

FORECASTING CONSTRUCTION SCHEDULE OF BORED PILE WITH DISCRETE EVENT SIMULATION TOOL

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Abstract

The paper conducts EZStrobe program to simulate the construction process of a bored pile. A simulation model, which with detailed activities of bored pile construction, has been developed to analyze and predict the construction time of a pile with random work times. The model and simulation results are also compared and evaluated with a published study, showing the suitability and high efficiency of the established model.

Keywords: *Discrete Event Simulation; EZStrobe; bored piles construction; construction schedule.*

1. Introduction

Bored piles are one of the foundation measures widely applied in the construction of high-rise buildings all over the world including Vietnam. The installation of bored piles is a complex process that includes many activities under a careful construction process, requiring high technical requirements. Currently, in most projects, when setting up the construction schedule of bored piles, the construction time is estimated based on the norms or experience of the contractor. In fact, during the construction process, the construction time often deviates much from the established schedule, affecting the management and administration of the project. Factors such as weather conditions, labor's skill of workers or geological conditions all greatly affect the actual construction time.

To solve the problem, previous researches about determining the construction time of bored piles using the random time of activity have been practiced such as studies by Tarek M. Zayed and Daniel W. Halpin [1] has studied and evaluated the productivity of bored pile construction process and construction cost by simulation on the program MicroCYCLONE; In [2], time and cost for the construction of bored piles using Artificial Neural Network (ANN) has been studied. Tarek M. Zayed and Daniel W. Halpin [3] have concentrated on evaluating the time, productivity and construction cost bored piles, consider the influence of factors affecting the construction process by regression analysis technique.

In Vietnam, several studies have discussed this problem: 1) Hoang Pham [4] studied the quality of construction methods according to the theory of reliability, with Monte Carlo simulation method; 2) The master thesis of author Thuan Huy Tran [5], has investigated the influence of geology and pile size through regression analysis

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method. The simulation method has been applied in predicting the construction time of bored piles in these studies [1] and [4]. However, MicroCYCLONE is a software on DOS (Disk Operating System) environment and has no longer been improved, leading to obsoleting of MicroCYCLONE [6], and the program in research [4] is for academic purpose only and difficult to apply in practice. Moreover, the above studies have not considered the possibility of equipment failure during operation causing the delay to construction of piles, the results are consequently limited.

In previous research of the authors [7], recognizing the outstanding capacity of the EZStrobe simulation program in scenario analysis and decision support, moreover the program is significantly user-friendly, the authors have developed a simulation model of the bored pile construction process based on the EZStrobe program to evaluate the productivity and forecast the construction schedule.

2. Introduction to simulation and EZStrobe program

2.1. Discrete Event Simulation (DES)

Simulation is the imitation of a real-world process or system over time [8]. Discrete event simulation has been applied to the planning and analysis of construction activities since the early 1970s and has achieved promising results especially for tunnel construction. Modeling systems simulate discrete events as a network of queues and operations in which state variables change at discrete points in time [9]. Accounting to the random factor of construction time, in the DES model, the duration of activities can be described by probability distribution functions. Therefore, the simulation time result of the system is the forecast time of the construction progress.

2.2. Simulation program STROBOSCOPE

STROBOSCOPE is an advanced discrete event simulation programming language, simulates the build process based on the current system state and the characteristics, attributes, and state of resources was developed by Martinez in 1996. STROBOSCOPE uses the Three-Phase Activity Scanning method with constraints and variables capable of modeling simple to complex construction operations [10].

STROBOSCOPE has been classified as a simulation tool to support planning and decision making. It focuses mainly on time forecasting and construction management to enable the process to be completed on time.

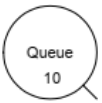

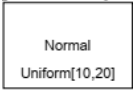




2.3. EZStrobe

EZStrobe is a discrete-event simulation system using STROBOSCOPE as simulation tool. It is a simple but powerful general purpose simulation system capable of modeling many complex operations in different domains. Program based on extended and

annotated Activity Cycle Diagrams (ACD). An EZStrobe simulation model is represented completely by a graphical network, whose nodes and links are built using drag-and-drop graphics from the EZStrobe Stencil [11]. The complete logic of an EZStrobe model is represented entirely by the ACD network and is visible at all times. All links are annotated to show the start-up conditions for activities and the routing of resources.

