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Sustainability Analysis of Tabriz Subway Tunnel, Line 1

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ABSTRACT: In recent decades, metropolises of Iran have been more populated and urban transportation has become a serious and important issue. Subway tunnel construction is one of the fundamental methods in solving heavy traffic problem of metropolises like Tabriz. Subway tunneling in loose urban lands causes different problems. Line one of twin tunnels of Tabriz subway is numerically analyzed using [1]$FLAC^{2D}_{V4.00}$ software: analysis after excavation of first tunnel without installation of supporting system, after installation of supporting system of first tunnel, and after construction of second tunnel. However, displacement around the tunnel, ground subsidence, forces on tunnel supporting system and safety factor of supporting system are analyzed. Results of the study show the first tunnel is totally falling without supporting system. After installation of supporting system in first tunnel using precast reinforced concrete (segment), maximum ground subsidence is 6.39 mm that increased 45% after construction of second tunnel and reached to 9.28. Safety factor of first tunnel supporting system against forces on it and safety factor after construction of second tunnel is 1.81 and 1.85, respectively.

Keywords: Sustainable Analysis, Tabriz Subway Tunnel, Subsidence, Forces on the Tunnel Support System

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INTRODUCTION

Development of urbanization culture increase urban population and people are seeking ways to overcome high population and traffic in cities. Therefore, urban train transportation or metro was practical as a proper solution. Iran is also dealing with this problem and metropolitans are having major traffic problems; therefore, subway tunnel implementation is inevitable.

These projects are specially prompted at the present and future. Thus, evaluation analysis of deformations and forces on tunnel support system in different situations is one of the concerns of engineers and experts.

One of the main issues in urban tunnels is studying and predicting ground treatment and deformations caused by tunnel excavation (Hage Chehade and Shahrour, 2008; Leca and New, 2007; Xu and Zhu, 2006; Sang-Hwan, 2004). Moreover, stabilization of excavation area and preventing possible subsidence at ground level are the main parameters in project design (Xu and Zhu, 2006; Sang-Hwan, 2004).

Ground level subsidence and forces on tunnel supporting system are strongly related. In this study, sustainability analysis of first tunnel of Tabriz subway is studied numerically using $FLAC^{2D}_{V4.00}$ software (Fast Lagrangian Analysis of Continua, 2002) in different conditions: after excavation of tunnel 1 without supporting system, after installation of supporting system of tunnel 1, and after construction of tunnel 2 (Akhgar, 2007).

However, displacement around the tunnel, ground level subsidence, forces on supporting system and safety factor of supporting system are analyzed.

MATERIAL AND METHODS

In general, Tabriz is found on deposits of different periods of third and fourth geological periods, including clay rocks, sandstone, conglomerate, tuff, gypsum, and alluvial sediments such as clay, silt, marl, sand and rubble. The major part of Tabriz valley in recent times is covered with younger and loose sediments that are mostly river and glacial sediments with different textures and granulations. Tunnel 1 of twin tunnels of Tabriz subway is constructed mechanized using one of the new tunnel cavitation machines in loose and falling grounds, known as earth pressure balance. The tunnel is started from south east of city, El Goli depot, and after passing city center ends in south west of city, Laleh Depot. From stations 7-16, the route is a deep tunnel for 7 km, including two shuttle lines with outer space line of 6.70 m, and 4.20 m near the station. Excavation diameter of tunnels is 6.88 m, external diameter of segments 6.60 m and internal diameter of tunnels 6 m, with 14 cm space between excavation diameter and external diameter of segments which will be filled with injecting concrete (Tabriz Urban Railway Organization, 2001).

Geotechnical data of model

Under study section is borehole no. FBH-15 located at km = 3 + 864.03, where the water is at the height of 8 m above ground level. Based on the data of borehole FBH-15, six main layers of soil can be cited on the site (Jehad Sahand Research Corporation, 2005). Specific weight of saturated soil, dry density, permeability coefficient, coefficient of elasticity, Poisson's ratio,

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coherence strength, internal friction angle and the angle of the different layers dilation cut by the borehole FBH-15 in different depth are shown in Table 1. Cross section plan and tunnel positioning is indicated in Figure 1.

