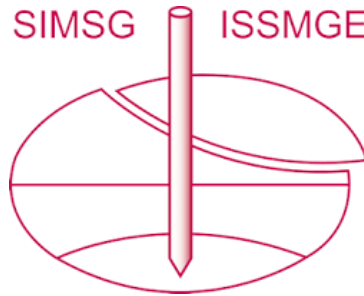


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Protection works for Kompleks Budaya Kraf located within MRT2 tunnel horizon in Kuala Lumpur limestone formation

Travaux de protection pour Kompleks Budaya Kraf situés dans l'horizon du tunnel MRT2 dans la formation calcaire de Kuala Lumpur

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ABSTRACT: The design of protection works for existing Kompleks Budaya Kraf buildings (near Conlay station) within proposed KVMRT Line 2 tunnel alignment in Kuala Lumpur limestone formation is presented in this paper. Kompleks Budaya Kraf are founded on driven pile foundations. Limestone rockhead level of the site is deeper than proposed tunnel crown levels at some localized areas. Building impact assessments have been carried out. Four existing columns are found to be affected by tunnelling works and required protection works including underpinning and piles removal works. As for the foundation underpinning works, transfer beams founded on vertical and raked micropiles are designed to support the affected columns before removing the existing piles. The structural settlement and distortion have been assessed to be within acceptable tolerance. Besides that, the segmental tunnel lining is also assessed for the influence from existing RC square piles and proposed Micropiles. Two piles removal schemes are proposed depends on site constraints, i.e. caisson shaft with mined adit and inclined coring methods. Assessment on the impact of proposed pile removal works by caisson shaft with mined adit method to existing structures and proposed underpinning structures have been conducted. This paper will share the assessment methods and design concepts of the proposed protection works.

KEYWORDS: Protection, Transfer Beam, Caisson Shaft, Mined Adit, Inclined Coring, Limestone

1 INTRODUCTION

Kompleks Budaya Kraf is located within the influence zone of tunnelling works for KVMRT Line 2 tunnel. This paper presents the impact assessment of the tunnelling works to Kompleks Budaya Kraf based on tender information at design stage and with further verification from site investigation works due to the absence of as-built information. The impacts of underpinning works and pile removal works are also assessed. Furthermore, additional assessment on the impact of existing building loadings to the proposed tunnel lining has been conducted.

The available information showed that the main buildings for Kompleks Budaya Kraf (i.e. Seri Anjung & Seri Budaya) are supported by RC square pile foundation. Based on subsoil condition at site, RC square piles are likely installed to set at hard layer or rock layer. No foundation information is made available for the wakafs (i.e. small pavilion) located within the influence zone and they are likely to be supported on shallow foundation in view of the light-imposed load.

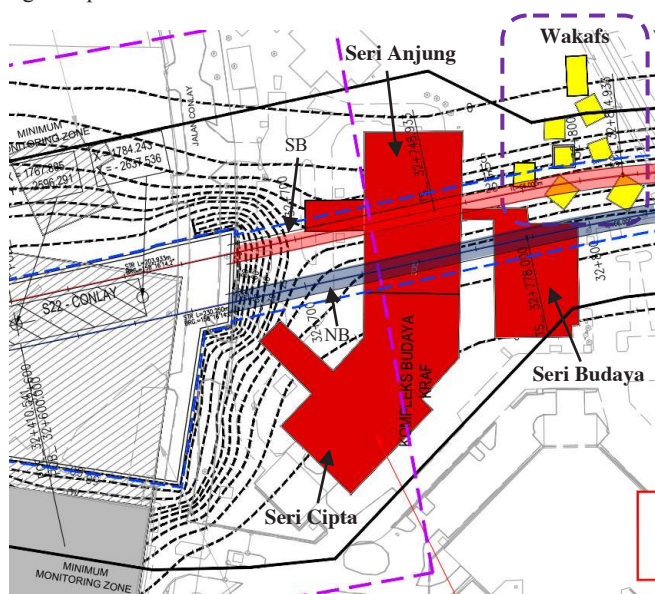


Figure 1 Building Layout Plan

2 FIELD INVESTIGATION WORKS

2.1 Introduction

Field investigation works have been carried out to confirm the as-built information of building foundations within the influence zone for building impact assessment and protection works design. The investigation works that were carried out are listed below in chronological order:

Table 1 Summary of Field Investigation Works

Method	Objectives
Boreholes	Five nos. boreholes (NCBH-246, NCBH-247, NCBH-248, NCBH-249 and NCBH-250).
Cross Hole Seismic Tests	To obtain subsoil profile especially bedrock levels. Continued from the above-mentioned five boreholes. Seven seismic lines.
Trial Pit for Wakaf	To obtain bedrock profiles within the five boreholes. One no. trial pit.
Additional Borehole with Cross Hole Seismic Test	To confirm as-built foundation type of wakafs. One no. borehole (UG-109-KBH1A). Three nos. seismic lines (KBH1A-NCBH248, KBH1A-NCBH249, KBH1A-NCBH246).
Rock Probes	To verify the bedrock level within NB tunnel alignment. Twenty-one nos. rock probes.
Trial Pits	To verify the bedrock levels next to existing columns within both NB & SB tunnel alignments which will be referred as existing pile toe levels for impact assessment. Two nos. trial pits for columns P2 & P8.
Parallel Seismic Tests	To verify the existence of piles for selected columns, i.e. columns P2 & P8. Four nos. Parallel Seismic Test for Columns P2, P4, P6 & P8. To verify presence of piles, as well as pile length estimation for selected columns.

2.1.1 Boreholes

Bedrock was encountered from depth 10.5mbgl to 23.5mbgl, i.e. from RL16.74m to RL25.88m from five initial boreholes (i.e. NCBH-246, NCBH-247, NCBH-248, NCBH-249 and NCBH-250). The proposed tunnel crown levels underneath Kompleks Budaya Kraf are at depth ranging from:

- Northbound (NB): 18.4mbgl to 20.9mbgl, i.e. from RL15.6m to RL18.1m.
- Southbound (SB): 16.7mbgl to 17.7mbgl, i.e. from RL18.8m to RL19.8m.