EZStrobe was developed in and runs within Microsoft Visio. Given a graphical network, EZStrobe creates the equivalent model using STROBOSCOPE statements and sends it to STROBOSCOPE to perform the simulation. This automation is completely hidden from the user. Thus, learning and using EZStrobe does not require any knowledge or use of STROBOSCOPE directly [11]. The results of an EZStrobe simulation are shown in Stroboscope's output window and in Visio by right-clicking each node. The basic modeling components of EZStrobe are shown in Table 1.

Table 1. Main components of the EZStrobe model [11]

Name and description	Link conditions	Parameter	Symbol
A Queue is a named element that holds idle resources	A Queue can follow any other node except another Queue. A Queue can only precede a Conditional Activity (Combi)	- Queue name - Number of resources	
A Conditional Activity (Combi)	Conditional Activities can only follow Queues, but can precede any other node other than a Conditional Activity	- The priority of activity - Active Name - The probability distribution of time	
A Bound Activity (Normal)	A Bound Activity can follow any node except a Queue, and can precede any node except a Conditional Activity	- Active Name - The probability distribution of time	
A Fork is a probabilistic routing element	It typically follows an activity but can also follow another Fork	N/A	
A Draw Link	Connects different activities and queues.	Condition necessary for the successor activity to start	
Release Link	Connects an Activity to any other node except a Conditional Activity	The amount of resource that will be released through the Link each time.	
Branch Link (Link by probability)	Connects a Fork to any other node except a Conditional Activity	Probability Ratio	

3. Technological process of bored pile construction

- The construction process of bored piles by wet drilling method using bentonite slurry to keep the wall is shown in Figure 1 [12].

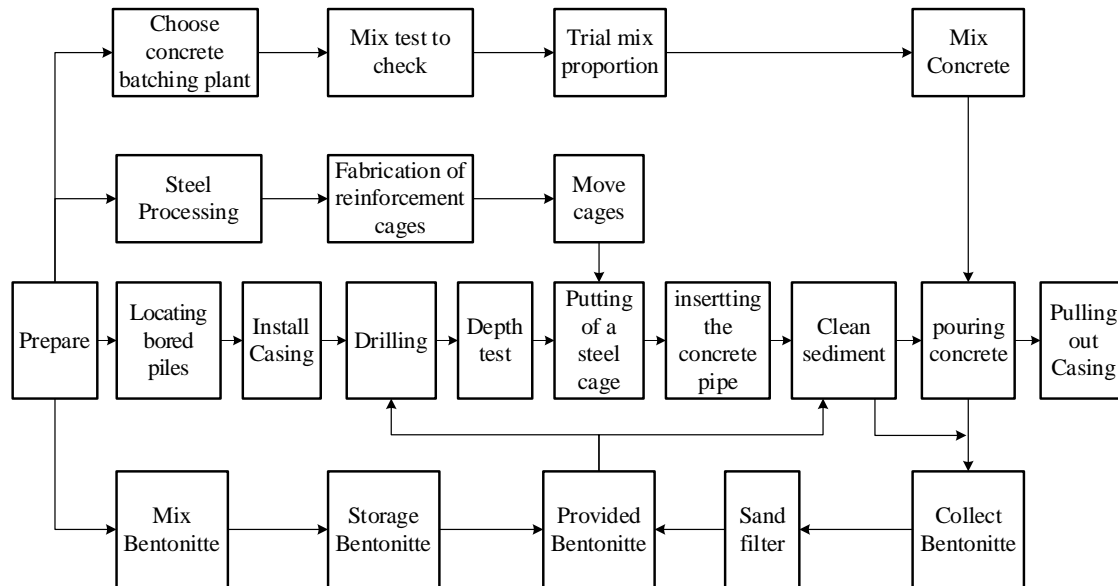


Figure 1. Construction process diagram of bored piles.