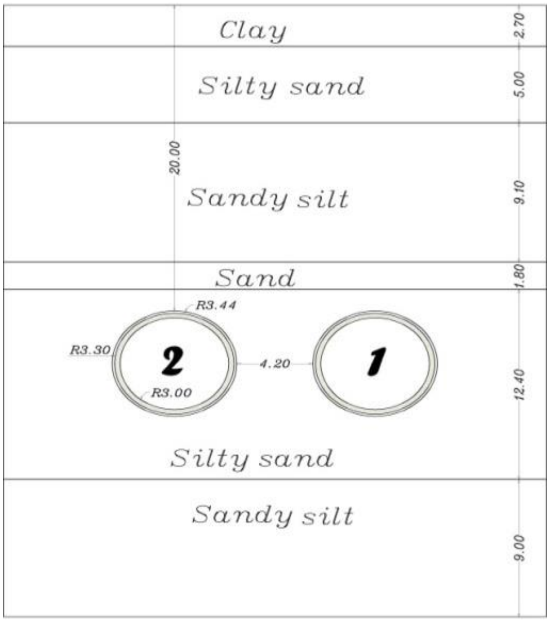

Figure 1. Cross section plan and tunnel positioning

To determine ratio of in situ horizontal stress on in situ vertical stress (K_0), various relationships are available regarding soil condition (Jehad Sahand Research Corporation, 2005). Given that the project is mainly granular soil, the following equation was used to calculate

$$K_0 = 1 - \sin\varphi \qquad (1)$$

where

φ is the degree of internal friction angle.

Since the internal friction angle of tunnels is 32 degree, K_0 = 0.47

Characteristics of segments and injection concrete

In tunnelling with Earth Pressure Balance, after a cycle (in this project 140 cm) within shield trail, supporting system is installed as concrete precast segment. Supporting system is installed circular within the shield trail; however, it forms a circular space with 14 cm thickness behind the shield trail. This space is limited between earth and segments. With progress of the shield, this space is filled with under pressure injection concrete. Segments are precast reinforced concrete, water resistance, 30 cm thickness and 140 cm width, with each rings formed of 6 sections. Characteristics of segments and injection concrete are shown in Table 2.

Table 1. Geotechnical characteristics of FBH-15 borehole layers

Layer	Depth (m)	γ_{sat} (KN/m^3)	γ_{dry}(kN/m^3)	K (m/s)	E (kPa)	ν	C (Kpa)	φ	ψ
Clay (manual soil)	0-2.7	18	16	1×10^{-7}	7500	0.3	5	20	0
Sandy silt	2.7-7.7	18.5	16.5	9×10^{-6}	10000	0.25	0	30	0
Silty sand	7.70-16.80	19	16	3.62×10^{-7}	15000	0.35	10	23	0
sand	16.80-18.60	21	20	2.03×10^{-7}	15000	0.25	0	32	2
Sandy silt	18.60-31	21	20	2.03×10^{-7}	20000	0.25	0	32	2
Silty sand	28-40	19	16	2.03×10^{-7}	12000	0.35	10	23	0

Table 2. Characteristics of injection concrete and segments

Supporting system	Elasticity modulus (kPa)	Uniaxial compressive strength (kpa)	Poisson's ratio	Specific weight (KN/m^3)	Thickness (m)
injection	9×10^5	40×10^3	0.3	25.5	0.122
segment	2.35×10^7	45×10^3	0.2	24	0.3

Tunnel modeling

To determine the model width, there should be at least a space as diameter of tunnel to the borders. Due to the limitation of FLAC software in using computer memory, the width of model was chosen 40 m.

In model length, turbulent zone space should be at least one times more than the lateral border of model. To minimize the effect of lateral borders on the model, this space was chosen as double. Considering the position of two tunnels, the model dimensions was selected 100×40.

For boundary condition, at the bottom of model the nodal velocities are considered zero in X and Y directions, in the lateral parts the nodal velocities are zero in X directions, and free above the free surface model. Model is considered gravitational. Applied meshing is block. In this meshing, smaller blocks are used in tunnel surrounding because of the importance of excavation zone, and larger blocks were used in sides. Tunnel position and applied meshing are shown in Figure 2.

Average diameter of tunnels using EPB in tunnel 1 of Tabriz subway is 6.88 m; according to external diameter of maintenance segments, 6.6 m, some of the space is immediately filled after displacement of soil layers and some will be filled with injecting grout. In excavation with shield of soil environments, however, the volume of excavation section will reduce. This amount in this project and in normal condition is less than 1%. To consider slopes and curves etc., it is necessary to analyze more quantities. Hence, all analyses are analyzed with 1%.

