10000	10000	15000	15000	48060	1.6	3
11	500	500	1.6	25	70	2800	20	25	1	500	25	25	10	6250	25	2	60	3000	25	1	120	3000	25	1	80	2000	8000	8000	12000	12000	38050	1.6	2
12	1500	1500	1.6	18	70	2016	20	18	1	360	25	18	10	4500	18	2	60	2160	18	1	120	2160	18	1	80	1440	5000	5000	5000	5000	24136	1.6	1
13	800	800	1.6	12	70	1344	20	12	1	240	25	12	10	3000	12	2	60	1440	12	1	120	1440	12	1	80	960	3500	3500	3500	3500	16224	1.6	1
14	600	600	1.6	37	70	4144	20	37	1	740	25	37	10	9250	37	2	60	4440	37	1	120	4440	37	1	80	2960	10000	10000	10000	10000	46574	1.6	3
33	1500	1500	1.6	30	80	3840	20	30	1.5	900	15	30	12	5400	30	2	70	4200	30	1	120	3600	30	1	80	2400	10000	10000	10000	10000	41840	1.6	3
34	1500	1500	1.6	14	80	1792	20	14	1.5	420	15	14	12	2520	14	2	70	1960	14	1	120	1680	14	1	80	1120	5000	5000	5000	5000	20992	1.6	1
35	1500	1500	1.6	11	80	1408	20	11	1.5	330	15	11	12	1980	11	2	70	1540	11	1	120	1320	11	1	80	880	4000	4000	4000	4000	16958	1.6	1
36	2500	2500	1.6	20	80	2560	20	20	1.5	600	15	20	12	3600	20	2	70	2800	20	1	120	2400	20	1	80	1600	7000	7000	7000	7000	30060	1.6	2
37	1250	1250	1.6	16	80	2048	20	16	1	320	15	16	10	2400	16	2	50	1600	16	1	110	1760	16	1	80	1280	4500	4500	4500	4500	19658	1.6	1
38	1500	1500	1.6	21	80	2688	20	21	1	420	15	21	10	3150	21	2	50	2100	21	1	110	2310	21	1	80	1680	6750	6750	6750	6750	27348	1.6	2
39	2500	2500	1.6	41	80	5248	20	41	1	820	15	41	10	6150	41	2	50	4100	41	1	110	4510	41	1	80	3280	13500	13500	13500	13500	53608	1.6	4
40	2500	2500	1.6	24	80	3072	20	24	1	480	15	24	10	3600	24	2	50	2400	24	1	110	2640	24	1	80	1920	7500	7500	7500	7500	31612	1.6	2
41	2000	2000	1.6	33	70	3696	20	33	1	660	25	33	10	8250	33	2	60	3960	33	1	110	3630	33	1	80	2640	10000	10000	17000	17000	51836	1.6	3
42	1500	1500	1.6	18	70	2016	20	18	1	360	25	18	10	4500	18	2	60	2160	18	1	110	1980	18	1	80	1440	5500	5500	8500	8500	27956	1.6	1
43	1500	1500	1.6	38	70	4256	20	38	1	760	25	38	10	9500	38	2	60	4560	38	1	110	4180	38	1	80	3040	10000	10000	10000	10000	47796	1.6	3
44	2500	2500	1.6	32	90	4608	20	32	1.5	960	15	32	15	7200	32	2	80	5120	32	1	140	4480	32	1	80	2560	11500	11500	11500	11500	50428	1.6	3
45	3000	3000	1.6	45	90	6480	20	45	1.5	1350	15	45	15	10125	45	2	80	7200	45	1	140	6300	45	1	80	3600	15000	15000	15000	15000	68055	1.6	4
46	1500	1500	1.6	36	90	5184	20	36	1.5	1080	15	36	15	8100	36	2	80	5760	36	1	140	5040	36	1	80	2880	12000	12000	12000	12000	53544	1.6	3
47		0				0				0				0				0				0				0		0		0	0		

Figure 3 A screen shot sample from MS Excel Sheet for Rig Cost Calculation (work package 1.1.1).

