Analysis of the effects of excavation speed, ground condition and tunnel dimension variations on urban tunnel subsidence in Tehran Niyayesh tunnel

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ABSTRACT

The occurrence of subsidence during driving of surface near tunnels, especially those connected with urban transport scheme, is a common phenomena. Such subsidence is related to some parameters such as the type of ground and rock structure between the tunnel and surface, dimension of the tunnel, method of tunnel excavation and support.

Niyayesh tunnel is located in the alluvial area of the city of Tehran, Iran. The support system used in this tunnel contains a latex membrane, a welded wire mesh and shotcrete with the thickness of 5 centimeters. For measurement purposes, settlement points, convergence pins, geodetic points, extensometers rods, crack meters and strain gages are used to measure the convergence and monitor the subsidence in the tunnel.

In this paper, the effect of variations in excavation speed, type of tunnel support and ground condition on subsidence in the intersection of two tunnels with the opening width of 32 meters (bifurcation) is studied and compared.

Keywords: surface subsidence, urban tunnel, excavating speed, tunnel support, ground condition

1 Introduction

Subsidence is defined as the settling of the earth's surface caused by a natural or man-induced modification of the underlying supporting structure. In the other hand, Surface tunnel subsidence has long been a subject of intensive research for scientist all over the world and considerable achievements have been obtained. The research approved that the depressions form on the ground surface as a direct consequence of subsidence.

Subsidence above such tunnel is related to the type of ground between the tunnel and the surface, the method of tunnel excavation, together with phasing and degree of permanent support, the dimensions of the tunnel, the depth of the tunnel below the surface and the stress condition and in this research the effect of ground conditions and dimension of the tunnel on the surface subsidence when tunnel is retreating, is surveyed.

Niyayesh tunnel is excavated by the New Austrian Tunneling Method (NATM).
The (NATM) is based on the philosophy of "Build as you go" approach with the following caution. "Not too stiff, nor too flexible, not too early, nor too late." It accomplishes tunnel stabilization by controlled stress release. The surrounding rock is there by transformed from a complex load system to a self-supporting structure together with the installed support elements, provided that

the detrimental loosening, resulting in a substantial loss of strength, is avoided. The self-stabilization by controlled stress release is achieved by the introduction of the so called "Semi-Rigid Lining," i.e., systematic rock bolting with the application of a shotcrete lining. On one side, this offers a certain degree of immediate support, and on the other hand, the flexibility to allow stress release through radial deformation. The development of shear stresses in shotcrete lining in arched roof is thus reduced to a minimum.

Niyayesh east-west tunnel is in excavating process in the northern part of Tehran city. From geological point of view, this tunnel is located in an alluvial area and in the activity zone of seasonal rivers and flood streams which have been originated in the southern flanks of Alborz highlands since Paleocene.

2 Subsidence in near surface tunnel

The Researches are shown that due to its difficulties and complicated nature of surface subsidence, the studying about overburden movement, needs. Surface tunnel subsidence can be lead to surface damages and understanding about type of surface ground disturbances is important. There are several types of surface ground disturbances, each of which is immediately transmitted to surface structure and causes damage of various forms, depending on the location of the structure in the subsidence basin. Subsidence measurements include surveys of surface and sub-surface movements and monitoring of surface structural damages. There are some methods for these measurements that need to two basic components. These are subsidence and displacement.

Some factors are effective on the near surface subsidence that said in above. The most important factors are ground conditions and tunnel width. Shallow tunnels are usually driven in soft ground Condition which necessitates special considerations to be given to temporary support. The generally weak character of the ground gives rise to proneness for roof falls to occur unless a highly effective and efficient means of temporary support is employed and even where such well- designed support schemes exist the occurrence of significant quantities of water can lead to cavities forming which could results in subsidence. The ground that is above the excavated area is altered, collapses, is partially compacted and progressively subsides as the work of extraction advances.

Tunnel excavation dimensions play a major role in influencing the likelihood of subsidence developing at the surface. The greater the tunnel width, the greater the imposition placed on the immediate roof to offer self- supporting ability.

