DETERMINING THE DISPLACEMENT OCCURRED IN THE TUNNELS USING DIFFERENT MEASUREMENT AND FINITE ELEMENTS METHODS: A CASE STUDY FOR TRABZON-2 TUNNEL, IN TURKEY

Mualla Yalçınkaya[1], Burak Satır[1], Mehmet Akköse[2]
[1] Department of Geodesy and photogrammetry Engineering
Karadeniz Technical University, Trabzon, Turkey
Email: mualla@ktu.edu.tr; buraksatir@mynet.com
[2] Department of Civil Engineering
Karadeniz Technical University, Trabzon, Turkey
Email: akkose@ktu.edu.tr

Abstract: Determining shape and position changes occurred in engineering buildings is one of an application area of geodetic surveys. Temporary and permanent deformations occur in engineering structures such as dam, bridge, tunnel, viaduct and tower due to natural and artificial forces. Causes of these deformations are usually physical properties of ground, weight of structure, active external forces etc. Because of highly cost in construction and intensive uses from people, it is very important to monitor engineering structures.

In mountainous areas, transportation is provided with tunnels in some location of roads such as highway. In turkey, especially, the East Karadeniz Region has a mountainous topography. So, in this region, tunnels are rather frequently used in road construction studies. Trabzon-2 tunnel is in this region. In this study, it was aimed to monitor deformations in the Trabzon-2 via geodetic and geotechnical methods. For deformation study, object points were established in 42-45 measurement periods with geodetic methods. Results were analyzed and deformations were determined. At the same time, geotechnical measurements were made with two inclinometer tubes to determine deformations. In addition, Trabzon-2 tunnel was modeled using finite element method and analyzed as statically. Deformations according to horizontal and vertical loads were determined taking into consideration material properties of it. Result from geodetic, geotechnical methods and finite element analysis were compared whit each other. So, deformations from different methods were examined and interpreted more realistically.

1. Introduction

Movements occur on huge engineering buildings such as dam, tunnel, bridge, tower, and industrial building and its surrounds should be monitored by deformation measurements. Thus, socio-economic damages can be prevented by taking actions according to the forming deformation. Tunnels providing road passing on areas which has uneven topography should be started monitored, and formed movement, its direction and it velocity during the construction stage should be determined. Therefore, both our economy and social environment take advantages due to taking actions at the beginning.

In this study, it is aimed to determine deformations formed during the construction stage of Tunnel 2 providing passing throuhgt inside the city Trabzon and Karadeniz Coast Highway-one of the tunnels built on Public Highway at East Karadeniz Region. Determination and interpretation of deformation more realistically depends on using deformation models, measurements methods and techniques. In our study, deformations were determined with geodetic, geotechnique measurements and finite elements method and results were examined.

2. Trabzon City Passing Tunnel 2 on Karadeniz Public Coast Road (KPCR)

Trabzon coast street is both an important transportation artery and street, and forms the part Karadeniz Coast Road passing throught inside the city and thus has an intercities transportation position. The important part in city inside of the street which is a divided road is used compulsory as an undivided-two banded road because of the one tunnel tube at tunnel building area. Thus, this tunnel part make road a crisis which down and in trouble with traffic. Highways Director Office of Trabzon Region has decided to open a second tunnel near and on the south part of the current tunnel. This second tunnel is between 0+542.500 and 0+670.870 km. Openning of this tunnel has an importance due to the dense settlement, historic buildings, passings with highway-bridge, topographical conditions and railway geometry. Because the ground inside the tunnel is weak-very weak rock, “Shield Tunnelling” method used in underwater tunnelling and called slow excavation is applied at tunnel opening (Domanic, etc., 2005; Jancsecz etc., 1999; Leca, 1989) (Fig.1).

Figure1: Trabzon City Passing Tunnel 2 on KPCR

Tunnel was opened with New Austria Tunnel Opening Method, when we take into account very short length of the tunnel, it is adopted two stage excavation approach by planning firstly to finish upper half excavation and then starting to lower half.

The New Austria Tunnel Opening Method can be explained shortly as taking control of stress distribution on 3-dimension, “minimizing of deformations and slacks” forming during excavation, “protecting of rock-ground resistance” on excavation area. In order to fulfill of explained conditions, it is necessary to permanently measure and elevate tunnel inside deformations and surface movements during and after excavation activities. In addition, it is necessary to measure and monitor deformations which could form at sensitive structures such as building, road, bridge on surface (Rabcewicz, 1964; Sauer 1990; Arioglu etc, 2002a).

3. Measurements Using for Monitoring of Tunnel Deformations

It is necessary to do geotechnique and geodetic deformation measurements starting from construction step because deformation velocity is more in tunnels. Therefore, it is provided to take necessary causes in advance by determining horizontal and vertical deformations.

