Safety inspection and reinforcement of South-link line railway tunnels

Yuan-Tu Wang[1], P.-H. Chang[1], Y.-T. Lee[1], and M.-C. Lee[1]

[1] Geotechnical Engineering Department, Sinotech Engineering Consultants, Ltd., 171, Nanking E. Rd., Sec. 5, 10570, Taiwan.

ABSTRACT

South-link line railway connects Fangliao station, Pingtung, in the west and Taitung station, Taitung, in the east. It is 98km long with 36 tunnels, and has been operated over 20 years since 1991. Cracks, spalls, and leakages of the tunnels have kept occurring due to external force, rock mass weakening, support material aging and groundwater. Safety inspection and reinforcement design was completed in the "South-link Line Railway Electrification Project." The tunnels' abnormal areas were judged by image scanning and visual inspection. The cavities inside or behind the lining, lining conditions, crack development, and cross-section convergence were interpreted and monitored by non-destructive methods. The causes of abnormal conditions were also discussed by means of hydro-geological analysis simultaneously in certain tunnels. This paper is aimed to collect all the inspection data and try to figure out the failure models and preliminary reinforcement strategies.

Keywords: South-link line railway; tunnel engineering; tunnel safety inspection; tunnel reinforcement

1 INTRODUCTION

Round island railway electrification project started since October, 1971. Chaozhou to Fangliao of Pingtung (Chao-Fang section) and Fangliao to Taitung (South -link line) are the only two un-electrified sections. Therefore, Railway Reconstruction Bureau, RRB in brief, actively gave an impetus to electrification of Taitung-Chaozhou section of South-link railway. Due to the fact that South-link railway was completed over 20 years ago, lots of abnormal conditions such as cracks, water leaking and spalls occurred on the tunnel lining. Although the authority in charge of operation has kept reinforcing and maintaining the relative serious sections, the objective of reinforcement was basically based on the current operation condition, not electrified condition. The Sinotech Engineering consultants, LTD., which was awarded the design work of civil and general E&M engineering, completed safety inspection in order to figure out the phenomenon, causes and location of abnormal conditions in these tunnels. Furthermore, environmental, structural and construction factors were all taken into consideration to put forth suggestions of maintenance and reinforcement before electrification.

98km-long South-link line, from Fangliao, Pingtung (0k+000) to Taitung, Taitung (98k+145), is consisted of 36 mountain tunnels with a total length of 38.9km, a shelter tunnel of 1.2km and 5 slope sheds of 0.5km in total. It is equal to say that there are 42 tunnels in South-link line. The plan map of South-link line railway is shown as Fig. 1. The location of mountain tunnels along this line is listed in Table 1.

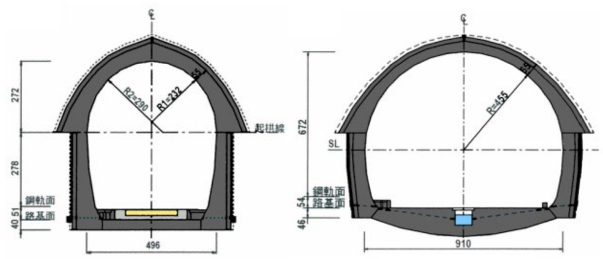
Except for 6 tunnels between Central signal station and Guzhuang station are double-rail tunnels with 6.72m high and 9.1m wide at spring line, rest of them are all belong to single-rail tunnels with 5.5m high and 4.96m wide at spring line, shown in Fig. 2.

Fig. 1. Plan map of South-link line railway

Table 1. List of mountain tunnels along South -link line

No.	Name	Starting Mileage	Ending Mileage	Length (m)
1	Fangdian No.1	12k+764	12k+804	40