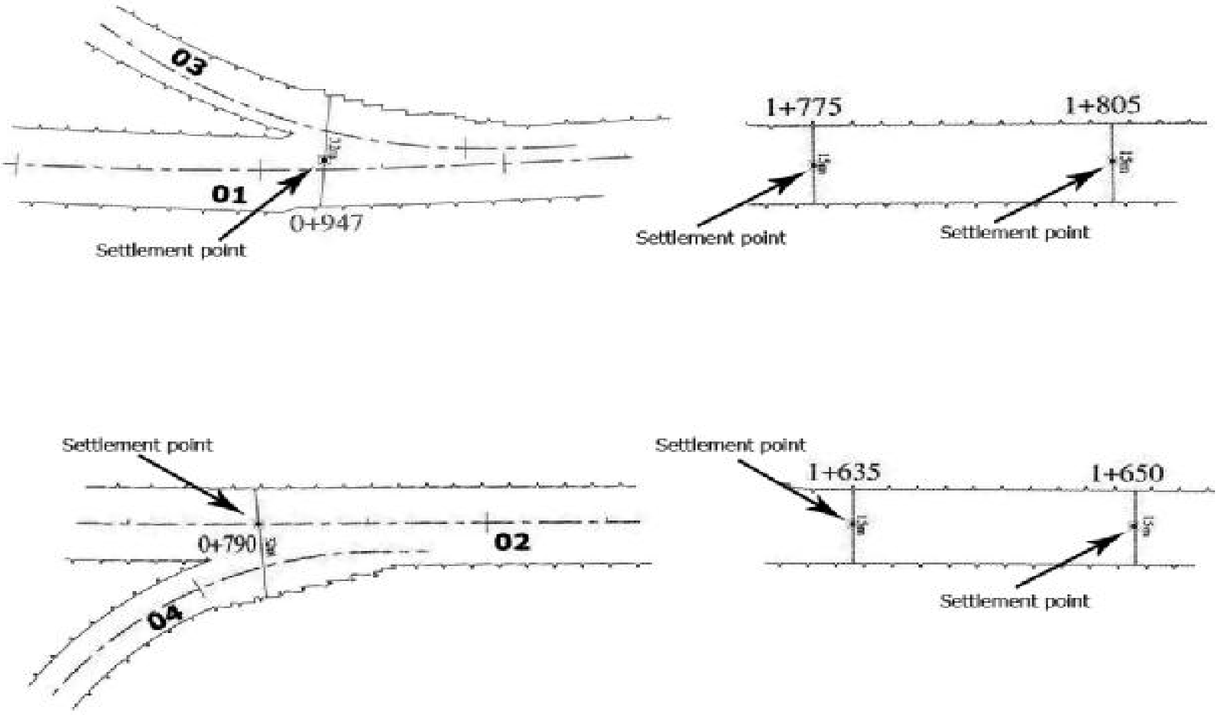
3 Analysis of surface subsidence in Niyayesh tunnel

Niyayesh tunnel is composed of 5 entrance and exit that is being excavated in two directions, east to west and west to east with the length of 3.6 kilometers for each direction.

The overburden in this tunnel varies from 8 to 45 m. This tunnel is being excavated by NATM method and is supported by shotcrete and latex. The investigation area contains two main tunnels namely tunnel no.1 and tunnel no.2. As can be seen in figure 1, in some parts of this tunnel, the width reaches 32 meters due to intersection of side tunnel which advances.

These sides of tunnels called no.3 and no.4. Tunnels become narrower with a width of 15 meters which tunnel advance to working face. In these parts of tunnels, excavation method changes due to the decrease in tunnel width.

Figure 1 The Niyayesh tunnels schematic view with tunnels no.1, 2, 3 and 4.