3.1. Geodetic measurements

Three dimensional coordinates of object points (deformation points) which will be constructed on ceiling, sole, and side walls of cross- section determined at different intervals on tunnels were measured by electronic instruments (Fig. 2). The coordinates of object points which were constructed on ceiling, sole, and side walls were measured at determined period intervals. By using coordinates measured at different periods, forming movements were determined. 5 cross-section at 6m intervals at Trabzon City Passing Tunnel 2 on KPCR were determined (Fig. 2).

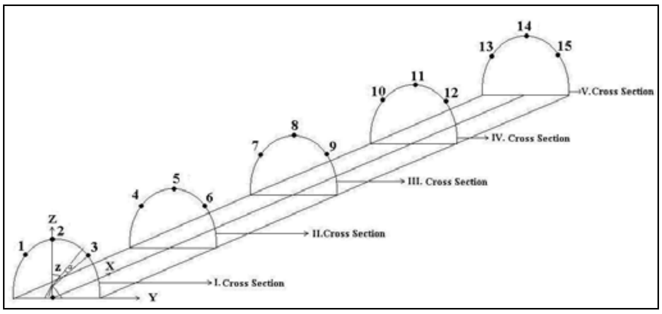

Figure 2: Tunnel object points and measurements done by electronic instruments

The coordinates of these points were determined with periodical measurements by using electronic measurements at February, March, April in 2005 (Table 1).

Cross-section	Month	Day	Number of periods
I	February	23, 24, 25, 26, 27, 28	40
	March	1, 2, 3, 4, 5, 7, 9, 11, 13, 17, 19, 21, 23, 25, 26, 27, 28, 29, 30, 31	
	April	1, 2, 3, 4, 14, 16, 18, 20, 22, 24, 26, 28, 30	
II	February	25, 26, 27, 28	42
	March	1, 2, 3, 4, 5, 7, 9, 11, 13, 17, 19, 21, 23, 25, 26, 27, 28, 29, 30, 31	
	April	1, 2, 3, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30	
III	February	28	39
	March	1, 2, 3, 4, 5, 7, 9, 11, 13, 17, 19, 21, 23, 25, 26, 27, 28, 29, 30, 31	
	April	1, 2, 3, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30	
IV	March	5, 7, 9, 11, 13, 17, 19, 21, 23, 25, 26, 27, 28, 29, 30, 31	27
	April	1, 2, 3, 4, 14, 16, 18, 20,22, 24, 26, 28, 30	
V	March	17, 19, 21, 23, 25, 26, 27, 28, 29, 30, 31	25
	April	1, 2, 3, 4, 6, 8, 10, 12, 14, 16, 18, 20,22, 24	

Table 1: Geodetic Measurement Periods at Cross-section

The coordinates determined at all cross-sections were evaluated separately. Time dependent coordinate changes of the points on I. and III. cross-sections at the beginning and middle of tunnel were given on Figure 3 and Figure 4.

