Monitoring of subway intersection tunnels during TBM excavation in urban distressed areas

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ABSTRACT: Field measurement and monitoring results during construction of civil projects is one of the most important usages of this field to keep health and safety of workers, equipments, building and other related items around the project.

Subway tunnel excavation under urban distressed areas has several uncertainties causing complicated condition to control and keep safety during execution of project. Execution of local borehole in geotechnical investigations and lack of continues soil information align tunnel path, lack of information about as-is condition of urban facilities and old buildings around tunnel path with high probability of collapse under small settlements, are examples of this uncertainties. Field measurement and monitoring is the best way to validating and updating design assumption and keep safety during tunnel construction.

This paper is focused on monitoring system of a subway intersection station (intersection of line 3 and line 7) in urban distressed areas of Tehran, Iran. Firstly, Tunnel Boring Machine (TBM) of line 7 passed from the station at elevation -31 meter from the ground, and immediately, TBM of line 3 passed from the station, above excavated part, at elevation -17 meter from the ground.

Monitoring system included rod extensometers, pressure cells, strain gages, pins and convergence meter and read in accordance to TBM's excavation time schedule. Finally tunnels were executed without any collapse.

After tunnel execution, it was predicted the probability of collapse during subway execution but continuing of monitoring was not accepted by the client. Unfortunately, there was collapse at street level in this phase.

١ INTRODUCTION

Unknown soil condition around tunnels and subway stations cause difficulties in modeling and prediction of its behavior during construction. It is complicated to evaluate exact soil behavior because of several parameters that should be considered. Monitoring is considered as a fundamental component of project engineering in many cases because it is a way to find out actual behavior of soil during excavation. It includes instrument selection, arrangement, installation, reading data and analysis. Monitoring results give proper structural stability and safety during construction.

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This paper is discussed on monitoring system of a subway intersection station, D3L7, (intersection of line 3 and line 7) in urban distressed areas of Tehran, Iran. This station was constructed at two levels. D3 station at upper level and L7 station at lower level with an offset from D3 station as could be seen in figure 1. Length and width of D3 station is 160 m and 14.4 m respectively. Top of rail of this station is about 17 m under ground level and there is about 9 m from top of station to ground level. Ticket hall of this station is shared with L7 station. Length and width of L7 station is same as D3 station and top of rail of this station is about 26 m under ground level.

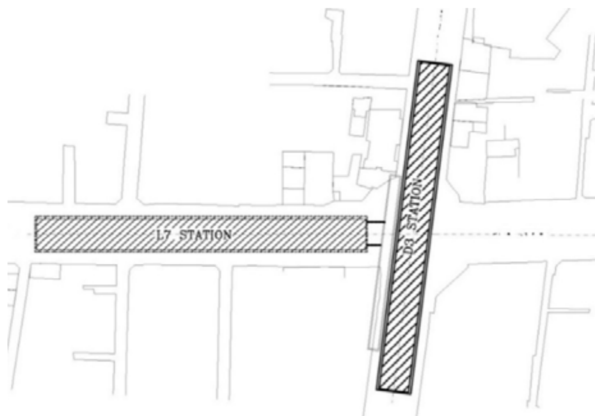


Figure 1. Layout of D3L7 subway station.

For construction of subway stations such as D3L7, excavation is executed after construction of sustaining structure including piles and ribs. In some parts of line 3 and line 7 of Tehran subway, Tunnel Boring Machine (TBM) is used for construction of tunnel. Therefore, it is necessary to consider TBM requirements in relation to other construction procedures of project. Continuation of tunnel excavation is one of the most important of these requirements.

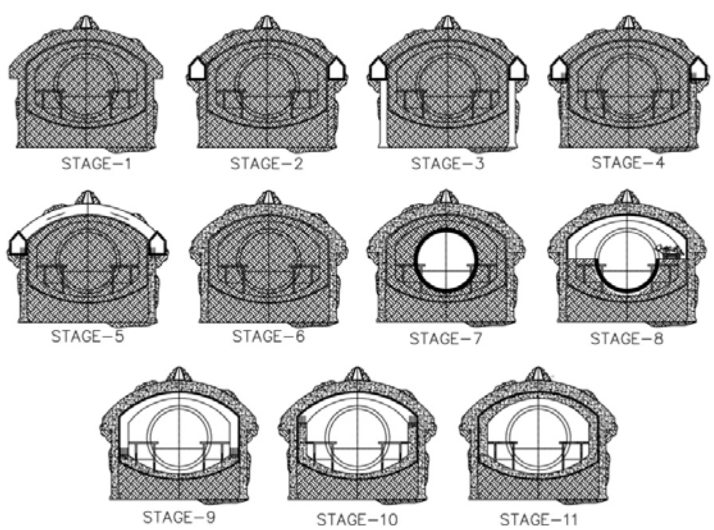


Figure 2. Construction procedure of D3L7 station considering TBM.