In this study, the subsidence in four parts of the tunnels is investigated;

1) Intersection of tunnel no.1 and no.3 with the width of 32 meters and length of 30 m.
2) Continuation of tunnel no.1 with approximate width of 15 meters tunnel advance to the working face.
3) Intersection of tunnel no.2 and no.4 with the width of 32 and length of 30 meters.
4) Continuation of tunnel no.2 with approximate width of 15 meters tunnel advance to the working face.

It has to be mentioned that these four areas are located in geologically different parts which in turn can affect the subsidence amount. With different amounts of tunnel advance, considering the width of tunnel and ground conditions of each tunnel, different amounts of subsidence has been measured with measuring instrument. In these tunnels, 2 devices have been used to measure the amounts of subsidence, Plaque and Green area. Plaque instruments works in asphalt area and is composed of stainless steel plate and Green Area has a pin with 30 cm length and Works in soil area and is covered by concrete. The amounts of instruments register with a camera with 1 mm calibration. By these instruments for different amounts of tunnel advance indicate the effects of tunnel advance, ground conditions and width of tunnel on subsidence of ground surface.

The measurements of subsidence amounts in wider parts of the tunnel (32m) has been obtained from a subsidence meter in the first point of the wider parts of the tunnel. But in narrower parts of the tunnel (15m), the subsidence is measured at two points with a distance of 15 and 30m. The diagram of subsidence in contrast with the tunnel advance will be presented in the figure 2. Also the location of tunnel1 and the positions of applied devices and their relative distances are shown in fig 1.

3.1 Intersection of tunnel no.2 and no.4 with the width of 32 m and length of 30m

The ground material in this area lies in C-Formation of Hezar Darreh and contains unconsolidated sandy gravel with weak cementation and high permeability. The cementation is stronger in the lower parts of the area and NSPT (number of standard penetration ratio) shows values below 50 in this area. Overburden is reported to be around 11 m in this part and the subsidence amount has been measured by the subsidence meter instruments. In this part, south drift was excavated after the completion of the north drift and measurement of subsidence during excavating process are presented in the table 1.

Table 1 the registered subsidence in the north drift of intersection of tunnel no.1 and no.3

NO.	Date	chainage	Tunnel Advance	North drift Subsidence
1	22-Jan-10	780.6	-10	0
2	29-Jan-11	785.6	-5	1
3	3-Feb-10	790	0	0
4	4-Feb-10	791.7	1.6	0
5	22-Feb-10	792.6	2.5	-1
6	28-Feb-10	794	4.4	-2
7	12-Feb-10	796.7	6.6	-4
8	23-Feb-11	798.5	8.5	-5
9	15-Apr-10	800.6	10.5	-6
10	17-Apr-11	800.6	10.5	-8
11	19-Apr-10	803.6	13.5	-9
12	22-Apr-10	808.5	18.4	-9
13	29-Apr-10	814.5	24.4	-9
14	10-May-10	825	34.9	-9

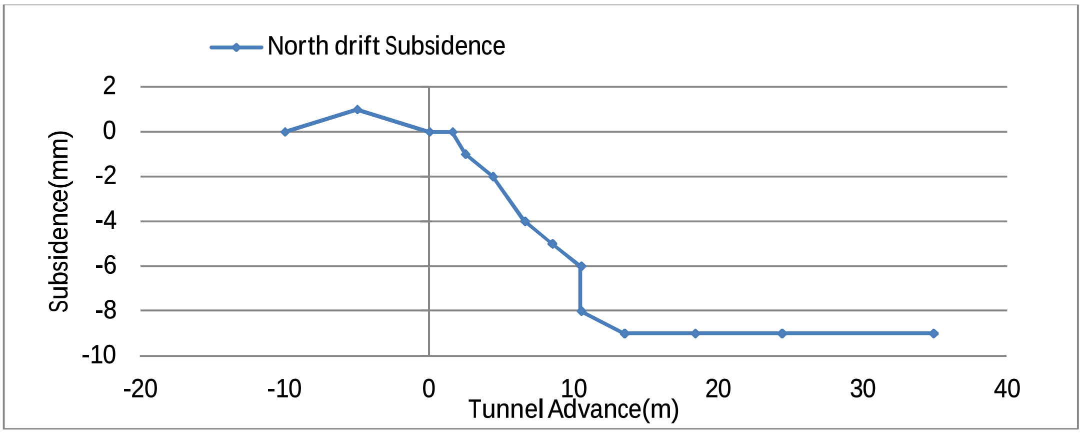


Figure 2 the registered subsidence in the north drift intersection of tunnel no.2 and no.4 during tunnel advance. (0 is the set point of measurement instrument), (width 32m)