Thus, some existing RC square piles that are located within or close to SB tunnel alignment may encroach into tunnel horizon or being affected by tunnelling works. Refer to Figure 2 for boreholes layout plan and Figure 3 for simplified borelogs.

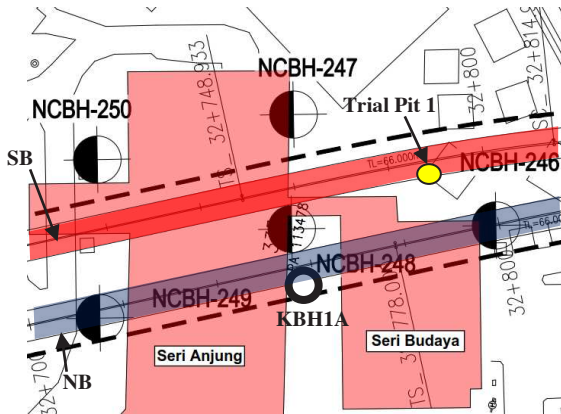


Figure 2 Boreholes Layout Plan

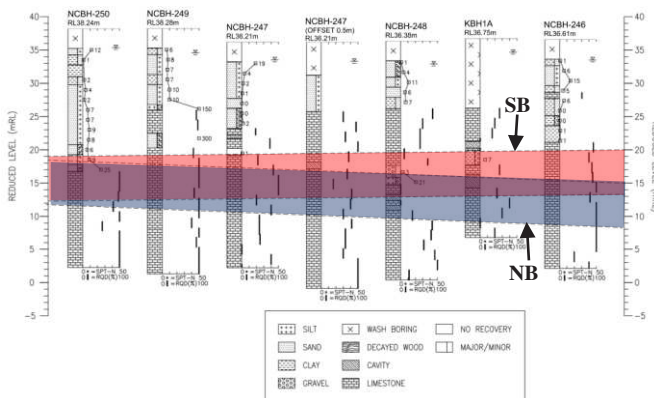


Figure 3 Simplified Borelogs

2.1.2 Cross Hole Seismic Tests

First stage Cross Hole Seismic Tests were carried out using the first five boreholes in order to generate the bedrock level within the influence zone.

The results showed that the bedrock levels within NB tunnel alignment are shallower as compared to SB and the existing RC square piles within NB tunnel alignment will not be affected by tunnelling works.

2.1.3 Trial Pit for Wakaf

Three wakafs are within tunnel alignment. Trial pit was carried out on one selected wakaf as shown in Figure 2 to confirm the foundation type of wakafs.

No pile or footing was found as shown in Figures 5 and 6, denotes the wakaf is supported by raft foundation. As such, other wakafs of similar building structure are assumed to have similar foundation type which is shallow foundation.

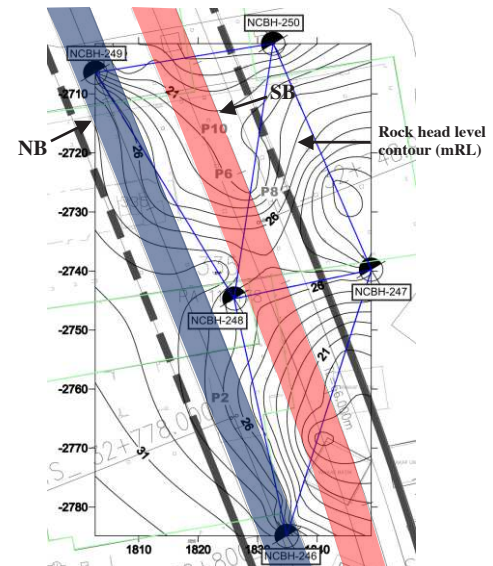


Figure 4 Interpreted Rock Head Level Contour from Cross Hole Seismic Tests Results

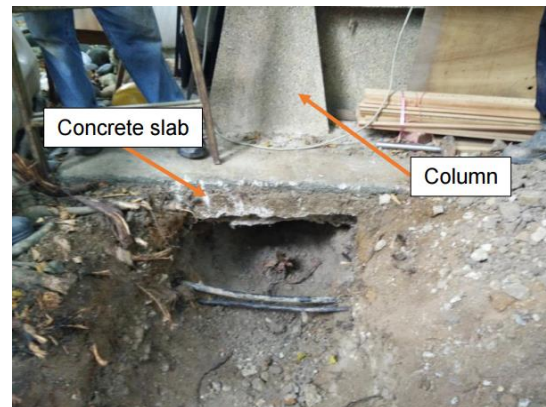


Figure 5 Site Photo

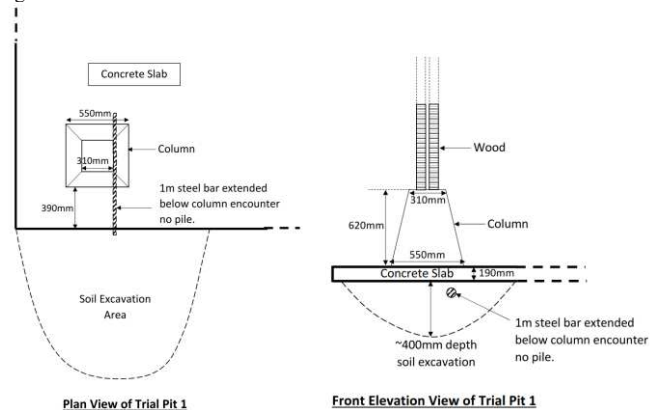


Figure 6 Trial Pit Findings

2.1.4 Additional Borehole with Cross Hole Seismic Test

Further to the findings as described in Section 2.1.2, additional borehole KBH1A was carried out within the NB tunnel alignment to verify the bedrock level. Besides that, additional cross hole seismic test was carried out with three seismic lines, i.e. KBH1A-NCBH248, KBH1A-NCBH249, KBH1A-NCBH246.

