Optimizing Construction Sequences for Secant Pile Walls

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Keywords: Pile Sequence, Optimization, Genetic Algorithm (GA).

Abstract: Secant pile walls are crucial in the construction of fossil-fuel power plants for water exclusion purposes. The construction time is the most critical factor that influences the entire construction project. Thus, shortening the time needed for building secant pile walls requires further investigation. Secant pile walls are not required to be constructed in any particular order; typically, site engineers assign construction crews to first build several primary bored piles, and then build secondary bored piles. However, building secant pile walls in this sequence generally requires the primary bored piles to be excessively cured and hardened. The construction of secondary bored piles in this manner thus results in construction difficulties, wasted construction time, and poor construction quality. To address this practical problem, this study adopted a genetic algorithm to investigate the optimal number of primary bored piles, the curing time, and the number of daily working hours for the construction crew. In addition, the relationship between the curing time for the primary bored piles and the construction time for the secondary bored piles was investigated by using a case study, to ensure the overall research results corresponded to practical operation. The findings of this study can facilitate the saving of construction time in the future construction of secant pile walls, enabling the whole construction project to be completed successfully and improving public welfare.

1 INTRODUCTION

Construction time matters for activities. The building of a secant pile wall requires the rental of equipment and finding the optimal sequence to minimize the construction time is one way to save construction costs. Secant pile walls are necessary in the fossil-fuel power plants construction project for water exclusion purposes. This research scope is limited to finding the optimal construction sequence of the work activities needed to build a secant pile wall, which include grading, positioning of the site, positioning of the equipment, driving the first 8-meter casing into the ground, boring and cutting (0 – 6 m),boring and cutting (6 – 12 m), driving the second 8-meter casing into the ground, boring and cutting (12 – 17 m), measuring the center of the pile, measuring the altitude, ultrasound measurements, placing of the steel cage, removal of bottom soil, application of Bentonite slurry, pouring the concrete, and removing the casing. Activities other than these 16 are not included. Such other activities could include, for example, time for equipment preparation, adjusting, relocating, and idle time. Human effects such as the how the operator's skill level and physical condition contribute to operations are also excluded. In this study we try to develop an effective and efficient model with Genetic Algorithm to minimize the construction time. The algorithm is applied to a case study to obtain the optimal sequences for both primary and secondary bored piles for a secant pile wall. Some factors affect the total construction time are discussed with sensitivity analysis, like the cement setting time of the primary bored piles, the quantity of the primary bored piles be done in a round and the working-hour/ per day of the crew. The optimal sequences for both primary and secondary bored piles are also determined.

Previous studies on optimal solutions for repetitive project scheduling have shown that when problems are complex and large-scale, the efficiency of analytical methods is considerably reduced; determining optimal solutions may thus be hindered by the excessively large amount of calculations and time required (Al-Harbi et al., 1996). In the problem of nonlinear optimization, the application of analytical methods is typically difficult if not impossible. A genetic algorithm (GA) is a direct stochastic search technique that has been applied widely in recent years. GA is used to determine

Huang R., Chen P. and Chen J..
Optimizing Construction Sequences for Secant Pile Walls.
DOI: 10.5220/0005553201450150
In *Proceedings of the 10th International Conference on Software Engineering and Applications* (ICSOFT-EA-2015), pages 145-150
ISBN: 978-989-758-114-4

optimal solutions based on the mechanism of natural selection and the principle of survival-of-the-fittest. GA generally yields satisfactory outcomes in a relatively short amount of time. Therefore, this study used the GA concept as basis to develop an algorithm for optimizing the scheduling of a full-casing secant pile wall.

2 PILE SEQUENCE OPTIMIZATION MODEL

2.1 Model Assumption

To reduce the number of variables, the research scope of this study was narrowed under several assumptions, as follows:

(a) Construction crew (resource) = 1

Only one construction crew was assumed to engage in the construction of the primary and secondary bored piles, which were assumed to be built at different times.