It means that tunnel segments should be executed in 160 m length of D3L7 station. After passing of TBM form the station, segments should be removed in 160 m length of D3L7 station. Figure 2 shows construction procedure of D3L7 station considering TBM.

D3L7 station is located in urban distressed areas of Tehran, Iran. There was a collapse near to this station (F3 station) that is shown in figure 3. Old buildings with high probability of collapse under small settlements, passing of two TBM machines at different elevations perpendicular to each other, unknown location of urban facilities, aqueducts and etc. increases the collapse risk of this project.

Figure 3. Collapse of the street at F3 station located in the next crossroad of D3L7 station.

Therefore it was decided to use monitoring system for more accurate control of the construction. This paper is focused on monitoring of D3L7 subway station during the period of passing TBM machines.

۲ DESIGN OF MONITORING SYSTEM

۲،۱ *Monitoring design considerations*

The goals of underground structural monitoring are validation of design assumptions, optimization of execution procedures, upgrading safety conditions during construction, construction cost reduction, assessment of new construction procedures and etc. In this project, for the period of passing TBMs, the main goals of monitoring were considered as the following:

- Detection soil compaction and extraction during TBM excavation and its probable effect on another TBM.
- Keeping safety of old buildings and urban facilities against settlement at ground level.

Therefore, settlement was selected as the most important parameter that should be checked during monitoring. Pressure was considered as the second important parameter.

۲،۲ *Instrument selection and arrangement*

Based on parameters to that should be detected during field measurement, the following instruments were selected.

۲,۲,۱ Rod extensometers

Rod extensometers, with two, three and four reading units at were selected for detection of settlement at different depths. Schematic view of this extensometer is shown in figure 4.

Figure 4. Rod extensometer used in monitoring of D3L7 station.

At D3 station top of ribs and top of piles were in depth of 9 m and 12 m from ground level respectively. Therefore, for measurement of settlement, T1 extensometers were installed in axis of the D3 station with two reading units at 4m and 8m depths. Also, T2 extensometers installed beside of the street for measurement of settlements at top of piles with three reading units at 4m, 8m and 11m depth.

Since top of L7 tunnel has 16m depth from ground level, T3 extensometers with four reading units at the depths of 4m, 8m, 11m and 21m were installed beside of the tunnel. Figure 5 shows rod extensometers arrangement at D3L7 station.

Figure 5. Extensometer's Arrangement at D3L7 station. T1 and T2: red square; T3: yellow square; drainage wells: blue circles; aqueduct above D3L7 station: Orange diagonal line

Urban facilities such as main sewer pipe, gas pipe, high-voltage cable and etc. are located at the axis and beside of the street in the depth of one meter to three meter. These urban facilities have clash with rod extensometers in many locations. Therefore, it was decided to install extensometers diagonally as shown in Figure 6.

