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The Cost Comparison of High-Rise Foundation for Mixed Bored Piles and Micro Piles Proposal with Solely Bored Piles Proposal at Project Rumawip Residensi Gembira 737, Kuala Lumpur

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ABSTRACT

The paper aims to construct a framework on how value engineering of bored pile foundation design can improve the value for the high-rise building projects and studies the optimum design for bored pile foundation. One of the Rumah Mampu Milik Wilayah Persekutuan (RUMAWIP) residential high-rise projects known as Happy Residency 737 was used as a case study to compare the original and alternative foundation designs. As a result of this study, original piles foundation design of bored piles and micro piles were over designed which increased the construction cost significantly. Therefore, an alternative design of bored piles foundation was proposed to replace original bored piles and micro piles foundations. The strength capacity of bored piles was designed to the optimum while maintaining satisfactory performance. Next, the pile length was analyzed and designed to optimum level based on the soil investigation report. The alternative design of bored pile required 227 number of piles and original foundation design required 353 number of piles. Therefore, total 126 number of piles were reduced, consequently led to cost saving. Based on the Bill Quantities comparison between alternative and original foundation design, the total cost saving is RM 2,822,104.40. Pile Dynamic Load (PDA) Test and Static Load Test (SLT) are used to determine the performance of bored piles with Factor of Safety (FOS) of 2.0. In fact, 87.5% of PDA test results and 100% of SLT test results shown passed. In conclusion, value engineering of new bored pile design is technically sound, save cost and time.

Keywords:
Bored pile foundation design, High-rise building, Pile load testing, Value Engineering, Factor of safety

INTRODUCTION

According to Department of Statistic Malaysia (DOSM), urban population is expected to increase to 76.6% in 2020 and 88% in 2050 which led to widespread urbanization of cities, especially in Kuala Lumpur, the capital city of Malaysia. The increasing urbanization in recent decades has led to an increase in the construction of high-rise buildings worldwide, particularly in emerging economies. Husin et al. (2021) highlighted that cities can no longer afford horizontal development strategies due to limited land availability and high cost. The increasing urban population could drive developers to opt for building high-rise building projects.

High-rise buildings are designed to safely support the great load applied to it. Therefore, to ensure the buildings are safe and stable, the foundation system must satisfy both the loads bearing capacity and settlement criteria. High-rise buildings are usually built on piled foundation subject to a combination of vertical, horizontal, and overturning forces. According to Shoib et al. (2017), bored piles are commonly used as deep foundations to support very heavily loading structures due to its great advantage of low vibration, low noise, and flexibility of diameter sizes. Bored pile foundation widely used in high-rise buildings often arrange identical piles in pile cap with constant spacing between them. Several value engineering works and design strategies for pile foundations are presented to achieve an economic, efficient, and safe design.

The process of value engineering (VE) pile foundation design and verification is described, then the application of these principles, data & results are illustrated via the 46 stories RUMAWIP high-rise building project. The objectives of this research are: (1) To determine an alternative design concept of bored piles; (2) To determine cost efficient alternative for bored piles foundation design; (3) To determine the safety factor for alternative bored piles foundation design.

LITERATURE REVIEW

According to Rane (2016), value engineering is a successful technique tested in many countries which could reduce the construction cost and add value to the project. Countless elite academicians with high standard of research interests and engineers with pragmatic design approaches have applied the principle of value engineering (VE) in high rise project especially in the foundation design. These include optimization design of long pile in deep soft soil foundation, pile group design optimization, piled raft foundation, soil stabilization consideration, etc. According to Surenth et al. (2019), the most critical cost affecting factors for bored piles are pile sizes, pile drilling time, depth of pile, rock socket length, drilling type, concrete pouring time, and weather conditions. Soil investigation is a very important step before design works begin. The case study of RUMAHWIP Happy Residency 737 was conducted for a total of four times (BH1, BH2, BH3 & BH4) of exploratory boreholes as per shown in Figure 1. Therefore, there are four sets of soil sampling used in each borehole. Subsequently, the bored pile length was divided into four zones based on each exploratory boreholes data. In fact, the bore log data was used to determine the bored pile length required for into soil or rock socketing. The bored pile length was divided into four zones which was a more optimal design compared to the single zone instead, because single zone was based on the weakest soil profile among the four boreholes data. In this case, the bored pile length design was conservative, which led to increasing the bored pile length.