The above diagram shows that subsidence leads to a constant amount after 15 meter advance from the measurement set point.

3.2 Intersection of tunnel no.1 and no.3 with the width of 32 meters and length of 30 m.

The ground material in this area lies in C-Formation of Hezar Darreh and contains of unconsolidated sandy gravel with weak cementation and high permeability with increase in clay concentration and NSPT values around 50. Overburden in this area is reported to be around 16m.The results of subsidence measurements in this area are presented in table 2.

Table 2 the registered subsidence in the south drift of intersection of tunnel no.1 and no.3

NO.	Date	Chainage	Tunnel Advance	South drift Subsidence
1	8-Jul-11	931	-16	0
2	9-Jul-11	934	-13	0
3	11-Jul-11	935	-12	0
4	13-Jul-11	938	-9	0
5	15-Jul-11	941	-6	1
6	16-Jul-11	944	-3	1
7	18-Jul-11	949	2	0
8	19-Jul-11	950	3	-1
9	20-Jul-11	953	6	-2
10	21-Jul-11	953	6	-2
11	23-Jul-11	956.3	9.3	-3
12	25-Jul-11	958	11	-5
13	27-Jul-11	960	13	-6
14	1-Aug-11	962	15	-7
15	2-Aug-11	964	17	-8
16	3-Aug-11	967	20	-8
17	4-Aug-11	970	23	-8

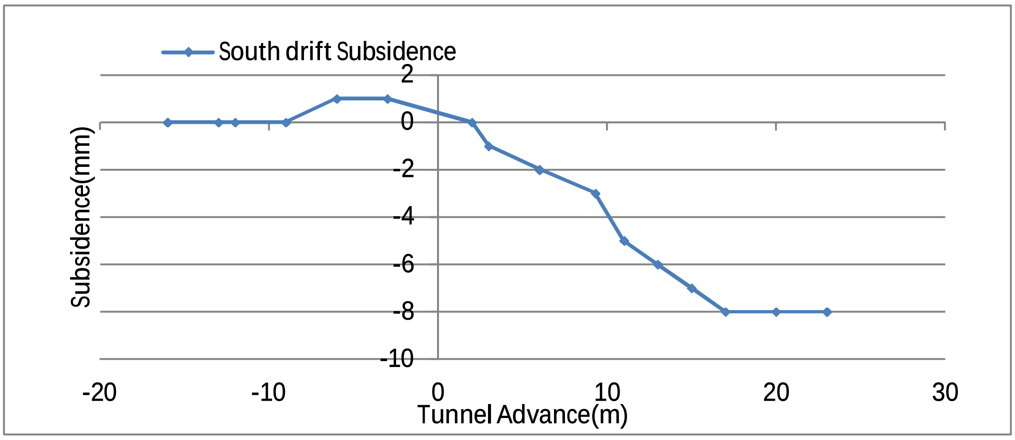


Figure 3 the registered subsidence in the south drift of intersection of tunnel no.1 and no.3 during tunnel advance. (Width 32m)

Considering that the southern drift has been excavated first and the northern drift has been excavated after the completion of the south drift, the recorded subsidence in this part is shown in the following table 3.