9. Cost estimating model

The total cost of a CFA piles construction job can be estimated by aggregating each individually computed cost item as shown in Eq. (1):

$$Total\ Cost = \sum_{i=1}^{48} C_i EGP \qquad (1)$$

where the unit cost (cost per meter run of a pile) can be calculated as shown in Eq. (2):

$$Unit\ Cost = TotalCost/Q \quad EGP/m' \qquad (2)$$

where

- C_i: is the individual cost of the i th work item.
- Q: is total quantity of piling in meter run.

The previous equation can be practically applied to real projects using a structured MS-Excel sheet known as CFA Cost Calculator (CCC) that works by entering each minor cost component, then calculating the individual work package costs by applying the previously recognized equations, aggregating them into control account costs and so forth the total cost of a CFA job; a sample of this sheet is shown in Fig. 3.

10. Cost model validation

The proposed model was validated by applying the CFA Cost Calculator to a sample of real projects. The sample size was chosen based on an automated sample size calculator (http://www.surveysystem.com/sscalc.htm) [18] based on confidence level of 95% and confidence interval of two; therefore, the minimum sample size of thirty-five piling projects out of seven contractors incurred in the questionnaire was based on meeting the following selection criteria: (1) minimum contractor experience of ten years, (2) maximum age of the rig is ten years, (3) pile length 10–30 m, (4) pile diameter is 40–60 cm, (5) minimum scope of 250 piles or 3000 m′ for a single project and (5) experienced company and site staff (construction and/or mechanical engineers).

Actually, the model was applied to an extended validation sample of fifty-one projects performed by seven experienced contractors who matched the prescribed selection criteria through an observation period of 327 working days started on January 18, 2015 till December 9, 2015 to cover a whole year with different working conditions. The sample scope of work was 12,398 piles with a total quantity of 188,980 m run. The sample was also selected, as available, to cover a variety of work locations in Alexandria, Delta, Cairo and Upper Egypt. Also, the study tended to approach multi-purpose structures such as residential, educational, industrial buildings, silos and tanks. The validation procedure was started by the following: (1) calculating the estimated cost (EC) of CFA construction in a sample project using the proposed model, (2) providing the result to the contractor, (3) determining the actual cost (AC) after work completion and (4) performing a variance analysis to recognize the magnitude and cause of variance between actual and estimated costs. An average percentage error of 4.1% was obtained which was very low compared to ordinary rough estimates used before; results of validation approach are shown in Table 3 comparing estimated costs, actual costs and individual percentage error.

11. Statistical analysis of cost items

The detailed cost data of the fifty-one studied projects were subjected to a statistical analysis using MS Excel software to determine the ratios between the components of the total cost to recognize the most important expenditure items that can be controlled in order to reduce the construction cost of CFA construction. This can also be beneficial to recognize the effect of any uncontrollable increase in any cost item on the overall construction cost of CFA piles. The results show that the rig, loader, mixer/pan, pump and mini loader costs represent 48%, 18%, 13%, 12% and 9% of the total direct cost of CFA construction as shown in Fig. 4.

Similarly, the results show that the costs of general expenditures, service staff and supervision staff represent 53%, 27% and 19% respectively of the total site overheads cost as shown in Fig. 5.

Table 3 Project validation results.