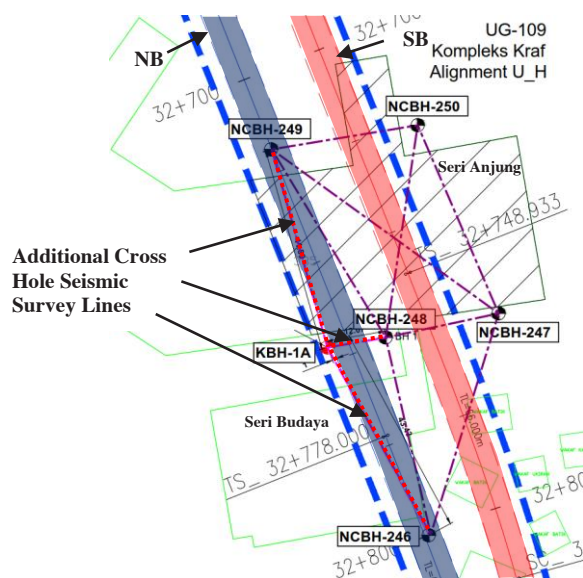


Figure 7 Cross Hole Seismic Tests Layout Plan

Cavity was detected from the seismic test results in seismic line KBH1A-NCBH246. The results show there is potential of pile toe encroachment into tunnel horizon at location around KBH1A.

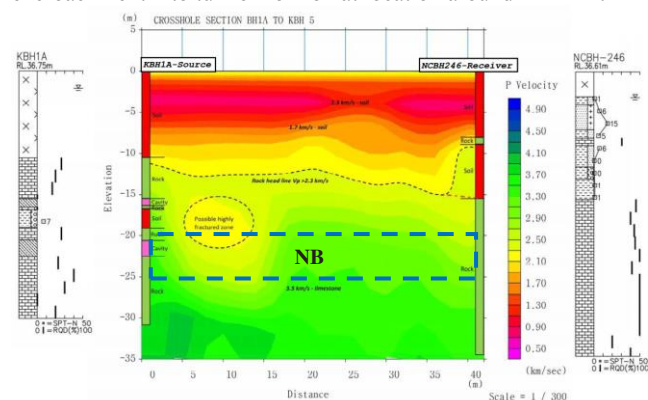


Figure 8 Cross Hole Seismic Tests Results (KBH-1A to NCBH-246)

2.1.5 Rock Probes

In view of the above findings, a total fifteen rock probes were carried out on all the columns of main buildings within tunnel alignment of both NB and SB alignments to verify the bedrock levels which will be referred as pile toe levels for existing piles for impact assessment.

The rock probe results were compared against the earlier cross hole seismic test results. It shows that the bedrock levels obtained from the rock probes results are different from the cross hole seismic test results (with largest difference of 10m deeper based on rock probes results).

Therefore, only the boreholes and rock probes results are adopted for impact assessment. Geophysical survey is excluded in the impact assessment as rock probes results should be more reliable.

2.1.6 Trial Pits for Columns P2 & P8

Two trial pits were carried out to verify the existence of piles for selected columns, i.e. columns P2 & P8. The results show that the main buildings of Budaya Kraf are supported by RC square piles.

2.1.7 Parallel Seismic Test for Columns P2, P4, P6 & P8

Total four parallel seismic tests were carried out to verify the presence of piles and pile length estimation for selected columns at P2, P4, P6 & P8. The results of Parallel Seismic Test are compared to the findings from rock probes and trial pit as described in Sections 2.1.5 and 2.1.6. The results showed that the detected pile length is slightly shorter than rock probes results, which is reasonable outcome for driven piles.

Nevertheless, the bedrock levels obtained from the boreholes and rock probes are conservatively referred as pile toe levels for impact assessment.

3 BUILDING IMPACT ASSESSMENT

With reference to the findings obtained from the above-mentioned field investigation works, building impact assessments have been carried out for the structure within 3m offset from the outer lines of proposed tunnel alignment as shown in Figure 12. Information and method of building impact assessment are shown in Table 2.

Table 2 Information and Method of Building Impact Assessment

	Main Buildings (i.e. Seri Anjung including Porch, Seri Budaya, Corridor)	Wakafs
Foundation Type	RC Square Piles	Shallow Foundation
As-built Pile Length	Pile toe at bedrock levels, obtained from boreholes and rock probes	N.A.
Assessment Method	Detailed Assessment (Stage 3)	Greenfield Assessment (Stage 1 & Stage 2)

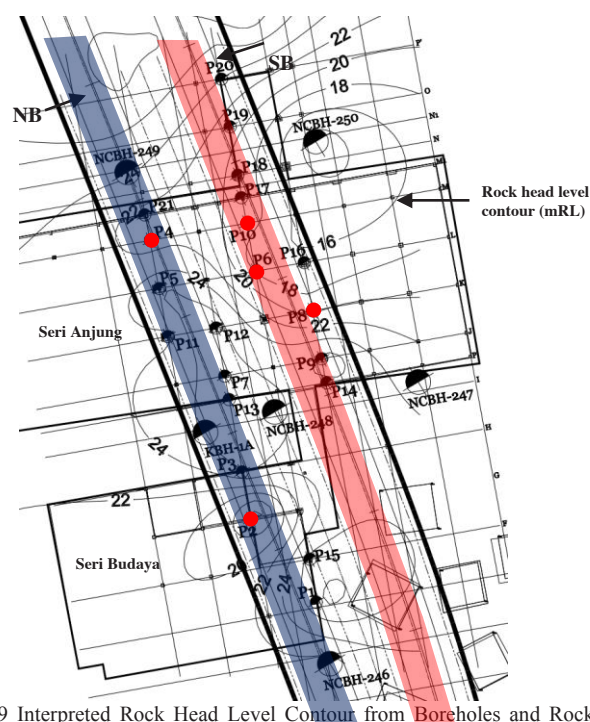


Figure 9 Interpreted Rock Head Level Contour from Boreholes and Rock Probes Results



Figure 10 Trial Pit Results

The methodology adopted for the building impact assessment is the staged approach proposed by Mair et al (1996).

