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ANALYSIS AND DESIGN OF MRT'S CIRCULAR TUNNEL IN CENTRAL JAKARTA

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ABSTRACT

Jakarta MRT was one of solution to solve the traffic jam in Jakarta. There are two physical constructions which serves as the main infrastructure of Jakarta MRT, elevated and underground track. It is not only the first MRT in Indonesia but also, the first large-scale underground works in Jakarta. The physical construction of underground structure became an interesting case to be researched. The use of precast concrete tunnel lining (PCTL) segment was necessary to hold the loads and to provide the space for underground track.

In designing the tunnel lining, calculation of the member forces and safety check are necessary to determine the amount of rebar and the dimension, and also to know the value of safety, so, the tunnel lining can be used as the function. According to the guidelines for the design of shield tunnel lining issued by International Tunnelling Association (ITA, 2000), the member forces of tunnel lining could be calculated by (1) Elastic Equation Method, (2) Bedded Frame Method, (3) Finite Element Method (FEM). In this research, the member forces of tunnel lining are calculated using analytical method, without computer program. Therefore, method (1) is used to know the value of each member forces to be used for designing the reinforcement bars. The member forces are analysed for tunnel lining with 6.8 m outer diameters, 1.5 m width and 0.25 m thickness in Jakarta MRT CP106 (Bundaran HI).

Based on research which has been done, obtained the maximum values for positive bending moment in the tunnel crown ($\theta = 0°$) is 101.352 kN.m, for negative bending moment in the tunnel axis ($\theta = 90°$) is -281.394 kN.m. In contrary, the value of maximum axial force is in the tunnel axis ($\theta = 90°$) is 1094.538 kN, for minimum axial force is in the tunnel crown ($\theta = 0°$) is 904.674 kN. While, the value of maximum shear force is in ($\theta = 120°$) is 118.740 kN, for minimum shear force is in ($\theta = 30°$) is -66.866 kN. The result of safety checks against member forces in tunnel lining, the value of nominal bending moment multiplied by reduction factor ($\phi \cdot M_n$) is 296.263 kN.m, bigger than the value of ultimate bending moment (M_u) is 281.394 kN.m. For the value of nominal shear force multiplied by reduction factor ($\phi \cdot V_n$) is 136.095 kN, bigger than the value of ultimate shear force (V_u) is 118.740 kN. While, safety check against thrust force of shield jack obtained the value of maximum compressive stress of concrete segment (σ_c) is 5.016 MN/m^2, bigger than the value of allowable stress (σ_{ca}) is 16 MN/m^2.

Keywords: *Jakarta MRT, underground, tunnel lining, member forces, Elastic Equation Method.*

1. INTRODUCTION

1.1 Background

The capital city of Indonesia, Jakarta, officially known as the Special Capital Region of Jakarta, is the capital and largest city of the Republic of Indonesia. Jakarta is the country's economic, cultural and political centre, with 10,075,300 of population (2014), with 661.5 km^2, this is the most populous city and the largest capital in South-East Asia.

Jakarta has similarity with others large capital and city around the world and it has several problems. The traffic jam is one of the problem is caused by several things, one of them is the capacity of traffic is not equal with the capacity of road. Construction of new roads or road widening also is a solution is not carried out, because there is no enough land in Jakarta.

One of the solution to solve traffic jam in Jakarta is with public transportation which is fast, convenient, and safe. On October 10, 2013, the Government of Jakarta held ground-breaking ceremony of The Jakarta MRT project after over the past thirty years. MRT (Mass Rapid Transit) is an urban transport system which has three main criteria, mass (large carrying capacity), rapid (faster travel times and high frequency), and transit (stops at many stations in the urban main point).

There are two physical constructions which serves as the main infrastructure of Jakarta MRT, elevated and underground track. It is not only the first MRT in Indonesia but also, the first large-scale underground works in Jakarta. The physical construction of underground structure became an interesting case to be researched. The use of precast concrete tunnel lining (PCTL) segment was necessary to against the loads and to provide the space for underground track.

1.2 Research Objectives

The main objective of this research is to analyse and design of shield tunnel lining of a shallow tunnel under the ground in soft ground in urban areas which can be used as reference for further studies in Central Jakarta or similar condition. In detail, the objectives of this research are:

1) To determine the geotechnical data for designing the tunnel lining;
2) To design the loads for tunnel lining;
3) To compute the member forces of tunnel lining;
4) To check the safety of tunnel lining.

1.3 Benefits of Research

There are several benefits which can be obtained from this research. In detail, the benefits of this research are:

1) To know the values of member forces caused by loads in tunnel lining;
2) To know the strength of shield tunnel lining to loads;
3) To know the safety of tunnel lining;
4) To be used as reference of designing the shield tunnel lining.

1.4 Scope of Research

In this thesis, scope of research is needed to focus on main problem is researched. This thesis focuses on the structural aspects of the interaction problem due to earth pressure. In detail, the scopes of research are addressed as follows:

1) Object of research is tunnel only of Jakarta MRT contract package CP-106 (Bundaran HI) in Central Jakarta;
2) Calculation method which is used is elastic equation method or usual calculation method as analytical calculation;
3) The data which are used are secondary data, were obtained from SMCC-HK JO. While, the data which are not available, are assumed base on theory which supports and from the previous researches;
4) Only primary tunnel lining which is computed;
5) The design of shield tunnel lining parameters according to the guidelines for the design of shield tunnel lining from International Tunnelling Association (ITA) (2000) and Standard Specification for Tunnelling – 2006: Shield Tunnels, issued by Japan Society of Civil Engineers (JSCE) (2006);
6) Key segment, bolt and gasket are not calculated;
7) Loads are calculated only primary loads (vertical and horizontal earth pressure, water pressure, dead load, surcharge, and subgrade reaction (soil reaction);

8) Damage the earthquake, building or influence and of on-linier building behaviour are not considered during this research.

2. LITERATURE REVIEW

2.1 Tunnel

Tunnel is defined as "the covered passage ways with vehicles or subways access that is limited to portals regardless of structure types and construction techniques" according to the American Association of State Highway and Transportation Officials (AASHTO) Technical Committee for Tunnels. There are 3 (three) different types of tunnels construction from different soil layer or location: (a) Soft ground; (b) Hard rock; (c) Underwater. Cut and cover method, Tunnel Boring Machine (TBM) method, and immersed tube tunnel method are the method of constructing tunnel in the recent years.