2	Fangdian No.2	12k+980	13k+065	85
3	Fangshan No.1	13k+942	14k+242	300
4	Fangshan No.2	14k+918	15k+503	585
5	Fangshan No.3	15k+795	16k+483	688
6	Fangshan No.4	17k+153	17k+315	163
7	Fangshan No.5	17k+730	17k+935	205
8	Fangye No.1	18k+219	20k+029	1,809
9	Fangye No.2	20k+780	21k+500	720
10	Fangye No.3	22k+004	23k+364	1,360
11	Central	23k+745	31k+815	8,070
12	Puan	32k+243	32k+382	139
13	Anshuo	32k+649	38k+130	5,484
14	Guzhuang No.1	38k+548	38k+726	178
15	Guzhuang No.2	38k+829	39k+114	285
16	Guzhuang No.3	39k+319	40k+009	690
17	Guzhuang No.4	40k+728	40k+881	153
18	Guzhuang No.5	41k+108	41k+478	370
19	Guzhuang No.6	41k+949	42k+127	178
20	Guzhuang No.7	42k+193	42k+394	201
21	Dawu No.1	42k+524	42k+896	372
22	Dawu No.2	44k+019	45k+199	1,180
23	Daniao	46k+146	49k+800	3,654
24	Jiajinlin	50k+230	50k+705	475
25	Fushan	52k+451	52k+525	74
26	Dazhu No.1	53k+514	54k+966	1,452
27	Dazhu No.2	55k+808	57k+044	1,236
28	Dazhu No.3	57k+521	57k+718	197
29	Longxi	58k+575	58k+713	138
30	Dazhu No.4	58k+749	58k+919	170
31	Duoliang No.1	58k+977	60k+617	1,640
32	Duoliang No.2	61k+248	61k+293	45
33	Duoliang No.2-1	61k+346	62k+869	1,523
34	Jinlun	64k+127	68k+519	4,392
35	Xianglan	69k+123	69k+473	350
36	Xinji	77k+223	77k+591	368



(a) Single-rail tunnel (b) Double-rail tunnel

Fig. 2. Standard section of tunnel in South -link line

Trandional construction method, ASSM (American Steel Support Method), was adopted in the early construction stage. New Austrian Tunnelling Method, NATM in brief, was brought in not until 1986. The tunnels were mainly for non-reinforced concrete lining design. According to the as-built drawings, in addition to the slope sheds and the cut-and-cover tunnels, only part of the tunnel sections and portals were constructed by reinforced concrete structure.

2 SAFETY INSPECTION AND EVALUATION

In order to understand the abnormalities of the tunnels, including the locations, the degrees, and the extensions, for evaluating the safety of the tunnel structure and proposing the maintenance methods and reinforcement requirements before the electrification of the tunnel, the tunnel related data were collected first, and then proceed to tunnel's cross-section inner clearance measurement and image scanning, abnormal areas mapping and interpretation, exploration behind lining, sampling and indoor test analysis, etc.. The main safety inspection items and quantities are shown in Table 2.

Table 2. Safety inspection

Work items	Quantity
Inner clearance measurement	8,145
Abnormal areas inspection & Image scanning interpretation	40,709 m
Lining and rear condition detection	41,083 m
Width and depth measurement of cracks	107 m
Schmidt hammer test	194
Concrete coring / Compressive strength test	89/83
Concrete neutralization test	83
Concrete chemical composition analysis	40
Water sampling and qualitative analysis	20
Concrete cover thickness measurement	76
Rebar corrosion inspection	47
Ballast thickness measurement	108
Knocking echo test	106
Drainage outflow monitoring	8
Cross section convergence monitoring	30
Crack development monitoring	15

2.1 Results of safety inspection

1. Inner clearance measurement

The tunnel cross-section information from image scanning by GRP5000 includes point coordinate data. The boundary of electrified tunnel can be drawn simultaneously on the results the cross-section inner clearance diagrams which were composed by the measuring points of each cross section, shown in Fig. 3.

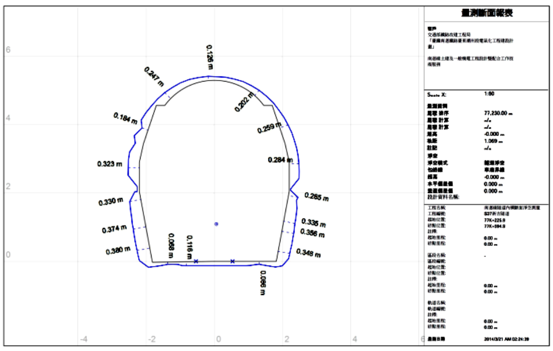


Fig. 3. Cross-section Inner Clearance Diagram

The results of the tunnel section overlapping showed that there were insufficient clearances in many sections. In order to accurately understand the thickness of the ballast for confirming whether there was enough space for adjustment to meet the electrification demand, the samplings for the thickness of the ballast were executed. The results showed that most of the thicknesses of the ballasts were over 25 cm except for partial sections.

