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FACTORS ACOUNTING FOR ACTIVITY-TIME AND PROJECT-TIME UNCERTAINITIES IN BORED PILES CONSTRUCTION PLANNING: CASE STUDY ON A BUIDLING PROJECT IN HONG KONG

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ABSTRACT: Planning the construction for a system of bored piles in building foundation engineering is (1) to predict the time duration required to complete all the bored piles with due consideration of relevant engineering factors and site constraints; then (2) to predict the total project time generally by aggregating the predicted working duration for construction of each bored pile. The duration for construction of an individual bored pile results from analyzing various working sequences and different activity duration (such as predrilling, excavation, steelfixing, air-lifting, and concreting, etc.), which is informed by experiences and site records of previous projects. However, determining the project duration for constructing many bored piles on one site is much more complicated than adding up the time duration for individual piles. In practice, project schedules are often found to be unrealistic and incorrect during the construction stage. This is because construction planning is not based on a exhaustive and comprehensive evaluation of site factors, such as site layout plan, site constraints, quality control, environmental control, safety control and logical relationships between different trades. In this paper, we identify those factors based on a foundation engineering site in Hong Kong with ninety-seven bored piles and address their effects on uncertainties in activity time and project time.

Keywords: Site Preparation, Bored Pile Construction, Scheduling, Site Layout Planning

[12)] The yellow sheet that indicates process progression ratios is configured so that users would enter or revise the values and based on the entries the values on the green sheets are automatically calculated.

1. INTRODUCTION

Generally, bored pile construction features tight schedule, limited site area, various working sequences, different geological conditions, large equipment transportation, large fabrication yard for steel works and intensive labor input. Schedule prediction for bored pile construction is not a simple task during the tendering stage as it involves comprehensive site layout planning and logistical planning for equipment, materials and manpower.

The layout of temporary facilities for a construction project greatly impacts project performances as demonstrated in many previous studies (e.g. [1]). In previous research projects, researchers have focused on the significance of the site layout planning. However, the research methodologies of the previous related efforts were mainly based on site interviews, telephone interviews, questionnaires, and literature review (such as in [2],[3],[4].) Nonetheless, the research would have been much insightful and comprehensive if the research were based on site daily and full-time site project participation.

When scheduling the construction for many bored piles, site logistics is a dominant factor to be considered. Therefore, it is crucial to assess the site layout planning in order to arrive at a more realistic project schedule.

Poor site layout planning for bored pile construction will result in significant time and cost implications; examples are listed below:

- Inadequate storage areas for equipment and casings, prevent their timely deliveries to start pile construction;
- Inadequate operation zones inhibit the realization of expected production rates of bored pile construction;
- Poor storage area planning makes it difficult to locate suitable plants and materials, such as selection and delivery of steel casings of correct sizes;
- Poor access roads planning results in lengthy transportation and lifting paths by crawler cranes;
- Inefficiency in site layout planning undermines efficiency and morale of the workforce;
- Poor site planning leads to incorrect selection of construction plants and equipment such as crawler cranes, reverse circulation drills (RCD), grabs, etc.

A good site layout planning is vital to enhancing the overall efficiency of construction operations and to reducing material handling and relocation costs. More importantly, it helps identify construction time periods with potential spatial conflicts due to limited space so that they can be avoided in early project plans. ([5]).

2. FORMULATING CONSTRUCTION SCHEDULE FOR A SINGLE BORED PILE

2.1 Predicting Working Duration for Construction of a Single Bored Pile

The total working duration for constructing a bored pile can be predicted by aggregating the working duration of different activities based on historical data from some previous projects with similar site conditions.

Table 1 below shows records of averaged working duration of different non-excavation activities on bored pile construction, which were sourced from a public hospital development project in Hong Kong.

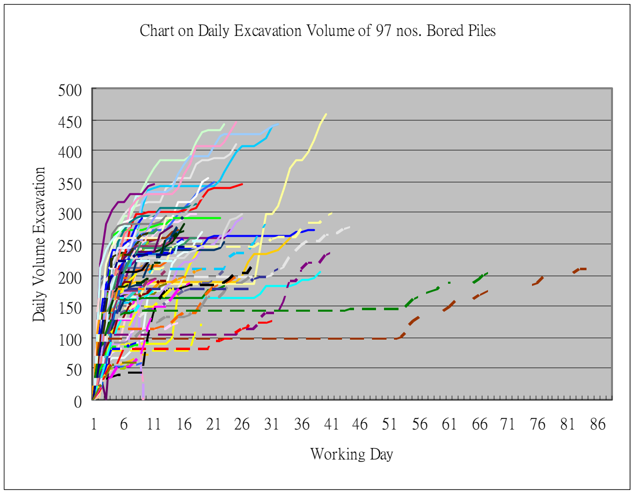
Table 1. Average Working Duration for Construction Activities of a Bored Pile