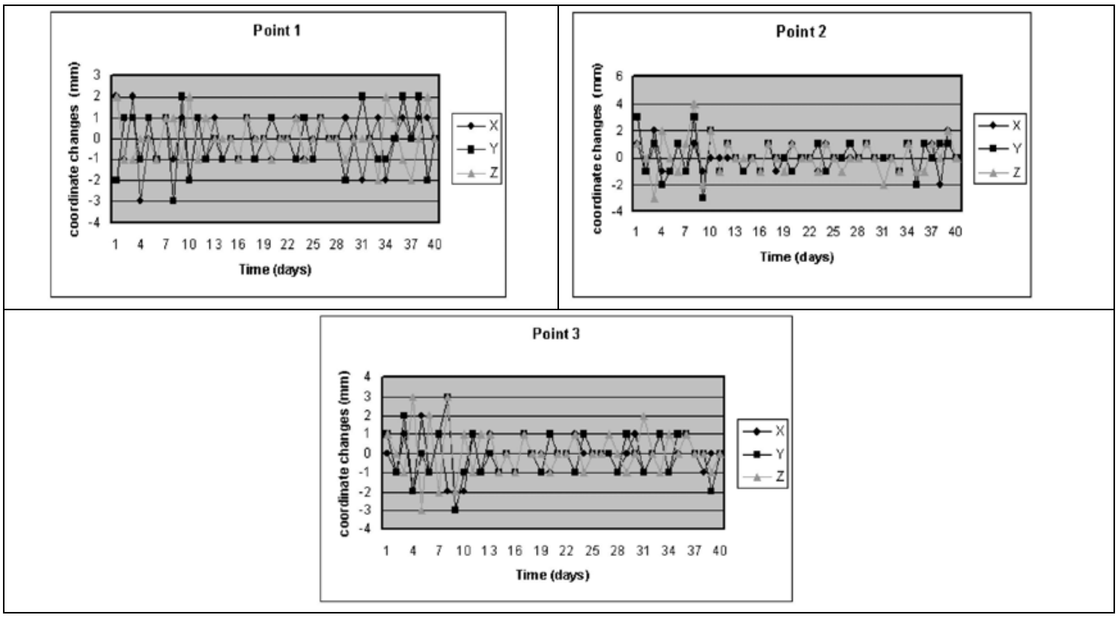

Figure 3: Time dependent coordinate changes of the points on I. cross-section

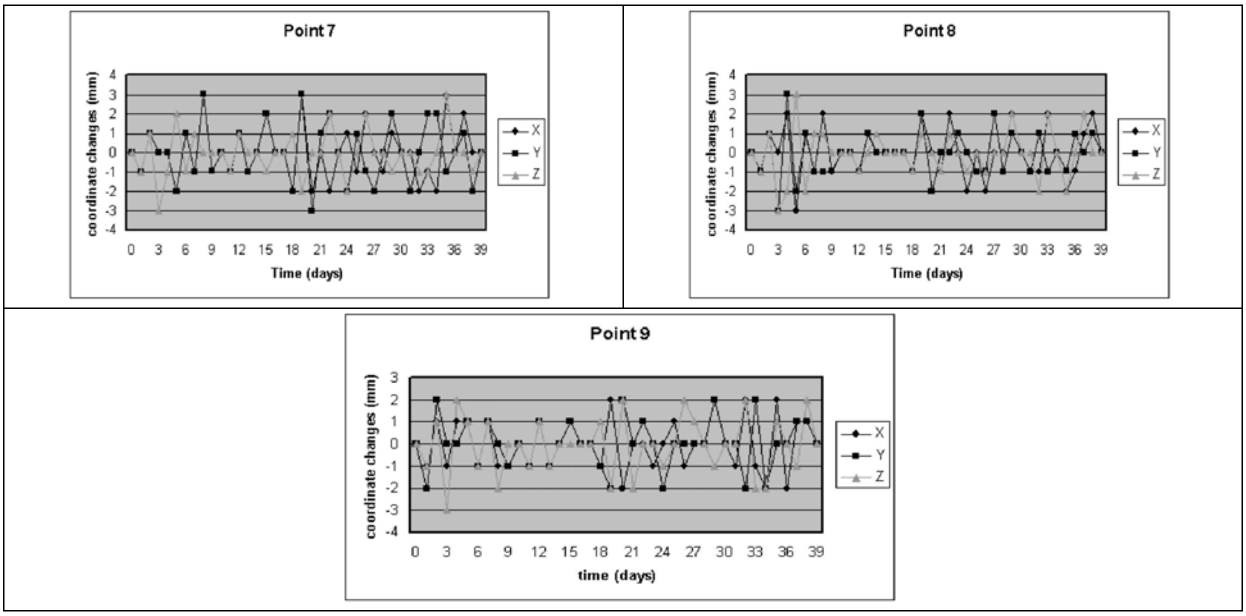

Figure 4: Time dependent coordinate changes of the points on III. cross-section

The mean square errors m_{o_j} of points on each cross-section were calculated by using point coordinates determined at different periods and difference (Vxi, Vyi, Yzi) of them from mean value of coordinates is,

$$m_{o_j} = \sqrt{\frac{(v_{x_i}^2 + v_{y_i}^2 + v_{z_i}^2)}{3(n-1)}} \quad (i=1, 2,\ldots, n); \quad (j=1,.., k) \qquad (1)$$

where n is the number of measurement; k is the number of points at cross-section. The general mean square error of all points is calculated by using mean square error of points is,

$$m_0 = \frac{\sum_{j=1}^{k} m_{o_j}}{k} \qquad (2)$$

At each station, coordinate differences were calculated by taking current measurement period and previous measurement period. The vector indicating points' movements calculated from differences of coordinates is as follows,

$$d_i = \sqrt{dx_i^2 + dy_i^2 + dz_i^2} \qquad (3)$$

Mean square error of d_i,

$$m_d = \sqrt{2} m_0 \qquad (4)$$

was calculated from Eq.(4). In order to determine whether the deformation vector is meaningful or not, test values, m_d; standard error of vector d were calculated by the following equation

$$T_i = \frac{d_i}{m_d} \qquad (5)$$

and compared with t-table value. If $T_i > t_{f,0.975,}$ it is decided that the points moved in the time between the periods (Welsc 1981;Niemeier 1985). Deformation analysis was made for all cross-sections. For example, the results of deformation analysis for I. cross-section points are given (Table 2).