Figure 1: Soil Investigation Layout Plan (August 2016)

METHODOLOGY

Conceptual Framework

Through the systematic and thoughtful approach at the initial stage of planning and design, the final design of high-rise building foundation could be a successful showcase of VE in foundation design. The foremost priority is to study the soil investigation report to determine the soil parameters. Next, to study the original foundation design and check any of possibilities for VE works. The alternative design for bored pile foundation was tailored based on the given column loading. The structural capacity and geotechnical capacity of bored piles were designed to optimum level. Finally, a few PDA tests and SLT tests were carried out to justify the pile load capacity and pile settlement.

Case Study of the Original Foundation Design

The original design of the high-rise project RUMAWIP Happy Residency 737 is the case studied in this research. The original conceptual design of piled foundation at the initial stage is a combination of bored piles and micro piles. There are 5 types of bored piles and 2 types of micro piles in the original conceptual design. The original proposed bored pile diameter sizes are 750mm, 1050mm, 1350mm, 1500mm, and 1800mm respectively, and for micro piles are 200mm and 300mm respectively. The original type of bored piles and micro piles details are shown in Table 1 and Table 2 respectively. The highest pile group in the original design pile is 5 pile group. Based on this design, the original proposal for bored pile type and micro pile type were rephrased. A foundation design with too many different types and sizes of piles will increase the construction cost significantly. In fact, the size of rotary rig for drilling machines are required to be changed frequently during construction works due to many types of bored pile sizes. These actions may prolong the rotary rig drilling operations. Besides that, the original geotechnical pile length design into soil and rock socketing were too conservative as it could lead to wastage, unsustainable, and expensive design.

Table 1: Original Design of Bored Piles

Bored Pile Type	Bored Pile Diameter (mm)	Bored Pile Working Load (ton)	Main Steels	Helical Links	Concrete Grade
A	750	320	14T16	T10-175	G35
B	1050	1000	15T25	T10-300	G35
C	1350	1350	18T25	T10-300	G35
D	1500	1850	22T25	T10-300	G35
E	1800	2150	32T25	T10-300	G35

Table 2: Original Design of Micro Piles

Micro Pile Type	Micro Pile Diameter (mm)	Micro Pile Working Load (ton)	Main Steels	Helical Links	Concrete Grade
F	200	55	5T16	T10-175	G30
G	300	80	6T16	T10-300	G30

Alternative Design of Bored Piles Foundation Design (V.E.)

To optimize the pile foundation design, the alternative design only proposed one type of pile which is bored pile. In the value engineering of bored pile design, the new bored pile type was proposed through the given loadings. Based on the single column loadings, the highest column loading was 40,335kN and the lowest column loading was 485kN. Therefore, the bored pile diameter sizes or capacity strength are designed based on the given highest and lowest values of column loading. In general, the bored pile foundations is designed to optimum capacity strength through a larger pile diameter size and lesser quantity of piles. The new bored pile sizes proposed are 600mm, 1350mm, and 1500mm diameter sizes. There are four types of new bored piles proposed as per shown in Table 3 based on the given column loadings. The pile groups are limited to 1, 2 and 3 pile groups only. The alternative design of bored pile numbers become lesser, consequently would reduce the quantity of concretes and steel reinforcements which could lead to cost saving.

Table 3: Alternative Design of Bored Pile

Bored Pile Type	Bored Pile Diameter (mm)	Bored Pile Working Load (ton)	Main Steel	Helical Links	Concrete Grade
C	1350	1520	12T25	T10-300	G40
D	1500	1850	15T25	T10-300	G40
E	600	130	6T16	T10-300	G35
F	600	240	6T16	T10-300	G35