(b) Construction machinery (resource) = 1

Only one set of machines, including the boring machine and spreader, were assumed in the construction of the primary and secondary bored piles. Every pile was assumed to be constructed separately.

(c) The machinery transport time is excluded.

According to on-site observations, the time required to transport machinery is approximately 5 minutes. This was negligible and consequently, the effect of transportation time was not taken into account.

(d) The secondary bored piles were assumed to be constructed after the primary bored piles were constructed, in sequence.

The construction of primary bored piles is affected by the geology of the area in which they are being built. This study assumed that the construction sequence for primary bored piles did not influence the overall construction time; only combinations to the construction sequence for secondary bored piles were considered.

(e) The drilling time for the secondary bored piles is related to the curing time of the primary bored piles.

Secant piles are composed of concrete, and their curing time and strength is identical to that of concrete generally. Increased curing time results in increased curing strength, but the strength plateaus after a specific time period.

(f) The secondary bored piles were assumed to be constructed the day after all the primary bored piles were built.

According to on-site observations, after the construction of primary bored piles, the construction site requires cleaning before machinery for the construction of the secondary bored piles can be brought in. Thus, the construction of secondary bored piles is generally initiated on the next day after the construction of primary bored piles is completed.

(g) The construction time was limited by the working hours of the construction crew each day.

If the construction time for the j^{th} pile on the i^{th} day is T_{ij}, then when ΣT_{ij} is larger than the construction time worked each day (T_k), the time spent on construction within one day is T_{ij-1}, and that of the next day is T_{ij}.

(h) The time required to construct the secondary bored piles was based on the curing time for the preceding primary bored piles.

Because the construction of secondary bored piles involves the drilling of primary bored piles to form a watertight surface, the time required for drilling is determined by the longest time needed to cure the preceding primary bored pile. For example, the time necessary to construct the sixth secondary bored pile is based on the curing time for the fifth secondary pile.

2.2 The Relationship Between the Construction Time for Secondary Bored Piles and the Curing Time for Primary Bored Piles

Because of the properties of secant piles, the primary bored piles must be established for a certain period of time before pile driving of secondary bored piles could be initiated, thereby achieving the goal of water exclusion. However, no specifications for the length of this waiting time are available. If the time period is overly short, the concrete strength is insufficient for construction processes. If the time period is excessively long, the time spent on pile driving may be considerable, or the machinery may be damaged, resulting in extensions to the total construction time. This study reviewed records of the construction of primary and secondary bored piles to understand the functional relationship between the curing time for primary bored piles and the construction time for secondary bored piles. This relationship can then be used to estimate the construction time needed for building secondary bored piles. Based on 104 on-site records, the maximum and minimum numbers of hours for the construction of primary bored piles were obtained to facilitate subsequent simulations, in which random numbers corresponding to the uncertainties existing in actual construction process were used. The minimum number of hours required to construct primary bored piles was 2.55, and the maximum was 4.55. Subsequently, regression analysis on the 104 on-site record data was performed to determine the construction time for secondary bored piles, as shown in Equation (1) and Fig. 1.

$$T_s = -0.00009\, T_p^2 + 0.0362 T_p + 2.9181 \qquad (1)$$

where T_s denotes the construction time for the secondary bored piles, and T_p denotes the construction time for the primary bored piles (the longest construction time was selected).

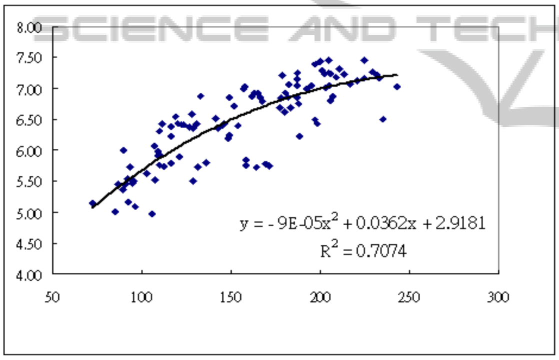

Figure 1: The estimation of the time spent on constructing secondary bored piles.