Activity	***Working Duration***
setting out, setup oscillator, casing	1 day
boulder broken by free falling grab/chisel; broken boulder /soil stratum excavated by grab	0.5day
no activity due to lack of RCD equipment	within 1month
install RCD package: mounting RCD, install drill bit and rock drilling, sludge tank, water pipe and generator	1 day
install bellout tool: rock drilling, disassembly drill bit and install bellout bit	1 day
dismount RCD tools: bellout formation, disassembly bellout bit and dismount RCD	1 day
grout plug to solve soil seepage at the bottom of casing *(if necessary)*	1 day
install tremie pipe and 1st air lifting	1day - 3day
steel cage installation: install steel cage by crawler crane, welding connection of sonic pipe and reservation pipe, fixing laps between steel cages	1 day
install tremie pipe and 2nd air lifting	1 day - 2 day
concreting and casing Extraction	1 day
remedial work of bored pile such as poor interface test, poor sonic test and poor full core test	Within 3 months

However, times for excavation activities in various soil strata and rock strata are subject to various underground site conditions such as boulder obstructions, underground utility obstructions and different underground soil properties in different soil strata. This will lead to broad fluctuation of the production rates and the time duration on excavation activities.

The fluctuation of accumulative excavation volume over working days for 97 bored piles on the case project can be observed from Figure 1. Generally, the work sequence of bored pile excavation can be classified into four categories as given in Figure 2.

Figure 1. Volume Excavated over Time Chart for 97 nos. Bored Piles on a Hospital Development Project.



Moreover, with regard to the soil excavation rate, the excavation rate changes with various strengths and consistencies of soil and rock at different soil strata. The soil property can be represented by the SPT value. Note, using the SPT index to classify the strength and consistency of underground soil is a common site investigation technique. Table 2 shows different soil strata with corresponding SPT values.

Table 2. The Soil Strata with correspondent SPT Index.

SOIL STRATA		SPT Index (N)
Fill	-	**9-31**
Marine Deposits	Clay	**4-60**
	Sand	
Alluvium	Clay	**12-32**
	Sand	

In the following Table 3, the likely ranges for volume excavation rates given the four types of soil strata with correspondent SPT index are summarized based on daily excavation records and site investigation reports obtained from the case study project. Based on data of previous projects, the excavation duration on each bored pile can also be predicted during the tender stage.

3. PLANNING AND DESIGN OF A SITE LAYOUT PLAN

3.1 Planning a Site Layout

For construction of a large number of bored piles, simply summing up the working duration of each bored pile, which is predicted by the above methodology, is still inadequate and inaccurate.

Table 3. The Likely Ranges of the Volume Excavation Rate for Four Types of Soil Stratum with Correspondent SPT Index

SOIL STRATA	SPT INDEX	DAILY VOLUME EXCAVATION RATE (m^3/d)
Excavate fill, MD(sand), MD(clay), Alluvium (clay), Alluvium(sand) by grabbing method	7-20	37.6 -41
Excavate GRADE V rock by grabbing method	30-80	16- 22
Excavate GRADE V/VI/III rock by grabbing method and reverse circulation drill method	170-200	3.9- 7
Excavate GRADE III rock by reverse circulation drill method	-	4

It is noteworthy that the above formulation of a single bored-pile construction schedule is based on following idealized assumptions. After evaluation of those factors, proper adjustments should be made to the predicted duration:

- The activities are carried out by appropriate personnel with suitable levels of qualifications and experiences
- Adequate site supervision and quality control
- Adequate environmental and safety control
- Good site layout plan for smooth site logistics
- Timely delivery of materials and fabricated items (semi-products)
- Reasonable site constraints
- Others

Among these afore-mentioned assumptions, site layout plan is the most critical factor with significant time and cost implications. Site layout (planning) considerably affects the efficiencies of construction operations and logistics on site [3],[4].