Structural Capacity Design of Bored Piles

The design of pile foundations and pile caps are in accordance with the following design codes and reference books: (1) BS8004:1986 Foundations; (2) BS8110:1985 Structural Use of Concrete; (3) “Pile Foundation Analysis and Design” Poulos and Davis for the design parameters of the new proposed bored piles. The concrete grade for the bored pile are 35N/mm^2 and 40N/mm^2 (Tremie II Mix). The main steel reinforcement of bored pile uses high yield type 2 steel bar, f_y is 500N/mm^2 and for helical links mild steel, f_y is 250N/mm^2. The minimum concrete cover for bored pile is 75mm. Steel reinforcement cage with minimum 0.4% of the pile cross section area is provided for every design pile. Nevertheless, for ease practices in construction, the minimum steel reinforcement length of 12m is provided right to the bottom through the bored pile to support the upper steel cage during concrete casting. The bored pile structural capacity is derived from the concrete strength itself and nominal steel reinforcement is advisable to provide to prevent damage during pile head cut-off. The maximum permissible stress under working load condition shall not exceed 0.25 times of the characteristic cube test strength of the concrete as given in Clause 7.4.4.3.1 of the BS8004:1986 Foundations. According to Wong et al. (2016), the structural capacity of bored pile is less issues if there is a proper control on concreting works and assurance of concrete supply time. In fact, the main challenge bored pile construction is the estimation and verification of the geotechnical capacity of bored pile from the pile shaft and base. The structural capacity of bored piles design is defined as:

$$Q_w = \{[\,\pi \times D^2/4\,] - A_s\,\} \times [\,0.25 \times f_{cu}\,] + f_{sc} \times A_s \qquad (1)$$

Where, D is Diameter of pile, Q_w is Allowable working load for pile, f_{cu} is Characteristic cube strength of concrete, f_{sc} is Permissible compressive stress of high yield reinforcement (175MPa), A_s is Area of Steel Reinforcement.

Based on the equation (1), four type of bored pile (Types C, D, E and F) are derived and the diameter sizes are 1350mm, 1500mm and 600mm as per shown in Table 3. Each of the categories of pile strength capacity is tailored through the column loading given. The proposal for alternative design of bored piles diameter sizes is lesser compared to original foundation design. Thus, the type of rotary rig for drilling machines are reduced which could increase the speed of piling construction works. The number of piles required are also reduced when compared to original foundation design which will discuss in Results and Discussion part.

Sub Soil Information for Geotechnical Design

According to Yusoff et al. (2016), Kuala Lumpur soil strata is underlain by three main rock types which are Kuala Lumpur limestone, Kenny Hill Formation and Granite. Kuala Lumpur limestone is the sedimentary rock formed through the intrusion of igneous rocks. Kenny Hill Formation is a metamorphic rock formation which compromise schist, phyllites, shale, sandstones and other similar sedimentary rocks. In fact, Kuala Lumpur limestone underlain the most at the Kuala Lumpur area. The 737 Happy Residency project is located at Kuala Lumpur area as shown in Figure 2. The project site is located within the Kuala Lumpur Limestone area and Kenny Hill Formation. The limestone area has always posed great problems to construction of piles due to karstic features of limestone such as steeply inclined bed rock, cavities, floater as per shown in Figure 3. Therefore, additional cost for pile remedial works has to be taken into considerations.

Figure 2: Geological Map of Kuala Lumpur (Department Mineral & Geosciences Malaysia, 2011)

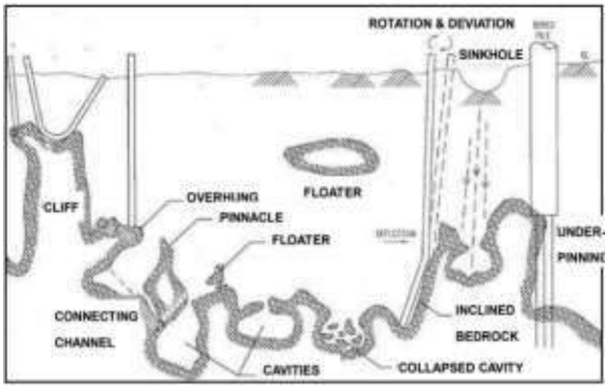

Figure 3: Typical Pile Problems Encountered At Limestone Area (Neoh, 1998)

In the assessment of a sub-soil model and the soil parameters for foundation design, a detailed site investigation (S.I.) is utterly important to provide soil strata information for design and construction. Because of the natural vagaries of soils, failure such as building settlement or crack tend to occur, regardless of how well these structures were designed. Some failures have been catastrophic and have caused severe damage to lives. In fact, it is first necessary to review the geology of the site and identify any geological features that may influence the design and performance of the foundation.

