A Study on the Shield Tunnel Deformation due to the Deposit and Scour of the Riverbed

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Abstract: The deformation of tunnel crossing through a river due to the deposit and scour of the riverbed was studied in this paper. Three-dimensional finite difference program, FLAC3D, with Mohr-Coulomb elasto-plastic soil model was used to perform the analysis. The results show that the lateral deflection of tunnel alignment is smaller than the allowable value determined by Department of Rapid Transit System.

Keyword: deposit, scour, TRTS tunnel, settlement, numerical analysis.

1. INTRODUCTION

Shield tunneling has become one of the most popular methods used in the construction of urban tunnels, such as rapid transit system and large diameter underground pipelines, in order to reduce the impact on the traffic. Safety assessment must be performed in order to evaluate the influence on the existing tunnel due to nearby underground construction.

Hsinchuang Line of TRTS (Taipei Rapid Transit System) runs underground from Hsinchuang passing through Sanchung and then crosses under the Tamshui River perpendicularly (included in Contract DK194) to join the Tamshui Line at Minchuan West Road station. The plane view and section layout of the tunnels crossing the river is shown in Fig.1 and Fig.2, respectively. The shield tunnels of Hsinchuang Line will be settled and uplifted in the crossing area due to the deposit and scour of the riverbed.

In this paper, the tunnel deformation due to the deposit and scour of the riverbed was studied and the critical depths of deposit and scour were determined according to the allowable lateral deflection of tunnel alignment determined by Department of Rapid Transit System (DRTS).

