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Reaserch Article

Deformation Analysis by Geomatic and Geotechnical Methods in Highway Tunnels

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Abstract

In the highway transportation network, the tunnel has an important place. Tunnels are used to provide safe, comfortable and economical transportation in areas where topography is not available. In addition to the facilities provided by the tunnels, there are various risks during and after the manufacturing phase. These risks need to be anticipated and manufacturing must be shaped to address these risks. Therefore, deformation analysis in tunnel projects has an important place. During and after manufacture, it is necessary to determine and follow the deformations.

In this study, Ayvacık - Küçükkuyu highway in Çanakkale will be dealt as T1 Tunnel between km 10 + 700 - 12 + 400. Due to the fact that the region is located on the earthquake zone and because of this reason it has a mixed lithology, it is very important to follow the deformations. In this context, it is aimed to analyze the relationship and dimensions of deformation factors in the structure by using geodetic and geotechnical measurement methods. The relationship between these data and the load, pressure and tension values observed on horizontal and vertical movements will be examined during the manufacturing process. Moreover, due to the fact that the zone is located on the earthquake zone, earthquakes that occur in the region during the manufacturing process and the manufacturing effects of these earthquakes will be investigated.

With this study, it is aimed to give guidance to manufacturing by predicting deformation and external effects that may occur and arise in engineering constructions. The required revisions should be made in the fortification systems in line with the predetermined parameters. In this way, it is aimed to ensure that the manufacturing process continues in the most economical and safest manner.

Keywords: Çanakkale, Tunnel, Deformation Analysis, Geodetic and Geotechnical Methods

Introduction

Nowadays, tunnels have an important place in highway transportation network. Tunnels are used in order to ensure the continuity of road standards in the areas where topography is not suitable and to provide the economy with the desired travel comfort.

The biggest problem in large-scale engineering structures such as tunnels is the determination of shape and position changes in the building (Jimeno, 1997). Temporary or permanent effects occur in engineering structures such as tunnels and their surroundings (Çepni & Arslan, 2017). Generally, these effects are composed of the physical properties of the ground, the current weight of the structure, moving external loads and similar effects. As a result, deformations are observed in and around the structure (Dinis, 2004). Since the engineering structures are of high cost and are of great importance in terms of usage, it is necessary to monitor these structures from a socioeconomic perspective. In addition, the determination of the external effects that cause deformations and analyzing the relations of these data with the deformation data enable the determination of the future problems in the engineering structures and the direction of the manufacturing in this direction.

In this study, the aim is not only to determine the movement in the analysis of deformation but also to analyze the causes of this movement and to make more meaningful results. Çanakkale province, which is our study region, is one of the important seismic zones. This is one of the first and most important parameters to be taken into account in the engineering structures to be made accordingly. As it is known, the fortification systems of the structure should be prepared in this direction and manufactured in a way to provide maximum durability. Studies on the importance of support systems for deformation monitoring are Monitoring of ground deformations in tunneling is a principal means for selecting the appropriate excavation and support methods among those foreseen in the design, for ensuring safety during tunnel construction (including personnel safety inside the tunnel and safety of structures located at ground surface) and, finally, for ensuring construction quality management according to ISO 9000. The contributions briefly describes the types of ground deformation measurements often used in tunneling, the difficulties in obtaining ground measurements and their subsequent evaluation, and the application of these measurements (a) in modeling tunnel excavation and support and (b) in establishing early warning systems against incipient ground collapses or damage to structures at ground surface.

Examples of ground deformation monitoring and their application in tunnel design and construction are illustrated via cases from the Jubilee Line Extension of the London Underground, from Lines 2 and 3 of the Athens Metro and from a nine-kilometer long mountain tunnel in Greece. In the first two examples, ground deformation monitoring aimed to ensure that structures at ground surface would not be harmed by the tunneling operations. In the third case, the objective was the optimization of the temporary support requirements as well as early warning against potential collapses. (Michael, 2003)

The other problems should be analyzed well by the mixed lithology of the region. Geodetic and geotechnical measurement methods to be used in the study to analyze the deformations seen in the structure not only to determine the displacement vectors, but the voltage, load distribution and seismicity data that cause this movement is aimed to be analyzed.

