SFRC Segment Lining in Singapore MRT T207 Project

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This paper presents the use of SFRC segment lining in Singapore MRT project. Since there is no reinforcing bar in the segment, the special treatment during segment installation is required to prevent tension cracks.

1. INTRODUCTION

Contract T207 awarded to Shimizu Corporation in January 2014 is a unique project of MRT Thomson East Coast Line which involves construction of two pairs of bored tunnels commencing from launching shafts from Contract T206 and T208 towards Escape Shaft (ES2) next to the RTS building as shown in Fig. 1. In this project, Land Transport Authority (LTA) specified to use Steel Fiber Reinforced Concrete (SFRC) as tunnel segment lining in Tunnel construction.

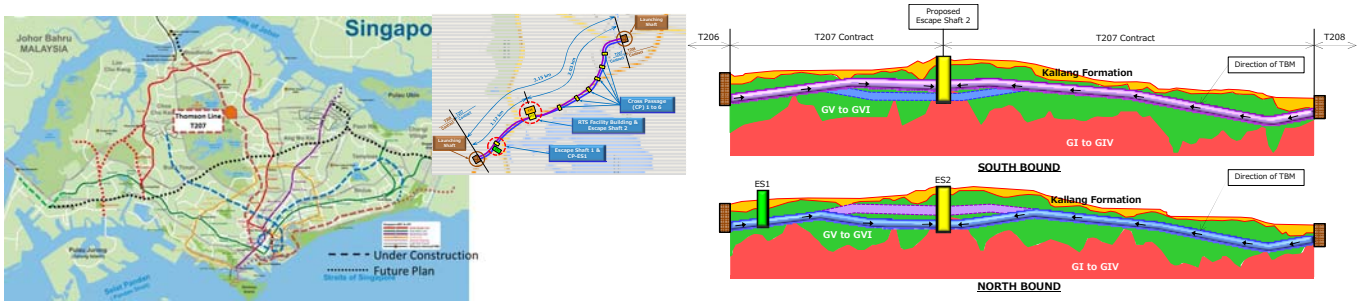

Fig. 1 General Layout and Geotechnical Profile of T207 Project

2. APPLICATION OF SFRC SEGEMENT LINING IN SINGAPORE MRT

For productivity improvement and innovation for Tunnel construction, SFRC tunnel segment lining was firstly employed in Downtown Line Contract C933 where ground condition (Old Alluvium) is stable. In Thomson-East coast line, SFRC segments are also specified in two contracts, T206 and T207. In geological profile of T207 as shown in Fig. 1, more than 95% of tunnel is aligned in completely weathered Bukit Timah Granite (G5) and residual soil (G6) which are stable ground but some sections of tunnel is aligned in rock and mix face condition. In order to minimize tension crack during segment installation and excavation; special cares during segment handling are required.

Table 1 Advantages and Limitations of SFRC segments

Advantages	Limitations
1. Productivity Improvement -> Reduce production time 2. Rebar assembly is not required -> Less manpower and yard 3. Fiber distributed everywhere in segment -> Minimize corner cracks or damages due to impact load during handling	1. Applicable only for stable ground with less unbalanced load condition (Small bending moment) 2. Due to smaller bending moment capacity, number of segments in one ring need to be increased from 5+1 to 7+1 -> More installation time

Fig 2 Segment Production

Shield jacks are used for pushing segment in place during tunnel excavation. During the first trial of segment installation, bursting force combined with bending moment occurred and it caused tension crack as shown in Fig. 4. 3D FEM analysis is conducted to review stress condition during segment installation in various load and boundary conditions.

Fig 3 Gasket/Plywood and Segment inside Tunnel

Fig 4 Cracks in Segment Lining during Trial Installation

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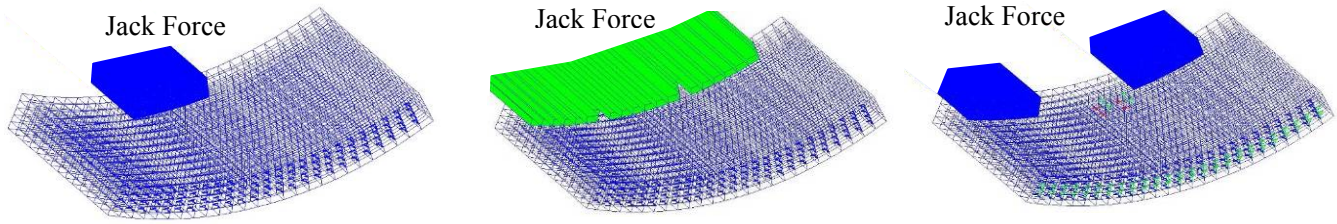
3. ANALYTICAL MODEL AND RESULTS

According to installation sequence, three load conditions as shown in Fig. 5 are simulated. LC1 and LC2 are the original proposed sequence (Jack force is applied at center jack following by both sides) while LC3 is to simulate load case when releases center jack after bolt tightening. Four models with different boundary conditions at supporting side are listed in Table 2 for studying the effect of support movement. The analysis results are shown in Fig. 6 and Table 2.

