Comparison of RC Segment Lining Design Method of Singapore NIPE C7 Project

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This paper presents the comparison between RC segment lining design by several approaches. Empirical design method such as Miur Wood and Duddeck and Erdmann(D&E) are introduced widely in overseas projects.

1. INTRODUCTION

Singapore NIPE C7 is the NEWater Tunnel construction comprises of bored tunnel for 2.2m steel pipe installation from Raffles Country Club to Pioneer Road. The project was awarded to Shimizu Corporation in Nov 2012 and completed in January 2016. One EPB TBM with precast segment lining was introduced for tunnel total length of 2.7 km. The overall site plan of NIPE-C7 and Geological information are as shown in Figure 1. Two characteristics of the project is two tight curve of radius 80m and the use of thin segment of 175mm thickness.

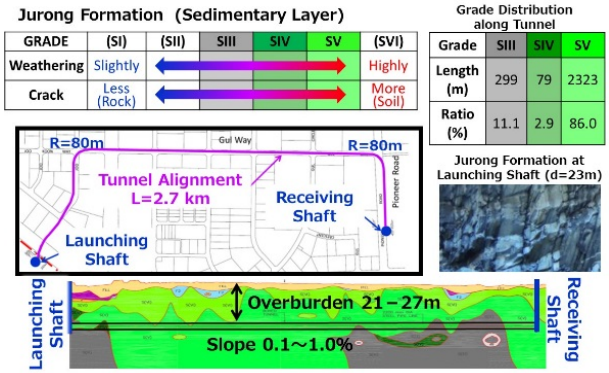

Figure 1 General Layout and Geotechnical Profile of NIPE C7 project

Figure 2 EPB TBM for Tunnel Excavation

2. DESIGN AND LOAD CONDITION

Load conditions for the segment lining design under permanent stages are shown in figure 3 and listed as below.

- Dead Load (Self-Weight of Material)
- Imposed Load (Surcharge) 75kN/m²
- Hydrostatic Load (Water)
  - Ground level
  - 5m below ground level
  - 1m above ground level
- Earth Load (Soil)
- Additional Distortion (±15mm)

Soil Type	K
E, M, F2	0.75
B, O, , GV, GVI, F1	0.5
SV, SVI	0.4
SIII, SIV, FCBB, GIII, GIV	0.3

FCBB : Fort Canning Boulder Bed

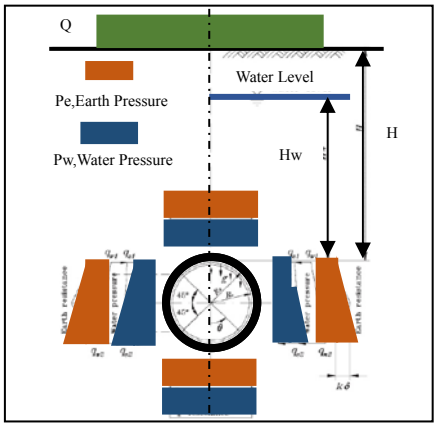

Figure 3 Load Consideration

3. DECISION OF SEGMENT DIMENSION

The bored tunnel with internal diameter of 3.8 m was excavated along 2.7km length. One of challenging of the project is the alignment with radius 80m. For normal part, the segment length is 1200 mm with taper of ±25mm and for tight curve (r < 150) the segment length is 800 mm with taper of ±25 mm. The design thickness of segments is 175 mm and one ring consists of 5 segments with 1 key segment (See Figure 4). The precast concrete segment lining was also designed for the temporary loading conditions during transportation and segment installation.

Figure 4 RC Segment Lining

Figure 5 RC Segment Lining during Construction

Keyword: Singapore NIPE, RC Segment Lining, Continuum Model, Bedded Beam Model
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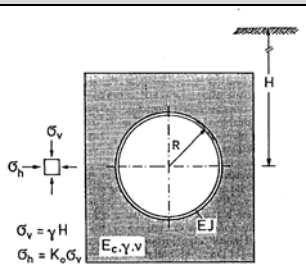
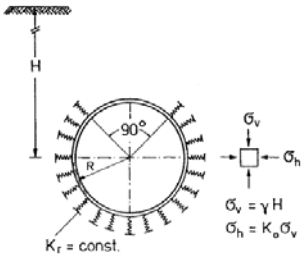
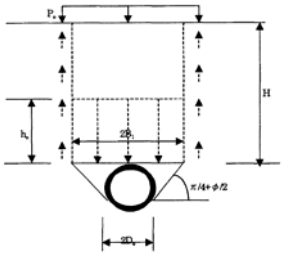
4. STRUCTURAL ANALYSIS AND RESULTS

In Singapore practice, analysis and design method for bored tunnel segment lining considers the interaction of segment lining and ground, deflection of lining, and re-distribution of loading dependent upon the relative flexibility of lining and compressibility of ground.