Stage 1 assessment is a preliminary assessment undertaken to identify buildings which require damage assessment using Greenfield method, where the bored tunnelling works will generally produce a settlement trough which can be described by a Gaussian distribution curve. The methodology in estimating the settlements due to bored tunnelling will be based on Peck (1969) and O'Reilly and New (1982) where there is no major loss of ground at the face of TBM and where there is little or no consolidation settlement.

Buildings will require further damage assessment if the maximum settlement exceeds 10mm and /or if the ground slope exceeds 1:500.

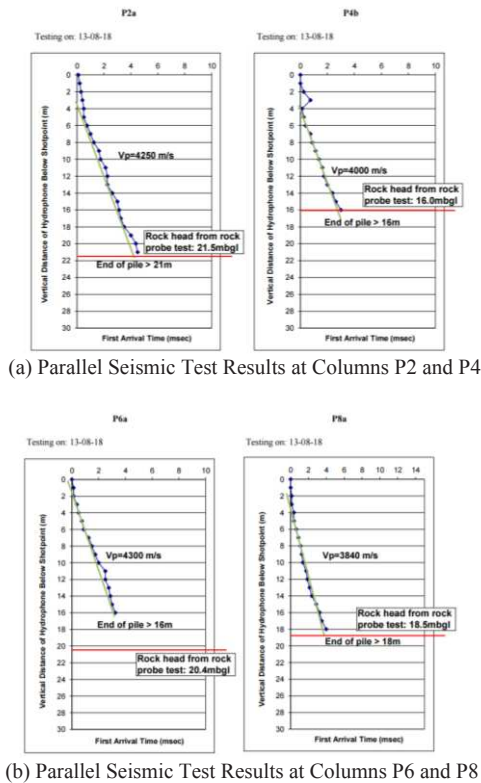


Figure 11 Parallel Seismic Test Results

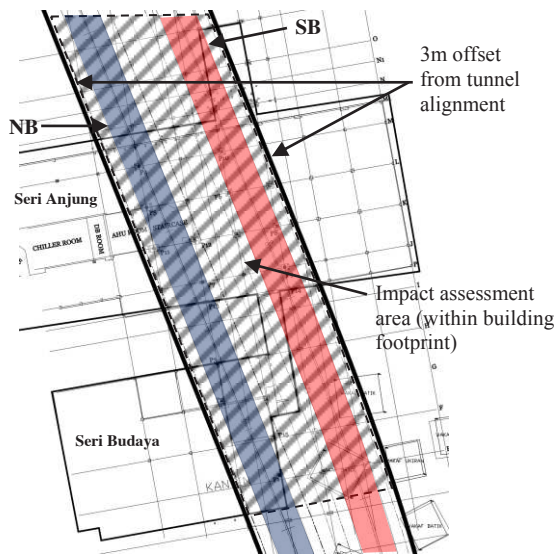


Figure 12 Building Impact Assessment Area

Stage 2 assessment is carried out for buildings identified through the preliminary assessment in Stage 1 which require further assessment. The assessment calculates the potential impact of ground movements on the building in terms of tensile strains. Tensile strains within the building resulting from Greenfield ground movements are first calculated. The method of calculating the limiting tensile strain is based on that proposed by Burland. Where a visual inspection of the building has been undertaken, the existing condition of the building is also considered in addition to the effects of the works and an overall tensile strain is determined. This corresponds to a damage category. The damage category determines whether further analysis of the structure and/or measures to mitigate the effect of settlement may be required.

Stage 2 assessment on wakafs shows negligible degree of severity. Thus, no Stage 3 assessment is required for wakafs.

Tunnelling impact assessment on the main buildings are carried out using Plaxis FEM software to identify pile locations and pile toe levels that will be subjected to tunnelling impact. The impact zone has been categorised into three groups as illustrated below:

- Group A – Rock head / pile toe level deeper than 2.5m above tunnel crown level, within tunnel alignment.
- Group B – Rock head / pile toe level deeper than 2m above tunnel crown level, within 2m offset from tunnel alignment.
- Group C – Rock head / pile toe level deeper than tunnel crown level, beyond 2m offset from tunnel alignment.

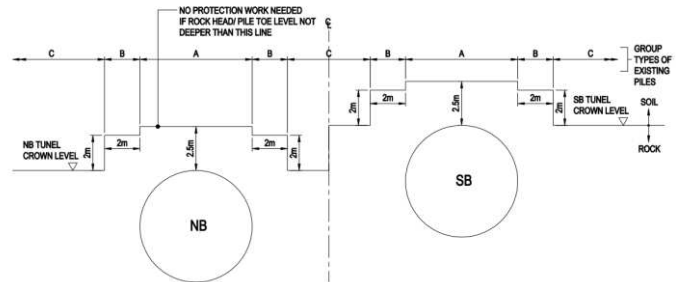


Figure 13 Categories of Impact Zone

After categorising all columns / piles to the groups, total four columns located in Zone A are found to have unacceptable impact which will be requiring protection works.

In view of inconsistency between the tender drawings and actual site observations, further investigation works (i.e. trial pit and rock probes) are proposed to confirm the assessment findings as follows:

- For columns without rock probe results, the assessment is based on interpreted bedrock levels. Further investigation is required to confirm the pile length.
- For retaining wall with pile foundation shown in tender drawing, the assessment is based on tender information and interpreted bedrock levels. Trial pit investigations are proposed to confirm the foundation type and pile length, if with pile foundation.
- For surveyed columns without pile shown in the tender drawing, the assessment is based on tender information and interpreted bedrock levels. Trial pit investigations are proposed to confirm the presence of piles and pile length, if with pile found.
- For pile groups shown in tender drawings but no column found in the surveyed as-built column layout plan, the assessment is based on tender information and interpreted bedrock levels. Trial pit investigations are proposed to confirm the presence of piles and pile length.