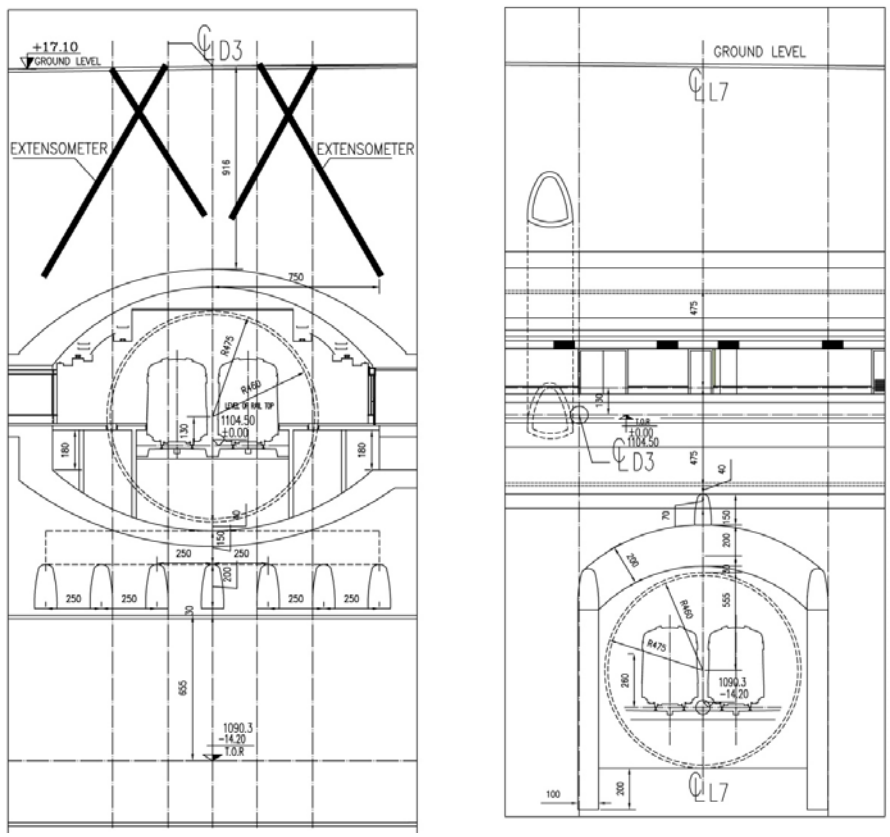


Figure 6. Sections of D3 station and L7 tunnel showing installed extensometers.

٢,٢,٢ Pressure cells, strain gages, pins and convergence meter

Because of two different contractors with unexpected problems were performing the excavation tunnels of line 3 and line 7, no one knows the exact time the each TBM reach to the station. Therefore, three scenarios for excavation of this station were considered. Scenario one shows passing of TBM of line 7 (lower TBM) firstly and passing of TBM of line 3 (upper TBM) secondly. Scenario two shows passing of TBM of line 3 (upper TBM) firstly and passing of TBM of line 7 (lower TBM) secondly. Scenario three shows passing of TBM of line 7 (lower TBM) and TBM of line 3 (upper TBM) simultaneously. Since each TBM had differed condition in operation with different contractors, it was decided to use pressure cells and strain gages too. These were installed in the access gallery at the top of piles before crossroad to measure pressure of soil affected by TBM during excavation in D3 station. Therefore, if there was any unexpected pressure from design considerations during excavation, it was detected before reaching TBM to crossroad and necessary hints will be announced by instrumentation team. Finally, first scenario was occurred and detected pressure was in allowable range.

Also, for assessment of old buildings settlements and inclination beside the crossroad, some convergence pins were installed in access shaft in the north-west of the crossroad to evaluate the effects of passing TBM at different elevations. Figure 7 shows access shaft convergence pins arrangement a

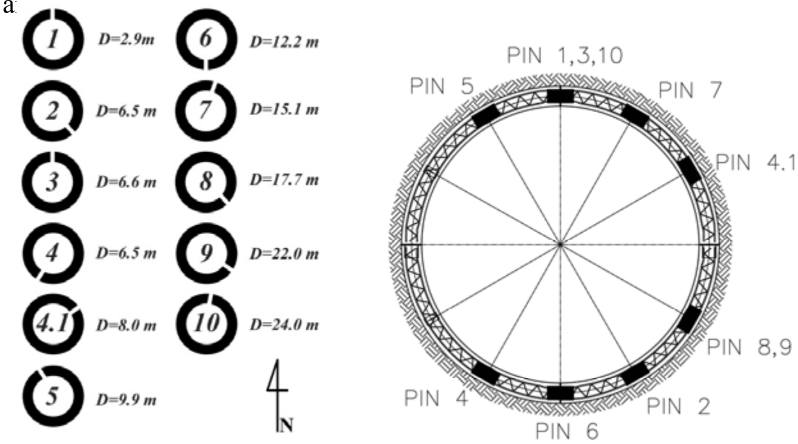


Figure 7. Access shaft convergence pins arrangement and elevations.

۳ FIELD MEASURMENT

۳,۱ *Reading data*

Usually, monitoring system of D3L7 station was read six times per month but in case of passing TBMs, it was required to change this schedule to daily reading of all instruments for a period of one month. This help to announce unusual results to project management immediately.

At the time of reading data some extensometers could not be used because of clashes with urban facilities such as sewer pipe and high-voltage cables. Eight, four and three numbers of T1, T2 and T3 extensometer were operated in this period respectively.

After passing TBM of line 7 (lower TBM), some parts of access shaft were field with foam. Therefore, reading of convergence pins could be done up to 10m from ground level (pin no.5) that was still useful for detecting the effects of TBM line 3 (upper TBM).