2.2 Tunnelling in Soft Ground

Soft ground in generally composed of clay, silt, sand, gravel or mud. In this type of tunnel, stand-up time of how long the ground will safely stand by itself of weight at the point of excavation is of paramount importance. Because, stand-up time is generally short when tunnelling through the soft ground.

According to Terzaghi's consolidation theory, a load suddenly applied on a water-saturated cohesive soil acts, in the first instance, only upon the pore water. Based on the mechanism of its collapse, soft ground in the tunnel is classified as follows (Terzaghi, 1950): Firm Ground; Ravelling Ground; Running Ground; Flowing Ground; Squeezing Ground; and Swelling Ground.

2.3 Types and Elements of Segments

An important component of tunnel infrastructure is the tunnel lining systems. Tunnel lining are normally constructed in a circular shape using tunnel boring machines (TBMs), is shown in **Figure 1**. As protective barriers against large overburden loads and complex geotechnical surrounding exposure condition. Single shell linings are often made of reinforced precast concrete segments is shown in **Figure 2**. Types of segments, are shown in **Figure 3**.

Key Segment

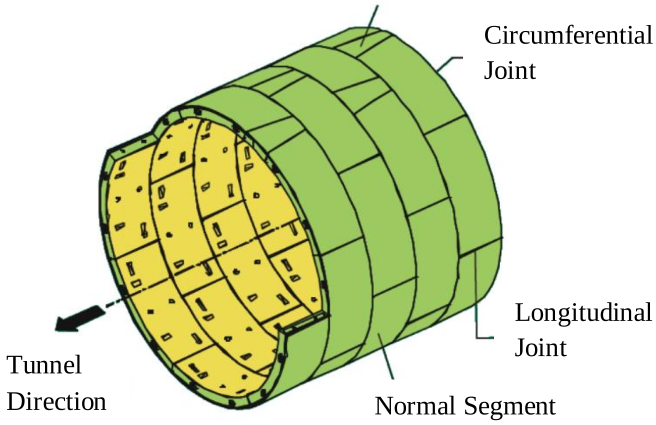

Figure 1. Structure and parts of tunnel lining

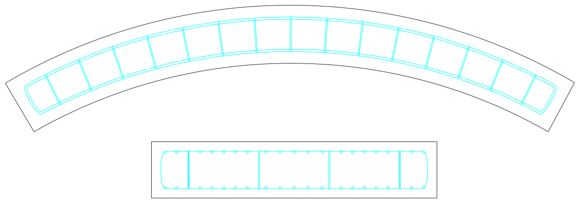

Figure 2. Example of reinforced segment

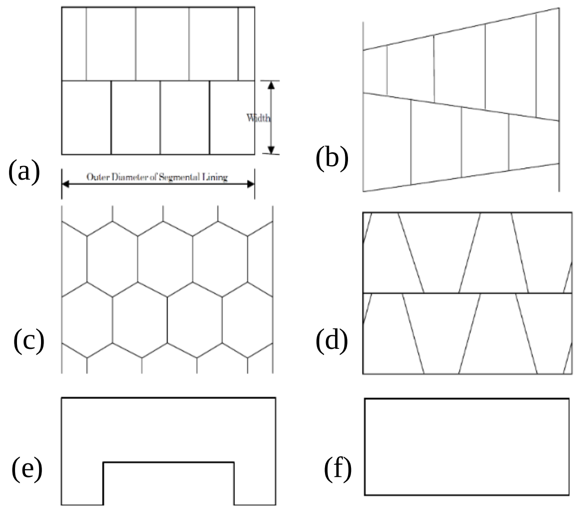

Figure 3. Types of segment
(source: ITA - WG, 2000)

2.4 Design of Shield Tunnel Lining

Following the planning works for the tunnel, the lining of a shield tunnel is designed according to the International Tunnelling Association - Working Group (ITA - WG) in 2000 the following sequence as a rule:

1) Adherence to specification, code or standard;
2) Decision on inner dimension of tunnel;
3) Determination of load condition;
4) Determination of lining conditions;
5) Computation of member forces;
6) Safety check;
7) Review;
8) Approval of the design.

2.5 Lining Loads

The following loads should be considered in the design of lining. There are several kinds of loads according to the Japan Society of Civil Engineers (JSCE) and International Tunnelling Association (ITA) as addressed in **Table 1**. A common loads distribution model is shown in **Figure 4**, where the vertical soil reaction is uniform and horizontal soil reaction is distributed in a triangular between 45° to 135° from the crown in the both sides.

Table 1. Kinds of lining loads
(source: JSCE, 2006)

Primary Loads	1) Ground Pressure (Vertical and Horizontal)
	2) Water Pressure
	3) Dead Load
	4) Surcharge
	5) Subgrade Reaction (soil reaction)
Secondary Loads	1) Internal Loads
	2) Construction Loads
	3) Effect of Earthquake
Special Loads	1) Effect of Adjacent Tunnels
	2) Effect of Settlement
	3) Other Loads

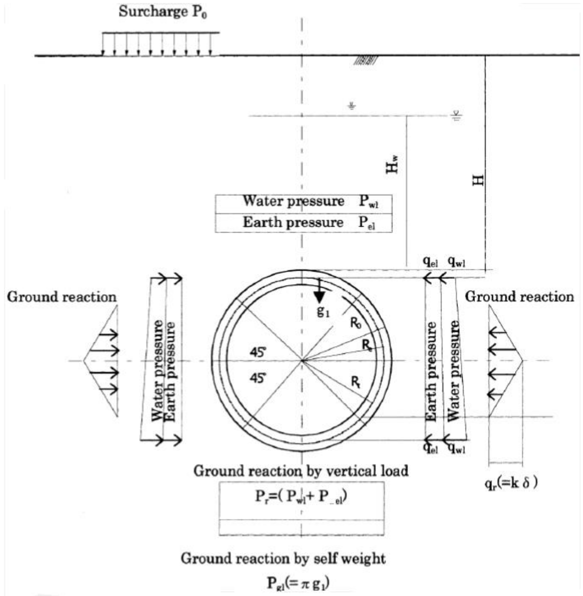

Figure 4. Conventional loads model
(source: ITA, 2000 and JSCE, 2001)

2.6 Structural Design of Segment

The design calculation of the cross-section of tunnel should be done by considering the following critical sections (**Figure 5**):

1) Deepest overburden;
2) Shallowest overburden;
3) Highest groundwater table;
4) Lowest groundwater table;
5) Large surcharge;
6) Eccentric loads;
7) Unlevel surface;
8) Adjacent tunnel at present or planned one in the future.

