

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

Mualla Yalçinkaya¹, Burak Satır¹, Mehmet Akköse²

*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 through inside the city and thus has an intercity transportation position. The important part in city inside of the street which is a divided road is used compulsorily 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. Opening 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).

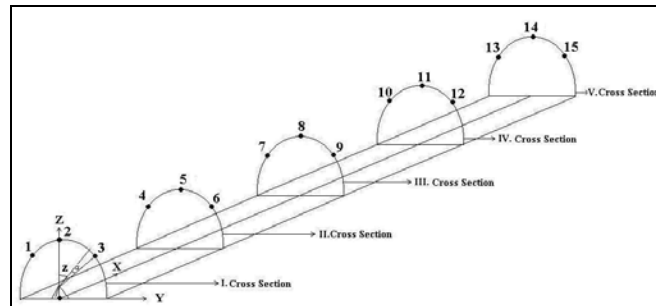


Figure 2: Tunnel object points and measurements done by electronic instruments

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.

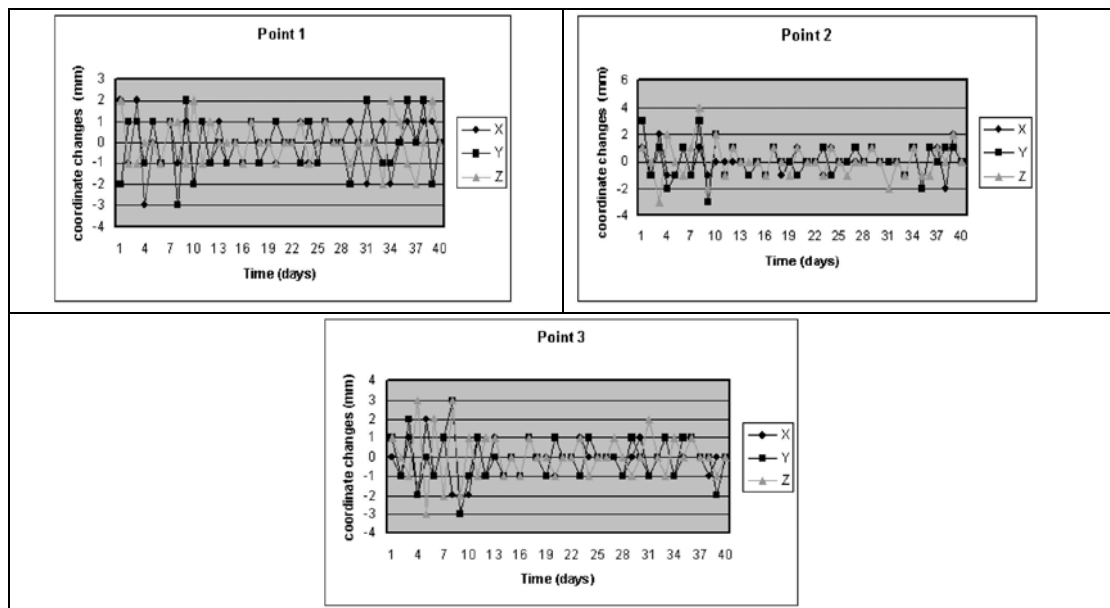


Figure 3: Time dependent coordinate changes of the points on I. cross-section

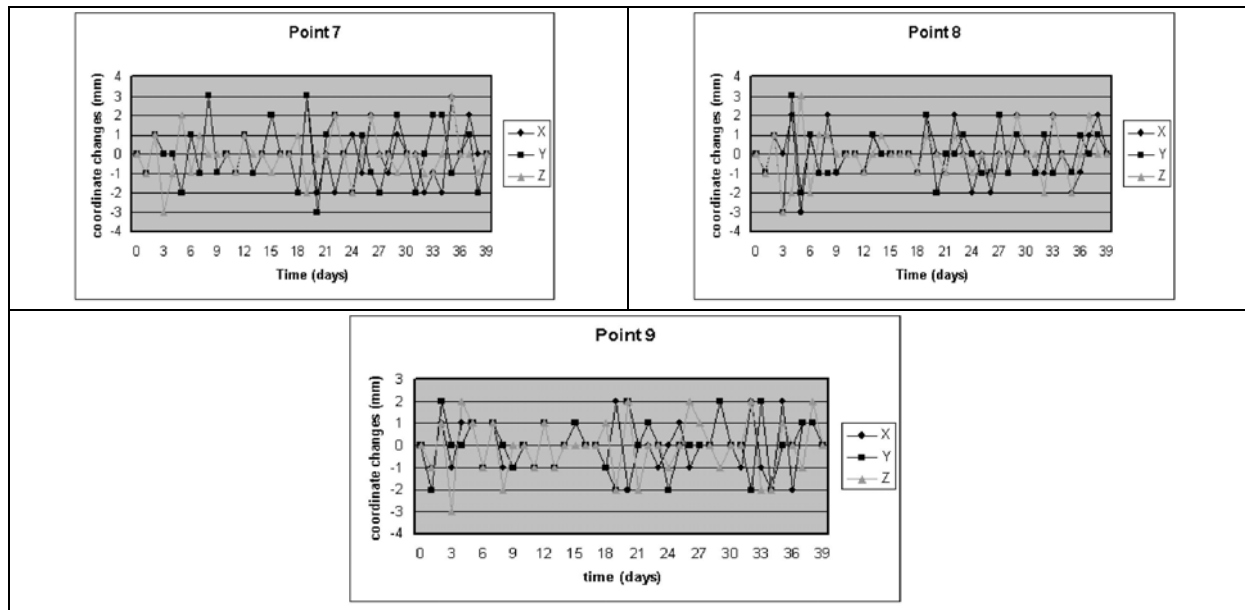


Figure 4: Time dependent coordinate changes of the points on III. cross-section

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 (V_{xi} , V_{yi} , V_{zi}) of them from mean value of coordinates is,

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

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,

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

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,

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

Mean square error of d_i ,

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

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

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

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 (Welsch 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	$dx_i = x_{i2} - x_{i1}$ (mm)	$dy_i = y_{i2} - y_{i1}$ (mm)	$dz_i = z_{i2} - z_{i1}$ (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	$dx_i=x_{i2}-x_{i1}$ (mm)	$dy_i=y_{i2}-y_{i1}$ (mm)	$dz_i=z_{i2}-z_{i1}$ (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		
II	4	(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		
		(22.04-20.04)	2,00	4,00	-2,00	4,90	2,84		
		(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		
	5	(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		
		(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		
	6	(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