Project (ID)	Estimated cost (EC)	Actual cost (AC)	Error	Comments
1	101568.75	97,500	0.040059	
2	161998.5	166,300	−0.026553	
3	66686.25	71,600	−0.073685	
4	115868.25	114,200	0.014398	
5	123512.5	126,900	−0.027426	
6	73081.25	75,500	−0.033097	
7	64122.5	67,300	−0.049554	
8	95806.75	91,000	0.050171	
9	122,209	117,600	0.037714	
10	175052.5	174,200	0.00487	
11	125343.75	119,900	0.043431	
12	83091.5	78,000	0.061276	
13	49,861	51,800	−0.038888	
14	133004.75	134,400	−0.01049	
15	78429.08	91,000	−0.160284	Unprofessional owner
16	233493.98	246,000	−0.05356	
17	134072.7	129,800	0.031869	
18	28455.32	30,500	−0.071856	
19	52192.2	53,300	−0.021225	
20	58229.08	61,250	−0.05188	
21	35,071	34,100	0.027687	
22–22″	254,987	233,500	0.084267	
23–23‴	686,363	640,000	0.067549	
24	326,069	308,000	0.055415	
25	78,110	81,000	−0.036999	
26	47,740	51,000	−0.068287	
27	68,476	70,700	−0.032479	
28	98,394	101,200	−0.028518	
29	47,948	48,800	−0.017769	
30	46,540	52,500	−0.128062	Site accident
31	67,668	66,400	0.018739	
32	133,689	128,000	0.042554	
33	149,510	151,800	−0.015317	
34	82,818	77,200	0.067835	
35	51,457	48,800	0.051635	
36	133,140	156,000	−0.171699	Rotary accident
37	76,846	74,300	0.033131	
38	95,739	91,200	0.04741	
39	190,009	180,600	0.049519	
40	97,844	93,450	0.044908	
41	144,493	153,000	−0.058875	
42	90,242	94,800	−0.050509	
43	168,177	176,600	−0.050084	
44	160,858	157,000	0.023984	
45	189,205	196,500	−0.038556	
46	147,634	155,500	−0.05328	

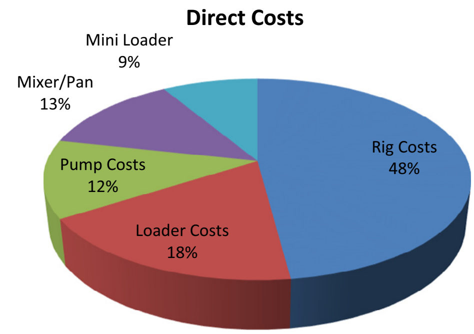


Figure 4 Ratios of direct cost elements.

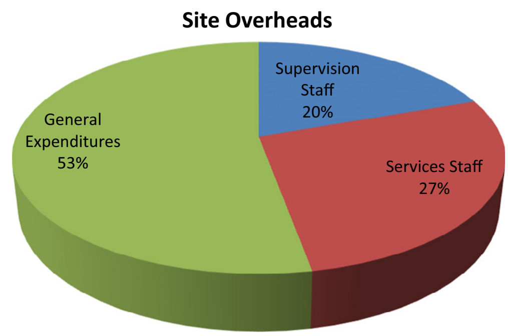


Figure 5 Ratios of site overheads cost elements.

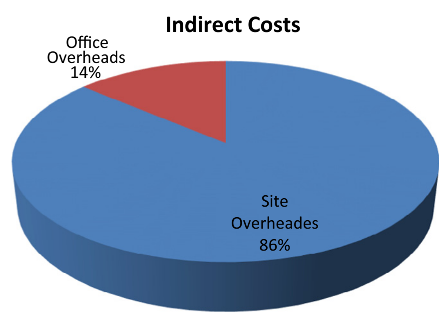


Figure 6 Ratios of indirect cost elements.

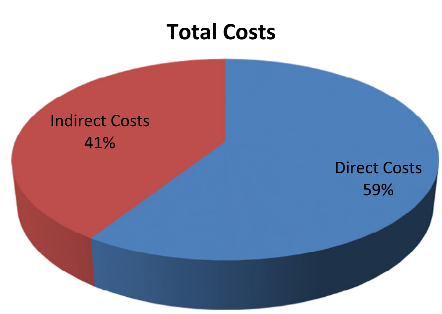


Figure 7 Ratios of total construction cost elements.

Regarding the total indirect costs, the results show that site overheads represent 86% while main office overheads represent 14% of the total indirect costs of CFA construction as shown in Fig. 6.

For the total construction cost of CFA piling jobs, it was obtained that the direct costs represent 59% and the indirect costs (site and office) represent 41% as shown in Fig. 7.