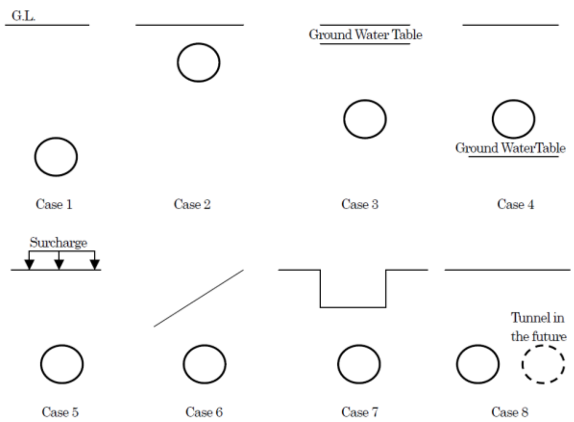

Figure 5. Critical section to be checked
(source: ITA, 2000)

The notations used for the member forces in the structural calculation of lining is defined as follows (**Figure 6**):

- Axial force (N)
- Shear force (Q)
- Bending moment (M)

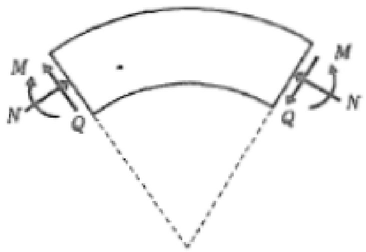

Figure 6. Notations used for the member force (source: Tóth, 2015)

The member forces are computed using various methods:

1) Elastic Equation Method;
2) Bedded Frame Method;
3) Finite Element Method (FEM);
4) Other analytical method.

The elastic equation method is a simple method for calculating member forces without a computer (**Table 2**). However, it cannot evaluate: (1) the ununiformly varying load due to charge of soil condition; (2) eccentric loads; (3) hydrostatic pressure; (4) spring force to stimulate subgrade reaction; (5) effect of joint by simulating joints as hinges or rotation springs (semi-hinge).

Table 2. Elastic equation method issued by JSCE in 2006

Loads	Bending moment	Axial force	Shear force
Vertical load ($P = P_{e1} + P_{w1}$)	$M = \frac{1}{4}(1 - 2\sin^2\theta)(P_{e1} + P_{w1}) R_c^2$	$N = (P_{e1} + P_{w1}) R_c \cdot \sin^2\theta$	$Q = -(P_{e1} + P_{w1}) R_c \cdot \sin\theta \cdot \cos\theta$
Horizontal load ($Q = q_{e1} + q_{w1}$)	$M = \frac{1}{4}(1 - 2\cos^2\theta)(q_{e1} + q_{w1}) Rc^2$	$N = (q_{e1} + q_{w1}) R_c \cdot \cos^2\theta$	$Q = (q_{e1} + q_{w1}) R_c \cdot \sin\theta \cdot \cos\theta$
Horizontal Triangular load ($Q' = q_{e2} + q_{w2} - q_{e1} - q_{w1}$)	$M = \frac{1}{48}(6 - 3\cos\theta - 12\cos^2\theta + 4\cos^3\theta)(q_{e2} + q_{w2} - q_{e1} - q_{w1}) R_c^2$	$N = \frac{1}{16}(\cos\theta + 8\cos^2\theta - 4\cos^3\theta)(q_{e2} + q_{w2} - q_{e1} - q_{w1}) R_c$	$Q = \frac{1}{16}(\sin\theta + 8\sin\theta\cos\theta - 4\sin\theta\cos^2\theta)(q_{e2} + q_{w2} - q_{e1} - q_{w1}) R_c$
Soil reaction ($q_r = k \cdot \delta$)	**If, $0 \le \theta < \frac{\pi}{4}$,** $M = (0.2346 - 0.3536\cos\theta)\, q_r \cdot R_c^2$ **If, $\frac{\pi}{4} \le \theta \le \frac{\pi}{2}$,** $M = (-0.3487 + 0.5\sin^2\theta + 0.2357\cos^3\theta)\, q_r \cdot R_c^2$	**If, $\frac{\pi}{4} \le \theta \le \frac{\pi}{2}$,** $N = (-0.7071\cos\theta + \cos^2\theta + 0.7071\sin^2\theta \cdot \cos\theta)\, q_r \cdot R_c$ **If, $0 \le \theta < \frac{\pi}{4}$,** $N = 0.3536\cos\theta \cdot q_r \cdot R_c$	**If, $0 \le \theta < \frac{\pi}{4}$,** $M = 0.3536\sin\theta \cdot q_r \cdot R_c$ **If, $\frac{\pi}{4} \le \theta \le \frac{\pi}{2}$,** $M = (\sin\theta \cdot \cos\theta - 0.7071\cos^2\theta \cdot \sin\theta)\, q_r \cdot R_c$
Dead load ($P_g = \pi \cdot g$)	**If, $0 \le \theta \le \frac{\pi}{2}$,** $M = (\frac{3}{8}\pi - \theta \cdot \sin\theta - \frac{5}{6}\cos\theta)\, g \cdot R_c^2$ **If, $\frac{\pi}{2} \le \theta \le \pi$,** $M = \{-\frac{1}{8}\pi + (\theta - \pi)\sin\theta - \frac{5}{6}\cos\theta - \frac{1}{2}\pi \cdot \sin^2\theta\}\, g \cdot R_c^2$	If, $0 \le \theta \le \frac{\pi}{2}$, $N = (\theta \cdot \sin\theta - \frac{1}{6}\cos\theta)\, g \cdot R_c$ If, $\frac{\pi}{2} \le \theta \le \pi$, $N = (-\pi \cdot \sin\theta + \theta \cdot \sin\theta + \pi \cdot \sin^2\theta - \frac{1}{6}\cos\theta)\, g \cdot R_c$	**If, $0 \le \theta \le \frac{\pi}{2}$,** $N = -(\theta \cdot \cos\theta + \frac{1}{6}\sin\theta)\, g \cdot R_c$ **If, $\frac{\pi}{2} \le \theta \le \pi$,** $N = \{(\pi - \theta)\cos\theta - \pi\sin\theta \cdot \cos\theta - \frac{1}{6}\sin\theta)\, g \cdot R_c$
Horizontal deformation of a ring at spring line (δ)	Without considering soil reaction derived from dead load of lining: $\delta = \frac{\{2(P_{e1} + P_{w1}) - (q_{e1} + q_{w1}) - (q_{e2} + q_{w2})\} \cdot r_c^4}{24(\mu \cdot E_c I_s + 0.045\, k \cdot r_c^4)}$ i) Considering soil reaction derived from dead load of lining: $\delta = \frac{\{2(P_{e1} + P_{w1}) - (q_{e1} + q_{w1}) - (q_{e2} + q_{w2}) + \pi \cdot g\} \cdot r_c^4}{24(\mu \cdot E_c I_s + 0.045\, k \cdot r_c^4)}$ ii)		

