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Foundation Value Engineering & Underpinning Using Micropile for Building Upgrading Works.

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ABSTRACT: Jobs involving upgrading of old structures into new modern buildings are common in this country. This paper presents the value engineering and underpinning design for an abandoned structure located in Southern Malaysia. The alternative design involved optimization of foundation design by assessing the various design elements including the structural and geotechnical capacity of piles. The common methods of piling design including the alpha and beta method etc. together with adopted parameters are also presented in this paper. The acceptance criteria for pile load test commonly adopted in Malaysia will also be shared in for reference. The design of Micropile will be elaborated for both structural and geotechnical capacity. Recommendations on design parameters and the relation with construction constraints are also be highlighted. Besides, the common misconception on structural design of micropile will be discussed and pile load test results are presented to substantiate the derived conclusion. Finally, there are many issues commonly faced in construction projects. Among them, the limitation of SI in determining the pile length, the importance of proper construction planning, working under limiting headroom and lesson learned will also be shared in this paper.

Keywords: Underpinning, micropile, structural, geotechnical

1. INTRODUCTION

The scarcity of land has always been an issue especially in big cities and capitals that serves as the hub for major business activities. Johor Bahru as one of the largest city in Malaysia is facing the same issue where land scarcity has recently becoming more prominent. The scarcity of land in Johor Bahru city has resulted in many "land making" activities by reclamation. Besides, upgrading of old/abandoned buildings has also been practiced due to high land demand. This paper will discuss on foundation value engineering and underpinning works of an abandoned building located in Johor Bahru. Due to the strategic location of the building, it has been identified by the current Owner to upgrade the abandoned structure into a service apartment together with modern shopping centre.

The site is located at the city centre of Johor Bahru located at approximately 350km away from Kuala Lumpur, Malaysia. The site is believed to have underlain with old alluvium which is termed as the "Simpang Formation". The deposit comprised of semi consolidated weathered coarse sand, sandy clay and also gravel. The geological map and location of the proposed site is presented in Figure 1.1 for reference. A total of 20 nos. of borehole were also carried out on site to establish the soil properties and profiles on site.

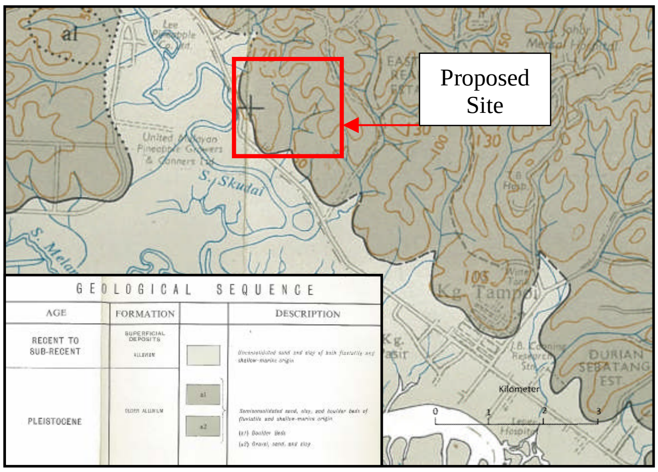

Figure 1 Geological map at site location

The existing building was a partially completed multi-storey complex abandoned 20 years ago. The existing foundation comprised mainly of bored pile with diameter ranging between 600mm and 1700mm. Due to the higher loadings from the proposed upgrading works, most of the existing foundation needed to be upgraded as well. Besides, the changed in structural layout required part of the building to be demolished and reconstructed. Based on the new layout plan, the Owner's consultant proposed that bored piles and spun piles to be adopted for building extension areas and also smaller structures located at the perimeter of the building. Besides, underpinning of the existing structure will be carried out using 250mm diameter micropile.