To model radial volume reduction caused by additional excavation and spaces back of the segments, in this software, after balancing primary model, the tunnel is excavated and 1% displacement is allowed that is equal to 17.24 mm to subsidence the tunnel crown to a considered amount; then, the injection is introduced with 12.2 cm thickness, supporting system is installed and the program is performed.

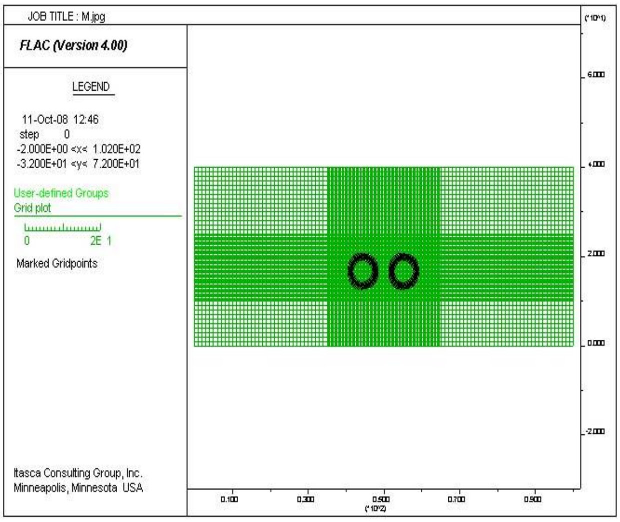

Figure 2. Meshing and tunnel position

Sustainable analysis

In model analysis, all calculations were in pristine condition with no excavated space; hence, model reached a primary balance. Unbalancing forces and nodal speeds tend to be zero. Unbalancing force tending to zero after primary balance is indicated in figure 3.

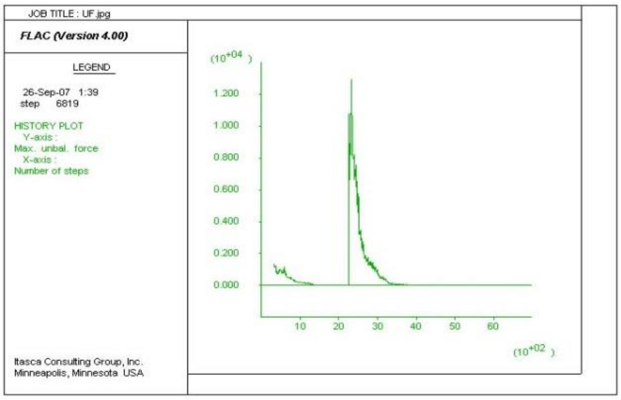

Figure 3. Unbalancing force after primary balance

Excavation of first tunnel

In second phase, after zeroing displacements and primary nodal speeds, the first tunnel was excavated. In this stage, unbalancing force and nodal speed in vertical and horizontal direction indicated high fluctuation and didn't tend to zero. Results indicated the model has not reached balance and is falling. Supporting system installed immediately after excavation.