2. Image scanning interpretation

In order to obtain the current status of the tunnel lining and the information of the abnormal areas for evaluating the cause of the abnormalities, the lining surface of the tunnel was scanned and the digital images of the linings were generated.

After the digital images were completed, they will continue processing the abnormal areas interpretation, including: cracks, spalls, leakages, rebar exposures, and water proof facilities failure. In addition to record the distribution of the abnormal areas and classify the degree of the damage, it is also transformed into a lining condition interpretation diagram (Fig. 4), which provides a reference for visual review, statistic, and safety evaluation. It offered great help for the design and the execution of repair and reinforcement.

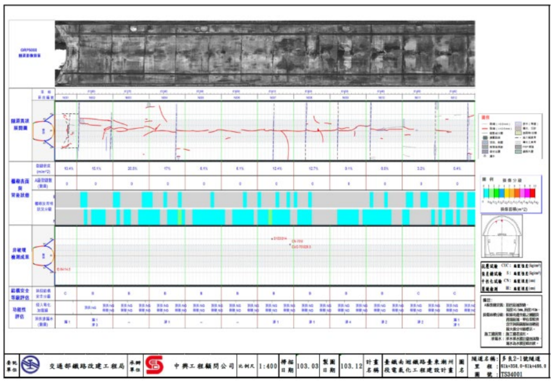


Fig. 4. Lining Condition Interpretation Diagram

3. Other inspections

Other inspections can be divided into nondestructive inspections and destructive inspections. Nondestructive inspections includes lining and rear condition detection by ground penetrating radar, width and depth measurement of cracks, Schmidt hammer test, concrete cover thickness measurement, rebar corrosion inspection, and knocking echo test. Destructive inspection is concrete coring, and the coring samples are for compressive strength test, neutralization test, and chemical composition analysis. The results from the inspections above were for subsequent assessment.

2.2 Safety evaluation

1. Tunnel monitoring

There are 3 kinds of monitoring held in the tunnels for tracing the development and the variation of the ground water, the cracks, and the inner clearances. They are drainage outflow monitoring (Fig. 5), crack development monitoring, and cross-section convergence monitoring.

Fig. 5. Drainage Outflow Monitoring

2. Hydro-geological analysis

According to the site investigation, the telemetry image interpretation, and the tunnel inspection, some tunnels were built closely to slope surface. Therefore, they have problems with shallow cover and stress bias. Lining cracks and leakages are easily found in the tunnels, especially during heavy rainfall. These phenomena may due to tunnel position, geological condition, and the impact of climate change. Among the tunnels of South-link line, the Daniao tunnel, the Dawu No.2 tunnel, the Jinlun tunnel, and the Duoliang No.2-1 tunnel, are with more serious leakage problems. Thus, hydro-geological analysis is applied.

The 3D hydro-geological analysis of the above 4 tunnels combines surface water system, regional geological structure, and strata orientation to construct a conceptual model (Fig. 6) to simplify the complex geographical environment. The model is integrated with the hydro-geological parameter setting and regional groundwater flow analysis to conduct regional groundwater environmental impact assessment.

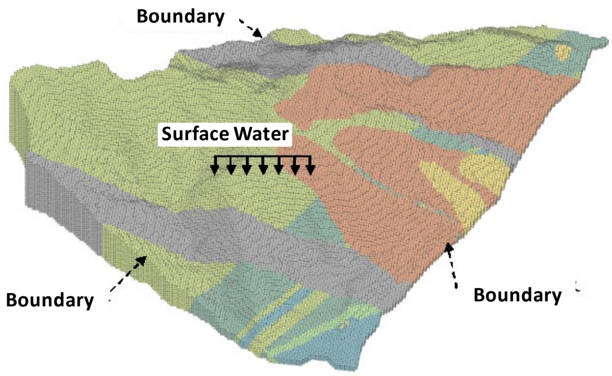


Fig. 6. 3D Hydro-geological Model (Daniao Tunnel)

3. Structure safety evaluation

Structure safety evaluation can be executed from 3 aspects: (1) the deformation due to external force, (2) the deformation due to lining degradation, and (3) the influence upon rail during operation. Hence, the safety degree classification of the tunnels was established and listed in Table 3. The unit length for the evaluation is 10m in this project.