Figure 7. Convergence measurement between elevations 2.9 m and 6.5 m in D3L7 access shaft

۳,۲ *Field measurement data analysis*

Summary results of field measurement of rod extensometers are presented in table 1. As mentioned before, TBM of line 7 (lower TBM) was passes from crossroad during first week and TBM of line 3 (upper TBM) was passed from the crossroad during third week. The following conclusions could be extracted from the results:

- During passing of lower TBM, T3 extensometers show settlement up to 240 mm.
- During passing of upper TBM, T1 extensometers show soil expansion up to 150 mm (D3 zone) and T2 extensometers show settlement up to 535 mm beside of the tunnel (L7 zone).
- Settlements in first week are in the range of 10 mm to 50 mm. According to project specification, this could causes apparent damages on buildings. This was approved by detecting some cracks in a public building in the south-east side of the crossroad during this period.
- Settlements in third week are more than 75 mm. According to project specification, this could causes damages on solid pipes of urban facilities. Based on these results, monitoring team requested an inspection from sewer pipe above D3 station. This inspection was not accepted and continuation of monitoring was not extended by client after passing of TBMs. After couple months, a collapse occurred at ground level because of soil scouring due to drainage of wastewater from cracked sewer pipe.

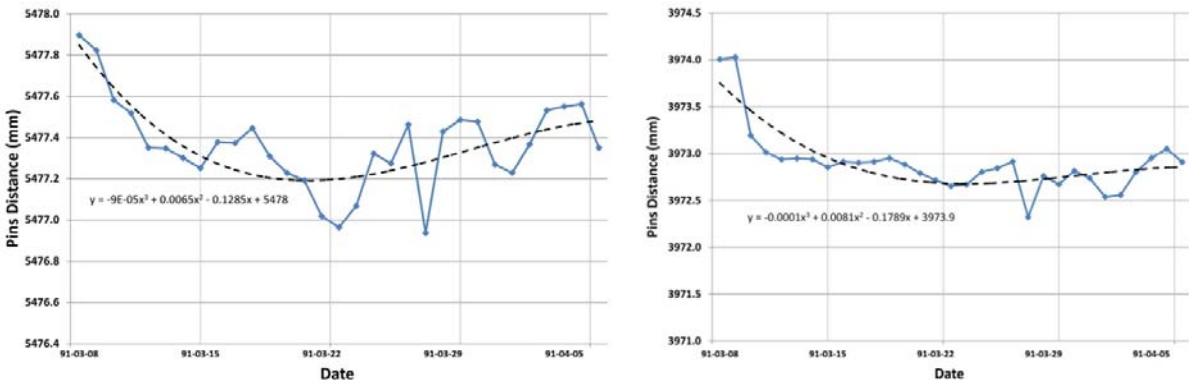
Table 1. Rod extensometer field measurement results (mm)

Date	Monitoring Location	T1		T2		T3	
		Max.	Min.	Max.	Min.	Max.	Min.
Week 1	Crossroad	2	0	25	-15	-	-
	D3 Station (South)	25	0	20	0	-	-
	D3 Station (North)	15	-15	-	-	-	-
	L7 Station	35	25	35	-11	25	-3
Week 2	Crossroad	18	-5	5	-5	-	-
	D3 Station (South)	-1	-40	10	-5	-	-
	D3 Station (North)	10	-10	-	-	-	-
	L7 Station	10	-8	15	-4	240	-15
Week 3	Crossroad	-105	-125	-112	-135	-	-
	D3 Station (South)	-5	-150	-90	-120	-	-
	D3 Station (North)	-70	-80	-	-	-	-
	L7 Station	150	-125	535	-235	-95	-357

Negative numbers denotes expansion of soil

Some of the results of convergence pins in access shaft of D3L7 station which was located in the north-west of the crossroad are shown in figure 8.

As could be seen, some convergences occurred between elevations 3m to 6.5m from ground level in the first two weeks during passing of lower TBM from crossroad. But, after passing of upper TBM, some extractions could be seen from the results during third week. This shaft was located beside of D3 station and L7 tunnel. According to the results, maximum convergences were about



(a) Pins 3-2 at elevation 6.5 m

(b) Pins 1-2 between elevations 2.9 m and 6.5 m

Figure 8. Access shaft convergence pins; (a): pins (1-2) and (b): pins (3-2).

two millimeters. This is not an important problem regarding inclination of old building beside of the tunnel.

٤ CONCLUSION

Monitoring of subway intersection tunnels during TBM excavation in urban distressed areas is discussed in this paper. Most important conclusion are as the following:

١- Tunnel Boring Machines causes changes in soil condition. It could be lead to deflections more than allowable limits in urban facilities. Collapse at ground level because of soil scouring due to drainage of wastewater from cracked sewer pipe after couple months of passing TBM is an example in this subway station. In these cases, inspection of urban facilities should be done before and after passing TBM.

٢- In addition to common practices for monitoring of inclination of buildings during excavation, one could use from convergence data from access shafts which is located beside of buildings.

٣- To avoid clash between instrument layout and urban facilities, it is necessary to have AS-IS layouts of urban facilities. Otherwise, clashes are inevitable.

٥ REFERENCES

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