During the boring of soil investigation works, SPT N value of soils were obtained. The number of blows required to effect 300mm penetration below an initial penetration of 150mm was recorded as penetration resistance or SPT N value. The SPT N value provide information regarding the soil strength. In Malaysia, the geotechnical design of bored piles is usually based on Standard Penetration Test SPT N value. The semi empirical equation which correlating the ultimate base resistance (f_{bu}) and ultimate shaft resistance (f_{su}) to SPT N value are very commonly practiced in Malaysia. In fact, a

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total 4 borehole logs were summarized and presented as shown in Table 4. The borehole logs data was used to determine the geotechnical capacity for bored piles. The project site ground level is flat in general, and the boring depth is start from reduced level of 0.0m.

Table 4: SPT N-Value Data based on Soil Investigation

	Boreholes Data							
Boring Depth (m)	BH1 Strata	BH1 (N)	BH2 Strata	BH2 (N)	BH3 Strata	BH3 (N)	BH4 Strata	BH4 (N)
0-1.5	Sandy Silt	6	Sandy Silt	10	Sandy Silt	10	Sandy Silt	9
1.5-3.0	Sandy Silt	10	Sandy Silt	5	Sandy Silt	4	Sandy Silt	14
3.0-4.5	Sandy Silt	16	Sandy Silt	25	Sandy Silt	12	Sandy Silt	19
4.5-6.0	Sandy Silt	23	Sandy Silt	64	Sandy Silt	16	Sandy Silt	44
6.0-7.5	Sandy Silt	31	Sandy Silt	61	Sandy Silt	64	Sandy Silt	83
7.5-9.0	Sandy Silt	64	Sandy Silt	94	Sandy Silt	88	Sandy Silt	94
9.0-10.5	Sandy Silt	94	Sandy Silt	83	Sandy Silt	86	Sandy Silt	83
10.5-12.0	Sandy Silt	120	Sandy Silt	150	Sandy Silt	88	Sandy Silt	94
12.0-13.5	Sandy Silt	100	Sandy Silt	100	Sandy Silt	91	Sandy Silt	86
13.5-15.0	limestone	100	Sandstone	100	Sandy Silt	83	Sandy Silt	83
15.0-16.5	limestone	100	Sandstone	100	Sandy Silt	91	Sandy Silt	150
16.5-18.0	limestone	75	Sandy Silt	112	Sandy Silt	100	Sandy Silt	150
18.0-19.5	Sandy Silt	79	Sandy Silt	100	Sandstone	143	Sandy Silt	86
19.5-21.0	Sandy Silt	120	Sandy Silt	120	Sandy Silt	94	Sandy Silt	64
21.0-22.5	Sandy Silt	120	Sandy Silt	120	Sandy Silt	83	Sandy Silt	91
22.5-24.0	limestone	300	Sandstone	300	Sandy Silt	94	Sandy Silt	88
24.0-25.5	limestone	300	Sandstone	300	Sandy Silt	94	Sandy Silt	88
25.5-27.0	limestone	300	Sandstone	300	Sandstone	300	Sandstone	300
27.0-28.5	limestone	300	Sandstone	300	Sandstone	300	Sandstone	300
28.5-30.0	limestone	300	Sandstone	300	Sandstone	300	Sandstone	300
30.0-31.5	limestone	300	Sandstone	300	Sandstone	300	Sandstone	300
31.5-33.0	limestone	300	Sandstone	300	Sandstone	300	Sandstone	300
33.0-34.5	NIL	NIL	NIL	NIL	Sandstone	300	Sandstone	300
34.5-35.0	NIL	NIL	NIL	NIL	Sandstone	300	Sandstone	300

Geotechnical Design for Bored Piles in Soil

The design of bored pile geotechnical capacity has adopted Semi Empirical Method. The geotechnical design of bored piles is based on the shaft friction and end bearing force. The contribution of the friction from the overburden soil is neglected in computing the geotechnical capacity of the pile. The geotechnical design of the bored pile is based on the following expression:

$$Q_w = Q_s / FOS_1 + Q_b / FOS_2 \qquad (2)$$

Where, Q_w is Allowable working load of pile, Q_s is Ultimate shaft capacity of pile, Q_b is Ultimate end bearing capacity of pile, FOS_1 is Factor of safety shaft capacity of pile, FOS_2 is Factor of safety end bearing capacity of pile

The factor of safety (FOS) normally is used to evaluate the bored pile geotechnical capacity are partial from Factor of safety on pile shaft and end bearing of pile. The proposed factor of safety for both FOS_1 and FOS_2 for geotechnical design bored pile is 2.0.

