TUNNEL-PILE-SOIL INTERACTION

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DEDICATION

This project report is dedicated to my father, Mr. Polanippan Maniam, and my mother, Mrs. Chellamah Athimulan who taught me with best kind of knowledge, attitude and self-discipline.

Not forgetting my wife Kogilavani Subramaniam and my two daughters, Danhushiyya and Jarshita, who always be patient with me during my absence at some family occasions. Their support has really boost me to complete my study successfully.

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ABSTRACT

Too many developments in urban area has forced the authority to look for alternative way to occupy the underground space for development. Many parts of the world especially developing countries has started utilizing subsurface area for development of transportation system, township, telecommunication, defence and etc. Tunnelling is needed to expand and provide better transportation in urban area which currently facing shortage of surface space. Therefore, tunnelling close to existing structure in urban area is become unavoidable. Tunnelling works close to existing structure will cause some effect to the existing structures when the structures falls in the tunnelling influence zone. Further to this, the risk arises to existing structures due to tunnelling works need to be seriously focused as it may cause catastrophic failures of structures and can cause losses of human lives. Considering these risks, this study focuses on the tunnel-pile-soil interaction by performing a physical modelling test. By doing laboratory tests, ground subsidence and displacement of piles which positioned in the tunnel influence zone has been measured and discussed. Volume loss and type of soil is kept constant while the location of ground subsidence is measured at different location along the tunnel alignment. The results obtained compared to previous studies and discussed. The axial and lateral displacement of pile is higher when it is placed close to tunnelling activity. The ground surface subsidence is lesser when the pile is close to tunnel during tunnelling advancement. Bending moment of the pile observed higher at Zone II of tunnel influence zone.

ABSTRAK

Pembangunan yang pesat di kawasan bandar yang padat dengan penduduk dan keperluan untuk mempertingkatkan kemudahan infrstruktur telah mendorong pihak berkuasa untuk membangun ruang bawah tanah sebagai alternatif kepada pembangunan infrastruktur. Kebanyakkan negara maju telahpun mula menggunakan ruang bawah tanah bagi tujuan pembinaan sistem pengangkutan, telekomunikasi, dan lain-lain infrastruktur berkaitan. Pembinaan terowong dilihat sebagai satu alternatif yang baik bagi penyediaan infrastruktur pengangkutan bagi kawasan bandar yang memerlukan fasiliti infrastruktur tambahan. Oleh yang demikian, pembinaan terowong di bandar melalui sturuktur sedia ada adalah sesuatu yang tidak dapat dielakkan. Kerja terowong berhampiran dengan struktur sedia ada akan mendatangkan kesan negatif sekiranya struktur berkenaan berada di dalam Zon Pengaruh Terowong. Maka, perhatian yang serius perlu diberikan ke atas struktur-struktur tersebut bagi mengelakkan sebarang bencana ke atas alam dan manusia akibat kegagalan tanah dan struktur semasa membina terowong. Dengan mengambilkira risiko ini, kajian berhubung terowong-cerucuk-tanah telah dijalankan di makmal menggunakan model fizikal. Hasil kajian menunjukkan pergerakkan cerucuk secara mendatar dan menegak (enapan) adalah rendah apabila cerucuk berada jauh dari aktiviti pengorekkan terowong. Pemendapan tanah adalah rendah apabila cerucuk berhampiran dengan terowong semasa aktiviti pengorekan terowong. Manakala lenturan momen cerucuk adalah tinggi di dalam Zon II, Zon Pengaruh Cerucuk.