The newly appointed design and built Contractor has decided to carry out a value engineering for the building design including the foundation works. During the value engineering exercise, two piling options have been considered for the underpinning works. The options including the proprietary jack in pile system where the jacking will be carried out using the installed piles as the reaction system and also the micropile that has more track records over the jack in system have been evaluated. The contractor had eventually decided that the same piling systems to be adopted as proposed by the Owner's consultant. However, design optimisation was carried out by adopting larger working load closer the pile structural capacity of 0.25 times the concrete strength and also reduction in pile length utilizing the individual borehole results together with verification by pile load test. During the value engineering process, the need to increase the API pile size was also identified according to the structural design approach specified in FHWA. The design approach, parameters including load testing results will be discussed in the subsequent sections of this paper.

2. FOUNDATION DESIGN BY OTHERS

The proposed foundation design by the Owner's consultant comprised a combination of spun pile, bored pile and underpinning using micropile. The information on existing pile design are presented in Table 1 for reference. The layout plan for the proposed development is also presented in Figure 1 to indicate the complication of the foundation works especially working within congested site and also under constraint headroom condition.

Table 1 Summary of Pile Sizes of Existing Design by Others

Pile Type	Pile Size	Pile Length	Working Load
	(mm)	(m)	(kN)
Micropile	250	25.0 - 38.3	700
Bored Pile	600	29.0 -37.2	1,700
	750	29.0 -37.2	2,310
	800	29.0-37.2	3,020
	900	29.0 - 37.2	3,820
	1000	30.0 - 37.2	4,710
	1100	30.1 - 41.5	5,700
	1200	30.1 - 40.5	6,790
	1300	30.1 - 41.5	7,860
	1400	31.0 - 44.0	9,230
	1500	31.0 - 46.0	10,600
	1600	31.0 - 48.0	12,060
	1700	31.0 - 49.5	13,620
Spun Pile	300	31.0	800

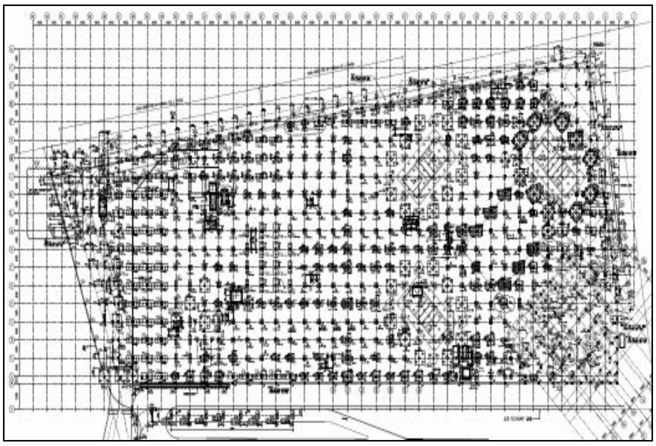

Figure 2 Site layout plan

3. ALTERNATIVE DESIGN

3.1 Geotechnical Capacity of Pile

Several methods commonly used in Malaysia for estimation of pile geotechnical capacity include the alpha method, beta method and also the more frequent used modified Meyerhof method. The following outlines the concept of each method in high level for reference:

Alpha Method

Shaft Resistance, $f_{su} = \alpha\, s_u$ (1)

End Bearing, $f_{bu} = N_c\, s_u$ (2)

where,

α = adhesion factor, e.g. Tomlinson, 1957
s_u = cohesion of soil from field/laboratory test
N_c = bearing capacity factor, $6+L/d \leq 9$
L/d = pile length/size

Beta Method

Shaft Resistance, $f_{su} = \beta\, \sigma_v'$ (3)

End Bearing, $f_{bu} = N_q\, \sigma_{vb}'$ (4)

Where,

β = $K_s \tan \delta$
N_q = bearing capacity factor, e.g. Berezantzev et. al, 1961
σ_v' = average effective stress along the shaft
σ_{vb}' = effective stress at pile base
K_s = coefficient of earth pressure, e.g. Stas & Kulhawy, 1984
δ = pile/soil friction angle, Stas & Kulhawy, 1984

Modified Meyerhof Method

Shaft Resistance, $f_{su} = K_s N$ (5)

End Bearing, $f_{bu} = K_b N$ (6)