Table 3 the registered subsidence in the north drift of intersection of tunnel no.1 and no.3

No	Date	Chainage	Tunnel Advance	North drift Subsidence
1	9-Jun-11	931	-16	-8
2	10-Jun-11	934	-13	-8
3	11-Jun-11	935	-12	-8
4	13-Jun-11	938	-9	-8
5	14-Jun-11	941	-6	-8
6	15-Jun-11	944	-3	-8
7	16-Jun-11	949	2	-8
8	18-Jun-11	950	3	-9
9	1-Jul-11	952	5	-11
10	2-Jul-11	955	8	-12
11	3-Jul-11	958	11	-14
12	5-Jul-11	961	14	-15
13	7-Jul-11	961	14	-16
14	8-Jul-11	963	16	-16
15	9-Jul-11	966	19	-16

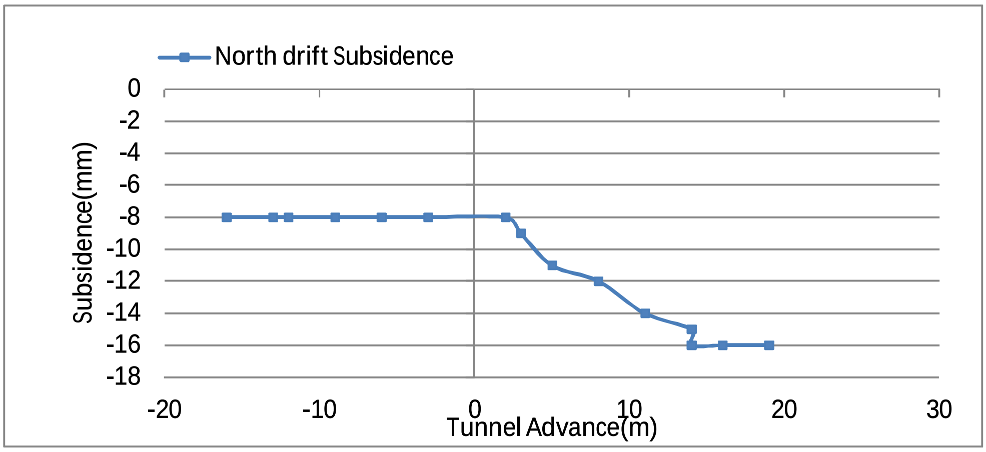


Figure 4 the registered subsidence in the north drift of intersection of tunnel no.1 and no.3 during tunnel advance. (Width 32m)

Subsidence in this area has a lower rate compared to the previous case which is due to higher stability of the ground in this part. The lower rate of subsidence shows that the subsidence is reduced by increasing the distance from measurements set point and in this study by nearing to working face.

3.3 Continuation of the tunnel no.1 up to the working face

This area is located in the conglomerate part of the C-Formation of Hezar Darreh which is characterized by the uniform grain size distribution with maximum diameter of 15 cm and strong cementation and impermeable. Also in this area present sub-ordinate rock particles and gravels along with sand, silt and clay cement and overburden is reported to be 40 m.

The subsidence in this area has been investigated considering present situation has been carried out in two stations with 30 m distance. The station no.2 is located 30 m ahead of station no.1The detail of this part of tunnel can be seen in table 4 and the subsidence diagram is showed in figure 5.

Table 4 the registered subsidence at 2 stations in Continuation of the tunnel no.1