In the construction industry, the task of site layout planning consists of identifying the different facilities needed to support construction operations, determining their sizes and shapes, and positioning them within the boundaries of the available on-site areas. Examples of these facilities include offices and tool trailers, parking lots, warehouses, batch plants, maintenance areas, fabrication yards or buildings, staging areas, and lay-down areas. [6].

A site layout designed for bored pile projects should fulfill the operational requirements that enable:

- good setting out operation
- good predrilling operation
- proper storage areas for predrilling
- good pedestrian/vehicle in/out access routes
- good access route design for concrete trucks, tower cranes etc., including suitable widths of the access routes, safe minimum turning radius of access roads for vehicles such as concrete trucks and tower cranes
- the minimum working area for each bored pile construction including water tank space, sludge accumulation space, truck and concreting car parking area, crawler crane and worker working space

Excavation Work Sequence 1: for soil and rock stratum

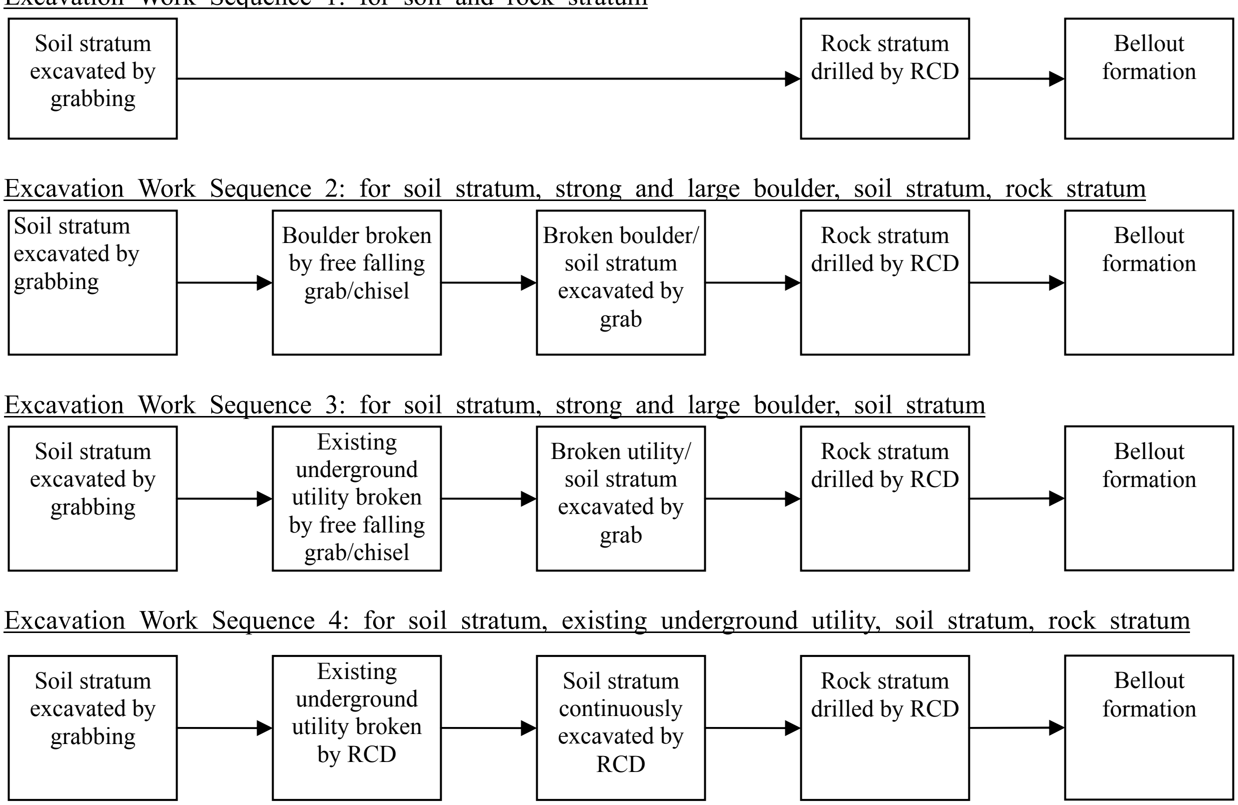


Figure 2. Work sequence of bored pile excavation

- proper sedimentation tanks setup
- proper unused large equipment storage space: tower cranes, reverse circulation drills, grabs, chisels, bell-out bits, drill bits and casings of different diameter
- proper steel yard space areas for steel bar storage and steel cage fabrication
- proper temporary sludge storage planning during excavation by grab and RCD
- fulfill specified minimum spacing of pile construction such as minimum bored pile circumferences in accordance with the contractual requirements and specifications
- suiting for tower crane jib working radius
- proper site office setup
- emergency assembly area
- proper staff entrance
- chemical waste storage area
- proper worker resting area
- proper vehicle wheel washing facility at site entrance
- proper guardhouse
- proper safety and environment measures for bored pile construction