In Malaysia, commonly engineers have been practicing geotechnical design for bored pile based on Standard Penetration Tests (SPT) data. The semi empirical equations which correlate to the value of the ultimate pile shaft resistance (f_s) and ultimate end bearing pile resistance (f_b) to SPT N values are suggested. The ultimate shaft resistance factor (K_{su}) and base resistance factor (K_{bu}) values were developed many years ago and have been in practice extensively over the years. The commonly used correlations for ultimate shaft and base resistance equations as per following:

$$f_{su} = K_{su} \times SPT\text{“N”} \qquad (3)$$

$$f_{bu} = K_{bu} \times SPT\text{“N”} \qquad (4)$$

For pile shaft resistance (f_s), Tan et al. (1998) have derived the value of K_{su} as 2.6 but limit the f_{su} values to 200kPa based on the results of 13 fully instrumented bored piles in residual soils. For base resistance (f_b), the values of K_{bu} varies greatly due to difficulties in base cleaning during the construction of bored piles. The contribution of base resistance can only be considered if a proper inspection of the base can be done or constructed in dry hole or base grouting is adopted. From back analyses and calculation of test piles, Toh et al. (1989) determined the value of K_{bu} is in between 27 to 60 and Chang & Broms (1991) determine the value of K_{bu} as in between 30 to 45. Lower values of K_{bu} between 7 and 10 were adopted by Tan et al. (1998). Chow (2016) designed the pile ultimate end bearing capacity based on 15% of pile working load. In this case study, the values of K_{su} and K_{bu} were adopted based on the derivation from Tan et al. (1998). The design parameter of end bearing capacity followed Chow (2016)'s recommendations.

Geotechnical Design for Bored Piles in Rock

In general, there are three major rock formations in Malaysia which are known as sedimentary, igneous, and metamorphic rocks. The geotechnical design approaches could vary significantly when designing bored pile capacity over these rock formations. Therefore, local experiences play an important role in determining a particular formation characteristic. Wong and Liew (2016) mentioned that to achieve a desired geotechnical capacity, bored pile is required to be socketed into competent stiff residual soils or bedrock for high shaft friction between rock mass and concrete. Therefore, conservative approach and semi empirical methods also need to be considered to ensure the bored pile socketing into desired length. According to Mustafal et al. (2016), empirical equations have been widely used for pile capacity calculation in current practices at Malaysia. In other words, design of bored pile capacity is usually based on the results of Standard Penetration Test SPT N value. Bored pile which socketed into rock area can be give higher capacity strength due to higher unit friction values. The Empirical equations of Qs and Qb at rock can be estimated as:

$$Q_s = A_s \times 0.05 \times q_{uc} \quad (5)$$

$$Q_b = A_b \times 1/3 \times q_{uc} \quad (6)$$

Where, A_s is Shaft area of the socketing length, A_b is Cross-sectional area of the pile, q_{uc} is Unconfined compressive strength of rock

According to Shoib et al. (2017), socketing the pile shaft into bedrock to transmit high foundation loads is becoming a common practice at Malaysia. The design load capacity of bored pile base is limiting due to relying upon on end bearing in rock due to soft toe issues. Unless pile base cleaning, works can be done properly. Thus, the alternative to bored piles have been to design an optimum length for shaft resistance in rock. Table 5 summarises the typical design socket friction values for various rock formation in Malaysia.

Table 5: Summary of Rock Socketing Unit Friction Design Values (Mustafa, 2016)

Rock Formation	Working Rock Socket Friction*	Source
Limestone	300kPa for RQD <25% 600kPa for RQD =25 – 70% 1000kPa for RQD >70% The above design values are subject to 0.05x minimum of $\{q_{uc}, f_{cu}\}$ whichever is smaller.	Neoh (1998)
Sandstone	$0.10 \times q_{uc}$	Thorne (1977)
Shale	$0.05 \times q_{uc}$	Thorne (1977)
Granite	1000 – 1500kPa for $q_{uc} > 30N/mm^2$	-

Where, RQD is Rock quality designation, q_{uc} is Unconfined compressive strength of rock

Based on the Soil Investigation boreholes, the limestone at BH1 is found at depth of 22.5m from ground level (0.0m). Next, for BH2, sandstone is found at depth of 22.5m as well. For BH3 and BH 4, sandstone is found at depth of 25.5m from ground level. The Rock Quality Designation (RQD) at BH1, BH2, BH3 and BH4 are equal to nil. These show the rock quality is very poor and completely weathered rock. Therefore, the allowable rock socket unit friction of 300kPa is adopted based on the limestone and sandstone conditions.