No	Date	Chaniag	Tunnel Advace	Subsidence(Station 1)	Subsidence(Station 2)
1	28-Sep-11	1622.4	-27.6	2	0
2	30-Sep-11	1628.2	-21.8	0	0
3	1-Oct-11	1629.9	-20.1	0	0
4	2-Oct-11	1631.6	-18.4	0	0
5	3-Oct-11	1636.7	-13.3	-2	0
6	4-Oct-11	1640.1	-9.9	-3	0
7	7-Oct-11	1643.5	-6.5	-3	0
8	8-Oct-11	1646.9	-3.1	-3	-1
9	9-Oct-11	1648.7	-1.3	-3	-1
10	10-Oct-11	1650.5	0.5	-4	-2
11	11-Oct-11	1654.2	4.2	-6	-4
12	12-Oct-11	1656.1	6.1	-6	-4
13	14-Oct-11	1663.8	13.8	-6	-6
14	15-Oct-11	1667.8	17.8	-7	-6
15	16-Oct-11	1679	29.8	-7	-9
16	17-Oct-11	1679	29.8	-8	-9
17	18-Oct-11	1681	31.8	-8	-10
18	19-Oct-11	1682.7	33.5	-9	-12
19	20-Oct-11	1684.2	35	-10	-13
20	21-Oct-11	1686.2	37	-10	-13
21	22-Oct-11	1689.2	40	-11	-13
22	23-Oct-11	1692.2	43	-11	-14
23	24-Oct-11	1694.2	45	-11	-14
24	25-Oct-11	1697.2	48	-11	-15
25	26-Oct-11	1699.2	50	-11	-15
26	27-Oct-11	1702.2	53	-11	-15

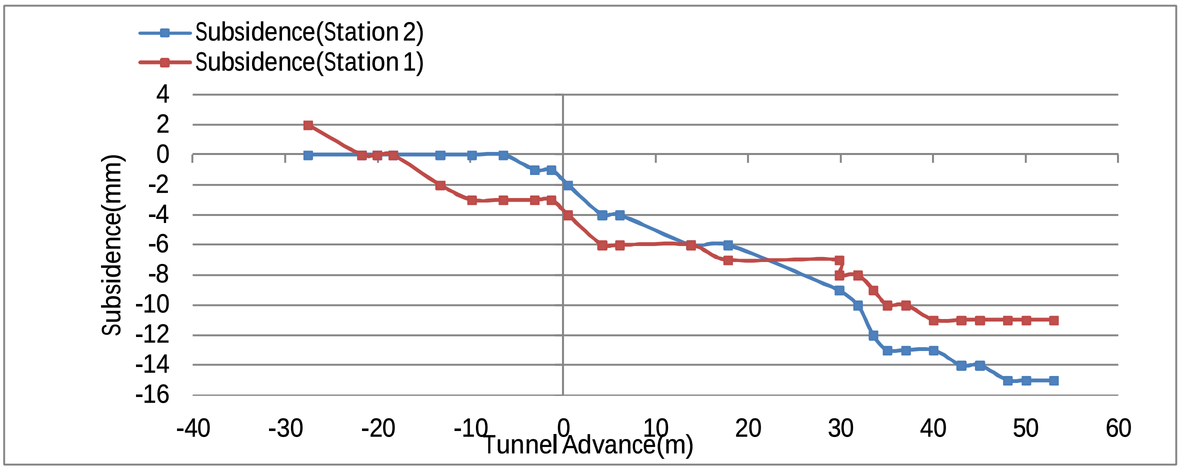


Figure 5 the registered subsidence at 2 stations in Continuation of the tunnel no.1

Diagrams show repeated subsidence in this part of the area which decreases with increase in the distance between the measurement point and the excavating working face.

3.4 Continuation of the tunnel no.2 up to the working face

The ground condition in this area is similar to the third area but the clay layers are more abundant between the rock particles. Presence of water and less ground stability of this area has led to local collapses and frequent subsidence in this part. The overburden in this part of the tunnel is reported to be 30m. Considering the advance amounts, different measurements have been recorded by subsidence meters. These measurements have been obtained from two stations with 35 meters distance (station no.2 is placed 35 meters ahead of station no.1).

Table 5 the registered subsidence at 2 stations in Continuation of the tunnel no.2