2.7 Geotechnical Characteristics

Jakarta is located on the lowland of the northern coast of the Java island in Indonesia. There are 5 (five) main landforms in Jakarta which reported by Rimbaban (1999), namely: (1) Located in the Southern part are volcanic alluvial fan landforms; (2) Located in the Northern part adjacent to the coastline are landforms of marine-origin; (3) Located in the Northwest and Northeast parts are beach bridge landform; (4) Located in the encountered in the coastal fringe are swamp and mangrove-swamp landforms; and (5) Located in running perpendicular to the coastline are former river channels. The geological map of Jakarta and surrounding area is shown in **Figure 7**.

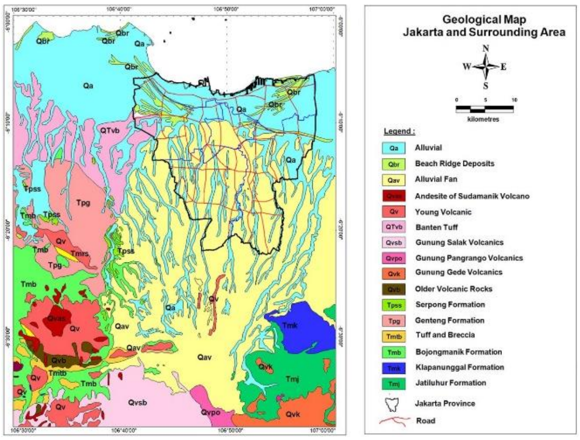

Figure 7. Geological map of Jakarta and surround area (source: Ridwan M., *et al*., 2016)

Rachmadi in 2012 has illustrated the sub-soil condition at project location, shown in **Figure 8**. According to Geotechnical Investigation Report of MRT plan locations in Jakarta, subsoil at the site of MRT Jakarta project can be divided into 2 (two) main formations. The first stratum is Weathered Volcanic ash (Acl) that consists of highly plastic volcano silty clay ranging from soft to very stiff with the thickness layer. Beneath the first layer, there is stratum of alluvial deposits which can be divided into 2 (two) sub layers, namely: the hard to very hard silt layer and occasionally is inserted by very dense sand layer. A simplified summary of the anticipated stratigraphy is provided in **Table 3**.

Table 3. General soil stratigraphy in project location

	Geology	Classification	Consistency
Upper Strata	Alluvial Clay	AC	Very soft to stiff clay
	Alluvial Sand	AS	Loose to medium dense sand
Lower Strata	Diluvial Clay	DC	hard clay
	Diluvial Sand	DS	Medium dense to very dense sand

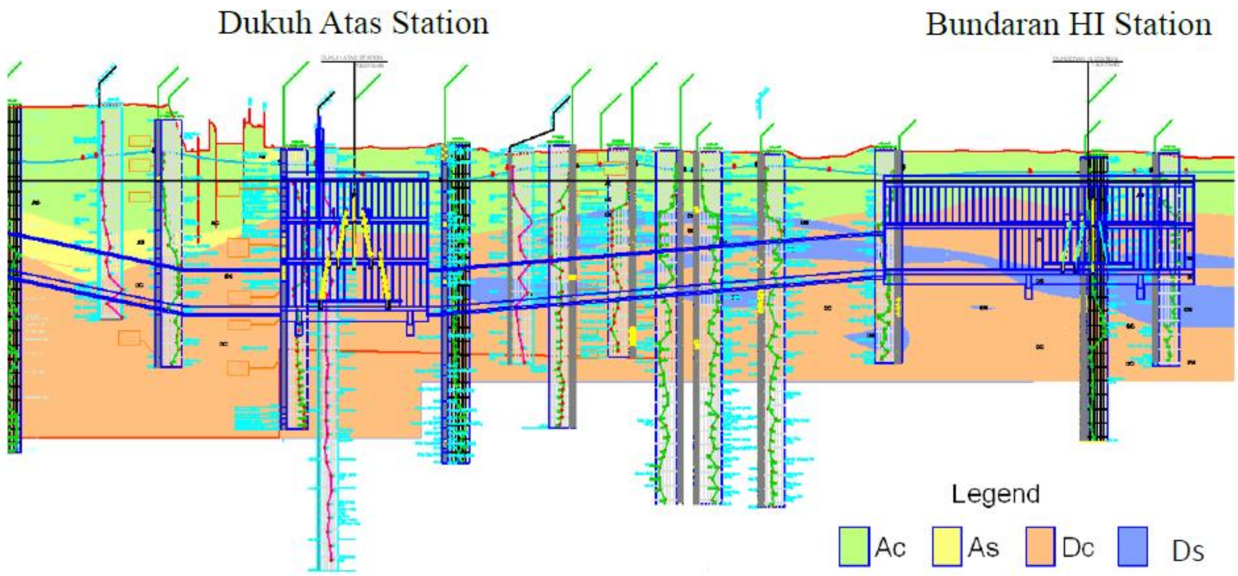

Figure 8. Soil stratification along Jakarta MRT CP106 project (source: Rachmadi, 2012)

3 RESEARCH METHODOLOGY

3.1 Research Stages

In general, stages of this research are shown in **Figure 9**. Stages of this research are: Literature review from books, journals research and papers which are related; Data collection from second parties and research which have been done by others which are related; Determine the geotechnical data; Define the specification of tunnel lining and material properties; Design the loads; Compute the member forces; Check the safety factor of tunnel lining; Conclusion and recommendations.