RESULTS AND DISCUSSION

Alternative Design Piling Layout Plan

The drawing of Alternative Piling Layout has is presented as shown in Figure 4. A total of 4 types of bored piles with diameter sizes of 600mm, 1350mm, and 1500mm were proposed. The bored pile diameter sizes and capacity strength were designed to optimum based on the given column loading. The layout plan was categorised into 4 zones. Each zone represents the borehole data characteristic and details. The geotechnical capacity of bored piles was designed based on each boreholes data.

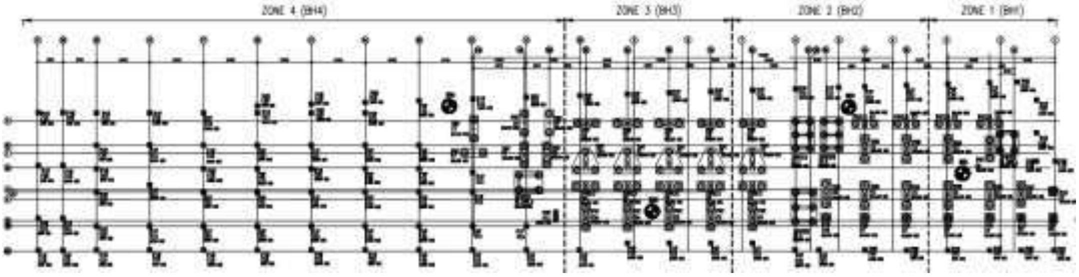

Figure 4: Alternative Piling Layout with Zoning Area

Table 6 shows Piling Table of Original Foundation Design tabulated based on original foundation layout plan. The total number of bored piles were 112 and micro piles were 241. The total number of piles for both bored piles and micro piles were 353.

Piling Numbers Comparison between Alternative and Original Foundation Design

Table 6: Piling Table of Original Foundation Design

	Bored Pile					Micro Pile	
	A	B	C	D	E	F	G
	750mm	1050mm	1350mm	1500mm	1800mm	200mm	300mm
Zone 1	0	4	6	9	2	28	16
Zone 2	0	0	20	20	2	5	22
Zone 3	0	0	10	26	0	0	24
Zone 4	1	0	8	3	1	0	146
Total in Zoning	1	4	44	58	5	33	208
Total =	353						

Table 7 shows Piling Table of Alternative Foundation Design tabulated based on alternative foundation layout plan. For bored piles types E and F have similar diameter sizes but different capacity strength. The bored pile capacity strength for type E was 130ton and type F was 240ton. The total numbers of bored piles were 227.

Table 7: Piling Table of Alternative Foundation Design

	Bored Pile			
	C	D	E	F
	1350mm	1500mm	600mm	600mm
Zone 1	25	3	19	2
Zone 2	33	13	2	8
Zone 3	24	12	0	8
Zone 4	16	0	25	37
Total in Zoning	98	28	46	55
Total =	227			

Pile Length Comparison between Alternative and Original Foundation Design

Table 8 shows Pile Length Requirement of Original Foundation Design tabulated based on original foundation layout plan. The Table 8 compromised pile length for both bored piles and micro piles.

Table 8: Pile Length Requirement for Original Foundation Design

	Type	Estimated Pile Length (m)	Rock Socketing Length (m)
Bored Pile	A	14.5	1.5
	B	12.5	10.0
	C	12.5	12.0
	D	12.5	13.5
	E	12.5	13.5
Micro Pile	F	12.5	4.0
	G	12.5	4.0

Table 9 shows Pile Length Requirement of Alternative Bored Piles Foundation designed based on semi empirical methods. The geotechnical capacity of bored piles in soil and rock are described under Methodology in Geotechnical Design part.