Where,

K_s = shaft resistance factor, e.g. 1.8-2.5 depending on soil type
K_s = base resistance factor, e.g. 40-45 for bored pile and depending on soil type
N = standard penetration resistance

Based on any of the above method, the ultimate pile capacity can be derived and with appropriate safety factors, the working load of a pile can be derived. The allowable pile working load can generally be estimated as follow: -

$$Q_{all} = \frac{Q_{su}}{F_s} + \frac{Q_{bu}}{F_b} \quad \text{or} \quad Q_{all} = \frac{Q_{su} + Q_{bu}}{F_g} \quad \text{whichever lower} \qquad (7)$$

where,

Q_{all} = allowable Geotechnical Capacity
Q_{su} = ultimate Shaft Capacity, $f_{su}\, A_s$
Q_{bu} = ultimate Base Capacity, $f_{bu}\, A_b$
F_s = factor of Safety for Shaft Resistance
F_b = factor of Safety for Base Resistance
F_g = factor of Safety for Global Resistance
A_s/A_b = pile shaft area/pile base area

3.2 Structural Capacity of Pile

For pile structural design, bored pile and spun pile adopted the design value recommended in BS 8004 while the method recommended in FHWA has been adopted for micropile design. FHWA recommended that the structural capacity of an uncased pile to be estimated from the steel pile and also the internal grout as shown in equation 8. Besides, FHWA also stated an important fact that by excluding both the internal and external grout may result in overconservative and uneconomical design.

$P_{allow} = 0.4 f_c A_g + 0.47 f_y A_s$ (8)

where,

f_c = characteristic grout strength
f_y = yield strength of reinforcement
A_g = area of grout
A_s = area of steel

3.3 Final Design

For the alternative design, foundation design using modified Meyerhof method has been adopted. As spun piles are mostly driven to refusal, no optimization was carried out. For bored pile, the pile capacity has been assessed with two (2) different sets of safety factors and the one with lower pile capacity will be adopted as the final pile working load. Higher safety factor on end bearing was adopted for set 1 to cater for the uncertain base cleaning especially for shorter end bearing pile while set 2 is mainly check for longer pile which rely more on the shaft resistance that is more cossistant.

Set 1 : F_s = 1.5; F_b = 3.0
Set 2 : F_s = 2.0; F_b = 2.0

Due to the small diameter of the micropile, base cleaning of the pile remained more uncertain. Thus, the end bearing of the micropile has been omitted in the design. For shaft resistance, a safety factor of 2.0 has been adopted to derive the pile length. Based on the adopted parameters, the results of the design are presented in Table 3.1 for reference.

Table 2 Summary of Pile Sizes of Alternative Design

Pile Type	Pile Size	Pile Length	Working Load
	(mm)	(m)	(kN)
Micropile	250	10.5 - 34.0	650
Bored Pile	600	15.0 - 31.5	1,700
	750	10.0 - 30.5	2,250
	800	19.5 - 28.0	2,350
	900	14.0 - 37.0	3,600 & 3,820
	1000	15.0 - 37.5	4,300 & 4,710
	1100	15.0 - 42.0	5,400 & 5,700
	1200	15.0 - 44.5	6,000 & 6,790
	1350	34.0 - 40.0	7,300 & 8,500
	1500	27.0 - 39.0	9,300

Comparing Table 1 & Table 2, it can be observed that the length of bored pile has generally been reduced especially the lower range pile length. Besides, some of the bored pile sizes have also been reduced by adopting higher working load closer to structural capacity. For micropile, the pile length and pile number have also been reduced by lowering the redundancy in pile design. On the other hand, the API pipe size of the micropile was increased from 88.9mm to 101.6mm according to the recommendation by FHWA.

Besides, to enhance the load transfer mechanism, the upper 3m of the micropile has been cased with mild steel casing as shown in Figure 3.