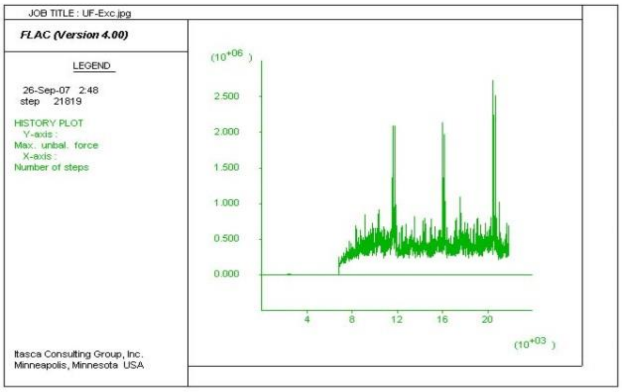

Figure 4. Unbalancing force after excavation

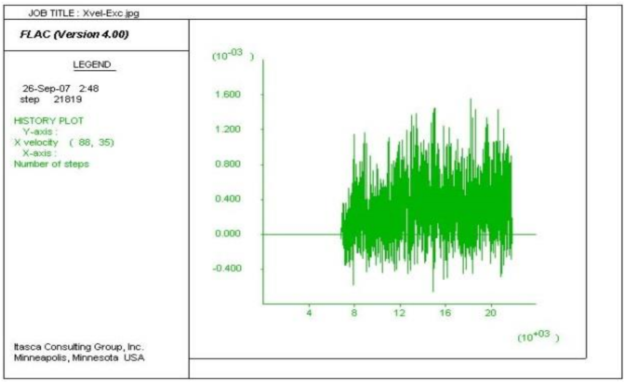

Figure 5. Horizontal nodal speed in crown of first tunnel

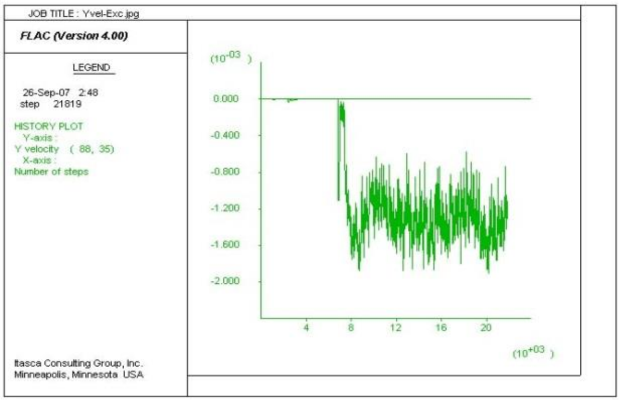

Figure 6. Vertical nodal speed in crown of first tunnel

Installation of supporting system in first tunnel

After installation of supporting system, the type of precast segment in reinforced concrete in the following of shield, displacement around the tunnel and its walls, ground subsidence, forces on supporting system and tunnel stability can be studied.

Displacement due to the construction of first tunnel

Quantity and direction of total displacement vector in first tunnel (right tunnel) is indicated in figure 7. As shown in figure 7, uplifting tunnel bottom and displacement of tunnel ceiling downward cause wall rejection, where the maximum vertical deformation is 39.32 mm in tunnel bottom. This is due to the high depth of tunnel bottom from ground level than depth of tunnel ceiling from ground level. Maximum vertical deformation in walls is 20.94 mm (figure 7).

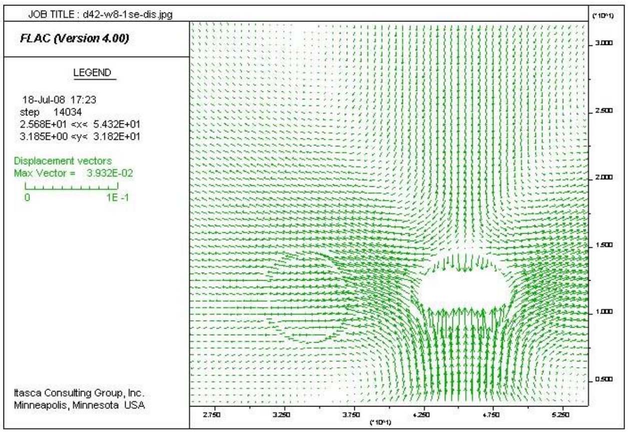

Figure 7. Total deformation of first tunnel

Vertical displacement after construction of first tunnel is shown in figure 8. In this case, formation of a large dome on the tunnel ceiling that continues to ground level, cased an approximate subsidence of 5-16 mm. In the sides, this dome is about 1-4 mm (Figure 8). Maximum subsidence of ground level above the first tunnel center is 6.39 mm.

Horizontal displacements after construction of first tunnel is shown in figure 9. According to figure 9, two side walls of first tunnel move in opposite direction and get away from each other. Horizontal displacement of sides are nearly the same and equal to 7.19 mm. Horizontal displacement of ground level is about -3.32 to 1.5 mm (Figure 9).