4 FOUNDATION UNDERPINNING DESIGN

A total 4 nos. of columns from the main buildings are identified to be affected by tunnelling works and requiring underpinning works, i.e. Columns P2, P6, P8 and P10. Trial pit investigation was carried out for the four columns to verify the as-built pile groups, as well as as-built pile cap details. The findings of trial pit investigation showed that the as-built pile groups are different from the available tender drawings. The underpinning designs will be based on trial pit investigation results.

Reinforced concrete transfer beams supported by Micropiles were proposed as foundation underpinning method for the four affected columns. The proposed Micropiles were to be located in position to assure sufficient offset from proposed tunnel position and with consideration of the tunnelling tolerance, pile deviation tolerance and pile verticality tolerance to ensure proper functioning of the foundation and free from clashing during tunnelling works.

Micropiles were designed with effective rock socket level started from 2m above proposed tunnel invert levels to avoid possible impact onto future tunnels. The proposed tunnel lining of KVMRT Line 2 tunnel has been assessed on the loadings imposed from the proposed Micropiles. Figures 14 and 15 show typical layout and

cross section for proposed foundation underpinning design at Column P8.

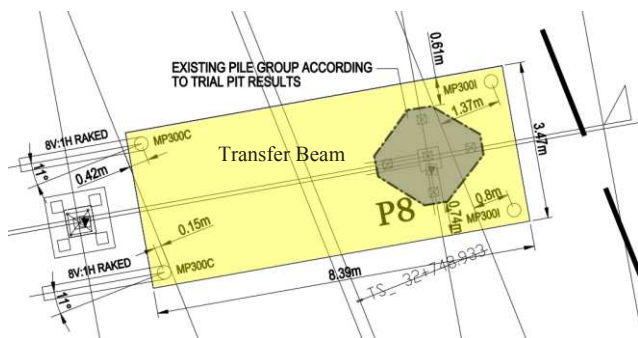


Figure 14 Layout Plan for Foundation Underpinning Design at Column P8

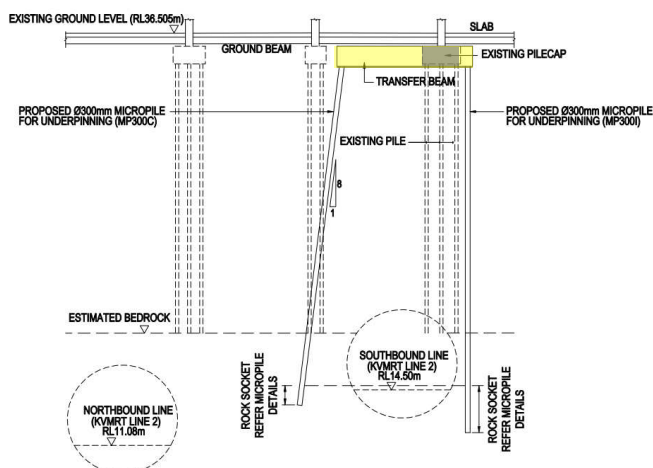


Figure 15 Cross Section for Proposed Foundation Underpinning Design at Column P8

The proposed underpinning systems are designed based on deformation tolerance of 12mm and distortion tolerance of 1:500.

5 PILE REMOVAL DESIGN

With reference to the available rock probe results and proposed tunnel crown levels, the existing piles (i.e. RC square pile) of Columns P2, P6 and P8 have encroached into the tunnel horizon. As such, pile removal is required for the encroached pile sections to prevent obstruction to the Tunnel Boring Machine (TBM) during tunnel operation. The proposed pile removal scheme for Columns P2, P6 and P8 consists of vertical caisson shaft with mined adit. Refer to Figures 16 and 17 for the typical details of proposed pile removal scheme.

Firstly, jet grout block will be provided to envelope the proposed caisson shaft and mined adit. A pumping well will be provided inside the shaft for dewatering as a measure to check efficiency of the jet grouting block prior to excavation. During dewatering, an observation well provided outside of the shaft will be used to monitor the ground water level as to ensure that the dewatering does not extend beyond the shaft vicinity. As an added mitigation measure, any subsequent ingress of water (if any) through the jet grouted block envelope will be indicated by an observation well installed inside the shaft. 100mm thick shotcrete with 1/2"x3" hexagonal wire mesh will be provided as caisson lining for the excavated shaft, if required.

Assessment on the impact of proposed pile removal works to existing structure and proposed underpinning structures have been conducted. The analysis was carried out with Plaxis FEM 3-D software where the existing RC square pile groups are represented by pile group being conservatively modelled at location immediate outside to the proposed jet grouted block which is the closest as compared to actual pile group locations.

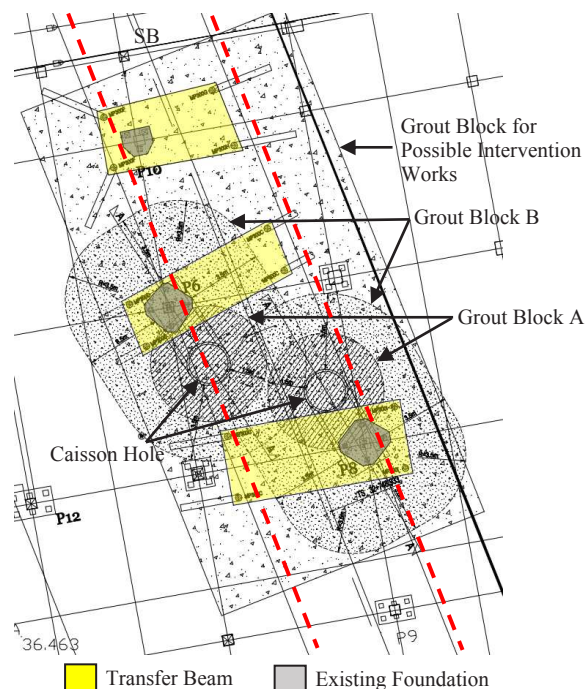


Figure 16 Layout Plan of Proposed Pile Removal Scheme (Caisson Shaft Method)