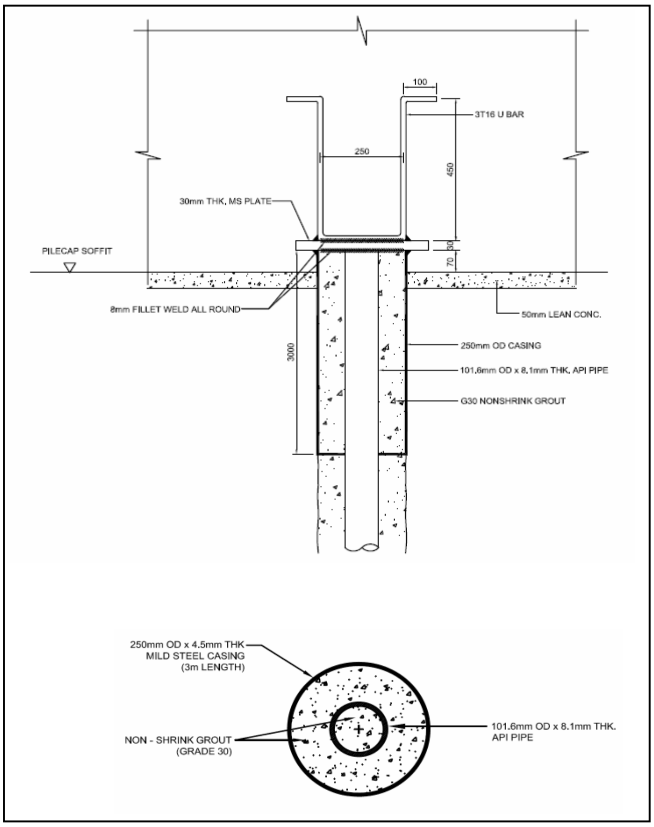

Figure 3 Cross Section of Micropile

3.4 Load Test Results

A total of seven (7) preliminary pile load tests up to three (3) times working load were proposed to be carried out at various locations on the site. Maintained load test using both kentledge blocks and reaction anchors were both adopted on site. Figure 4 shows the typical set up for maintained load test using ground anchors carried out on site.

Figure 4 Maintained Load Test Using Ground Anchors

The maintained load test results for both the bored pile and micropile are summarised in Figure 5 and 6 for reference.

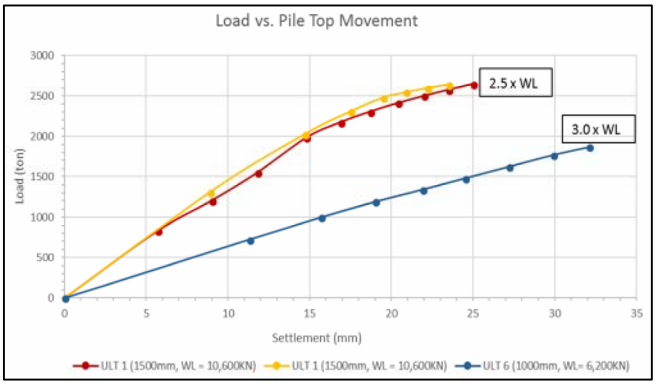

Figure 5 Pile Load vs Pile Top Settlement Curve for Bored Pile

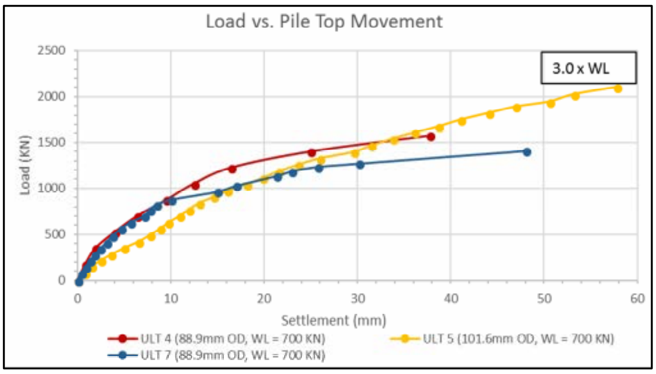

Figure 6 Pile Load vs Pile Top Settlement Curve for Micropile

In Malaysia, the test piles are usually deemed acceptable when the load test results meet the limiting settlement criteria of 12.5mm and 38mm at one time working load and two times working load respectively. The limiting criteria may alter to include elastic shortening for long and slender piles. Based on the test results, all bored piles managed to achieve the desired test load and meeting the limiting settlement criteria. For micropile, only one (i.e. ULT 5) out of three of the tested piles has achieve the required test load. Due to the large pile top movement on piles, further assessment on toe settlement for micropile was carried out and results are presented in Figure 7 for reference.