2.3 Development of the GA Model

In the GA model developed in this study, piles were numbered. Odd numbers signified primary bored piles, and even numbers signified secondary bored piles. Fig. 2 displays 5 primary bored piles and 4 secondary bored piles, or 9 units of full-casing secant piles in total. Therefore, the chromosome displayed in Fig. 2 indicates that the construction sequence for a full-casing secant pile wall is 1→3→5→7→9→2→4→6→8.

- Construction sequence for primary bored piles
- Construction sequence for secondary bored piles
- Construction sequence for a full-casing secant pile wall
- Genetic codes

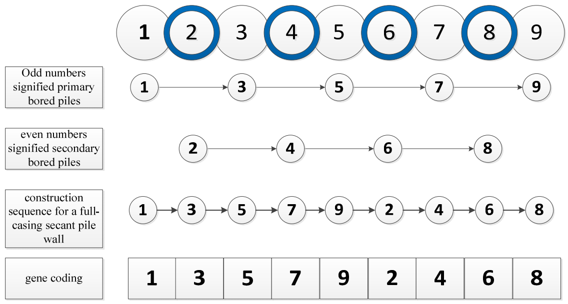

Figure 2: Construction sequence for secant piles and its genetic representations.

(a) Production of parents: After the number of primary bored piles (P) was input into the model, random numbers were used to produce a sequence (P-1) for the construction of secondary bored piles.
(b) Crossover: One-point crossover was adopted.
(c) Mutation: Single-point mutation was conducted in the model.
(d) Penalty function: The penalty function adopted in this study was different from that commonly used. Typically, a relatively extreme value is used as a penalty function. For example, the target value in this study was the total working time consumption, which was a small value. A total of 999 hours were allocated to a selected pile that is not yet ready for pile construction. Thus, the gene representative of that pile becomes an undesired choice and has a low possibility of being selected in the crossover pool. However, this study adopted a deferred penalty function. The produced parent construction sequence was 2, 4, 6, 8, and 10, and in other words, the second pile was the first to be constructed. If the curing time for the preceding first pile was shorter than the minimum curing time, the second pile can only be processed when the curing time (for the preceding first pile) equaled the minimum curing time. This waiting time was the deferred penalty. Compared with the fixed penalty, the deferred penalty allows the generation of reasonable parent solutions.
(e) Selection: After the operation of the stated four steps, the produced offspring T (the total time consumption) was obtained by calculation. This study adopted the roulette wheel selection, where the roulette area was determined as 1/T, which was used to select and retain the offspring. Additionally, an elitist selection was employed to retain superior combinations among various generations and increase the convergence speed.

3 CASE STUDY

The case study involved the Siphon well construction for circulating water in the Datan power generation project, which is located in Datan Village, Guanyin Township, Taoyuan County, Taiwan. The parameters were set as follows:

(a) The number of primary bored piles: The number of primary bored piles was denoted as N_p, which conformed to the principle of $N_p \geqq 2$ to enable the construction of secondary bored piles. The adopted numbers of primary bored piles in this study were 5, 6, 7, 8, 9, 10, 15, 20, 25, and 30, enabling the observation of variations in construction times spent on various numbers of primary bored piles.

(b) The construction time for the primary bored piles: The construction time for the primary bored piles was calculated based on the 104 on-site construction data, from which the maximum (4.55) and minimum (2.55) hours were extracted. The system-produced time for constructing primary bored piles (i.e.,T_p) was generated using random numbers; T_p ranged from 2.55 to 4.55.

(c) Number of working hours per day: The construction crew's working hours each day were denoted as T_p. Through interviews, this study categorized the working times as 8 hours (one-day work), 12 hours (one-day of work and 4 hours of overtime), 16 hours (shifts taken by two construction crews), and 24 hours (shifts taken by three construction crews, that is, the full-day construction crews).