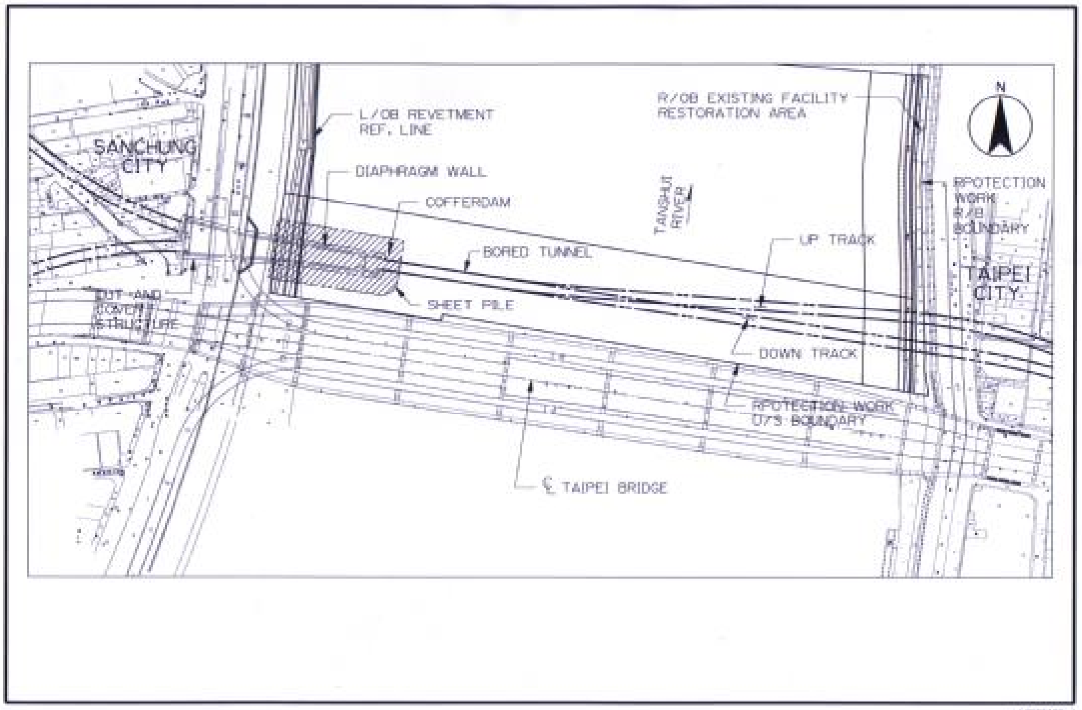

Fig 1 Plane view of TRTS crossing tunnels layout

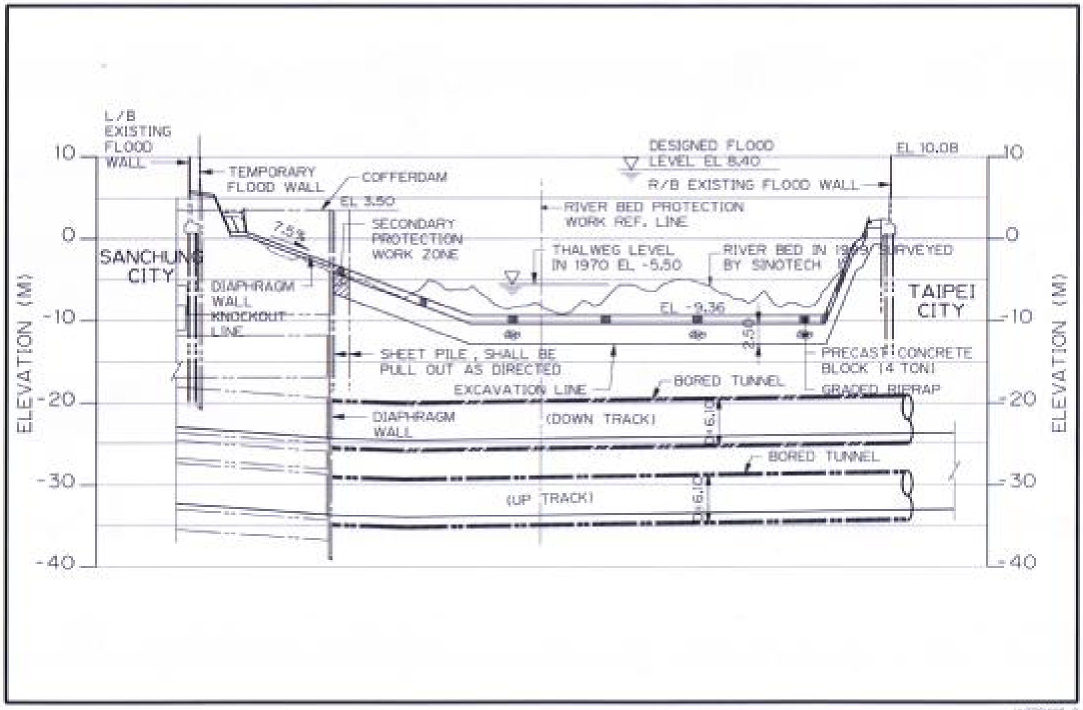

Fig. 2 Section layout of TRTS crossing tunnels

2. GEOLOGICAL CONDITIONS

According to the geological information obtained from the additional geological investigation report of Contract DK194 of TRTS, the soil strata encountered consist mainly of silty sand and sandy silt with one layer of silty clay interbeds. The thickness of each layer is 9m to 10m except the first layer. The SPT-N values for silty sand and sandy silt layers are in the range of 10 to 30, and 8 to 22 for silty clay strata. In this study, simplified soil strata and soil parameters based on laboratory and in-situ testing were summarized in Table 1.

The construction sequence of tunnels was completed prior to the simulation of deposit and scour of the riverbed. Deposit of riverbed was simulated by applying the normal pressure on the upper boundary, the original riverbed, based on the unit weight of 1.75 t/m^3 of river mud to account for the thickness of deposit. Four cases of deposit thickness, 1m, 2m, 3m, and 4m, were considered in the analysis. Next, the pressure was removed to simulate the scour of riverbed.

Table 1 Ground Parameters

Layer	Elevation (m)	Classification	SPT-N	Unit Weight (t/m^3)	Friction Angle (deg.)	Cohesion (t/m^2)	deformation modulus (t/m^2)
1	95.3~93.1	SF	-	-	-	0	-
2	93.1~84.1	SM	10	1.91	30	0	1500
3	84.1~75.1	CL	8	1.81	28	0	1550
4	75.1~65.5	SM	20	1.86	31	0	2600
5	65.5~55.6	CL	22	1.86	30	0	2900
6	55.6~46.0	SM	30	1.94	32	0	5200

3. NUMERICAL SIMULATION

Numerical analyses were carried out to simulate the influence of deposit and scour of the riverbed on the shield tunnels in the crossing area. 3-D explicit finite difference code, FLAC 3D, developed by ITASCA Consulting Group [1] was used. To simplify the model geometry, the crossing area was separated to two analysis models. Model 1, shown in Fig. 2, ranges from 0k+400 to 0k+620 with tunnels clear separation of 12m and 10m for horizontal and vertical direction, respectively. From Fig. 3, tunnels clear separation of 10m for vertical direction was used for model 2 from 0k+620 to 0k+850.