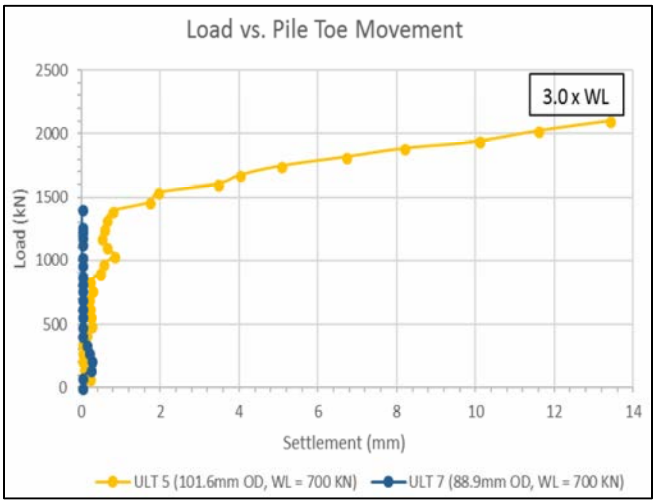

Figure 7 Pile Load vs Pile Toe Settlement Curve for Micropile

From Figure 3.4 and 3.5, it can be observed that ULT 7 with smaller pipe size (88.9mm) managed to achieve a lower toe settlement as compared to ULT 5. However, at higher induced load, the pile failed to sustain the loading with relatively large pile top movement. On the other hand, ULT 5 with larger pipe size (101.6mm) managed to complete the entire load test cycle. In view of the relatively large pile top movement and negligible pile toe movement for ULT 7, the pile with smaller API pipe size is lightly to have failed structurally.

4. CONSTRUCTION

The foundation construction for the project was carried out between year 2014 & 2015. Soil investigation works were commenced slightly ahead the foundation construction in order to enable the pile design to be finalized. Generally, both bored pile and micropile activities started almost in parallel while spun piling works only started midway through the piling construction. Bored piles were mainly carried out at the building extension areas and also at locations where demolishing of buildings was carried out. Micropiles with smaller machines focused mainly within the existing building areas due to congested site and limiting head room condition. Spun piles were later carried out for smaller structures positioned along the perimeter of the proposed building. Similar to other constructions, many issues were encountered during the actual physical works on site. Among those are lack of soil investigation information for decision on pile termination, tight construction schedule, congested and low head room and also sloping ground condition etc.

As there was only limited SI carried out on site, the finalising of actual pile length can only be confirmed by the site personal with reference made to the nearest soil investigation information. Even with the presence of geotechnical engineer on site, the identification of suitable materials for pile termination on site has never been easy. Thus, the termination of pile was purely based on the engineers on site with feedback from the design office. At location where confirmation of suitable pile length was difficult, the approach by lengthening the pile has to be taken.

Tight construction schedule has always been an issue for most construction projects. As the construction involved demolishing part of the existing structure to cater for piling works, it requires proper planning in order to ensure work continuity. Figure 8 showing the bored pile rig working on the partially demolished structure.

Figure 8 On going Bored Pile Works on Site

Low head room and confined work space posted a very challenging environment to the site workers. Movement between existing columns, flooding of site and providing fresh air to workers requires proper safety and operating procedures to ensure accident free site. Figure 9 & 10 showing the micropile rig working under congested site and low head room condition.