As specified in LTA Civil Design Criteria (2012), the acceptable methods in the design in Singapore are continuum model proposed by AM Muir Wood and DJ Curtis, bedded beam model as per Duddeck and Erdmann and Finite Element. Bedded beam design approach shown in JSCE tunnel design code (2016) is also used for comparison study in this study. Using these various approaches, bending and axial force were calculated. Summary table is shown in table 2.1.

Table 4.1 Comparison table of various approach

Design Approach	**Continuum Model by Muir Wood**	**Bedded Beam by Duddeck and Erdmann**	**Bedded Beam by JSCE**
Model			
Design Principle	Model assumption is that circular lining deforms into an elliptical mode taking into account the lining-ground relationship. Lining deformation results in reaction stresses in the ground.	Model has a bedding spring around the lining except at the crown 45° each side of tunnel center to eliminates the load reduction effect when the lining deflects inwardly. The effect of tangential stress is also considered.	Model has a bedding spring at both side of lining to act as the passive pressure when vertical and uplift force is induced to lining. A reduction of primary stress as per Terzaghi theory.

Bending moment and axial force of segment lining in three different sections are compared in Figure 6. It is found that D&E method gave 15% and 12~20% higher compare to continuum model of Muir Wood and Bedded beam by JSCE simplified methods respectively in completely weathered Jurong Formation (N50~100). However, when tunnel is in fracture rock (SIV and SIII) JSCE approach will give 50% higher bending moment.

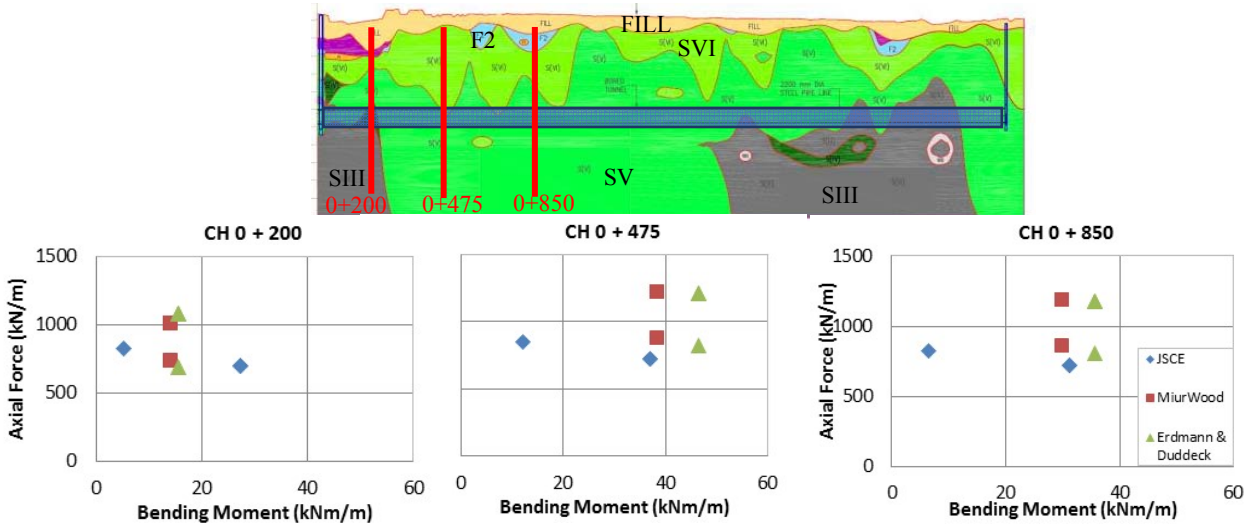


Figure 6 Graph of Bending Moment and Axial Force of Various Approach and Section Locations

5. CONCLUSIONS

Empirical approaches are used in the tunnel segment design in Singapore. The classical papers of Muir Wood (1975) and Duddeck and Erdmann (1982) are most referred. It is found that in stiff ground condition D&E method gives highest sectional forces while in fracture rock JSCE method shows the highest. 2349 rings of tunneling segment lining with internal diameter of 3.8m were successfully installed and consequently permanent steel pipes with 2.2m diameter were installed inside segment linings with grouting material.

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