An example of what has been done about this subject; Current safety requirements. The convergence of conventional Techniques Measurements are characterized by intermittent recordings, frequently interrupting construction procedures and are not applicable to the survey tunnel stability upon its completion. The new extensometric method is aimed to override those difficulties by means of installing sets of electric resistance strain gages (or fiber optics sensors) on the steel arches of any tunnel support system, thus providing continuous recordings of deformations, even beyond the construction phase. Many description of laboratory and field tests there are performed to validate the process, as well as the mathematical models formulated to implement it, are presented in association with examples of application. Comparison of field results with those provided by conventional techniques indicated good agreement in terms of obtained convergence values (Dinis, 2004).

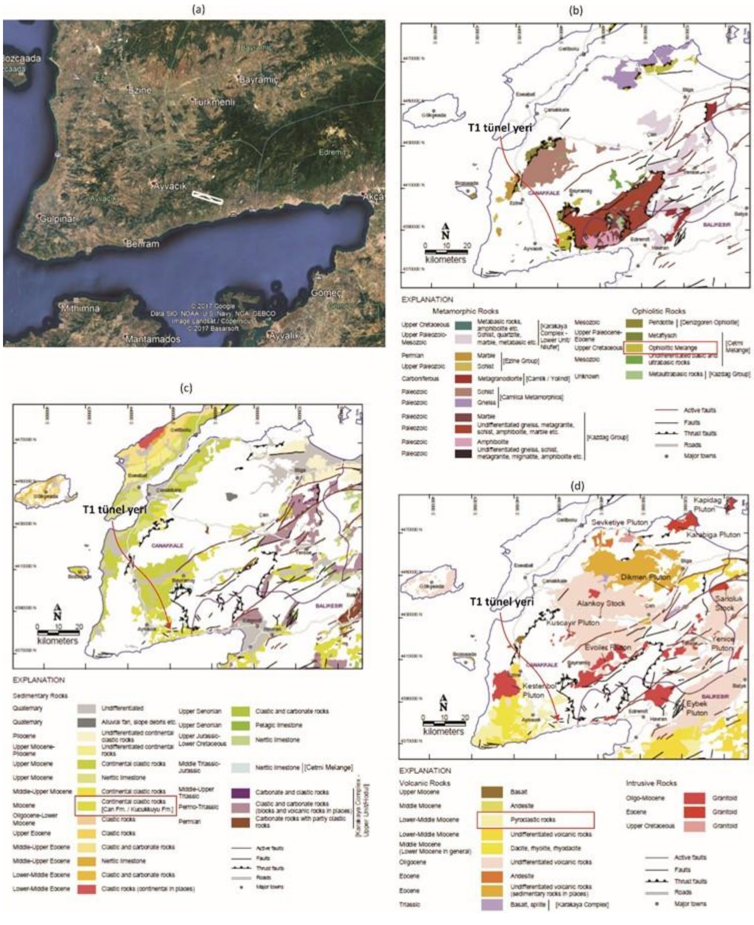


Figure 1 (a) The Location of the T1 Tunnel on the Google Earth Image, (b) The Metamorphic and Ophiolitic Rock Outcrops on the Biga Peninsula, (c) Sedimentary Rock Outcrops and (d) Volcanic Rock Outcrops (Modified from Yiğit 2012 and Öztürk & Serkendiz, 2018).

Çanakkale-Ayvacık Road Tunnel and the Geology of the Near Environment

The study area is located on the Biga Peninsula. Although there are many studies on the geological status of this region, the geological maps of metamorphic and ophiolithic rocks, sedimentary rock outcrops and volcanic rock emerged from different researches were presented to the international literature by Yiğit, (2012) and Öztürk & Serkendiz (2018) (Fig. 1). Although the geological structure of T1 tunnel site is located just to the west of the ophiolitic melange boundary, the presence of sedimentary rocks and lower middle Miocene aged pro-rock rocks are observed (Fig. 2).

In the different mirror photographs in the tunnel, in addition to the sub-middle myocene proklastic rock mass defined as tuff within the scope of the project, the Miocene aged sedimentary sequence was also observed (Fig. 2). Correlations of the cuts in the drilling works during the projecting stage of the tunnel were performed and the tunnel was divided into 5 sections as follows (Table 1).