Elasto-plastic soil model with Mohr-Coulomb failure criterion was used in the analysis. According to the loading-reloading test and Ng and Lo [2], the deformation modulus of soil under unloading condition is chosen as triple as the deformation modulus of soil under loading condition. Segment linings was modeled using linear elastic shell element with 30020 kN-m^2/m bending rigidity. To simulate the tunnel construction with earth pressure balancing (EBP) shield machine, the soils in the tunnel area were removed in steps and a pressure equal to 1.1 times the lateral earth pressure applied immediately on the advancing face. Segment linings was installed after tunnel deformation equivalent to 30% of the tail void has occurred according to local experiences[3].

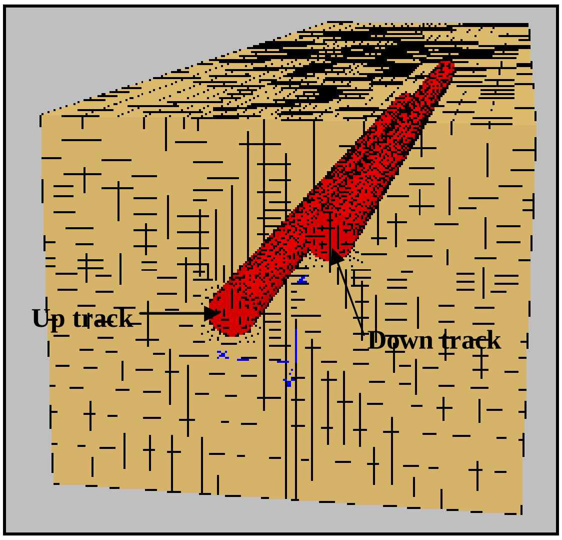

Fig. 2 3-D finite difference mesh of model 1

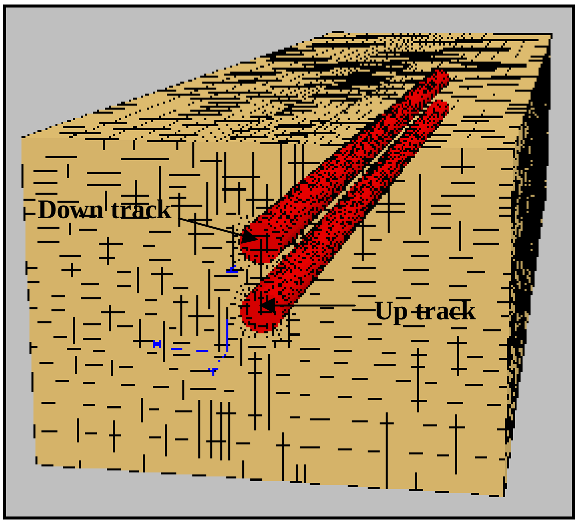

Fig. 3 3-D finite difference mesh of model 2

4. RESULTS OF ANALYSES

The deformations of tunnel alignment in the crossing area, combined model 1 and model 2, are shown in Fig. 4 and Fig. 5 for down track tunnel and up track tunnel, respectively. It shows that down track tunnel with shallow depth results in larger crown settlement due to the deposit and the coming scour of riverbed. However, the differential settlement between down track and up track tunnels is insignificant after scour of riverbed. The maximum crown settlement of down track tunnel is 12mm due to 4m deposit of riverbed. Fig. 6 and Fig. 7 are the rotations of tunnel alignment in the crossing area for down track tunnel and up track tunnel, respectively. It shows obviously that the maximum rotation of tunnel alignment occurred near both river banks for down track and up track tunnels. However, the maximum rotation is relatively small to 0.1%, the allowable rotation of tunnel alignment determined by DRTS.

In order to give suggestions for tunnel maintenance and running management, the tunnel deformation is the most important issue concerned in this study. According to the allowable lateral deflection of tunnel alignment, 10mm, determined by DRTS, the allowable thickness of riverbed deposit must be determined. The relationship between thickness of deposit and crown settlement of tunnels is shown in Fig. 8. The straight lines indicated that soil behavior remains elastic region during riverbed deposit for four cases analyzed. The allowable thickness of riverbed deposit is 3.3m corresponding to the allowable lateral deflection, 10mm, of tunnel alignment.