Table 9: Pile Length Requirement for Alternative Foundation Design

	Zone 1 (BH1)		Zone 2 (BH2)		Zone 3 (BH3)		Zone 4 (BH4)	
Bored Pile Type	Pile Length (m)	Rock Socket Length (m)	Pile Length (m)	Rock Socket Length (m)	Pile Length (m)	Rock Socket Length (m)	Pile Length (m)	Rock Socket Length (m)
C	19.5	5.4	19.5	5.4	23.0	5.4	23.0	5.4
D	20.0	6.0	20.0	6.0	23.5	6.0	23.5	6.0
E	10.0	NIL	10.0	NIL	10.0	NIL	10.0	NIL
F	12.0	NIL	12.0	NIL	12.0	NIL	12.0	NIL

Bill Quantities Comparison between Alternative and Original Foundation Design

Table 10 shows Bill Quantities (BQ) between original and alternative foundation designs calculated based on the number of piles required, pile length into soil and rock, piling equipment, piling records, pile tests, and total amount of concrete and steel reinforcement. The Bill Quantities of total amount for original foundation design was RM 8,859,487.50 and BQ for alternative foundation design was RM 6,037,383.10.

Table 10: Bill Quantities (BQ) Comparison for Foundation

	Amount
Original Foundation Design	
BQ for Bored Piles	RM 7,783,744.00
BQ for Micro Piles	RM 1,075,743.50
Total	RM 8,859,487.50
Alternative Foundation Design	
BQ for Bored Piles	RM 6,037,383.10

Test Results for Bored Piles

According to Hussein (2021), the Static and Dynamic Pile Testing Methods are two main types of pile tests used to access bored piles load capacity and settlement behavior of pile. Thus, Static Load Test (SLT) and Pile Dynamic Load Test (PDA) were applied in this project to check the bored piles performances overall. The pile test results for each type of bored piles are shown in below Table 11 and Table 12.

Table 11: Pile Dynamic Load Test Results

No.	Pile Diameter (mm)	Date	Working Load (tonne)	Test Load (tonne)	Total Load (tonne)	Factor of Safety	Working Load Settlement (mm)	Test Load Settlement (mm)
BP35	600	20/3/2017	240	480	620	2.6	2	8
BP13	1350	16/6/2017	1520	3040	3750	2.5	4	10
BP17	600	19/6/2017	130	260	500	3.8	2	3
BP72	1500	5/7/2017	1850	3700	2460	1.3	14	-
BP108	1350	8/7/2017	1520	3040	3100	2.0	6	15
BP58	1500	6/7/2017	1850	3700	4100	2.2	4	9
BP178	600	7/8/2017	240	480	490	2.0	2	5
BP215	600	7/8/2017	240	480	678	2.8	2	5

Table 12: Static Load Test Results

No.	Pile Diameter (mm)	Date	Working Load (tonne)	Test Load (tonne)	Total Load (tonne)	Factor of Safety	Working Load Settlement (mm)	Test Load Settlement (mm)
BP96	1350	3/6/2017 - 5/6/2017	1520	3040	3156	2.1	3.879	8.434
BP158	600	17/6/2017 - 19/6/2017	240	480	498	2.1	4.638	7.004

The dynamic load test was used to provide field estimates of the mobilized static load carrying capacity of the bored piles. In addition, it can be used to check the bored pile structural integrity and to obtain field data for later computer signal matching to determine capacity and soil resistance distribution. The Static load test or Maintained load test can be used to determine the settlement that can occur at working load, or a multiple of it, and can also be used to verify the ultimate bearing capacity of a pile. Pile settlement was recorded using the dial gauges or electrical displacement transducers. The applied load was monitored using calibrated load cells, and up-to-date systems can be controlled automatically using a portable computer and a compressed air pump.

DISCUSSION

The selection of appropriate pile foundation, pile capacity, diameter sizes for high rise loading are critical to ensure an optimal design for foundation could be carried out successfully. In this case, bored pile foundation was selected due to suspect of floating boulders at intermediate level of boreholes BH1, BH2 and BH3. The designed bored piles were required to penetrate through the boulders and socket into sound bed rock or desired hard layer. The alternative design for bored pile capacity was tailored carefully based on the lowest, intermediate, highest column loading. Thus, four types of bored piles were proposed for the alternative design. Technically, the foundation piles with a greater diameter or a higher capacity could be used to replace the original diameter pile sizes to reduce the number of piles required. For example, the 3-pile group of micro piles were replaced by 1 pile group of bored piles. Eventually, the number of piling requirements could be reduced based on this conceptual idea which would lead to cost saving.