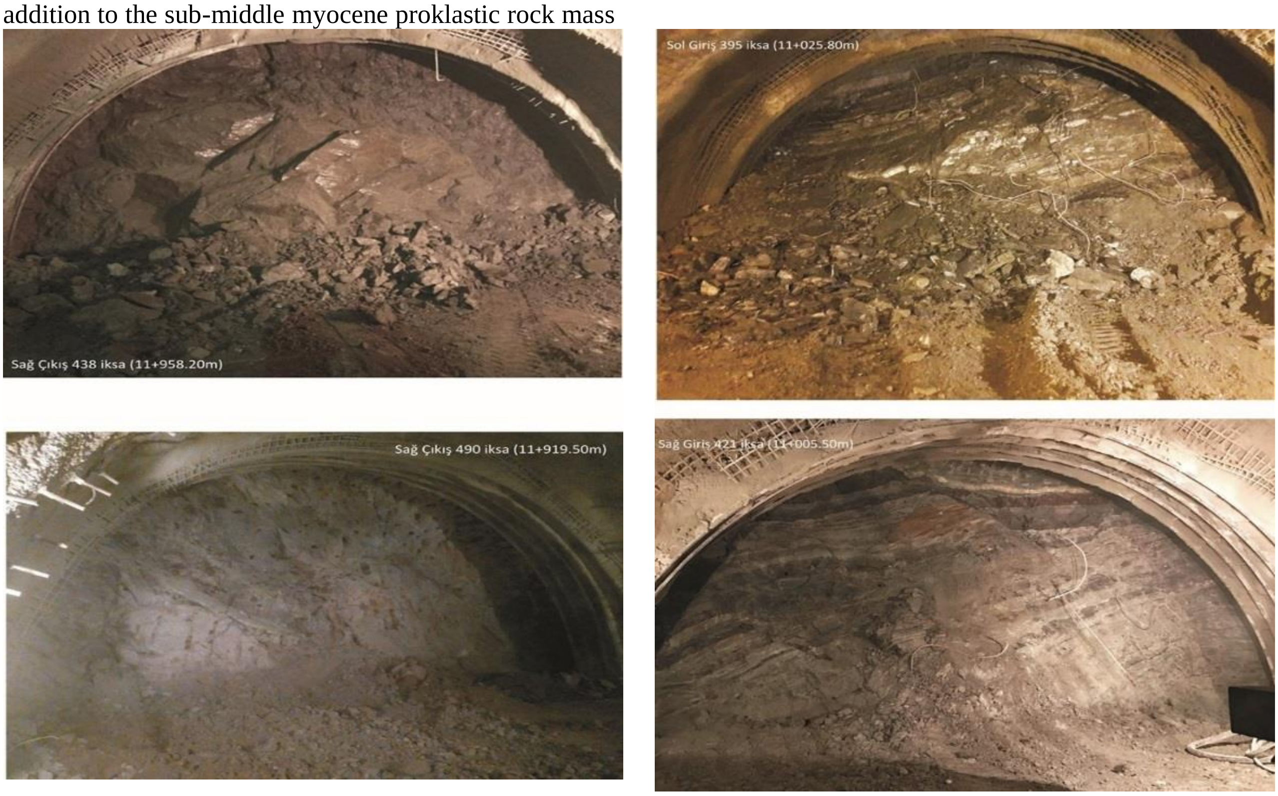


Figure 2. T1 Tunnel Face Photos

Table 1. Geotechnical designation of the tunnel by taking into consideration the geological definitions

Section	Mileage Range	Geological Unit
Introduction Portal	10+680-10+730	Claystone-Sandstone
Axis-I Section	10+730-10+860	Sandstone-Tuffite
Axis-II Section	10+860-11+140	Sandstone-Tuffite
Axis-III Section	11+140-12+370	Andesitic Tuffite
Exit Portal	12+370-12+403	Andesitic Tuffite

As can be seen from the mirror photographs of the tunnel, it is seen that the hard-lined-brown colored clay unit, which is fragmented with shiny shear surfaces that are cut in places during the opening of the tunnel from the exit portal, is not mentioned above in terms of definition. This unit is also seen in the form of interlayers in the sedimentary sequence, while andesitic tuff is also found in the large cracks that are opened due to the tectonic forces inside the unit. Red-brown colored clay appears to be particularly high in observational identification. However, when the water condition in the tunnel is considered, it can be said that the cut units are in the natural moisture contents and there is no significant water problem in the tunnel. The development of the cracks is not only explained by the potential of the swelling of clay when the location of the cracks from the entrance and exit portal of the tunnel and the geological units in these parts is considered.

Materials and Methods

Study Area

T1 Tunnel Project The state road of Çanakkale province Ayvacık Küçükkuyu is located between (10 + 700) km and (12 + 400) km. It has an important position in the highway network of Çanakkale-İzmir (Fig. 3).