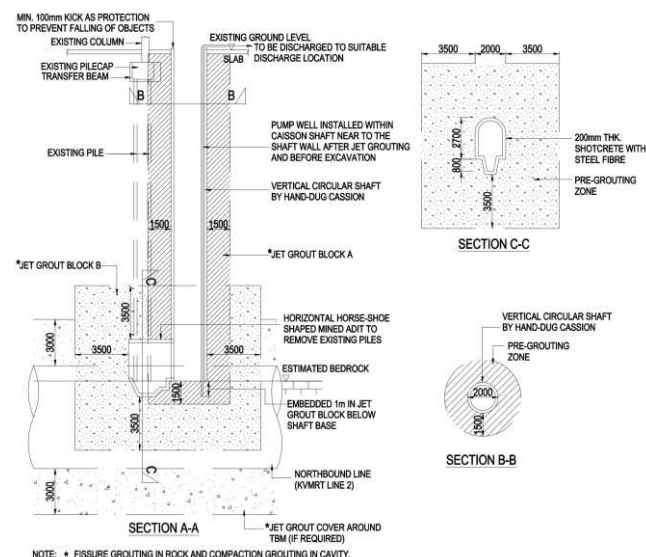


Figure 17 Typical Details of Proposed Pile Removal Scheme (Caisson Shaft Method)

Besides, in modelling the proposed Micropiles, two scenarios of pile locations, i.e. within and outside the extent of proposed jet grout block A which is along the caisson shaft have been captured. The results showed that the proposed Micropile within the proposed jet grout block A is affected by the grouting works but still within the allowable capacity. As such, the proposed caisson shaft is located according to this analysis finding where no Micropiles are located within the extent of proposed jet grout block A. Refer to Figure 18 for the Plaxis analysis model.

Table 3 Ground Deformation

Stage	Maximum Settlement (mm)
Apply Loading on Existing Pile group (Initial)	-
Install Micropiles	0.03
Provide Grout Blocks	0.23
Construct Transfer Beam	0.44
Detach Existing Piles	5.109
Caisson Hole Excavation	5.162
Mined Adit (Final)	5.20

Table 4 Displacements of Existing RC Square Piles (RC200)

Pile Reference	Vertical Displacement (mm)	Horizontal Displacement (mm)
	Mined Adit (Final)	
5	0.42	1.32
6	0.40	1.32
7	0.28	1.32
8	0.31	1.32

Table 5 Forces of Existing RC Square Piles (RC200)

Pile Reference	Initial	Final	Initial	Final	Initial	Final
	Axial Load (kN)		Shear Force (kN)		Bending Moment (kNm)	
Allowable Pile Capacity	450		39		9	
5	458.6	466.6	27.06	29.49	1.58	1.66
6	457.4	464.4	28.70	31.55	1.39	1.41
7	457.5	456.6	11.68	13.35	1.84	2.58
8	464.3	464.8	19.12	21.06	1.33	1.46
Total Reaction:	1837.8	1852.4				

Notes:

1. Initial: Apply Loading on existing pile groups.
2. Final: Mined adit.
3. The analysed pile axial forces are to simulate the impact of proposed pile removal works to existing piles in percentage only.
4. Additional pilecap self weight has been included on top of the column load back calculated based on the pile capacity to obtain a more conservative results.

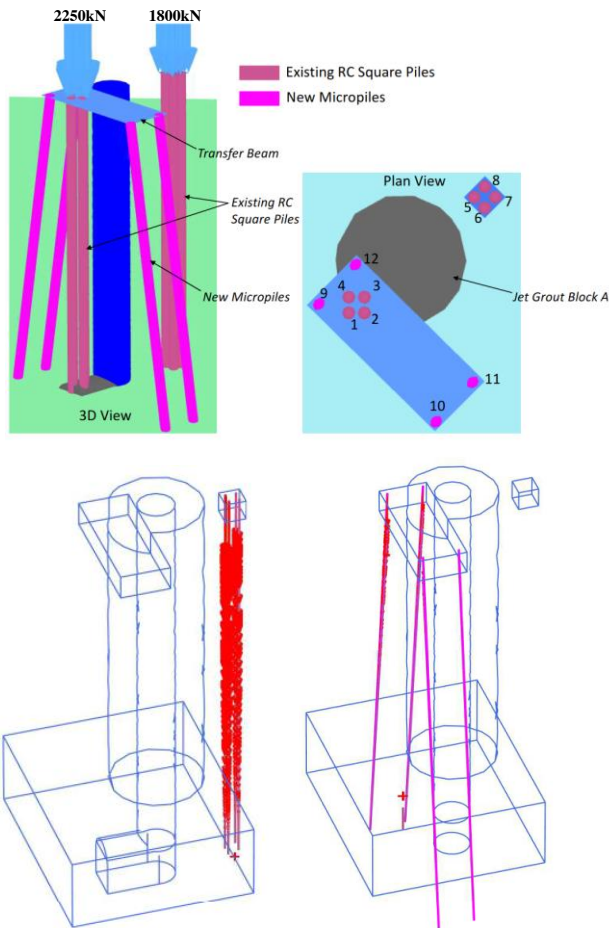


Figure 18 Plaxis FEM 3-D Model for Impact Assessment on Pile Removal by Caisson Shaft Method

Table 6 Displacements of Proposed Underpinning Micropiles (MP300)

Pile Reference	Vertical Displacement (mm)		Horizontal Displacement (mm)	
	Initial	Final	Initial	Final
9	4.74	4.82	2.72	2.79
10	2.57	2.61	1.89	1.94
11	1.03	1.00	1.97	2.02
12	3.28	3.28	2.77	2.83

Notes:

1. Initial: Cut-off existing piles with underpinning.
2. Final: Mined adit.

The 3-D FEM analysis results show negligible impact on ground deformation, settlement and capacity of existing RC square piles and proposed underpinning Micropiles.