Analysis of data was carried out by comparing the Original and Alternative Foundation Designs as shown in Table 13. According to Table 13 results, the number of piles difference is 126. Therefore, the total number of piles required for the high-rise project was reduced to 126. Furthermore, the pile length requirement for Original and Alternative Foundation Designs is presented in Table 8 and Table 9. The geotechnical design for bored pile was carried out based on a semi empirical equation. The semi empirical equations correlating to the value of the ultimate pile shaft resistance (f_s) and ultimate end bearing pile resistance (f_b) to SPT N values were applied. In this case, the values of K_{su} and K_{bu} were adopted based on the derivation from Tan et al. (1998). The design parameter for end bearing capacity in rock followed Table 5 recommendation. In fact, the alternative geotechnical design for bored piles was designed based on recommendations of local experiences and a conservative approach.

Table 13: Original & Alternative Design Comparison in Cost Saving & number of Piles

	Total Cost	Total Piles
Original Design	RM8,859,487.50	353
Alternative Design	RM6,037,383.10	227
Total Saving	RM2,822,104.40	126

The pile length requirements for alternative foundation design are lesser when compared to the original foundation design. In other words, the amount of concrete, steel reinforcement, and pile testing requirements are reduced as well. Thus, there was some saving of piling numbers and pile length requirement in the alternative foundation. Therefore, it could lead to cost-effectiveness as well. Refer to Table 13, the total cost for the original foundation design was RM 8,859,487.50 and the total cost for the alternative foundation design was RM 6,037,383.10. Therefore, the total cost saving was RM 2,822,104.40 based on the alternative bored pile foundation design.

In addition, the time for piling construction works could reduce as well since the numbers of piles, pile length requirement, type of pile proposed were reduced. If the bored pile sizes are too many, it could affect the drilling works and prolonged construction works. In fact, the type of rotary rig for drilling works have to be changed constantly due to the different types of piles. Eventually, it will affect the piling construction progress.

A total of Pile dynamic load test (PDA) and two Static Load test (SLT) were conducted in this project. The PDA test and SLT test are presented in Table 11 and Table 12 respectively. According to Mustafa et al. (2016), Jabatan Kerja Raya (JKR) standard specification for pile load test, a pile test shall be deemed to failed if: (1) the residual settlement after removal of the test load exceeded 6.5mm.

(2) the total settlement under working load exceeded 12.5mm (3) the total settlement under twice the working load exceeded 38mm or 10% of pile diameter whichever is lower value. In this case, the PDA test and SLT test results for bored piles are deemed to have passed as it was able to meet the pile settlement criteria and pile capacity requirements which is more than FOS of 2.0. In fact, 87.5% of PDA test results and 100% of SLT test results passed the specifications.

CONCLUSION

The alternative design of bored pile capacity was tailored based on the given loading of lowest, intermediate and highest column loading. The alternative design of bored pile sizes or capacity are greater when compared to the original foundation design which could lead to a reduction in the number of piles required. The geotechnical capacity of bored piles is designed to optimum level which led to a reduction of the pile length requirement. Besides that, micro piles are not recommended for high loading building structure due to its limitation in capacity strength. Therefore, the alternative bored pile design saves time and is cost-effective when compared to the original foundation design. A few of the bored piles were selected to conduct PDA and SLT tests. The bored piles test results were mainly deemed to have passed as it satisfied the pile load bearing capacity requirements and settlement criteria. In conclusion, the value engineering approach in bored piles design for high rise building was carried out successfully in terms of cost-wise, save time and comply the factor of safety (F.O.S) requirements.

RECOMMENDATION

The project site is located at Kuala Lumpur area. The soil strata of 737 Happy Residency project is underlain within Kuala Lumpur Limestone and Kenny Hill Formation. The characteristic of limestone area could post various problems to geotechnical engineers such as steeply inclined bed rock, floater, cavities, collapsed cavity underneath and so on. Besides that, one pile group and two pile group post a greater risk in remedial cost due to piles eccentricities issues. Therefore, additional remedial costs have to be taken into consideration in the Value Engineering Design Works. Value Engineering in Foundation Design not only aims to cut cost but also add value to the foundation works such as improving pile performances, cost-effective and sound safe in technically.

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