Point	Distinctions Period	$dx_i=x_{t2}-x_{tt1}$ (mm)	$dy_i=y_{t2}-y_{tt1}$ (mm)	$dz_i=z_{t2}-z_{tt1}$ (mm)	d_i (mm)	$T_i=d/m_d$ (m_d= 1,13 mm) ($t_{f,0.975}$=1,98)
1	**(24.02 -23.02)**	**2,00**	**-2,00**	**-2,00**	**3,46**	**2,17**
	(25.02 -24.02)	-1,00	1,00	-1,00	1,73	1,08
	(26.02 -25.02)	2,00	1,00	-1,00	2,45	1,53
	(27.02 -26.02)	**-3,00**	**-1,00**	**0,00**	**3,16**	**1,98**
	(28.02 -27.02)	0,00	1,00	0,00	1,00	0,63
	(01.03 -28.02)	-1,00	-1,00	-1,00	1,73	1,08
	(02.03 -01.03)	1,00	1,00	1,00	1,73	1,08
	(03.03 -02.03)	**-1,00**	**-3,00**	**-1,00**	**3,32**	**2,08**
	(04.03 -03.03)	1,00	2,00	-1,00	2,45	1,53
	(05.03 -04.03)	**-2,00**	**-2,00**	**-2,00**	**3,46**	**2,17**
	(07.03 -05.03)	1,00	1,00	-1,00	1,73	1,08
	(09.03 -07.03)	-1,00	-1,00	1,00	1,73	1,08
	(11.03 -09.03)	1,00	0,00	0,00	1,00	0,63
	(13.03 -11.03)	-1,00	-1,00	0,00	1,41	0,88
	(15.03 -13.03)	0,00	0,00	0,00	0,00	0,00
	(17.03 -15.03)	-1,00	-1,00	-1,00	1,73	1,08
	(19.03 -17.03)	1,00	1,00	1,00	1,73	1,08
	(21.03 -19.03)	0,00	-1,00	0,00	1,00	0,63
	(23.03 -21.03)	0,00	0,00	0,00	0,00	0,00
	(25.03 -23.03)	-1,00	1,00	-1,00	1,73	1,08
	(26.03 -25.03)	0,00	0,00	0,00	0,00	0,00
	(27.03 -26.03)	0,00	0,00	0,00	0,00	0,00
	(28.03 -27.03)	1,00	-1,00	1,00	1,73	1,08
	(29.03 -28.03)	-1,00	1,00	-1,00	1,73	1,08
	(30.03 -29.03)	0,00	-1,00	0,00	1,00	0,63
	(31.03 -30.03)	1,00	1,00	1,00	1,73	1,08
	(01.04 -31.03)	0,00	0,00	0,00	0,00	0,00
	(02.04 -01.04)	0,00	0,00	0,00	0,00	0,00
	(03.04- 02.04)	1,00	-2,00	-1,00	2,45	1,53
	(04.04 -03.04)	0,00	0,00	0,00	0,00	0,00
	(14.04 -04.04)	-2,00	2,00	0,00	2,83	1,77
	(16.04 -14.04)	0,00	0,00	0,00	0,00	0,00
	(18.04 -16.04)	1,00	-1,00	-2,00	2,45	1,53
	(20.04 -18.04)	-2,00	-1,00	2,00	3,00	1,88
	(22.04 -20.04)	0,00	0,00	1,00	1,00	0,63
	(24.04 -22.04)	1,00	2,00	-1,00	2,45	1,53
	(26.04 -24.04)	0,00	0,00	-2,00	2,00	1,25
	(28.04 -26.04)	1,00	2,00	0,00	2,24	1,40
	(30.04 -28.04)	1,00	-2,00	2,00	3,00	1,88

Table 2: Deformation analysis results of point 1 of I. cross-section

For the other points, the same calculations were done and only movement expected periods were given at Table 3. When we look at Table 2, it can be seen that there is a movement in y direction (-) and in x direction (-) on the point 1 at left side wall. This condition was ascertained similarly at other cross-sections.