The site layout should be planned to satisfy the above mentioned requirements and thus provide just-in-time logistics for bored pile construction. If the site layout planning does not fully satisfy these requirements, some uncertainty factors should be applied to extend the predicted working duration and account for the inadequacy in the site layout planning.

3.2 Preparing and Evaluating a Site Layout Plan

To evaluate the site layout planning evaluated, the equation given below is generalized and can be followed as guidelines:

Site area within boundary
= working area for bored pile construction + non-working area + area of pedestrian/vehicle in/out access route + working area for each bored pile construction + unused large equipment storage space + steel yard space area + water circulation system + worker working space + others factors relating to the site area use

An example of site layout plan is demonstrated in the following Figure 3.

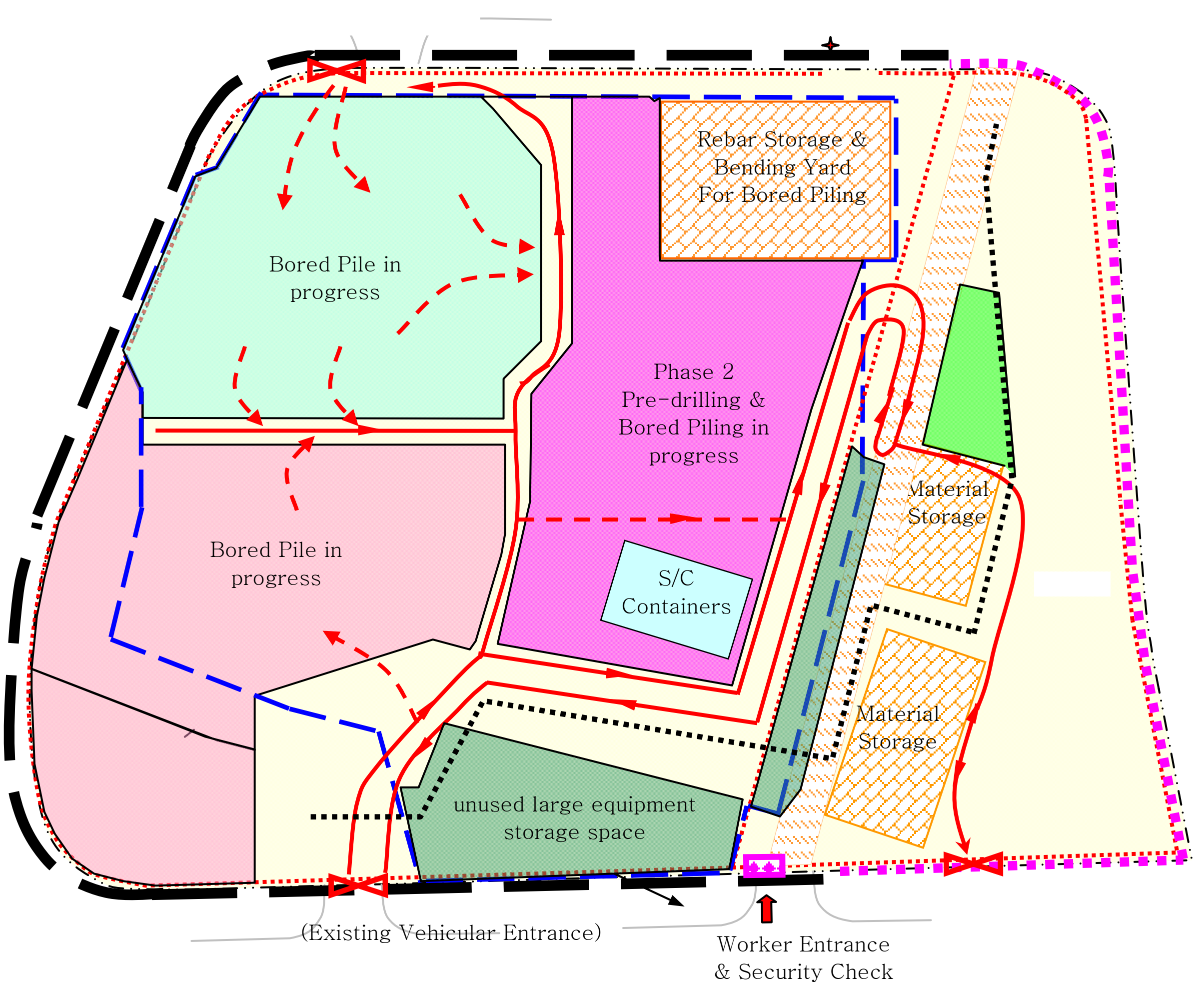


Figure 3. Site layout plan

where

"*site area within boundary*" is the total site area within the site boundary lines;

"*non-working area*" is the site area which can not be used for the construction use;

"*pedestrian/vehicle in/out access route*" can be one way or two way depending on the transportation capacity. The transportation vehicles include crawler cranes, crane lorries and etc.

"*working area for bored pile construction at a time*" holds the generator, water tank, submersible pump, air-compressor, water tank, desilting tank, crane lorry, submersible pump, drill bit, grab, chisel, bellout bit

"*unused large equipment storage space*" holds 100 MT crawler crane, 80 MT crawler crane hydraulic crane, semi-auto welding set, oscillator, reverse circulation drill, grab, chisel, drill bit, bellout bit, power pack, RCD, rotary drilling rig, water pump, backhoe with hydraulic breaker.

"*steel yard space area*" holds steel cage, steel bending machine;

"*water circulation system planning*" is the area including water tanks for the water treatment system

"*worker working space*" accommodates ganger (foreman), rigger, fitter, welder, electrician, skilled laborer, plant operator, crane lorry operator, RCD operator, driver, survey ganger, chainman, driller, excavator, steel fixer, carpenter, metal worker, plumber, concretor, backhoe operator, lorry operator, site toilets, site car park area, site office container and worker container.

3.3 Estimation on the Number of Bored Piles to be Constructed Simultaneously within a Limited Site Area

Resource management includes the allocation of equipments, tools, crawler cranes, reverse circulation drill (RCD) and etc. Input of manpower and delivery of materials on a project are also critical issues to be investigated. We need to predict how many bored piles, in maximum, can be constructed simultaneously (or concurrently) within the limited site area for a new project so that the maximum site progress rate can be achieved. Either overcrowding or underuse of space can have adverse effects on the operation, transportation and efficiency of plants/equipment, efficiency of manpower and also delivery of materials. As a result, this potentially undermines site productivity and the production rates of bored pile construction.