From the latest restricted report (in press) of DRTS, the allowable lateral deflection of tunnel alignment increases from 10mm to 20mm according to some technical considerations, including clearance envelop of the train, the strength of the track fastener, and the safety of segment linings. Therefore, the lateral deflection of tunnel alignment will be smaller than the allowable value for four cases considered in this study. It is assumed that if the soil behavior still remains elastic region when riverbed deposit over 4m and the allowable lateral deflection of tunnel alignment is 20mm, then the allowable thickness of riverbed deposit can be extrapolated from Fig. 8 to be 6.6m.

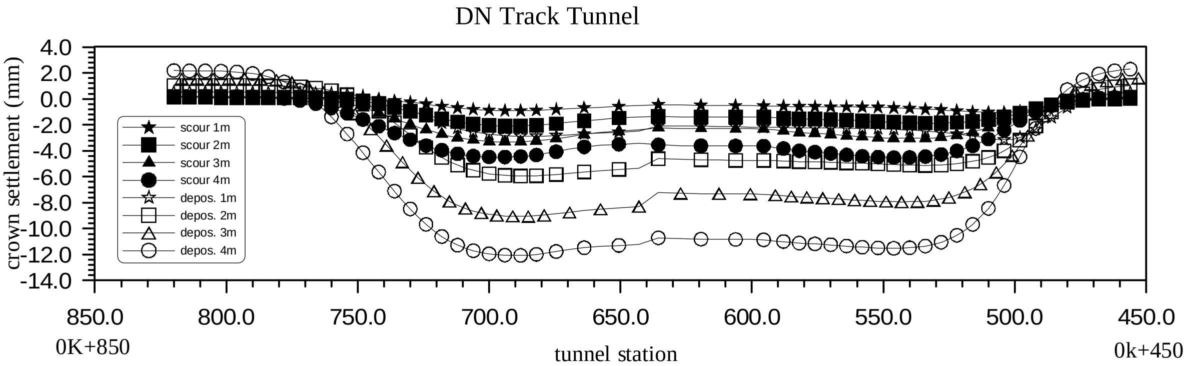

Fig. 4 Crown settlement profile of down track tunnel

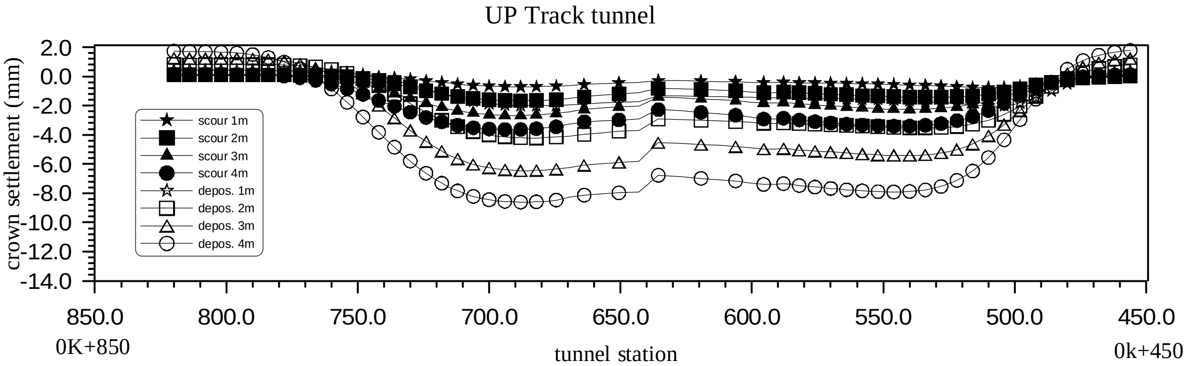

Fig. 5 Crown settlement profile of up track tunnel

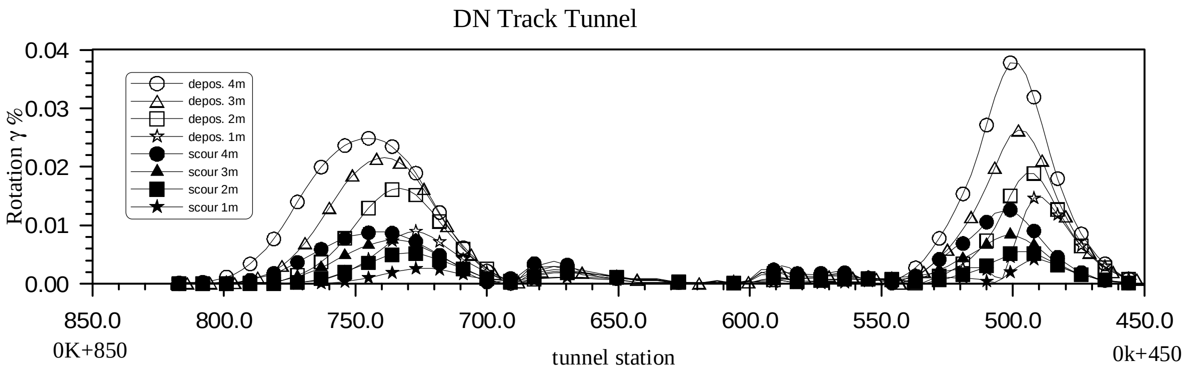

Fig. 6 Rotation distribution profile of down track tunnel

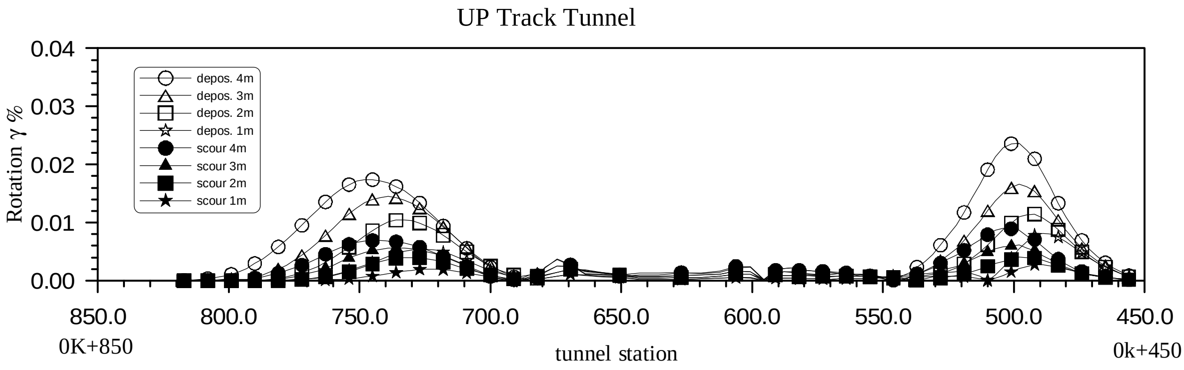

Fig. 7 Rotation distribution profile of up track tunnel