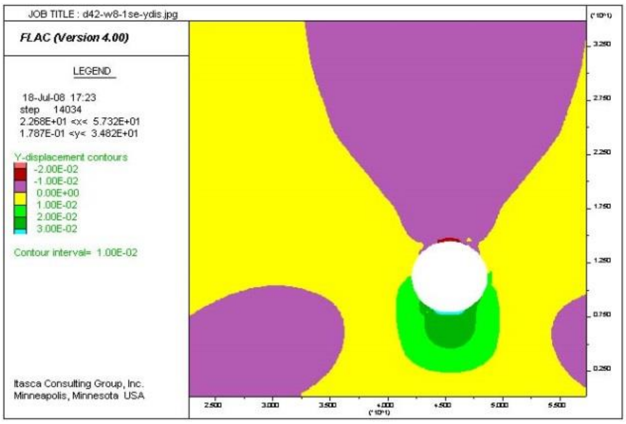

Figure 8. Vertical displacement after construction of first tunnel

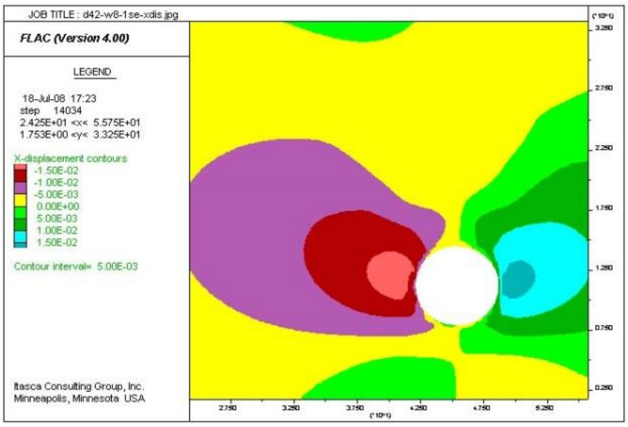

Figure 9. Horizontal displacement after construction of first tunnel

Forces on supporting system after construction of first tunnel

Axial forces on supporting system of first tunnel are shown in figure 10. Maximum axial forces on supporting system of tunnel wall are 1400 KN. Minimum axial forces in tunnel ceiling and bottom is 832.1 KN. According to figure 10, axial force is almost uniform and positive. Maximum and minimum forces are on tunnel wall and on tunnel bottom and ceiling, respectively (figure 10).

Bending moment on supporting system of first tunnel is shown in figure 11. Maximum Bending moment in tunnel bottom enforced on supporting system is 302.2 KN/m and minimum bending moment in four zones with 45 degree angel is in horizontal position and -6.31 KN/m. According to figure 11, bending moment on tunnel walls is negative and positive in tunnel ceiling and bottom. This indicate the pressure on ceiling is falling and in tunnel bottom is uplifting that lead to positive bending moment; that is, inner side of supporting system is in ceiling, the bottom is under the tensile stress and external side is under pressure stress. Ceiling and bottom supporting system pressurize the walls, that inside the supporting system walls is under pressure and external part is under tension that cause negative moment in supporting system walls (Figure 11).

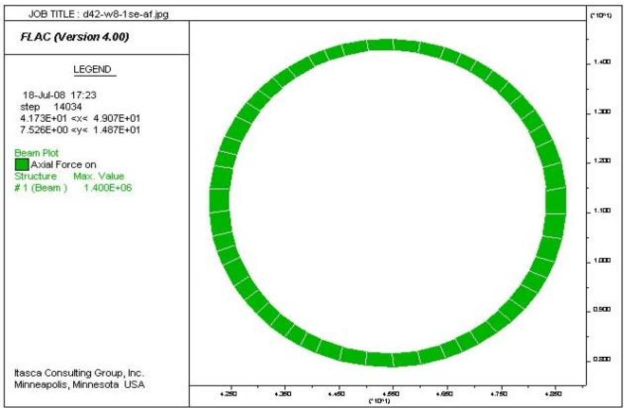

Figure 10. axial force on supporting system of first tunnel

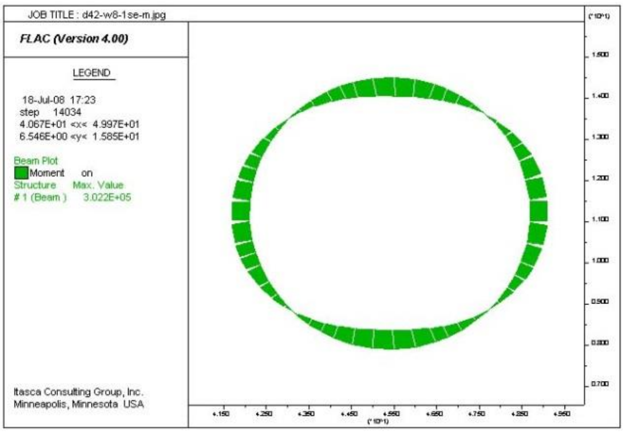

Figure 11. Bending moment on supporting system of first tunnel

Shear force on supporting system of first tunnel is shown in figure 12. Maximum shear force on supporting system is in angle 225 ° in trigonometry degree and equal to -194.1 KN; the minimum force is in four zones of ceiling center, bottom and walls, equal to 0.54 KN (figure 12). It worth to note that, in zone with maximum shear force, the minimum bending moment is on supporting system. In zone with maximum bending moment, minimum shear force is applied that is the same on strength of materials (Figure 12).