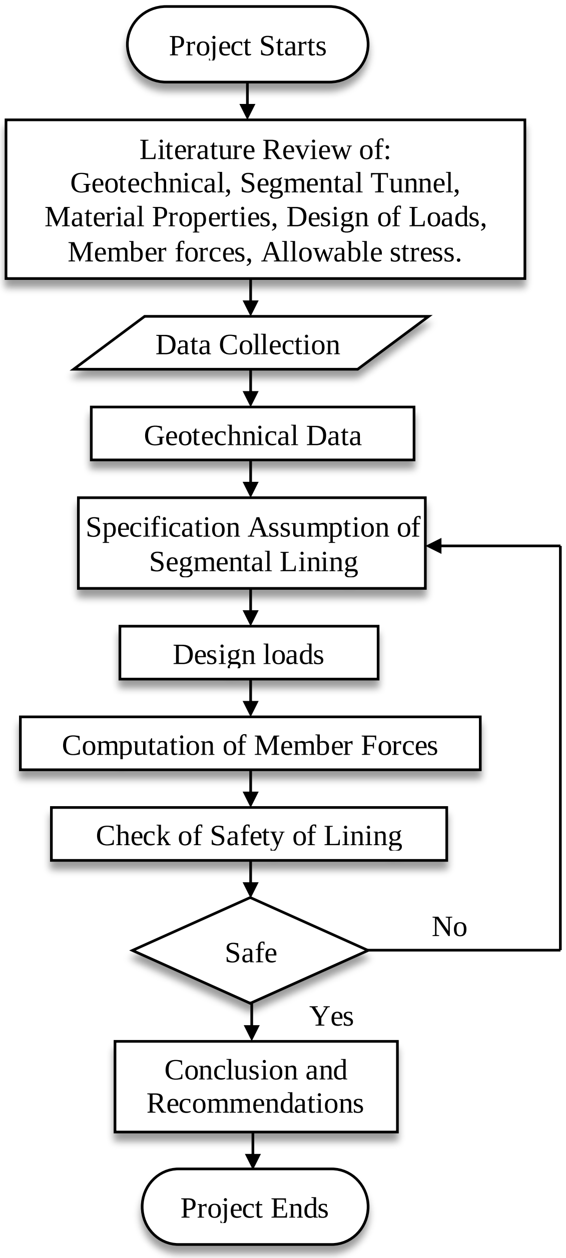

Figure 9. Research flowchart

A. Literature Review

In this stage, review of many literatures has been done to support this research to determine the problem, solve the problem, process of writing, and discussion especially about the problem which occur in soft ground related about the analysis and design of tunnel lining. Study has been done according literatures, journals, research and papers which has been done by others, include geotechnical condition, allowable stress of materials, design the loads, computation the member forces, and also safety check. Literatures in this research are obtained in types of books, journals, papers and research, articles, and also from internet.

B. Data Collection

The data which are used are secondary data, were obtained from SMCC-HK JO. While, the data which are not available, are assumed base on theory which supports. There are data were obtained indirectly from the project site, but from other sources was associated with geotechnical condition in Central Jakarta especially which are related to "Construction of Jakarta Mass Rapid Transit Project Underground Package CP106", like a books, journals, research and papers, and also internet.

C. Determine Geotechnical Data

Geotechnical data are required to design the loads. In this study, geotechnical data are obtained from investigation of other researchers which have researched the geotechnical properties of Jakarta, especially in Central Jakarta and in project location. Geotechnical data which have needed are specific gravity, cohesion friction angle, modulus of elasticity, modulus of deformation.

D. Define Specification of Tunnel Lining

Specification of tunnel lining should be defined to know the, usage of tunnel lining, dimension, class, strength, and allowable of materials. Material properties which have to define are concrete class, compressive strength, modulus of elasticity of concrete and steel. The Japan Industrial Standard (JIS), Deutsche Industrie-Norm (DIN), and American Concrete Institute (ACI) Standard specify the test methods of materials.

E. Design Loads

Design of loads are needed to know the value of loads. In this study, only the primary loads which are calculated: vertical and horizontal earth pressure; water pressure; dead load; surcharge; soil reaction. According to the Japan Society of Civil Engineers (JSCE) and International Tunnelling Association (ITA), the following loads should be considered in the design of lining.

F. Compute the Member Forces

In this stage, member of segmental of tunnel lining is calculated to know the strength. Usual calculation method or elastic equation method as an analytical calculation is used in this study. This method is a simple method to calculate member forces without a computer. Mainly based on the ground-lining interaction concept and they are treated either as the simplified solution methods (Duddeck, H. & Erdman, J., 1982; ITA, 2000; JSCE, 2006, 2010) in which the segmental lining is considered as a solid ring with equivalent flexural rigidity. In current design, the method of JSCE (2006) was applied.

G. Check of Safety

The safety factor should be considered in designing tunnel lining. It should be based on the ground loading and should be defined in accordance with the structural requirements and codes. So, the tunnel lining can be used as the function.

H. Conclusions and Recommendations

The conclusions have to be given to know the result and to give some recommendations of this study, to be better for the future. The conclusion should be based on the purpose of the research. The future research is given in the recommendation to continue and evaluate this study.

3.2 Research Methods

The quantitative method and qualitative method are used as the method of this research:

1) Quantitative method is a method which is done by reviewing from the references and literatures for support this research.
2) Qualitative method is a method which is done by collecting data to be used for this research, were obtained from the object which is researched.

4 ANALYSIS AND DISCUSSION

4.1 Geotechnical Investigation

Geotechnical investigation was carried by the Contractor from June to September 2013 for Jakarta MRT CP106 project, start from Bundaran HI station and stop at Dukuh Atas station.

4.2 Design of Tunnel Lining

Elevation (m)		:	-13.6 to -21.1
Soil type		:	DS1
Consistency		:	Medium Sandy
SPT	N	:	18
Unit weight of soil (kN/m^2)	γ	:	17
Cohesion (kN/m^2)	c'	:	35
Friction soil (°)	ϕ	:	32

A. Dimension of Segment

In designing the tunnel lining, dimension of segment is needed to know the diameter, width, and thick of segment. Dimension of segment can be illustrated in **Figure 10**.

Purpose of usage of planned tunnel		:	Subway tunnel
Type of segment	RC	:	Flat type
Diameter of segmental lining (mm)	Do	:	6800
Radius of centroid (mm)	Rc	:	3275
Radius of outer (mm)	Ro	:	3400
Width of segment (mm)	b	:	1500
Thick of segment (mm)	t	:	250

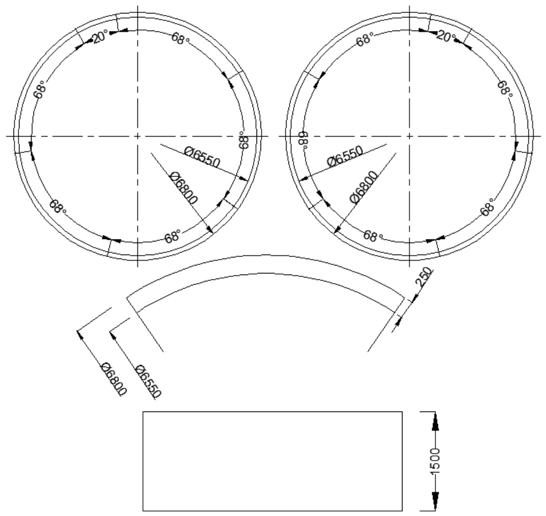

Figure 10. Dimension of segment

B. Material Properties

Material properties are needed to be used in designing tunnel lining for concrete and steel bar. The allowable stress of materials accordance of Japan Society of Civil Engineers (JSCE) in 2006.