By applying the proposed equation, we can predict how many bored piles in maximum can be constructed simultaneously in two steps and then perform resources planning accordingly.

Step 1:

"working area for bored pile construction at a time" = The site area within boundary – non-working area – area of pedestrian/vehicle in/out access route (based on one way or two way) - unused large equipment storage space - steel yard space area (based on maximum daily production rate) - water circulation system planning (based on maximum daily production rate) - worker working space

Step 2:

Roughly estimating how many bored pile can be installed simultaneously = total working area for bored pile construction at a time / working area for each bored pile construction

Undoubtedly, the construction schedule cannot be realistic without careful consideration of a workable site layout plan. The site layout plan should be also planned so to avoid safety hazards and prevent accidents. The site layout needs to be checked to avoid any minor accidents affecting site logistics while providing proper logistical efficiency to achieve a target production rate. The plants logistics as to crawler crane operations and RCD operations etc should be checked as the operational cost of plants and equipment for bored pile construction is high.

Other key logistics should also be checked are listed below as those aspects of site logistics have more marked time and cost effects for bored pile construction:

- soil grabbing operation
- steel fixing logistics flow
- concrete trunk logistics during concreting
- water treatment operation

Any bottleneck found or any slow process observed during the construction stage should be resolved to attain high productivity for bored piles construction projects.

4. CONCLUSIONS

When planning a bored pile construction project, the development of a schedule for constructing each single bored pile is a first step, which can be informed by the historical data from previous projects with similar site conditions. To further formulate a schedule for the entire project consisting of many bored piles to be constructed simultaneously, evaluation of site layout plan and site logistics is a second step to be further considered. Thirdly, the estimation on how many bored piles can be constructed simultaneously within a limited site area should be evaluated with care and with regard to both productivity and safety. Those steps should be well executed in order to prepare effective and realistic schedules for bored pile construction projects.

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