The main stages of the process are described by detailed activities as follows [12, 13]:

- *Drilling hole process:* After having the grid to locate the center of the pile, the construction process of drilling holes is divided into the following basic stages:

- (1). Install the drill bucket;
- (2). Adjust the center of the drill bucket to coincide with the center of the pile;
- (3). Drilling to the bottom of the Casing;
- (4). Installation Casing, acceptance of Casing;
- (5). Remove the drill bucket;
- (6). Install the main drill bucket and start the drilling cycle with the following small steps:
 - Swing the bucket to the drilling position;
 - Lower the bucket to the bottom of the hole;
 - Drilling until the bucket is full;
 - Returning the bucket to the top of the bore hole;
 - Swing to Unload Area and dump soil.

The drilling process consists of many cycles, each cycle takes the above steps until drilling to bearing layer (the design soil layer) at the pile tip.

(7). Check the depth of the hole when drilling up to the cobble layer to determine the level of the cobble layer.

(8). Continue drilling into the cobble layer until the design requirements are met and check the depth of the hole to determine the bottom level of the hole.

(9). Remove the main drill bucket, install the dredging bucket, dredge the sediment and check the hole.

During the construction process of drilling holes, Bentonite is provided with full and quality assurance.

- *Installation of steel Cage:* The bored pile reinforcement is divided into 11.7 m length steel cages that have been prefabricated. The steel cage segments are hoisted, lowering and connecting. Then proceed with welding to prevent upward floating during concreting.

- *The process of lowering the pour pipe, cleaning the hole and pouring concrete:* Concrete pouring pipes with a diameter of 25 cm to 30 cm are combined by 1 m, 2 m or 3 m pipes depending on the depth of pile drilling. The pour pipe is lowered from a level of 20-30 cm above the bottom of the pit. A blower pump is installed and setup a Bentonite solution supply line to clean the borehole after lowering the pour pipe. Cleaning process is carried out by blowing compressed air with a pressure of 7 kg/cm^2 for about 40 minutes. The washing pipe is lowered to a depth equal to 80% of the pile depth to blow off the sediment. The process of installing the concrete pipe is consequently divided into two stages. The first stage is to install the pouring pipe with a length equal to 80% of the pile length, then install the washing pump inside the pouring pipe and flushing dredged muck from bottom of pile. After cleaning, removing the pump and proceed to install the remaining pouring pipes to pour concrete. The process of pouring concrete piles takes place continuously with the concrete pouring speed of $0.5 \text{ m}^3/\text{min}$. The arrived concrete truck is checked for slump. During the pouring process, measuring and checking the level of the concrete mortar to ensure that the concrete pipe is always submerged in the mortar for about 1.5 m. Make a cut of the pour pipe so that the concrete does not clog during the pouring process. After completion of pouring concrete pile, the Casing pipe is removed within 15 minutes and the hole is filled with sand.

4. Building a model to simulate the construction process of bored piles

4.1. Description of the case study

The case study is the Central Hospital of Dermatology project, Hanoi [4]. The 800 mm bored pile is used and the designed depth is 49.4 m. The soil types and depths of each soil layers are shown in Table 2.

Table 2. The soil types and depth

No.	Soil layer	Top elevation (m)	Bottom elevation (m)	Soil depth (m)
1	The fill land	+0.0	-1.5	1.5
2	Flexible hard clay	-1.5	-6.0	4.5
3	Flexible soft clay	-6.0	-15.9	9.9
4	Medium grain dense sand	-15.9	-25.9	10
5	Flexible hard clay	-25.9	-27.3	1.4
6	Flowing flexible clay	-27.3	-30.3	3
7	Medium grain dense sand	-30.3	-33.3	3
8	Flexible hard clay	-33.3	-36.9	3.6
9	Flexible soft clay	-36.9	-38.9	2
10	Medium dense sand	-38.9	-40.0	1.1
11	Flexible soft clay	-40.0	-44.0	4
12	Small grain, medium dense sand	-44.0	-47.6	3.6
13	Cobble-gravel, medium dense sand	-47.6	-49.4	1.8

4.2. Collecting input data for simulation

a) Resources for simulation model

The resource variables used in the model are described in Table 3, which shows the variable symbols on the model and their actual values in the queues.