Concrete:	:	Nominal strength (N/mm^2)	$f'c$	:	42
		Allowable compressive strength (N/mm^2)	σ_{ca}	:	16
		Modulus elasticity (kN/mm^2)	Ec	:	33
		Unit weight of RC segment (kN/m^3)	γ_c	:	26
Steel Bar	:	Tensile strength (N/mm^2)	fy	:	400
		Modulus elasticity (kN/mm^2)	Es	:	210
		Diameter (mm)	D	:	19

C. Ground Condition

Figure 11 shows an illustration of ground condition

Overburden (m)	H	:	14
Groundwater level (m)		:	1.6
Groundwater table (m)	H_w	:	12.4
Unit weight of water (kN/m^3)	γ_w	:	10
N value	N	:	18
Unit weight of soil (kN/m^3)	γ	:	17
Submerged unit weight of soil (kN/m^3)	γ'	:	7
Angle of internal friction of soil (°)	ϕ	:	32
Cohesion of soil (kN/m^2)	c'	:	35
Coefficient of reaction (kN/m^3)	k	:	20000
Coefficient of lateral earth pressure	λ	:	0.5
Surcharge (kN/m^2)	P_o	:	10
Soil condition	DS1	:	Medium Sandy

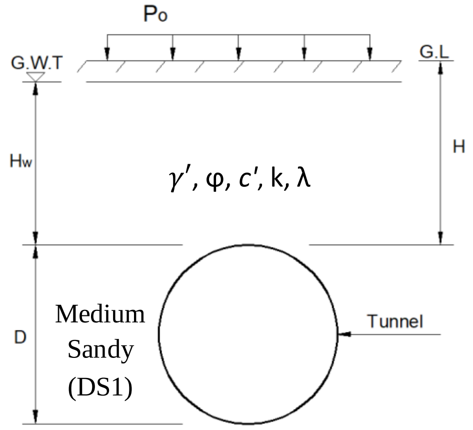

Figure 11. Ground condition

D. Design Method

This tunnel shall be design accordance with the Specification for Design and Construction of Shield Tunnel issued by Japan Society of Civil Engineers (JSCE).

- How to compute member forces: Elastic Equation Method
- How to check safety against member force: Ultimate Strength Design Method
- How to check safety against thrust forces of shield jack: Allowable stress design method

E. Design Loads

Figure 12 shows the loads condition around the tunnel lining.

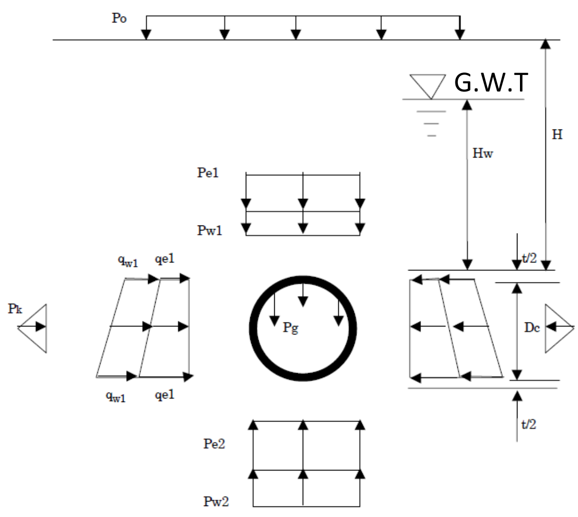

Figure 12. Loads condition around tunnel lining

1) Computation of reduce Earth Pressure at Tunnel Crown

The vertical earth pressure at the tunnel crown (P_{e1}) is computed by Terzaghi's). In sandy soil and cohesive soil ($N \geq 8$), if the overburden (H) > 2Do, the loosening earth pressure is often adopted (JSCE, 2006).

$$\sigma_v = \frac{B_1\left(\frac{\gamma - c}{B_1}\right)}{K_o \tan\phi} \cdot \left(1 - e^{-K_o \tan\phi \cdot \frac{H}{B_1}}\right) + \left(P_o \cdot e^{-K_o \tan\phi \cdot \frac{H}{B_1}}\right)$$

$$B_1 = R_o \cdot \cot\left(\frac{\frac{\pi}{4} + \frac{\phi}{2}}{2}\right)$$

$$= 3.4 \cdot \cot\left(\frac{\frac{\pi}{4} + \frac{32}{2}}{2}\right)$$

$$= 23.04$$

$$\sigma_v = 187.17 \text{ kN/m}^2$$

(used the lower limit of vertical earth pressure for subway tunnel according to JSCE in 2006, $P_{e1} = 200$ kN/m^2)

$$h_o = \frac{\sigma_v}{\gamma} = \frac{187.17}{17} = 11.01 \text{ m}$$

(used for calculating P_{e1}, if $h_o \leq H_w$, when the full overburden earth pressure is adopted as vertical earth pressure)

2) Computation of Loads

a) Dead load

$$g = \gamma_c \cdot t = 26 \cdot 0.25 = 6.500 \text{ kN/m}^2$$

Reaction of dead load at bottom

$$P_g = \pi \cdot g = \pi \cdot 6.5 = 20.420 \text{ kN/m}^2$$

b) Vertical pressure at tunnel crown

Earth pressure: $P_{e1} = 200$ kN/m^2

Water pressure: $P_{w1} = \gamma_w \cdot H_w = 10 \cdot 12.4 = 124.000$ kN/m^2

So, $P_1 = P_{e1} + P_{w1} = 324.000$ kN/m^2

c) Vertical pressure at tunnel bottom

Water pressure: $P_{w2} = \gamma_w\,(Do + H_w) = 10 \cdot (6.8 + 12.4) = 192.000$ kN/m^2