Alternative pile removal proposal by inclined coring method can also be considered. Firstly, jet grout line blocks will be provided as a guidance for the inclination of coring holes as well as in controlling ground movement. The inclined coring holes are designed to be located at positions to reach and fully cover the estimated section pile within tunnel horizon. Refer to Figure 19 for the typical details of alternative proposed pile removal scheme by inclined coring method. This method was successfully used in other location as reported by Tan et. Al. (2019).

Table 7 Forces of Proposed Underpinning Micropiles (MP300)

Pile Reference	Initial	Final	Initial	Final	Initial	Final
	Axial Load (kN)		Shear Force (kN)		Bending Moment (kNm)	
Allowable Pile Capacity (MP300C)	500		122		53	
Allowable Pile Capacity (MP300D)	1200		137		83	
9 (MP300D)	1069	976	24.39	24.64	13.71	13.85
10 (MP300C)	454	458	26.11	28.21	10.04	10.84
11 (MP300C)	407	404	35.96	28.37	9.66	10.54
12 (MP300D)	926	946	89.87	81.42	21.06	19.16
Total Reaction:	2856	2784				

Notes:

1. Initial: Cut-off existing piles with underpinning.
2. Final: Mined adit.
3. The analysed pile axial forces are to simulate the impact of proposed pile removal works to existing piles in percentage only.
4. Pile ref. 12 is Micropile being modelled within proposed Jet Grout Block A which is significantly affected by the Jet Grout Block A.

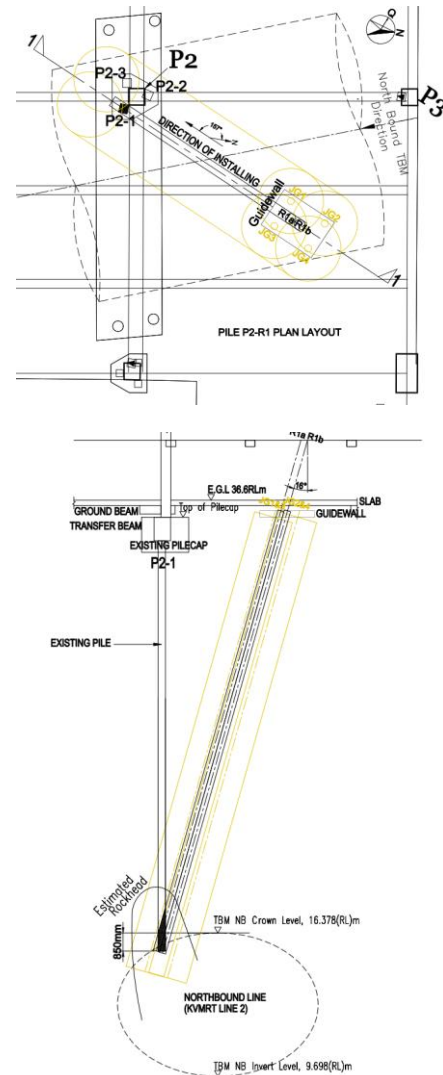


Figure 19 Typical Details of Proposed Alternative Pile Removal Scheme (Inclined Coring Method)

6 TUNNEL LINING IMPACT ASSESSMENT

The segmental lining is checked for any influence from both existing and underpinning piles during segmental lining design

stage. Analysis by Plaxis FEM software have been carried out to assess the impact on tunnel lining from existing piles and proposed underpinning Micropiles. Refer to Figures 20 and 21 for the analysed cross section A-A which is the most critical section, i.e. lowest bedrock levels zone within the assessment extent where the existing pile toe levels are the closest to the tunnel lining.

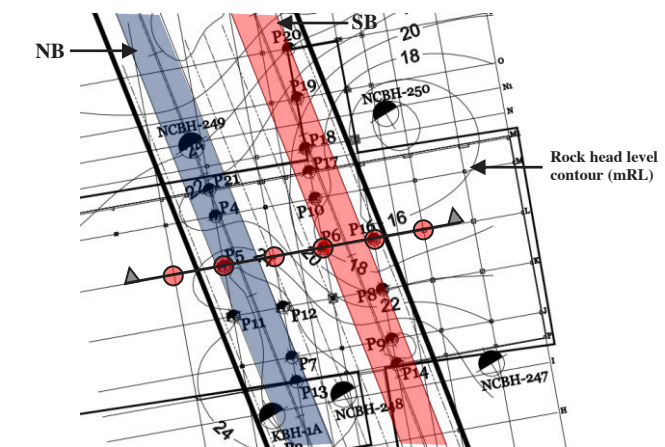


Figure 20 Location Plan of Cross Section for Tunnel Lining Impact Assessment from Existing Piles

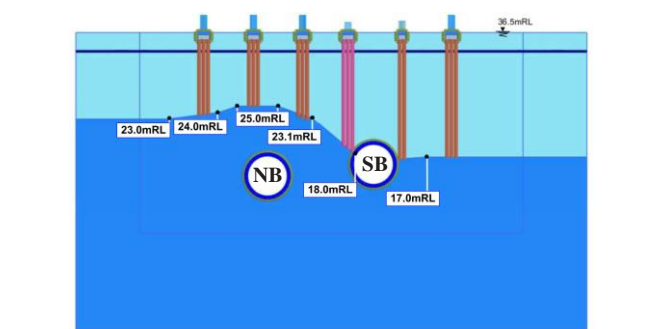


Figure 21 Plaxis Model Cross Section for Tunnel Lining Impact Assessment from Existing Piles

Table 8 Forces on Tunnel Lining from Existing Piles

Tunnel Lining	Axial Forces (kN/m)	Bending Moment (kNm/m)
NB	-761.6	-6.71
SB	-841.1	-72.51