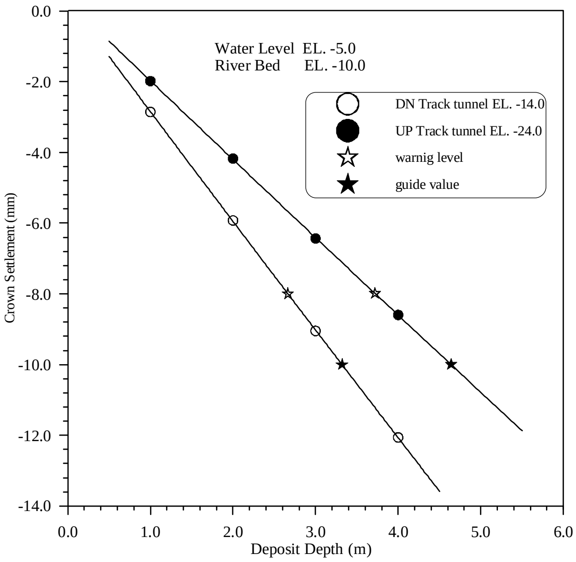

Fig. 8 Deposit thickness versus the crown settlement of tunnels

5. CONCLUSIONS

In this study, the influence of riverbed deposit and scour on the deformation of tunnels crossing the river was studied. From numerical analyses, the results can be summarized as follows:

(1) The deposit and scour of riverbed will indeed cause the settlement and uplift of crossing tunnels. However, the deformation of tunnel alignment is relatively small.

(2) Down track tunnel with shallow depth possesses larger settlement than that of up track tunnel with deeper location during the deposit of riverbed. Besides, the differential settlement between down track and up track tunnels is insignificant.

(3) In this study, the soil behavior remains in elastic region during riverbed deposit condition as well as riverbed scour condition.

(4) The allowable thickness of riverbed deposit is 3.3m corresponding to the allowable lateral deflection, 10mm, of tunnel alignment.

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