Earth pressure: $P_{e2} = P_{e1} + P_{w1} + \pi\, P_g - P_{w2}$

$= 200 + 124.00 + \pi \cdot 20.42 - 192.00$

$= 196.151$ kN/m^2

d) Lateral earth pressure at tunnel crown

Earth pressure: $q_{e1} = \lambda\,(P_{e1} + \gamma' \cdot \frac{t}{2})$

$= 0.5\,(200 + 7 \cdot \frac{0.25}{2})$

$= 100.437$ kN/m^2

Water pressure: $q_{w1} = P_{w1} = 124.000$ kN/m^2

So, $q_1 = q_{e1} + q_{w1} = 224.437$ kN/m^2

e) Lateral pressure at tunnel bottom

Earth pressure: $q_{e2} = \lambda\,[P_{e1} + \gamma'(2R - \frac{t}{2})]$

$= 0.5\,(200 + 7\,(2 \cdot 6.8 - \frac{0.25}{2})$

$= 147.162$ kN/m^2

Water pressure: $q_{w2} = P_{w2} = 192.000$ kN/m^2

So, $q_2 = q_{e2} + q_{w2} = 339.162$ kN/m^2

f) $I_s = \frac{1}{12} \cdot b \cdot t^3 = \frac{1}{12} \cdot 1.5 \cdot 0.25^3 = 0.001953125$ m^4/m

$$\delta = \frac{\{2(P_{e1} + P_{w1}) - (q_{e1} + q_{w1}) - (q_{e2} + q_{w2})\} \cdot r_c^4}{24(\mu \cdot E_c I_s + 0.045\, k \cdot r_c^4)}$$

$= 0.002408256011$ m

$q_r = k \cdot \delta = 20000 \cdot 0.006077635696 = 48.165$ kN/m^2

Table 4. Result of design load using elastic equation method

Load	Result (kN/m^2)
Vertical load ($P = P_{e1} + P_{w1}$)	324.000
Horizontal load ($Q = q_{e1} + q_{w1}$)	224.437
Horizontal Triangular load ($Q' = q_{e2} + q_{w2} - q_{e1} - q_{w1}$)	114.725
Soil reaction ($q_r = k \cdot \delta$)	48.165
Dead load ($P_g = \pi \cdot g$)	20.420

F. Computation Member Forces

Member of segment have to be computed to know the value of bending moment (M), axial force (N), and shear force (Q).

Table 5. Member forces of segmental lining

θ (°)	Moment (kN.m)	Axial (kN)	Shear (kN)
0	101.352	904.674	0.000
10	92.639	912.553	-29.966
20	68.258	934.807	-53.875
30	33.144	967.576	-66.866
40	-5.564	1005.323	-66.203
50	-39.891	1041.646	-52.085
60	-63.548	1069.573	-29.909
70	-73.842	1086.422	-6.470
80	-71.959	1093.346	11.710
90	-281.394	1094.538	19.935
100	-243.141	1093.724	70.416
110	-205.653	1090.477	103.861
120	-176.265	1084.667	118.740
130	-159.251	1076.695	116.952
140	-155.089	1067.758	102.835
150	-160.766	1060.641	81.783
160	-171.010	1055.964	56.457
170	-180.093	1053.445	28.740
180	-183.660	1052.667	0.000

According to the result of computation which has been done in tunnel crown (θ = 0°) to tunnel bottom (θ = 180°) every 10°, will be obtained the same bending moment, axial force, and shear force for 180° rotate clockwise from tunnel crown as well as opposite clockwise, it is caused by loads which are symmetrical.

Table 6. Member forces of segmental lining

Critical Condition		θ (°)	Bending Moment (M) (kN.m)	Axial Force (N) (kN)
Segment	+ Max	0	101.352	904.674
	- Max	90	-281.394	1094.538
	+ Max	120	Shear Force (Q) = 118.740 kN	
	- Max	30	Shear Force (Q) = -66.866 kN	

Distribution of bending moment, axial force, and shear force are important to be used as planning the tunnel lining which consists of segments. Each segment holds the member forces which have different value which appropriate of segments location, the great maximum value will be used to plan the reinforcement.

G. Check of Safety Against Member Forces

1) Against Bending Moment

Bending moment nominal in tunnel lining,

Nominal strength of concrete (N/mm^2)	$f'c$	:	42
Tensile strength of steel bar (N/mm^2)	fy	:	400
Diameter steel bar (mm)	D	:	19
The effective height of segment from outer surface to the centroid of the tensile steel (mm)	d	:	210
The effective height of segment from outer surface to the centroid of the compression steel (mm)	d'	:	40
Reduction factor of bending moment	ϕ	:	0.8
Reduction factor of axial force	ϕ	:	0.7
Reduction factor of shear force	ϕ	:	0.6

$$a = \frac{A_s \cdot fy}{(0.85 - f'c \cdot b)}$$

$$= \frac{5104 \cdot fy}{(0.85 - 42 \cdot 1000)}$$

$$= 57.182 \text{ mm}$$

$$M_n = A_s \cdot fy \cdot \left(\frac{d-a}{2}\right) \cdot 10^6$$

$$= 5104 \cdot 400 \cdot \left(\frac{210 - 57.182}{2}\right) \cdot 10^6$$

$$= 370.329 \text{ kN.m}$$

Resistance of bending moment nominal in tunnel lining,

ϕ M_n= 296.263 kN.m

Check:

$\phi \cdot M_n \geq M_u$

296.263 kN.m ≥ 281.394 kN.m

2) Against Shear Force

Shear Force nominal in tunnel lining,

$$V_n = V_c + V_s$$

$$V_c = \frac{1}{6} \cdot \sqrt{f'c} \cdot b \cdot d$$

$$= \frac{1}{6} \cdot \sqrt{42} \cdot 1000 \cdot 210$$

$$= 226825.934 \text{ N or } 226.825 \text{ kN}$$

$$V_s = 0 \text{ kN}$$

Resistance of shear force nominal in tunnel lining, Check:

$\phi\, V_n$	$\geq$	V_u
136.095 kN	$\geq$	118.740 kN

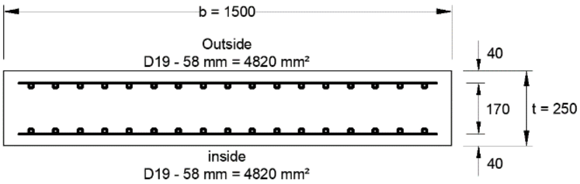

Figure 13. Section of segment and arrangement of bars

H. Check of Safety Against Thrust Forces of Shield Jacks

Total thrust force of shield (kN)	T	:	20000
Number of thrust jack (pieces)	N_j		8
Thrust jack force (kN) per piece	P		2500
Allowable compressive strength of concrete (N/mm^2)	σ_{ca}	:	16
Eccentricity between centre of working thrust force by one jack segmental lining (cm)	e	:	1
Space between adjacent two jacks (cm)	I_s	:	10