NO.	Date	Chaniage	Tunnel Advance	Subsidence(Station1)	Subsidence(Station2)
1	25-Sep-11	1767.8	-37.2	0	0
2	26-Sep-11	1771.5	-33.5	1	0
3	30-Sep-11	1777.9	-27.1	1	0
4	1-Oct-11	1781.5	-23.5	1	0
5	2-Oct-11	1783	-22	1	0
6	3-Oct-11	1788.1	-16.9	1	0
7	4-Oct-11	1791	-13.3	0	0
8	10/8/2011	1802	-3	-1	0
9	10/9/2011	1804.6	-0.4	-1	0
10	10/10/2011	1808.2	3.2	-1	0
11	10/11/2011	1811.8	6.8	-1	0
12	10/12/2011	1813.6	8.6	-1	-1
13	10/14/2011	1818.1	13.1	-1	-1
14	15-Oct-11	1820.5	15.5	-1	-2
15	16-Oct-11	1823	18	-2	-3
16	17-Oct-11	1828.1	23.1	-2	-3
17	19-Oct-11	1832.6	27.6	-2	-4
18	22-Oct-11	1836.6	31.6	-2	-4
19	24-Oct-11	1840	35	-2	-4

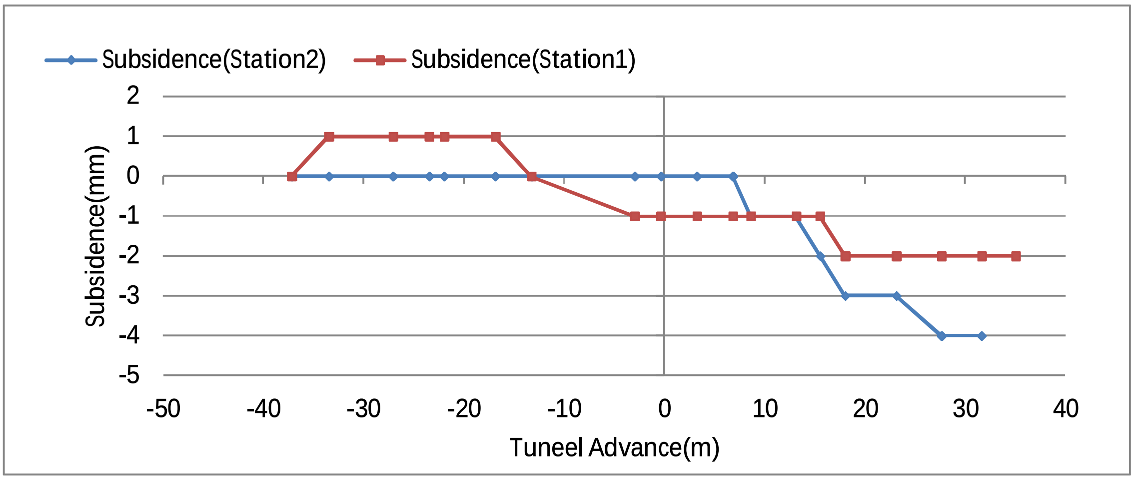


Figure 6 the registered subsidence at 2 stations in Continuation of the tunnel no.2

4 Conclusions

1. Results show that in places with good ground conditions, even in narrow parts of the tunnels, uplift was observed in the measurement point before the working face reaches the measurement point. In addition to this, lower overburden in places without good ground conditions, has led to uplift.
2. In parts of the tunnels with 32 m width, where tunnel no.3 joins the tunnel no.1, (as shown in fig 3 and 4), due to presence of clay material and lack of water, it shows more stability and less subsidence.

3. Results show in fig 5 and 6. Indicate conformity of subsidence values in two points with different distances from working face. Finally the total subsidence amount will be constant in a specific distance.
4. Fig 6. Indicates that the local collapse and high amounts of subsidence is due to presence of water and clay material in tunnels.
5. Comparison of fig 4 and fig 5 shows that the subsidence in 32 meter wide tunnels is relatively more than the subsidence in 15 meter wide tunnels.
6. Subsidence in 15 meter wide and 32 meter wide tunnels is highly dependent on the quality of ground i.e. the tunnel which has better ground conditions (more stable) shows less amounts of subsidence.
7. Fig 4 and fig 5 show that excavating a new drift beside the earlier drift and increase in tunnel width can increase the total subsidence amount.
8. Results show that with increase in distance between the working face and the measurement point (more than 15 m); subsidence reaches its maximum amount and becomes constant.

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