Cross-Section	Point	Periyod	$dx_i=x_{t2}-x_{t1}$ (mm)	$dy_i=y_{t2}-y_{t1}$ (mm)	$dz_i=z_{t2}-z_{t1}$ (mm)	d_i (mm)	T_i ($t_{f,0.975}$=1,98)
I	2	(24.02 -23.02)	1,00	3,00	-1,00	3,32	2,08
		(26.02 -25.02)	2,00	1,00	-3,00	3,74	2,34
		(03.03 -02.03)	1,00	3,00	-4,00	5,10	3,19
		(04.03 -03.03)	-1,00	-3,00	-2,00	3,74	2,34
	3	(27.02 -26.02)	-2,00	-2,00	3,00	4,12	2,58
		(28.02 -27.02)	2,00	0,00	-3,00	3,61	2,26
		(03.03 -02.03)	1,00	3,00	-4,00	5,10	3,19
		(04.03 -03.03)	-1,00	-3,00	-2,00	3,74	2,34
II	4	(22.04-20.04)	2,00	4,00	-2,00	4,90	2,84
	5	(27.02-26.02)	-2,00	-1,00	-3,00	3,74	2,17
		(05.03-04.03)	-2,00	2,00	-3,00	4,12	2,39
		(29.03-28.03)	3,00	2,00	-2,00	4,12	2,39
		(30.03-29.03)	-3,00	-2,00	-2,00	4,12	2,39
		(24.04-22.04)	4,00	3,00	-1,00	5,10	2,96
		(30.04-28.04)	1,00	3,00	2,00	3,74	2,17
	6	(29.03-28.03)	2,00	2,00	-2,00	3,46	2,01
		(30.03-29.03)	-2,00	-2,00	-2,00	3,46	2,01
		(12.04-10.04)	2,00	2,00	-2,00	3,46	2,01
		(24.04-22.04)	2,00	0,00	-3,00	3,61	2,09
III	7	(11.03-09.03)	3,00	3,00	0,00	4,24	2,38
		(29.03-28.03)	3,00	3,00	-2,00	4,69	2,63
		(30.03-29.03)	-2,00	-3,00	0,00	3,61	2,03
		(24.04-22.04)	3,00	-1,00	-3,00	4,36	2,45
	8	(03.03-02.03)	0,00	-3,00	-3,00	4,24	2,38
		(04.03-03.03)	2,00	3,00	-2,00	4,12	2,32
		(05.03-04.03)	-3,00	-2,00	3,00	4,69	2,63
	9						
IV	10	(29.03-28.03)	2,00	3,00	-1,00	3,74	2,45
	11	(07.03-05.03)	4,00	-1,00	-2,00	4,58	3,00
		(23.03-21.03)	-2,00	3,00	0,00	3,61	2,36
	12	(29.03-28.03)	2,00	1,00	-3,00	3,74	2,45
V	13	(20.04-18.04)	3,00	2,00	-2,00	4,12	2,35
	14						
	15	(25.03-23.03)	-3,00	2,00	1,00	3,74	2,13
		(22.04-20.04)	3,00	1,00	-2,00	3,74	2,13
		(24.04-22.04)	1,00	-3,00	-2,00	3,74	2,13

Table 3: II. Deformation analysis results of point at right side wall of cross-section

3.2. Geotechnique Measurements

Geotechnique measurements are used in determination of ground mechanic at constructions which has necessity deep excavation and whose ground properties can not estimated exactly and in examining of supports which carry construction load conducted by foundations at construction materials. The following geotechnique measurements on the surface and inside tunnel at tunnel constructions were made,

- surface dwelling measurements
- deformation measurements inside the tunnel
- extensometer and inclinometer measurements
- radial and pressure cells, settlement and measurement
- determination of geological map and geomechanic sizes (Arioglu etc, 1994; Arioglu etc, 2002b; Chrazanowski etc, 1986). Trabzon City Passing Tunnel 2 on KPCR, investigations of pressure resistance of ground and inclinometer measurements were done.

3.2.1. Investigation of pressure resistance of the ground

It was determined that there were weak - very weak resistible aglomera and tufa units belonging to Eosen old Kabaköy Formation along Trabzon City Passing Tunnel 2 on KPCR. Appearance of aglomera is like gravel and sand rock whose dough material formed by tufa and much decomposing, crushed zoned, and can be scattered by water. It was determined that algomera including limestone lens in middle levels at test bore studies. Tufa are generally yellow colored, much more separated (c=0,35 Mpa, %=25). It includes place to place 10-11 north inclined crushed zones place to place. Tufa are horizontal layered, and they include clay filling between layers. Geomechanic definitions of tunnel rock are given Table-4 according to geological-geotechnique investigations along basic line and results of test bones and laboratory.

RQD (Rock Quality Designation)	< 25
Q (Rock Quality Index)	0,2 - 0,3
RMR (Rock Mass Roting)	21 ≤ RMR ≤ 40
Ø (Friction cone)	23°-25°
C (Chosion)	0,30 – 0,35 MPa
Permeability	Medium
NATM rock classification	C2 – C3

Table 4: Strength values of rock

During the tunnel excavation, mirror excavation was finished completely by the excavating machines, at the beginning approximately 4 liter/min water flows through tunnel cross section. Tunnel excavation was provided by support like steel equipment supported and invert excavated, spray concrete with steel fiber H-200 steel profile radial systematic retaining.

3.2.2. Inclinometer Measurements

Inclinometer instruments are used in vertical drifts of holes which are opened on land. Measured drifts can be converted to trigonometric functions (Hill 2002). This instrument takes form from probe which is brought down in hole inside flexible pipe as tied one control box and one cable. Probes generally require flexible circular pipes which hold 4 grooves inside putting 90 intervals. Electricity exit in probe is bound control box and converts measurements to visual values and graphic forms (Fig. 5).