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LIST OF ABBREVIATIONS

EPB	-	Earth Pressure Balance
LVDT	-	Linear Variable Differential Transformers
NATM	-	New Australian Tunnelling Method
TBM	-	Tunnel Boring Machin
UTM	-	Universiti Teknologi Malaysia
GRC	-	Ground Reaction Curve
LDP	-	Longitudinal Displacement Method

LIST OF SYMBOLS

C	-	Cover of tunnel
D	-	Tunnel Diameter
d_p	-	Pile diameter
d_{50}	-	Mean grain size
D_r	-	Relative density
H	-	Tunnel depth to the axis level
i	-	Horizontal distance from tunnel centre line to inflection point
i_x	-	Initial position of the tunnel
k	-	Empirical constant
l_p	-	Pile lateral movement
L_p	-	Pile length
S	-	Ground surface settlement
S_p	-	Pile settlement
S_v	-	Vertical settlement
S_{max}	-	Maximum surface settlement
V_L	-	Ground loss
V_S	-	Volume of surface settlement trough
z_o	-	Tunnel depth
X	-	Distance from tunnel centre
x	-	Distance from the tunnel centre line
Y	-	Length of tunnel longitudinally
Z	-	Pile depth
x_f	-	Location of the tunnel face

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CHAPTER 1

INTRODUCTION

1.1 Background of the Problem

Moving towards developing country, more constructions are concentrated at urban area. Transportation, power supply, sewerage, water and other related facilities need to be upgraded to support the demand of the development. Further developments in the crowded city center will cause environmental problems and create disturbance to the public. As an alternative solution, the underground structures has seen as a way to overcome this issues or problems. Construction of underground structures in urban area such as long length tunnels provide time and cost saving journey, minimizing impact to the environment with increased safety.

Transportation and service providing industry gives more priority to tunnel construction nowadays. The construction of tunnel would be a good choice for the place where ground surface has been occupied mostly by buildings, roads and highways. Selection of tunnel construction depends on few criteria like functions, soil characteristics, alignment and project cost or budget. Tunnel alignment basically depends on the locations with highly ridership (ITA Working Group Number 13, 2003). Factors such as project cost, safety, right of way in tunnel construction, accessibility, environmental impact and schedule. At most cases the tunnel alignment is not avoidable to pass below or in between existing structures or services.

Size of the building, foundations and other existing structures which available underground might be subject to movement during the tunnel excavation. Tunnel size and method of tunnel excavation also give an impact to the existing structures in the tunnel alignment. Tunnelling activity can give an impact in term of displacement or settlement to its surrounding ground, structures (substructure or superstructure) and existing facilities (above or below ground). In order to minimise the impact of the tunnelling activity, it is critical to understand and analyses the effect of tunnelling before, during and after the construction so that hazard can be minimised and risk mitigation can be prepared beforehand. The settlement of the ground surface due to the soil movement is the major constraints that cannot be avoided during tunnelling.

There were a lot of research has been conducted to study the relationships between tunnel-soil-structure in identifying the respond of the interaction. Some of the approaches which has been used include analytical, empirical, physical modelling, numerical and full-scale field approach (Mair and Williamson, 2014). The physical modelling is the most preferred method due to the repeatable tests and boundary condition can be prearranged depending on the required situations. Recent research was carried out by (Franza and DeJong, 2019) in relation with “Elastoplastic Solutions to Predict Tunneling-

Induced Load Redistribution and Deformation of Surface Structures" which is focused on the development of routine design tool by investigating the tunnel structure relationships that is able to justify foundations and structure characteristics. The studies take into account the direct greenfield inputs and relying on a limited number of rational parameters for both continuous and separated footings.

1.2 Statement of the Problem

Tunnelling can be constructed by few methods like cut and cover, shield driven, bored tunnel, immersed tube, drill and blast, Sequential Excavation Method (SEM) and jacked tunnel. Commonly, drill and blast, cut and cover and bored tunnelling method were used in the construction of tunnelling. Ground movement due tunnelling is unavoidable. Ground movement due to tunnelling either vertically or horizontally occurred as a result of stress release (Soomro, Ng, Liu, and Memon, 2017) by ground around excavated tunnel surface (after excavation) and also face pressure created by some tunnel construction method (during excavation). This stress release and face pressure directly or indirectly will give an impact to the existing underground structures such as pile. The impact to the pile foundation may give negative implication on structural serviceability and integrity to the pile. Therefore potential risk of negative impact due to ground and pile settlement need to be studied in detail.