Figure 9 Micropile Rig Working Under Limiting Head Room

Figure 10 Micropile Rig Working Under Limiting Head Room

As the site was surrounded by existing structures and roads, part of the site that was founded on higher ground needed to be trimmed to facilitate the piling construction. The maximum difference in ground level was recorded to be approximately 7.5m. As such, cut slope and temporary shoring works were required to facilitate the piling activities and site works. The slope was check to ensure that no excessive movement that may result in damage on the completed piles. The design was coupled with instrumentation monitoring during excavation to ensure nominal movement on the cut slope. Figure 11 shows the cut slope formed during construction to facilitate the piling works.

Figure 11 Cut Slope Near Piling Works

As there were also nearby structures surrounding the site, permanent retaining wall using contiguous bored pile (CBP) wall with strutting were also introduced to prevent movement of the surrounding structures. Figure 12 shows the layout plan of CBP wall constructed on site.

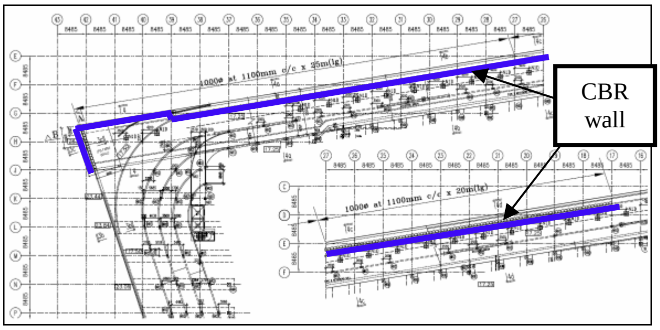

Figure 12 CBP Wall Layout Plan

5. DISCUSSION & LESSON LEARNED

Many methods are available for estimation of pile geotechnical capacity. The common used methods include the alpha method, beta method and also the Meyerhof method. The different methods are each suitable for different soil conditions. The alpha method will be more appropriate for foundations under soft ground condition whereas the beta method will be more appropriate for piles in cohesionless ground condition. The modified Meyerhof method is suitable for both cohesive and cohesionless ground condition but will have limitation when dealing with soft ground with very low SPTN value (e.g. SPTN 0). The designer shall select the method of design carefully by referring to sufficient SI information with proven of load test results. The checking of geotechnical capacity for bored pile with more than one set of safety factors will help to prevent overlooking on design due to uncertainties in construction method especially for shorter piles which relies more on end bearing. For structural capacity of micropile, it is recommended that only the grout within the cased section to be used for estimating the structural capacity of pile. Including the grout for uncase section may overestimate the pile structural capacity.

Sufficient SI with proper planning are necessary to achieve optimise pile design. Besides, good construction planning is always necessary to ensure smooth and safe working environment such that the works can be completed on time.

6. CONCLUSION

Land scarcity especially in the city centre area has resulted the reuse and upgrading of abandoned and old building structures. An abandoned complex in Johor was identified to be upgraded to service apartment with modern shopping centre. Several underpinning options have been assessed during the value engineering exercise including proprietary jack-in pile system where installed piles are used as the reaction system for jacking. The final adopted option involved bored piling at the extension areas, micropile for the underpinning section of the building and also spun pile for smaller structure positioned at the perimeter of the proposed building.

It is important that sufficient SI to be planned such that sufficient geological sections can be generate with reasonable interpolation for foundation design. As SI costs is merely a fraction of the total construction cost, sufficient SI with good engineering judgement will result in economical foundation design. Foundation design and checking with different sets of safety factors is a good practice to prevent overlooking in foundation design especially when dealing with uncertainties in construction methods.

The use of uncase grout section for structural capacity in micropile design especially in soil with low confining pressure will likely to overestimate the pile structural capacity. For micropile design, it is also a good practice to omit the end bearing of the pile due to the small pile diameter where base cleaning cannot be ascertained. Finally, underpinning of foundations using micropile is a proven solution with many successful case histories. The selection of foundation solutions for underpinning shall take consideration of other factors including the soil condition, availability of rigs, schedule etc. and proper construction planning is necessary to ensure on time delivery of a project.

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