12. Sensitivity analysis

The research is extended to perform a sensitivity analysis which was focused on determining the amount of change in direct cost (DC) as a result of any probable variation in the costs of equipment. The analysis shows that on increasing rig cost by 1%, 5% and 10%, the direct cost (DC) will increase by 0.48%, 2.40% and 4.79% respectively and vice versa. The

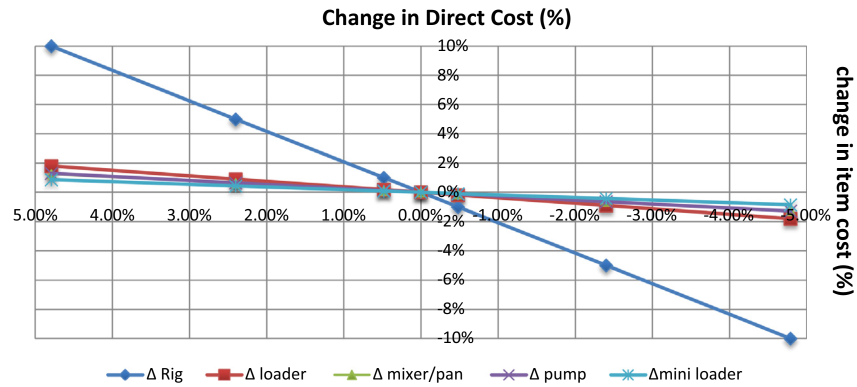


Figure 8 Sensitivity analysis of equipment cost on direct cost.

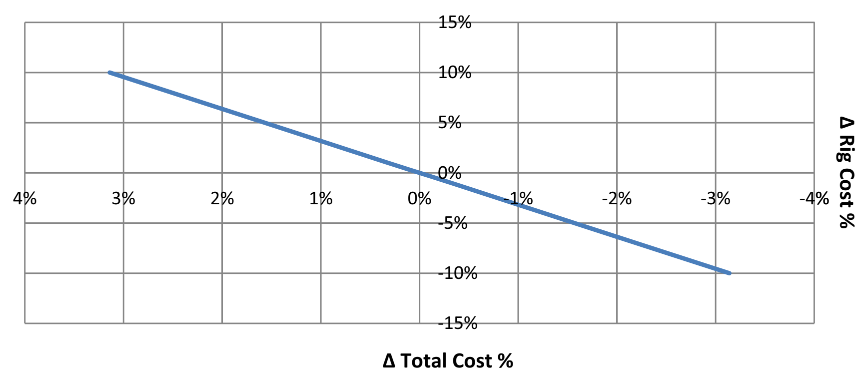


Figure 9 Sensitivity analysis of rig cost on total cost.

rig cost was calculated to be the most effective equipment cost as compared to loader, pump, mixer-pan, and mini loader costs upon the same amount of increase and decrease as shown in Fig. 8.

Similarly, the sensitivity analysis was performed to determine the effect of rig cost variation on total cost (TC) which was found to be 0.32%, 1.57% and 3.14% upon increasing rig cost by 1%, 5% and 10% respectively and vice versa as shown in Fig. 9.

13. Conclusion and recommendations

This research presents an approach to develop a comprehensive model to predict the total construction cost of Continuous Flight Auger (CFA) piles, especially under the working conditions of the Egyptian market. The model was developed based on expert judgment to determine the basic cost elements along with primary data concerning the characteristics of equipment, human resources and supplies which contribute in the completion of a proposed CFA construction job. A cost calculation equation was developed to each single cost element as a step to construct the entire model. The model was presented to industry stakeholders and validated on a sample of fifty-one projects. The validation calculations resulted in a model average percentage error of 4.1% which was satisfactory as per their feedback where seven contractors decided to use the model in planning their work under a free technical support by the research team. The collected data were analyzed statistically to know the ratios of each cost element to the total construction cost; the total direct cost (rig, main loader, pump, mixer, pan and mini loader) represented 59%, site overheads (supervision, technical staff and miscellaneous) represented 35% and main office overheads represented 6% of the total construction cost of CFA piles. The research was extended to perform a sensitivity analysis to recognize the most effective equipment on total cost of CFA projects which were the rig, loader, pump, mixer/pan and mini loader respectively.

For the future studies, the researchers recommend peers to (1) include the cost of materials such as reinforcement steel and concrete, (2) perform a complete risk assessment to precisely calculate risk reserves in time and cost, (3) study the effect of currency exchange rates on costs (US dollars and Euros), and (4) perform a detailed analysis for cost of quality (cost of conformance and costs of non-conformance).

Declaration

This paper is based on a Ph.D. thesis, prepared by the third author and supervised by the first two authors.

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