(d) The upper limit of the function: The upper limit of the function was the condition for terminating system operation. When the waiting time exceeded the upper limit of the function, the resulting sequence was regarded as inadequate and would not be adopted subsequently. In this study, the upper limit was assumed to be 200 hours.

(e) The minimum curing time: At a construction site, the time when the construction of the secondary bored piles can be initiated (denoted as T_a) is generally based on a standard of seven days. However, construction may also be initiated after only three days of curing of primary bored piles. In other words, the standard curing time is not fixed. In this study, various lengths of curing time were employed in the analysis: 3 days (72 hours), 4 days (96 hours), 5 days (120 hours), and 7 days (168 hours).

The number of primary bored piles in a single cycle: In one cycle, the number of constructed primary bored piles may influence the time consumption in that cycle and further influence the total construction time. Accordingly, the quantities of primary bored piles in one cycle were set as 6, 7, 8, 9, 10, 15, 20, 25, and 30 for the analysis, to understand the required construction time when the amounts of curing time were 72 hours, 96 hours, 120 hours, 144 hours, and 168 hours.

3.1 Analysis of Working Hours per Day

The construction crew's working hours each day may influence the construction time of one cycle, thereby influencing the total time consumed to complete the entire construction project. Thus, the quantity of primary bored piles in one cycle was set as 5, 6, 7, 8, 9, 10, 15, 20, 25, and 30, and the curing times were set as 72 hours, 96 hours, 120 hours, 144 hours, and 168 hours, for the subsequent analysis of the working hours per day, which were 8 hours, 12 hours, 16 hours, and 24 hours.

The total amount of construction time was influenced when the daily working hours were 12 and 16 hours. However, when the number of working hours was 8 and 24 per day, the working hours did not positively influence the total construction time, because the required curing times remained the same.

3.2 Sensitivity Analysis

The analysis in the previous section focused on a single cycle. This study analysed three influencing factors (the quantity of constructed primary and secondary bored piles, the working hours per day, and the curing time for the primary bored piles) and employed the GA to optimize the construction sequence for the secondary bored piles, yielding satisfactory research outcomes. However, in practice, a given project may need to construct a fixed number of secant piles. In addition, the working hours for each day and the possible curing time are determined using cycle-number calculations employed by previous studies. For example, in a given project, 300 primary bored piles and 299 secondary bored piles must be completed. Assuming that the curing time is 72 hours, working hours are 8 hours per day, and the number of primary bored piles constructed in each cycle is 20, then the total time consumption is calculated as follows:

Table 1: Curing time, quantities of primary bored piles, working hours per day, and the total amount of construction time.