Table 3. Variables on resources used in the model

No.	Variable model	Symbol	Unit	Quantity
1	Boring drill machine	-	machine	1
2	Self propelled crane	-	machine	1
3	Weld machine	-	machine	1
4	Pump, blow wash	-	machine	1
5	Drilling bucket D1000	-	bucket	1
6	Drilling bucket D800	-	bucket	1
7	Dredging bucket	-	bucket	1
8	Pile steel cage	-	cage	4
9	Casing pile	-	pile	1
10	Concrete pouring pipe	-	pile	17
11	Construction service workers	-	man	5
12	Hole drill	nHK	hole	1

No.	Variable model	Symbol	Unit	Quantity
13	Depth of fill land	h1	m	1.5
14	Depth of flexible hard clay, layer 1	h2	m	4.5
15	Depth of flexible soft clay	h3	m	15.9
16	Depth of flexible hard clay, layer 2	h4	m	5
17	Depth of medium grain dense sand	h5	m	13
18	Depth of medium dense sand	h6	m	1.1
19	Depth of flowing flexible clay	h7	m	3
20	Depth of small grain, medium dense sand	h8	m	3.6
21	Depth of cobble-gravel, medium dense sand	h9	m	1.8
22	Concrete volume one pile	Vbt	m ³	22.8

b) Time of activities in the model

The execution time of each activity during bored pile construction is based on the data base in [4], where the duration of the activities has been tested and described by normally distributed functions. The main stages of the bored pile construction process (from the preparation of drilling to create the pile hole to the completion of the pile construction) are divided into detailed activities [4] as detailed below and the duration of the detailed operation is denoted as in parentheses.

- Prepare the first drill: Install the drill bucket D1000 (t1) → Adjust the bucket center to coincide with the pile center (t3).

- Lower the Casing pipe: Lower the casing pipe (t4) → Adjust and check the casing (t5) → Fill the soil around the casing (t6).

- Prepare the second drill: Remove the drill bucket D1000 (t2) → Install the drill bucket D800 (t1).

- Drilling to create holes in phase 1, drilling primers to lower the Casing pipe: (+0.00 to -6.00 m):

- + Drilling in the fill land: Lower the bucket (t18); Drill until the bucket is full (t27) → Returning the bucket to the top of the hole (t7) → Swing to unload area (t16) → Dump soil (t35) → Swing the bucket to the drilling position (t17).

- + Drilling in flexible hard clay, layer 1: Similar activity to drilling in fill land, with the times (t19) → (t28) → (t8) → (t16) → (t36) → (t17).

- Drilling to create holes in phase 2, from the bottom elevation of the Casing to the design elevation (-6.00 to -49.4 m), the drilling operations are described as similar to the phase 1 hole drilling with specific geological layers. The corresponding time intervals are:

- + Drilling in flexible soft clay: (t20) → (t29) → (t9) → (t16) → (t37) → (t17).
- + Drilling in flexible hard clay, layer 2: (t21) → (t28) → (t10) → (t16) → (t36) → (t17).
- + Drilling in medium grain dense sand: (t22) → (t30) → (t11) → (t16) → (t38) → (t17).
- + Drilling in medium dense sand: (t23) → (t31) → (t12) → (t16) → (t39) → (t17).
- + Drilling in flowing flexible clay: (t24) → (t32) → (t13) → (t16) → (t40) → (t17).
- + Drilling in small grain, medium dense sand: (t25) → (t33) → (t14) → (t16) → (t41) → (t17).
- + Drilling in cobble-gravel: (t26) → (t34) → (t15) → (t16) → (t42) → (t17).
- Wait for dredging: Measure hole depth (t43) → Wait for dredging (t44).
- Dredging: Remove the drill bucket D800 (t2) → Installing the dredging bucket (t45) → Dredge (t46).
- Acceptance test hole: Acceptance test hole (t47) → Remove dredging bucket (t48).
- Prepare the welding machine: Move weld machine (t49) → Install weld machine (t50).
- Lower the steel pile cage: Crane the steel cage into the borehole (t51) → Connect steel cage and ultrasonic pipe (t52) → Weld to position the steel cage (t53).
- Installing the concrete pouring pipe: Crane the working platform into position and adjust (t54) → Crane pouring pipe into the hole (t55) → Connect the concrete pouring pipe (t56).
- Blow, washing hole: Installing washing pile (t57) → Crane pump, installing pump, install supply and return Bentonite pipe (t58) → Blow-out (t59) → Remove pump and washing pile (t60).
- Pouring concrete: Install the concrete pouring hopper (t61) → Wait for the concrete truck to return to the construction site (t62) → Measure the slump (t63) → Pour the first batch of concrete with the height of the mortar column 3.5 m (t64) → Pouring concrete for the second phase with the height of mortar column 3 m (t65) → Pouring concrete for the third phase with a height of mortar column of 0.9 m (t66) → Measuring the height of concrete (t67) → Cutting the concrete pouring pipe (t68).
- Remove the Casing: Wait to remove the Casing (t69) → Remove the Casing (t70).