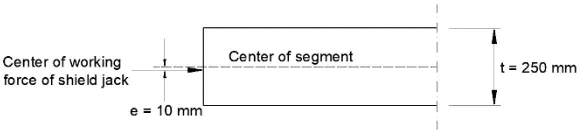

Figure 14. Segment and thrust force of shield jack

A= B · t = touching area of spreader of one jack on segmental lining

where, t = thickness of segment = 25 cm

$$B = \frac{2 \cdot \pi \cdot Rc}{N_j - I_s}$$

$$= \frac{2 \cdot \pi \cdot 3.275}{8 - 0.1}$$

= 2.472 m

So, A = B · t = 0.618 m^2

$$I = \frac{B \cdot t^3}{12}$$

$$= \frac{2.472 \cdot 0.25^3}{12}$$

= 0.00322 m^4

So, σ_c= maximum compressive stress of concrete of segment

$$= \frac{P}{A} + P \cdot e\left(\frac{h}{2}\right) / I$$

$$= \frac{2500}{0.618} + 2500 \cdot 0.01\left(\frac{0.25}{2}\right) / 0.00322$$

= 5015.804 kN/m^2 or 5.016 MN/m^2

Check:

σ_c	<	σ_{ca}
5.16 $/m^2$	<	16 MN/m^2

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The main purpose of this study is to design the tunnel lining due to loads which occurred by earth and water pressure in Bundaran HI that located in Central Jakarta. Based on research which has been done, the major conclusions are presented below, as follows:

1. From the result in determining geotechnical parameter, obtained the value of SPT-N is 18, with unit weight of soil (γ) is 17 kN/m^3, unit weight of water (γ_w) is 10 kN/m^3, cohesion of soil (c') is 35 kN/m^2, angle of friction soil (ϕ) is 32°, coefficient of reaction (k) is 20000 kN/m^3, coefficient of lateral earth pressure (λ) is 0.5, and type of soil is DS (Diluvial Sand) with the consistency is medium sandy, where, to use Terzaghi's formula the ground is assumed to be monolithic.
2. From the result in designing the loads, obtained the value of vertical load using Terzaghi's formula is 324.000 kN/m^2, for the value of horizontal load is 224.437 $kN//m^2$, for the value of horizontal triangular load is 114.725 kN/m^2, for the value of soil reaction is 48.165 kN/m^2, and for the value of dead load is 20.420 kN/m^2.
3. From the result in computing the member forces in the tunnel lining using elastic equation method, obtained the maximum values for positive bending moment in the tunnel crown (θ = 0°) is 101.352 kN.m, for negative bending moment in the tunnel axis (θ = 90°) is -281.394 kN.m. In contrary, the value of maximum axial force is in the tunnel axis (θ = 90°) is 1094.538 kN, for minimum axial force is in the tunnel crown (θ = 0°) is 904.674 kN. While, the value of maximum shear force is in (θ = 120°) is 118.740 kN, for minimum shear force is in (θ = 30°) is -66.866 kN.

4. From the result in checking the safety against member forces in tunnel lining, obtained the value of nominal bending moment multiplied by reduction factor ($\phi \cdot M_n$) is 296.263 kN.m, bigger than the value of ultimate bending moment (M_u) is 281.394 kN.m. For the value of nominal shear force multiplied by reduction factor ($\phi \cdot V_n$) is 136.095 kN, bigger than the value of ultimate shear force (V_u) is 118.740 kN. While, safety check against thrust force of shield jack obtained the value of maximum compressive stress of concrete segment (σ_c) is 5.016 MN/m^2, bigger than the value of allowable stress(σ_{ca}) is 16 MN/m^2.

5.2 RECOMMENDATIONS

Considering the result of this study, recommendation for future research would be:

1. Regarding the geotechnical parameters, further investigation and researches on determination of them are still in a great need for Central Jakarta soil.
2. Since the MRT project will also be expanded, the measurement data need to be conducted in the future for another part of Jakarta.
3. In computing the member forces in tunnel lining needed finite element software to know the value of member force for more detail and accurate than manual computation.
4. In computing elastic equation method, bolt and gasket could be computed to know the influence at joint on segment for more detail and in actual condition of tunnel lining.
5. Computation the secondary loads (effect of earthquake, internal loads, and Construction Loads) and special loads (Effect of Adjacent Tunnels, Effect of Settlement, and Other Loads) could be done to know the value of them for computing the member forces.
6. In computing, needed a meticulousness and patience to obtain the best result.

REFERENCES

Aila, W., 2016. *"Establishment of Geotechnical Properties and 3D Numerical Models for Deep Excavation in Central Jakarta"*. Master Thesis, National Taiwan University of Science and Technology
(Taiwan-Tech), Taipei, Taiwan.

Society of Civil Engineers (JSCE), 2006. *"Standard Specifications for Tunneling: Shield Tunnels"*. Tokyo, Japan.

Official Report of the International Tunnelling Association (ITA), 2000. *"Guidelines for the Design of Shield Tunnel Lining"*. In Tunnelling and Underground Space Technology Journal, Vol. 15, No. 3, pp. 303-331, 2000, Bron Cedex, France.

Rachmadi, 2012. *"Tunnel for Jakarta MRT Project presentation file"*. Paper presented at the workshop Teknologi Jembatan dan Terowongan, Bandung.

Ridwan M., *et al*., 2016. *"Development of an Engineering Bedrock Map Beneath Jakarta Based on Microtremor Array Measurements"*. In Geological Society, London, Special Publication, 441, 153-165, London, England.

Rimbaban, S. P., 1999. *"Geomorphology in: Coast plan Jakarta Bay Project, Coastal Environmental Geology of the Jakarta Reclamation Project and Adjacent Areas"*. CCOP COASTPLAN case study report (pp. 21-25).

Terzaghi, K., 1950. *"Geological Aspect of Soft Ground Tunnelling"*. John Wiley & Sons.

Tóth, Dr. Ákos, 2015. *"Underground Construction Technology"*. In Presentation Course Lectures, Part 4.2 – Permanent support.