Curing time	Working hours/day	Number of piles									
		5	6	7	8	9	10	15	20	25	30
72 hr	8hr	**10450.8**	9911.0	9531.9	10144.9	9818.3	9556.5	10691.0	11258.3	10734.6	10625.5
	12 hr	7871.4	7492.5	6665.6	6519.8	5988.3	5943.9	7331.0	7298.3	8142.6	8705.5
	16 hr	7545.0	6555.0	6422.1	5628.4	5188.7	5217.0	4443.0	5138.3	5341.3	5171.1
	24 hr	7014.6	6283.0	5621.1	5114.6	4715.7	4494.9	3593.4	3142.2	**2958.4**	3075.2
96 hr	8 hr	**11904.6**	11121.5	10565.6	10144.9	9818.3	9556.5	10691.0	11258.3	10734.6	10625.5
	12 hr	9358.2	8709.0	8501.6	7432.1	7413.3	7395.6	7331.0	7658.3	8142.6	8945.5
	16 hr	9370.8	8711.0	7728.9	7439.3	6822.3	6672.9	5540.6	5498.3	5341.3	5345.5
	24 hr	8565.6	7502.0	6683.6	6061.5	5573.3	5225.1	4086.6	3521.7	3400.4	**3316.6**
120 hr	8hr	13351.8	12327.0	11595.0	11045.6	10618.3	10276.5	10691.0	11258.3	10734.6	10625.5
	12 hr	**13352.4**	12327.5	11595.0	11045.6	10618.3	10276.5	9251.0	9098.3	9294.6	9425.5
	16 hr	10842.0	9921.5	8777.1	8344.5	7633.0	7396.2	6022.2	5498.3	5341.3	5345.5
	24 hr	10461.6	9030.0	7743.0	7002.4	6613.3	6143.4	5061.0	4418.3	3980.0	**3731.1**
144 hr	8 hr	**14793.0**	13527.5	12623.6	11945.6	11418.3	10996.5	10691.0	11258.3	10734.6	10625.5
	12 hr	14793.0	13527.5	12623.6	11945.6	11418.3	10996.5	9731.0	9098.3	9294.6	9425.5
	16 hr	12300.0	11127.0	9816.4	9245.6	8437.0	8116.5	6502.2	5858.3	5341.3	5345.5
	24 hr	11910.6	10247.5	9057.4	8345.3	7635.0	7066.2	5542.2	4778.3	4268.0	**3971.1**
168 hr	8 hr	**16233.0**	14727.5	13652.1	12845.6	12218.3	11716.5	10691.0	11258.3	10734.6	10625.5
	12 hr	16233.0	14727.5	13652.1	12845.6	12218.3	11716.5	10211.0	9458.3	9294.6	9425.5
	16 hr	13746.6	12327.5	10847.6	10145.6	9237.0	8836.5	6982.2	6218.3	5629.3	5345.5
	24 hr	13353.0	11782.0	10098.0	9245.6	8655.7	7790.1	6022.2	5138.3	4556.0	**4211.1**

Total time consumption = 300 (number of piles) / 20 (number of piles/cycle) * 750.55 (hours/cycle) = 11258.3 (hours)

Accordingly, this study investigated the total time consumption under various standards of curing time.

Assuming that the curing of concrete requires 72 hours, the total construction time is 10450.8 hours at most and 2958.4 hours at least.

Assuming that the curing of concrete requires 96 hours, the total time consumption is 11904.6 hours at most and 3316.6 hours at least.

Assuming that the curing of concrete requires 120 hours,the total construction time is 13352.4 hours at most and 3731.1 hours at least.

Assuming that the curing of concrete requires 144 hours, if the number of working hours is between 8 hours and 24 hours per day, the total construction time is 14793.0 hours at most and 3971.1 hours at least.

Assuming that the curing of concrete requires 168 hours, if the number of working hours is between 8 hours and 24 hours per day, the total construction time is 16233.0 hours at most and 4211.1 hours at least.

In sum, full-day construction requires the shortest work duration. But the full-day crews may cost over the budget of the project.

4 CONCLUSIONS

1. This study established an optimal construction sequence model for secant pile walls. Regression equations corresponding to various geological conditions can be used for optimization computations. Construction teams can reference this method when determining the sequence of secant pile wall construction.
2. A case study was conducted based on on-site observations. Regression analysis was applied according to the curing times for primary bored piles and the drilling times for secondary bored piles. The regression results indicated that the two variables exhibited a strong correlation.
3. A close relationship was observed among the working hours per day, the minimum curing time, and the number of constructed piles. This study conducted simulations on these three variables in various combinations. Future studies are recommended to focus on using these three variables in simulations to determine the optimal combinations of these variables, thereby providing a reference for on-site construction teams.

ACKNOWLEDGEMENTS

This research is partially supported by the "Developing a Simulation-Based Carbon Footprint Assessment Model for Construction Operations" of Ministry of Science and Technology, Taiwan, R.O.C. under Grant no. MOST103-2221-E008-071-MY2.

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