Consequently, the duration of each activity in the simulation model is determined. In this paper, the special capacity of determining the duration of an activity in the EZStrobe simulation are used. Activities that involve many small or repeated steps such as those listed above, when the duration distributions of each small activity are known, their duration is determined by the sum of the durations of the component activities [14]. The duration of activities in the simulation model is determined and shown in Table 4.

Table 4. Probability distribution of duration of bored pile construction activities in EZStrobe simulation model

No.	Operation model	Variable symbol	Duration (seconds)
1	Prepare boring drill machine 1	tCBMK1	t_1+t_3
2	Drilling in the fill land (3 times)	tKhoan1	$\sum_{i=1}^3 (t_{18}^i + t_{27}^i + t_7^i + t_{16}^i + t_{35}^i + t_{17}^i)$
3	Drilling in flexible hard clay layer 1 (9 times)	tKhoan2	$\sum_{i=1}^9 (t_{19}^i + t_{28}^i + t_8^i + t_{16}^i + t_{36}^i + t_{17}^i)$
4	Lower casing	tHaCasing	$t_4+t_5+t_6$
5	Prepare boring drill machine 2	tCBMK2	t_1+t_2
6	Drilling in flexible soft clay (26 times)	tKhoan3	$\sum_{i=1}^{26} (t_{20}^i + t_{30}^i + t_{10}^i + t_{16}^i + t_{38}^i + t_{17}^i)$
7	Drilling in flexible hard clay layer 2 (8 times)	tKhoan4	$\sum_{i=1}^8 (t_{21}^i + t_{28}^i + t_{10}^i + t_{16}^i + t_{36}^i + t_{17}^i)$
8	Drilling in medium grain dense sand (23 times)	tKhoan5	$\sum_{i=1}^{23} (t_{22}^i + t_{30}^i + t_{11}^i + t_{16}^i + t_{38}^i + t_{17}^i)$
9	Drilling in medium dense sand (2 times)	tKhoan6	$\sum_{i=1}^2 (t_{23}^i + t_{31}^i + t_{12}^i + t_{16}^i + t_{39}^i + t_{17}^i)$
10	Drilling in flowing flexible clay (5 times)	tKhoan7	$\sum_{i=1}^5 (t_{24}^i + t_{32}^i + t_{13}^i + t_{16}^i + t_{40}^i + t_{17}^i)$
11	Drilling in small grain, medium dense sand (8 times)	tKhoan8	$\sum_{i=1}^8 (t_{25}^i + t_{33}^i + t_{14}^i + t_{16}^i + t_{41}^i + t_{17}^i)$
12	Drilling in cobble-gravel (3 times)	tKhoan9	$\sum_{i=1}^3 (t_{26}^i + t_{34}^i + t_{15}^i + t_{16}^i + t_{42}^i + t_{17}^i)$
13	Wait for dredging	tChoVL	$t_{43}+t_{44}$
14	Dredging	tVLHK	$t_2+t_{45}+t_{46}$
15	Acceptance test bore hole	tNTHK	$t_{47}+t_{48}$
16	Prepare the welding machine	tCBMH	$t_{49}+t_{50}$
17	Lower the steel pile cage	tHaLT	$\sum_{i=1}^4 t_{51}^i + \sum_{i=1}^3 t_{52}^i + t_{53}$
18	Installing the concrete pouring pipe	tLapODBT	$t_{54} + \sum_{i=1}^{17} t_{55}^i + \sum_{i=1}^{16} t_{56}^i$
19	Blow, washing hole	tTRHK	$t_{57}+t_{58}+t_{59}+t_{60}$