With axial force and bending moment on supporting system, tension on tunnel supporting of segment is calculated as follow (Biron, 1981):

$$\sigma_b = \frac{N}{A} + \frac{M_{\max}}{W} \qquad (2)$$

where,

σ_b = tension on segments (Kpa)

N= axial force on segment cross section (KN)
A= segment cross section (m^2)

M_{max}= maximum bending moment on segments (KN/m)
W= segment section base (m^3)

Tension on segments according to relation 2 is 24813.33 kpa, that according to segment characteristics (Table 2), the pressure strength of uni-axis is 45000 kpa, with higher reliability. Segment safety factor is 1.81 $\left(F_s = \frac{45000}{24813.33} = 1.81\right)$.

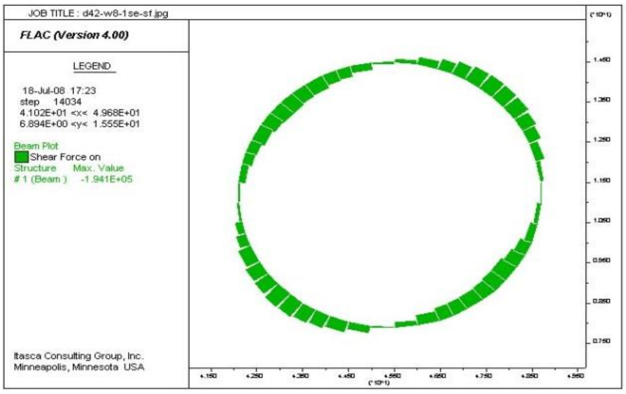

Figure 12. Shear force on supporting system of first tunnel

Construction of second tunnel

In this stage, the second tunnel is excavated after the first tunnel. In this part, tension changes, displacements and forces on supporting system after construction of second tunnel is studied. After construction of second tunnel maximum total and effective stress is disturbed, so that maximum total stress is -663.8 Kpa, and maximum effective stress is -401.2 kpa.

Displacements after construction of second tunnel

Tunnel deformation after construction of second tunnel (left hand tunnel) is shown in figure 13. After construction of second tunnel, the maximum deformation has increased from 39.32 to 49.33 mm, which is like an uplifting in the bottom of second tunnel. Maximum vertical deformation at the bottom of first tunnel is also 39.39 mm with no significant deformation. In this condition, maximum vertical deformation of wall at the right side of first tunnel is 26.40 mm with 6 mm increase than single tunnel. External walls of both tunnels had rejection, while internal walls had 13 mm lump (Figure 13).

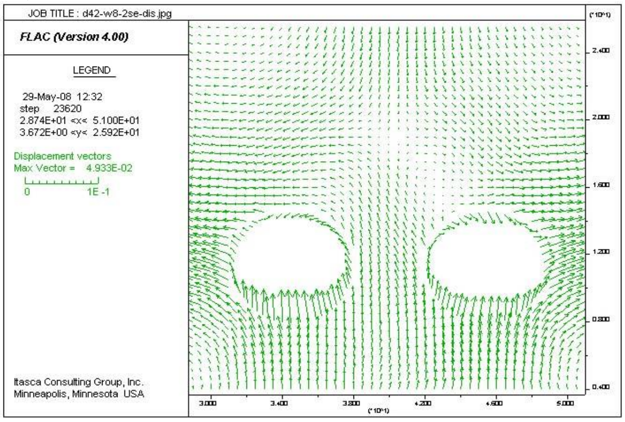

Figure 13. Deformations of tunnels after construction of second tunnel

Vertical displacements of model after construction of second tunnel (left hand side) is shown in figure 14. Subsidence area at the top of tunnels is widening after construction of second tunnel and creates 5-10 mm subsidence (Figure 14). This area is not completely symmetrical and the first tunnel (right) is wider that is because of primacy of the first tunnel excavation. In the sides of this area a 0-1 cm uplifting is considered. Between two tunnels a 1-2 cm uplifting is observed and at the bottom of first tunnel the uplifting is approximately 2-3 cm that shows this area is more extended than the bottom of second tunnel (Figure 14).