Basically, settlement or ground movement (vertically and horizontally) from tunnel excavation will result in short or long term conditions to the existing pile foundation and surrounding ground. Short term settlement is refers to volume loss created surround the tunnel lining surface due to stress relief and ground surface settlement. For long-term settlement, it normally happens in cohesive soil where primary and secondary consolidation will take place (Oh, Park, Kim, Chang, Lee, and Choi, 2017). Previous researchers focused in investigating tunnel-pile interaction based on ground surface settlement, tilting of the pile foundation or load transfer mechanism. However the tunnel-pile-soil interaction less discussed (Dias and Bezuijen, 2014). Therefore, a study aiming to the relationships of newly constructed tunnels towards existing pile foundations is crucial besides analysing the ground deformation and the pile settlement simultaneously. The inter-relationships between tunnel-pile-soil is noticeable when the soil and pile located in the tunnel influence zone (Vu, Broere and Bosch, 2016).

Detail study need to be carried out to determine the respond of the tunnel-pile-soil due to tunnelling in order to minimise the damage to the existing facilities (Al-Omari, Al-Soud and Al-Zuhairi, 2019). Movement of existing pile are referred to pile head settlement and its lateral displacement. The mechanism of ground movement and the behavior of existing pile exposed to the tunnel construction can be analysed by using a reduced scale of physical modeling. Any negligence in identifying the effect of tunnelling to the surroundings will cause catastrophic failures to the existing substructures, superstructures and infrastructure. P. Kirsch, A. Kirsch, Calderon, Marling, Harris and Shi (2014) investigated tunnel construction risks and concluded that tunnelling is clearly a dangerous high-risk activity.

1.3 Objectives of the Study

Physical modelling approach will be used in this study:

i. To obtain the response of the existing pile (long pile) in terms of its lateral and vertical movement with previous study due to tunnelling.

ii. To obtain the transverse and longitudinal surface settlement of soil block above tunnel alignment.

iii. To obtain the response of the existing pile (long pile) in terms of its bending moment with previous study due to tunnelling.

iv. To validate and evaluate the obtained test results with previous study by means of physical modelling.

1.4 Scope and Limitations of the Study

The study will be conducted based on physical modelling. The method is based on:

i. An assessment of the pile settlement due to the tunnelling.

ii. The study will not observe on the tilting of pile or load transfer mechanism.

iii. The physical model test will be carried out using a box of 60 x 60 x 50 cm (length x width x height) under a single gravity condition.

iv. The relative density of the sand used is maintained at 50% (medium sand) while cover to diameter ratio (C/D) of 3.0 was used with the presence of pile (long pile).

v. The tunnel constructed has a 49 mm outer diameter and shielded by a tube of 50 mm outer diameter. It is made up of aluminium and in a circular shape which then represents the Tunnel Boring Machine technique.

vi. Long pile with 9 mm diameter and 181.5 mm length (embedded length in sand) are placed at distance of 1.5D (tunnel diameter, D)

1.5 Significance of the Study

As the demand for the public transportation keep increasing at the development of urban area, exploration to utilize the underground space is currently studied and adopted for development. Tunnels are constructed to provide access to the transportation, water supply, sewerage disposal, power supply, telecommunication, defence and others to minimise the surface congestions and environmental impact. It is common for tunnels being constructed close to pile foundation. Physical modelling test and its analysis will help in giving a well understanding and verification of the field study. By doing this study, the risks due to unexpected failures with regards to tunnelling activity can be identified or predicted as part of precaution measures.

This study is crucial in understanding the performance and response of the soil and the existing pile due to tunnel excavation works; taking into account the relationship of tunnel-pile-soil interaction. Ground surface settlement and pile displacement prompted by tunnelling actions may happen due to various reasons. The study concentrate on the factors related to the pile location with regards to tunnel depth over diameter ratio (C/D ratio) and the pile behavior with regards to the distance from tunnel axis. With the selection of relevant boundary condition, a proper correlation can be made to represent the actual conditions at site.

1.6 Hypothesis

From the research which will be conducted later, the results expected is as below:

i. The surface settlement trough pattern is predicted to be same with or without the presence of pile.
ii. Lateral movement to be higher than the settlement/ vertical movement of the pile.
iii. Bending moment to be higher at the top part (Zone I and Zone II of tunnel influence zone) of the pile.

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