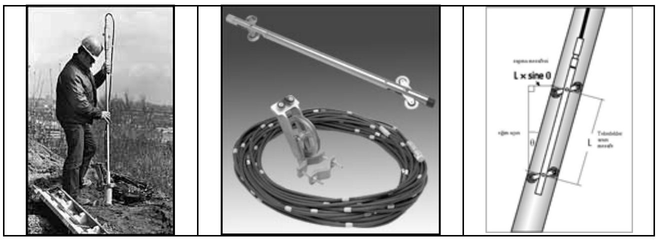

Figure 5: Settlement and Measurement of Inclinometer

Inclinometer pipe was set up in a hole near perpendicular having intersected with movement expectation area. Opened hole should be extended inside movement unexpected area (can be ground and rock surroundings) till 4.5m ahead movement expected area. Inclinometer pipes are 3.0m length and plastic. Installation is finished by turning using guide in left and right direction in order to make grooves on the same vertical level from bottom to top. The accuracy of the first position of pipe should be proved according to measurements which will be done as at least two periods, the position of the inclinometer pipe at the installation instant till calculation of the all displacement. The top of pipe should be oriented one point on surface outside of the movement expectation area. The interval of measurements depends on different reasons. The most important one is proportion of movement.

At KPCR Trabzon City Passing Tunnel 2: Km: inclinometer-1 was installed on Km:0+519 and inclinometry-2 was installed on Km:0+513. Since January 2004 measurements have been saved on computer by using Slope indicator instrument periodically (Fig. 6).

Figure 6: Inclinometer pipe and instrument installed on tunnel

Movements were determined by putting results of measurement graphically on computer. It was found out that the graphics which were taken from periodic measurements at inclinometer-1 pipes and inclinometer-2 pipes were approximately the same. For example, it is given here time dependent graphics of movements determined from March 2005 measurements.

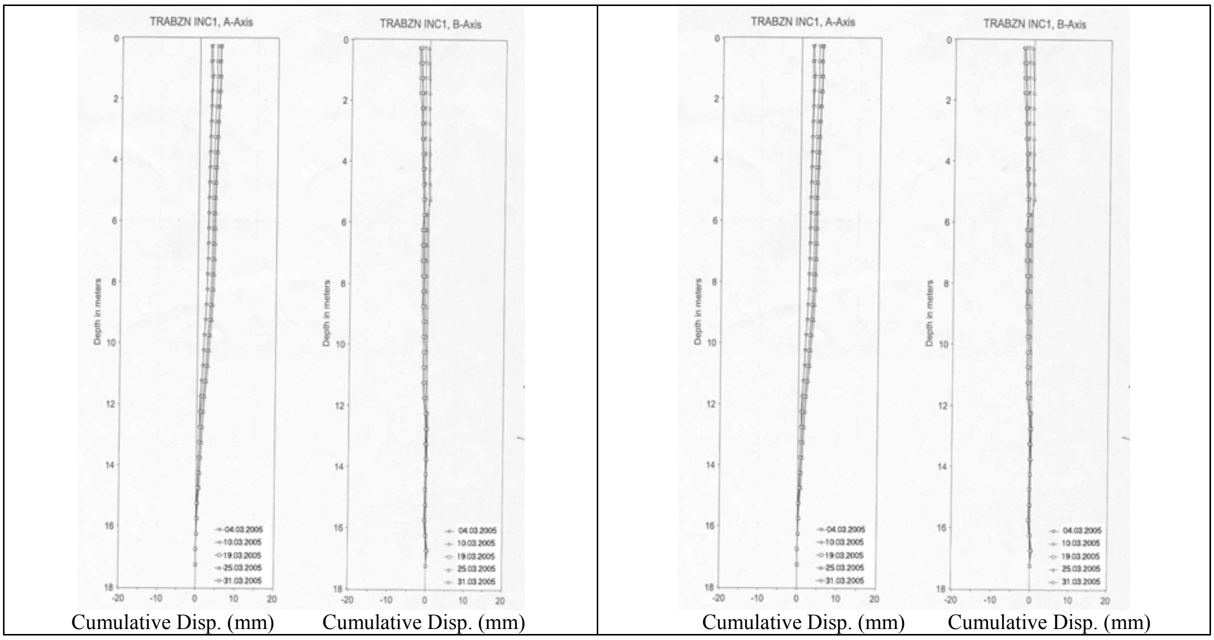

Figure7: Determined deformation from inclinometer-1 pipe

When we look at the Figure 7, it is seen that the maximal deformation value is approximately 4-5 mm. Because allowed deformation limit was 10mm at temporary steel arch systems with anchorage, it was seen that the determined deformation value was not above the deformation limit.