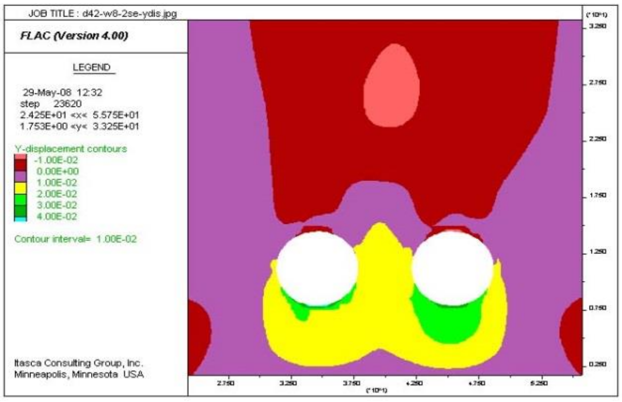

Figure 14. vertical displacement after construction of second tunnel

At the ground level, the maximum subsidence from top center of first tunnel is transferred to between of two tunnels (one meter to first tunnel) and 9.28 mm subsidence was accomplished. It seems this asymmetry is because of primacy of excavation of tunnel and subsidence at the ground; after construction of second tunnel the maximum subsidence toward first tunnel occurred. Subsidence is increased 45% than single tunnel. Above the ground level at the top of first tunnel a 7.88 mm subsidence occurred, that had 23% increase than single tunnel and at the ground level at the top of second tunnel a 6.06 mm subsidence occurred.

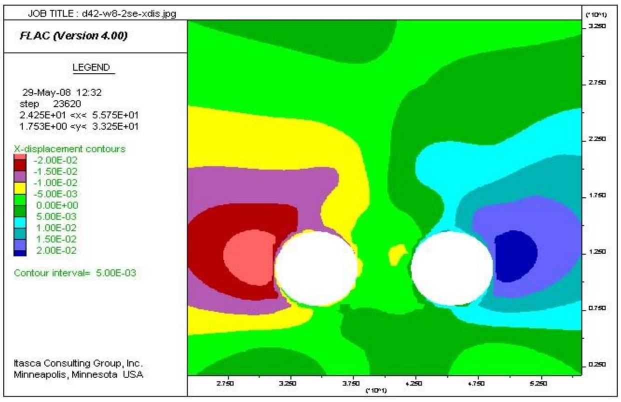

Figure 15. horizontal displacement after construction of second tunnel

Horizontal displacements of model after construction of second tunnel (left) are shown in figure 15. Horizontal displacement has increased after construction of second tunnel. Maximum horizontal displacement in the right wall of first tunnel is 13.66mm with 90% increase than single tunnel that is doubled. In

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left wall of first tunnel horizontal displacement is 3.05 mm, in right wall of second tunnel it is -9.11 mm and on the left wall of second tunnel is -7.11 mm. In ground level the horizontal displacement is -3.03 to 3.22 mm with no significant change than single tunnel (Figure 15).

Forces on supporting system after construction of second tunnel

Axial force on supporting system of tunnels after construction of second tunnel is shown in figure 16. Maximum axial force on segments has considerable difference with previous condition and is changed from 1400 to 1450 KN. In fact, maximum axial force of first tunnel has a little reduce from 1400 to 1393 KN. Axial force of second tunnel is more than first tunnel and reached 1450 KN (Figure 16).

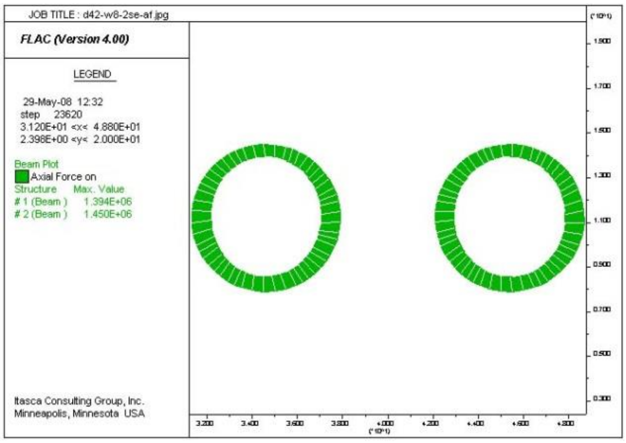

Figure 16. Axial force on supporting system of tunnels after construction of second tunnel

Bending moment on supporting system of tunnels after construction of second tunnel is shown in figure 17. After construction of second tunnel, maximum bending moment on segments is reduced from 302.2 KN on single tunnel to 291.6 KN/m at the bottom of second tunnel. Bending moment on supporting system of first tunnel has more reduce from 302.2 to 262.5 KN/m (Figure 17).