In this study, the situation where the drilling machine had a problem and needed to be repaired during the drilling process was considered. The probability of failure (probability of failure) and the probability of normal working when using a drilling machine are determined by the Fork element and the branch links created from it. A Fork is a probabilistic routing element. It typically follows an activity but can also follow another Fork. When a preceding activity instance finishes, the Fork chooses one of its successors can be an activity, a queue, or another Fork. The relative likelihood that a particular successor will be chosen on the "P" property of the Branch Link that emanates from the Fork towards the successor.

Looking at picture 2 can see the operation repair boring drill machine (if a problem occurs) is inserted into each drill and is marked from 1' to 9'. During the drilling process, the probability that the drill has a problem that requires repair at each drilling session is assumed to be 5%. Thus, with the ability of the simulation program EZStrobe can consider situations occurring during the drilling process to assess construction time in a more realistic way. This is also a new point compared to the model of previous studies mentioned in section 1.

5. Simulation results and evaluation

The model is checked for errors by running the animated model. The results show that the model has worked correctly and can be used for simulation. Running the model with 10,000 trials, the results obtained for the construction time of a bored pile with the parameters are shown in Table 5. The table also shows the time forecast construction a pile results in the published research [4] for comparison.

Table 5. Construction time of a bored pile

	The average value	Deviation	Max value	Min value
Discrete event simulation:				
- Drilling machine breakdown	570.05	4.18	584.65	553.18
- Drilling machine no problem	581.36	18.45	699.53	553.67
Monte Carlo simulation [4]	554.36	6.80		

The above results show that: Bored pile construction time is a random quantity. With the same case study, when comparing the results of predicting the construction time of a bored pile by the two methods, we find that the simulation is discrete when considering the case of the drilling machine having a problem requiring repair, the pile construction time is longer. In case the drill is conducted without problems, the construction time is the smallest and is very close to the analysis results from the Monte

Carlo simulation. From there, it shows that the construction time prediction results by the discrete event simulation method are reliable and predict the time to complete the construction of a bored pile. The construction time of a bored pile d800 in this case study ranged from 553.67 minutes to 699.53 minutes.

6. Conclusions

The study has built a simulation model reflecting the actual construction process of a bored pile. In this model, the construction procedures according to the required technological processes, as well as the intention to organize the use of resources (such as using labor, equipment) are included, so it is very close to the actual implementation. The duration of the activities in the simulation model is determined through the probability distribution function. Therefore, the simulation results of the construction time of a bored pile are highly predictive assisting managers to identify and base that time to detailed construction schedule for the entire project.

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DỰ BÁO TIẾN ĐỘ THI CÔNG CỌC KHOAN NHỒI BẰNG CÔNG CỤ MÔ PHỎNG SỰ KIỆN RỜI RẠC

Nguyễn Quang Nam, Bùi Đức Năng

Tóm tắt: Bài báo trình bày việc nghiên cứu sử dụng chương trình EZStrobe để mô phỏng quá trình thi công một cọc khoan nhồi. Một mô hình mô phỏng bao gồm các hoạt động chi tiết của quá trình thi công cọc khoan nhồi đã được lập để phân tích và dự báo thời gian thi công một cọc với thời gian các công việc là ngẫu nhiên. Mô hình và kết quả mô phỏng cũng được so sánh đánh giá với một nghiên cứu đã công bố, cho thấy sự phù hợp và hiệu quả cao của mô hình đã lập.

Từ khóa: Mô phỏng sự kiện rời rạc; EZStrobe; thi công cọc khoan nhồi; tiến độ thi công.

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