4. Finite Elements Method

The finite element method is widely used in solution of many engineering problems. In the finite element method, a geometrically complex domain of a given system is represented as a collection of a finite number of geometrically simple subdomains. This is called discretization of the domain. Each subdomain is called an element. The collection of the elements is called the finite element mesh. The elements are connected to each other at joints called nodal points. After the domain of the system is discretized, stiffness matrix of each individual element is computed according to the nodal degrees of freedom and the force-deformation relationships defining the element. The stiffness matrices of the individual elements are assembled to form the stiffness matrix of the complete system. Then, appropriate boundary conditions and equilibrium conditions at the nodal points are defined. The resulting set of equations for the assembled system may be expressed as

$$[K]\{U\} = \{P\} \tag{6}$$

Where $[K]$ is the stiffness matrix of the assembled system, $\{P\}$ is vector of forces applied at the nodal points of elements, and $\{U\}$ is vector of nodal displacements. The unknown nodal displacements are obtained by solving the set of the equations. If it is desired, it can be calculated element stresses from the relationship between element strains and the nodal displacements.

In this study, deformations at Second Tunnel constructed in Trabzon were also obtained by the Finite Elements Method. The cross-section of the Tunnel is given in Figure 8. The finite element mesh of the Tunnel is presented in Figure 8. It was used 674 quadrilateral plane elements in the mesh. The quadrilateral elements have two displacements (horizontal and vertical displacements) at each nodal point. There are 841 nodal points in the mesh of the Tunnel. At the boundaries of the Tunnel, there are 88 restrained degrees of freedom. Hence, the active degrees of freedom (or equations) for the Tunnel were determined as 1594 in total.

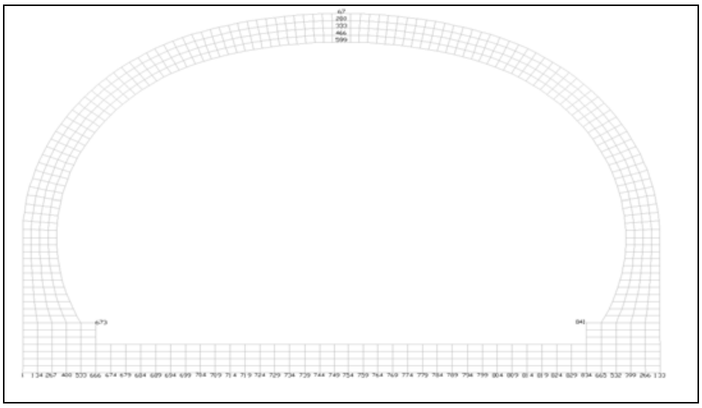

Figure: 8 Elements at KPCR Trabzon City Passing Tunnel 2 formed by finite elements method

Deformations in the Tunnel subjected to lateral and vertical loads were obtained by the program SAP2000, which is general-purpose computer program for analysis of structural systems. The Tunnel was treated as a plane strain problem. Deformed shape of the Tunnel is presented in Figure9.

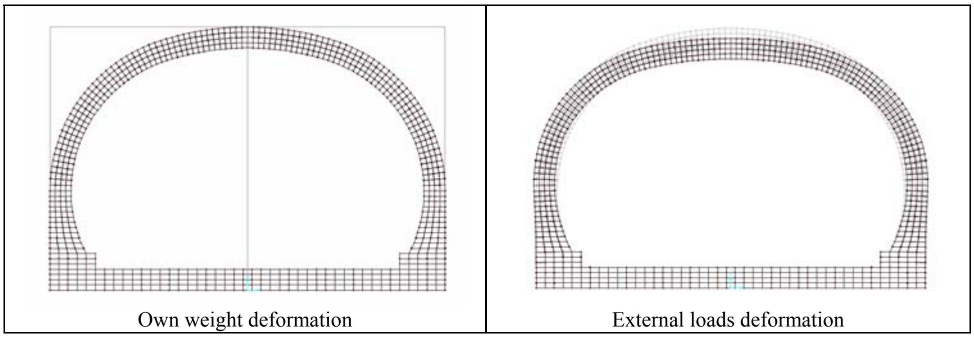

Figure 9: Deformation under external loads of tunnel by finite elements method

5. Conclusion

In order to determine deformations on KPCR Trabzon City Passing Tunnel 2 and take precautions, deformation measurements were taken on tunnel and its surroundings starting from in advance of construction stage. Movements occurring on tunnel were determined by using different methods such as geodetic, geotechnique and finite elements in order to explain deformations in a meaningful way.

As a result of geotechnique studies, ground structure has been determined as weak-very weak. By using these information, approximately 4-5 mm movements has been determined on this region by using measurements taken on inclinometer tubes established on appropriate places near tunnel.

As a result of geodetic measurements taken on ceiling and side wall of 5 different cross-section determined with definite intervals, 3-4 mm subsidence in vertical direction and 1-2 mm movement in horizontal direction at ceiling; approximately 2-3 mm subsidence in vertical direction and 3-4 mm movement in horizontal direction straight to tunnel axis at side walls.

By Finite Elements method, deformations have been determined by taking into account external loads of the tunnel and by separating the tunnel to 674 elements and 841 knot points. In this case, approximately 8 mm subsidence at ceiling, approximately 2-3 mm movement straight to tunnel axis at side walls.