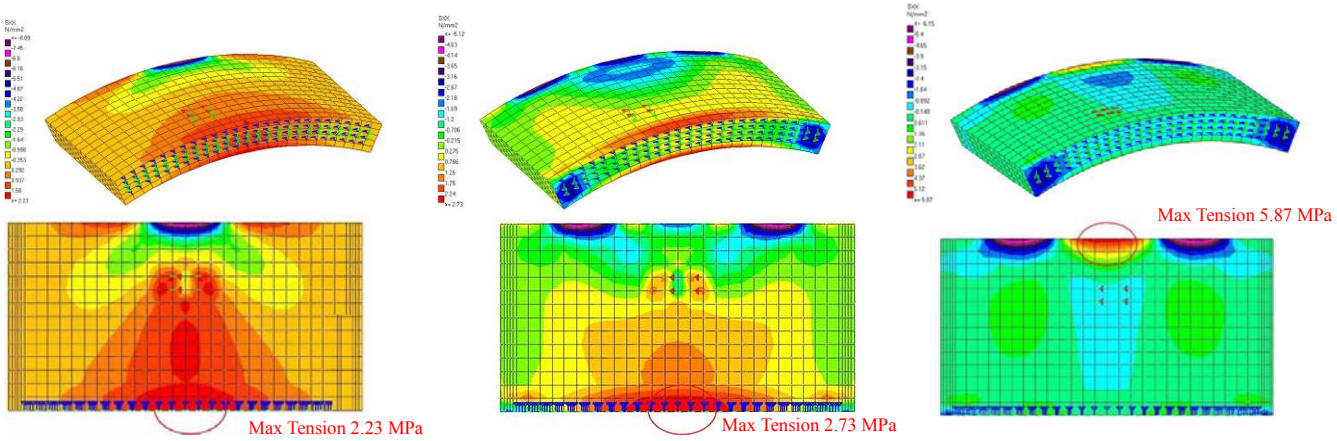


(a) Load Case 1 (LC1) (b) Load Case 2 (LC2) (c) Load Case 3 (LC3)

Fig. 5 Load Conditions

Table 2 Summary of Boundary Conditions

Model	Support Conditions	Remarks
1	Pin Support Z Axis	Uniform Support representing Plywood
2	Uniform Spring Support	Plywood but consider elastic elongation of gap and plywood
3	Uneven Spring Support	Some parts of support softer than others
4	Spring Support only at Gasket Location	Before plywood touch, Gasket deform and act as line support



(a) Model 1-LC1 (b) Model 1-LC2 (c) Model 1-LC3

Fig. 6 Analytical Results where Jack Force is 975 kN (Stress Distribution)

Table 3 Max tensile stress and Crack checking

Model	Load Case	Jack Force 975 kN		Jack Force 580 kN	
		Tensile Stress(MPa)	Remarks <4.5MPa?	Tensile Stress(MPa)	Remarks <4.5MPa?
1	1	**2.23**	No Crack	1.34	No Crack
	2	**2.73**	No Crack	1.63	No Crack
	3	**5.87**	**Crack**	3.51	No Crack
2	1	4.87	Crack	2.92	No Crack
	2	4.69	Crack	2.81	No Crack
	3	6.18	Crack	3.70	No Crack
3	1	4.63	Crack	2.77	No Crack
	2	6.39	Crack	3.83	No Crack
4	1	5.64	Crack	3.38	No Crack
	2	6.52	Crack	3.90	No Crack

From the results in Table 3, it is found that

1. Model 1 LC3 shows that tension crack happens when releases only center jack. This is agreed with the sequence observed when crack occurred during trial installation
2. LC3 causes the largest tensile stress and it should be avoided during segment installation.
3. When support condition is softer (Plywood and Gasket spring is applied), tension stress increases.
4. Jack Force 975 kN applied during segment installation is too high since tensile stress of most cases are more than tensile strength capacity of SFRC.
5. When jack force is limited to 580 kN, tensile stress of all cases is smaller than tensile strength of SFRC. It is recommend to reduce jack force to be less than 580 kN during segment installation

4. CONCLUSIONS

For construction productivity and innovation, SFRC segment lining is introduced in Singapore MRT T207. Since there is no rebar to resist bursting force in segment lining, tensile stress during segment installation shall be minimized. By applying 3D FEM analysis, stress distribution against jack force can be reviewed. The possible causes of tension cracks are identified and it is agreed well with the load condition when tension crack occurred during trial installation. Good practices for segment installation as listed below are proposed before tunnel excavation.

1. Too high jack force → Limit jack force to 580 kN during segment installation.
2. Uneven plane of segment support → Check plywood and plane at the support side
3. Jacking Sequence → Recommend to push center jack first before applying remaining and avoid LC3 condition

As a result, it is successful to prevent tension crack in SFRC segment lining during segment lining installation.