Table 3. The safety degree classification of the tunnels

	Work items				
Lining condition	Influence on structure	Influence on operation	Influence on maintenance	Handle Priority	Safety Degree
Extremely bad	Huge	Dangerous	Obvious	Immediate	A
Function loss	Sooner/later will be huge	Sooner/later will be dangerous	Large	ASAP	B
May cause function loss	May be huge	May be dangerous	Medium	Attention	C
Slight	None	None	Small	None	D

According to the results of the evaluation, the tunnels will be on the focus list if the safety degree of the tunnels had more than 20% sections were evaluated as degree "A," including the Fangshan No.3 tunnel, the Central tunnel, the Puan tunnel, the Guzhuang No.2 tunnel, the Jiajinlin tunnel, and the Duoliang No.1 tunnel.

3 REINFORCEMENT STRATEGY

According to the results of the safety evaluation, the main abnormalities of the South-link line railway tunnels can be divided into two parts: "functional" and "structural". Functional abnormalities are insufficient inner clearance and leakage, both of which directly affect railway electrification in the future; as for structural abnormalities, they can be divided into 3 categories: spalls, cracks and others. The abnormalities need to be treated under structural safety and economy consideration in tunnel reinforcement design. The reinforcement strategies are listed in Table 4.

Table 4. Reinforcement strategy

Abnormality condition		Reinforcement strategy
Functional	Insufficient inner clearance	Alignment optimization, Rail level lowering
	Leakage	Water-stopping grouting, Drainage facilities, protection sheets for electrification facilities
Structural	Spalls	Spall filling, Carbon fiber sheets
	Cracks	Crack grouting, Rock bolts
	Others	Back filling grouting, Rebar exposure strategy, Foundation consolidation grouting

3.1 Functional abnormality

1. Insufficient inner clearance

In order to establish the electrification system, the clearance requirements for tunnels are stricter than non-electrical sections. The assessment of clearance sufficiency is based on the regulations from Taiwan Railways Administration. Rail level lowering will be the first choice for insufficient inner clearance. If the rail level is impossible to lower, it will be delivered to the future electrical system contractor to solve.

2. Leakage

Most of the South-link line railway tunnels are designed and constructed by traditional methods. Most of them are not equipped with water-proof facilities. Therefore, the water-stopping measures may not completely solve the leakage problems. The principle of "water-conducting first, then water-stopping" is adopted to treat the leakages.

3.2 Structural abnormality

1. Spalls

Spalls directly affect the safety of railway operation. It may cause interruption due to lining concrete blocks falling. The spalls should be cautiously faced. Carbon fiber sheets are selected to apply for the large spall areas.

2. Cracks

The crack is the most common abnormality in the tunnels. The reinforcement is mainly for the structural cracks. The priority of the crack treatment depends on the safety level of the safety evaluation and the severity of the crack itself. If the priority of the reinforcement is decided by the crack's direction, the order will be vertical, oblique, and hoop.

4 CONCLUSION

South-link line railway connects Pingtung in the west and Taitung in the east. It is 98km long. The whole line runs through the mountains. The mountains are steep and the terrain changes rapidly. In addition, the geological condition is complex and variable, the rock mass is fragile and the groundwater is abundant, the slope is weathered severely, and the erosion of gully is obvious.

South-link line railway consists of 36 mountain tunnels, 5 slope shed tunnels, and 1 shelter tunnels. According to the safety evaluation results, lining cracks, leakages and concrete spalls are common. Thus, the safety reinforcement for the "functional abnormalities" and "structural abnormalities" is applied. The vision of electrical railway around the island will be completed and the life cycle of the South-link line railway can be extended.

REFERENCES

Lee, J.H. and Wang, T.T. (2014). Study on Diagnostic Methods of Cracks in Lining of Mountain Tunnels: A Case Study of Mechanical Factors, Tunnel construction, 34, 82-87.

Lee, J.H., Wang, T.T., Xue W.C. and Huang, T.H. (2010). Tunnel Maintenance and Reinforcement Technology and Case Study, Tunnel construction, 30, 113-119.

Kojima, Y., Yashiro, K., Asakura, T., Koyama, Y. (2000). Presumption of Cause of Railway Tunnel Lining Spalling Accident, Tunnel and underground, 31(10), 63-69.

Kojima, Y., Yashiro, K., Asakura, T., Koyama, Y. (2000). New Conservative Management of Railway Tunnels, Tunnel and underground, 31(10), 69-76.

.