As understood from the results, deformation values determined by geodetic measurements, geotechnique measurements and finite elements have been found as consistent to each other. By taking into account of the results of these methods, reliable interpretation could be done and precautions could be taken according to these results. By taking precautions in advance, it is thought to be help of economy, and prevent of possible accidents.

In conclusion, it is advised that deformations at huge engineering structures should be determined by working together with neighbor scientific fields and by using different methods such as geodetic, geotechnique and finite elements and interpretations should be done according to these different methods and necessary precautions should be taken in time.

Acknowledgements. The authors are grateful to the Karadeniz Technical University Research Fund for their financial support. In addition, we thank for constructive support of Yüksel Domaniç Limited Company for given data.

References:

[1] Arıoğlu, B., Yüksel, A., Kurtuldu, S. ve Arıoğlu, E., (2002a). İzmir Metro projesinde Yeni Avusturya Tünel Açma Metodu Uygulamaları, *Yapı Dünyası*, **73**, 35-49, İstanbul.

[2] Arıoğlu, B., Yüksel, A. ve Arıoğlu, E., (2002b). İzmir Metro Projesi Nene Hatun Tünelindeki Geoteknik Çalışmalar ve Değerlendirilmesi, *ECAS 2002 Uluslararası Yapı ve Deprem Mühendisliği Sempozyumu,* ODTÜ, Ankara.

[3] Chrazanowski, A., Chen, Y., Romero, P. ve Secord, J. M., (1986). Integration of geodetic and geotechnical deformation measurements in the geosciences, *Tectonophysics*, **130**, 369-383.

[4] Clough, R. W., (1960). The Finite Element Method İn Plane Stress Analysis, *Proceedings of American Society of Civil Engineers*, 2nd Conference on Electronic Computations, **23**, 345-378, USA

[5] Hill, C. D. ve Sippel, K.D. (2002). Modern Deformation Monitoring: A Multi Sensor Approach, *Proc. of 12th FIG Int. Symp. Deformation Measurements*, Washington, DC, USA.

[6] Hillier, F.S. ve Lieberman, G.J., (1995). *Introduction to operations Research*, 6th ed. New York.

[7] Hınton, E. ve Owen, D.R.J., (1977). *Finite Element Programming*, Academic Pres, London.

[8] Jancsecz, S., Krause, R. ve Langmack, L., (1999). Advantages of Soil Conditioning İn Shield Tunneling Experiences of LRST İzmir, *Proceeding of The World Tunnel Congress'99 OSLO "Challenges for The 21th Century"* Alten et al (eds), Balkema, Rotterdam.

[9] Leca, E., (1989), Analysis of NATM and Shield Tunnel in Soft Grounds, *PhD Thesis*, Virginia Polytechnic Institute and State University, Blacksburgs, USA.

[10] Moaveni, S., (2003). *Finite Element Analysis, Pearson Education*, New Jersey.

[11] Niemeier, W., (1981). Statistical Tests for Detecting Movements in Repeatedly Measured Geodetic Networks, *Tectonphysics*, **71**, 335-351.

[12] Niemeier, W., (1985). Deformationsanalyse, In: *Geodatische Netze In Landes- Und Ingenieurvermessung Ii*, Kondrad Wittwer, 559-623, Germany.

[13] Koch, K.R. (1999). *Parameter Estimation and Hypothesis Testing in Linear Models*, Springer-Verlag, Berlin.

[14] Rabcewicz, L., (1964). *The New Austrian Tunnelling Method*, Water Power, Nov.

[15] Sauer, G., (1990). NATM in Soft Ground, *World Tunnelling*, **3**, No. 6.

[16] Segrlind, L., (1984). *Applied Finite Element Analysis*, 2d. ed. John Wiley and Sons, New York.

[17] Welsch, W., (1981). Gegenwartigen Stand der Geodatischen Analyse und Interpretation Geometrischer Deformationen, *Allgemeine Vermessungsnachrichten*, 88 (2), 41-51.

[18] Welsch, W., (1983). *Deformationsanalysen*, Schriftenreihe Vermessungswesen HSBw, 9, München.

[19] Domaniç, Y. ve Karahan, E., *eds.* (2005). Karadeniz Sahil Devlet Yolu Trabzon Şehir Geçişi 2. Tünel Etüt Proje Mühendislik Hizmetleri İşi Kesin Proje Raporu, Bayındırlık ve İskan Bakanlığı Karayolları 10. Bölge Müdürlüğü, Ankara.

[20] Arıoğlu, B., Yüksel, A., Ünlütepe, A. ve Arıoğlu E., (1994). İncirli-M.İnönü Tünelinde Uygulanan Geoteknik Ölçümler ve Değerlendirmesi, *Ulaşımda Yeraltı Kazıları 1. Sempozyumu,* TMMOB Maden Mühendisleri Odası, İstanbul.