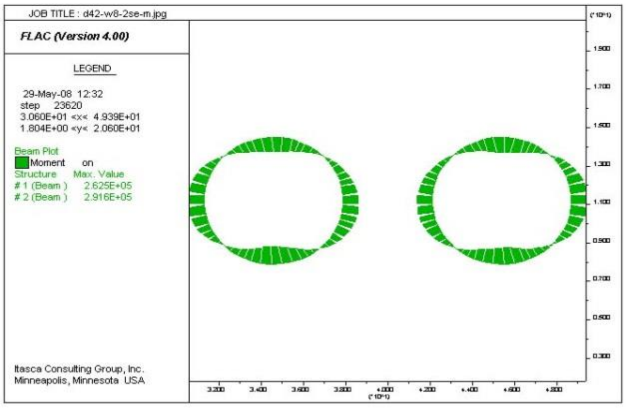

Figure 17. Bending moment on supporting system of tunnels after construction of second tunnel

Shear force on supporting system of tunnels after construction of second tunnel is shown in figure 18. Maximum shear force is also changed like bending moment and changed from -194.1 KN in single tunnel to 189.9 KN after construction of second tunnel. In first tunnel, shear force after construction of second tunnel has changed from -194.1 to -168.1 KN (Figure 18).

In general, it can be concluded after construction of second tunnel, axial force is more than single tunnel. After construction of second tunnel, forces on supporting system of first tunnel has reduced and forces on supporting system of second tunnel are in general more than first tunnel.

Therefore, stress on segments is 24273.33 Kpa that is less than single tunnel that shows the high effect of bending moment than axial force. Final safety factor has increased than single tunnel and is 1.85 $\left(F_s = \frac{45000}{24273.33} = 1.85\right)$.

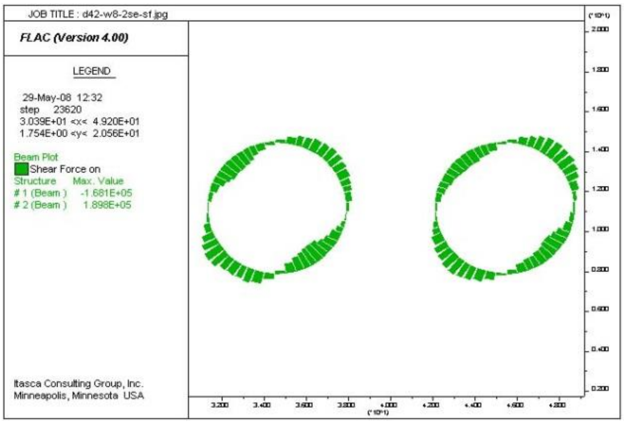

Figure 18. Shear force on supporting system of tunnels after construction of second tunnel

CONCLUSION

1. Numerical sustainable analysis of tunnel without installation of supporting system using $Flac^{2D}_{V4.00}$ software indicates the tunnel is closely falling. Hence, the supporting system should be installed immediately after construction.

2. After construction of first tunnel, maximum ground level subsidence is 6.39 mm and vertical displacement of tunnel wall is -7.19 mm and uplifting of tunnel bottom is 39 mm.

3. Maximum axial force on supporting system of tunnel is 1400 KN, maximum bending moment 302.2 KN/m and maximum shear force is -194.1 KN. Here, safety factor is 1.81.

4. After construction of second tunnel ground level subsidence have increased 45% and achieved 9.28 mm, and is transferred from higher than center of first tunnel to middle of two tunnels in ground level. Uplifting of tunnel bottom is increased 10 mm, vertical displacement of tunnel walls has 6mm increase and horizontal displacement of tunnel walls has doubled.

5. After construction of second tunnel, axial force on supporting system of tunnel has considerable increase, bending moment and shear force has little reduce and safety factor is 1.85

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