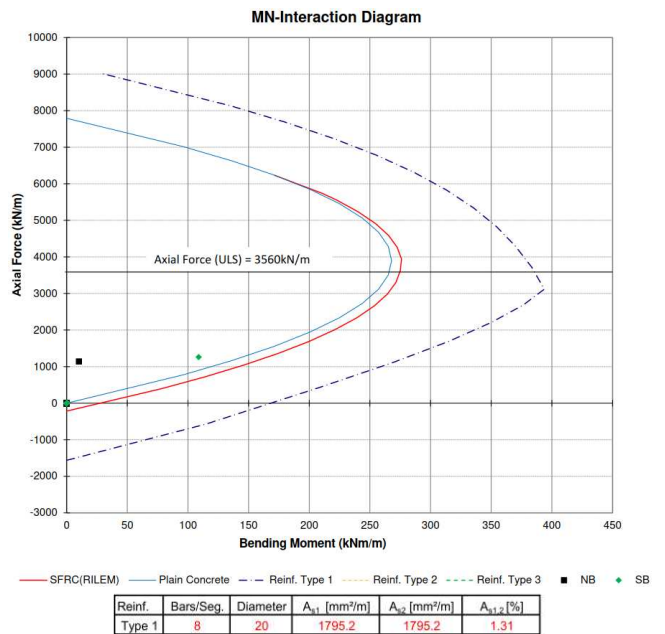


Figure 22 N-M Chart for Tunnel Lining Impact Assessment from Existing Piles

For the tunnel lining impact assessment from proposed underpinning Micropiles, designed rock socketing levels and lengths are considered and being modelled. The bedrock levels are slightly simplified to be at the lowest levels at the analysed cross section. Refer to Figures 23 and 24 for the Plaxis Model cross section.

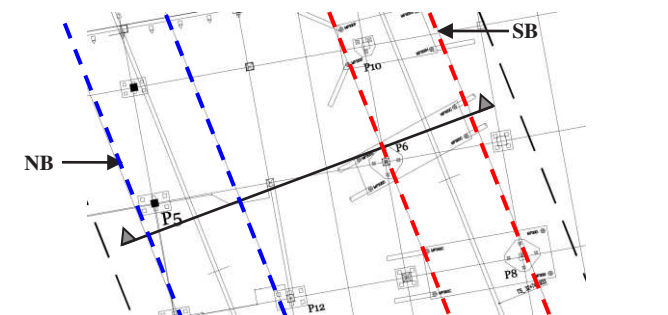


Figure 23 Location Plan of Cross Section for Tunnel Lining Impact Assessment from Proposed Underpinning Micropiles

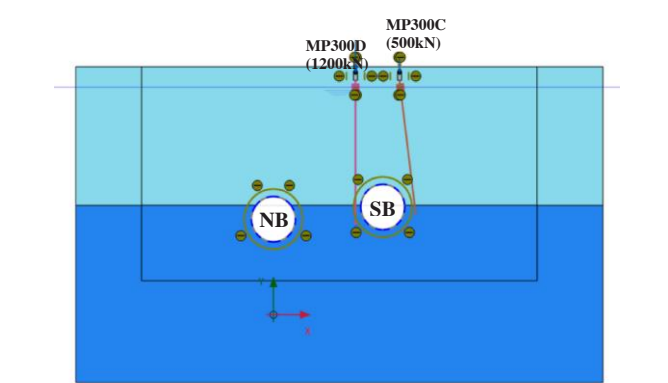


Figure 24 Plaxis Model Cross Section for Tunnel Lining Impact Assessment from Proposed Underpinning Micropiles

Table 9 Forces on Tunnel Lining from Proposed Underpinning Micropiles

Tunnel Lining	Axial Forces (kN/m)	Bending Moment (kNm/m)
NB	-1150	22.61
SB	-1119	-38.33

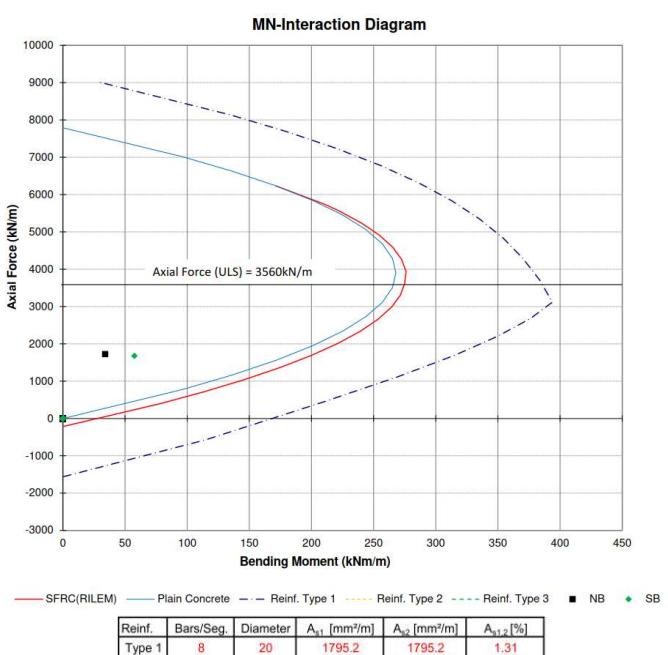


Figure 25 N-M Chart for Tunnel Lining Impact Assessment from Proposed Underpinning Micropiles

Plaxis analysis details and results show that the proposed tunnel lining is with adequate capacity when under influence from existing piles and proposed Underpinning Micropiles respectively.

7 CONCLUSIONS

The analysed column settlements after underpinning works are within the allowable settlement and with acceptable distortion thus the structural conditions of the main buildings are within structural allowable tolerance. Plaxis analysis of proposed pile removal works shows the impact to existing structures and proposed underpinning structures are within the acceptable tolerance. Besides, the impact assessment on the tunnel lining shows that the proposed tunnel lining has adequate capacity to withstand the effect of existing piles and proposed Micropiles onto the structure.

However, instrumentation monitoring has to be carried out during underpinning works, pile removal works and tunnelling works to monitor the settlement/displacement of existing buildings of Kompleks Budaya Kraf to ensure the safety of building.

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