Geodetic Methods

Geodetic measurements and analysis have been developed in geodetic terrestrial measuring instruments with developments in technology (Avşar, et al., 2016). Geodetic instruments such as Total Station, Precision Laser, Laser Scanner are used for monitoring tunnel deformations as in underground engineering structures (Martisek & Prochazkova, 2018). In recent years, the flexibility of the use of Total Station instruments, the accuracy and reliability of the measurement results, as well as the time-saving operation, has provided a cost-reducing feature in design, research, production and quality control applications (Yakar, et al., 2015).

Automatic total stations have automatic target recognition and monitoring feature. It provides 0.3 mm point positioning (20 m) and ± 0.2 mm distance measurement accuracy (120 m). Point heights can be determined using modern design, ergonomically structured, simple and precise automatic digital levels (URL-1, 2019). Precise nivos with a height adjustment accuracy of 0.8 mm are frequently used in deformation measurements.

With the fast scanning mode of the laser scanners with powerful equipment, the scans can be performed from 250,000 to 500,000 in 5–10 minutes. Laser scanners are not suitable for the determination of small deformations. Laser Trackers are portable 3D coordinate measuring systems. The system consists of software and hardware parts. The equipment consists of a laser interferometer placed in the system and a high-accuracy distance meter. It can give 3000 readings and 1000 coordinate outputs per second (URL-2 and URL-3, 2019). This feature provides high accuracy in static measurements and fast and secure digitization in scanning measurements.

In determination of tunnel deformations, terrestrial geodetic instruments are generally used in total station and laser scanners. In order to determine the geodesy deformations in the tunnel, the object points (deformation points) are installed on the ceiling and side walls of the sections at the stations determined at various intervals following the excavation stages.
These points are measured periodically by geodetic methods and displacement vectors between the periods are obtained. Within the scope of the study, deformation tracking method (Fig. 4), type section representation (Fig. 5) and photographs of the deformation target points used (Fig. 6) are shown.

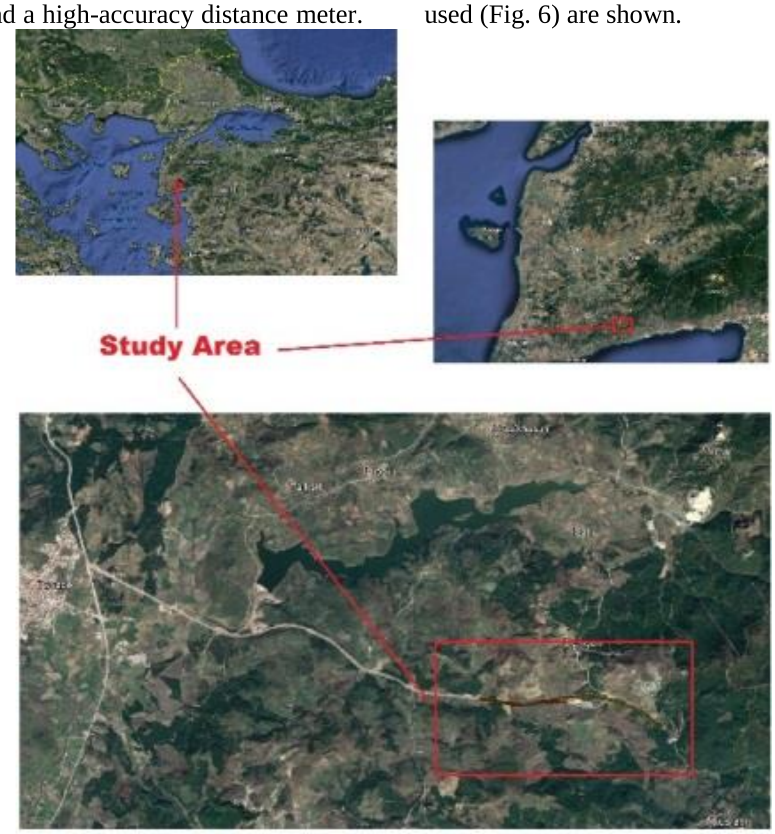
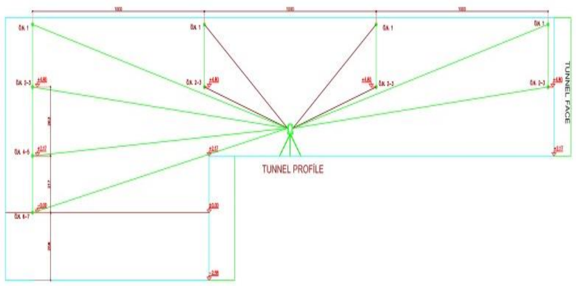


Figure 3. Study area and location of the tunnel project.

Geotechnical Method

The extensometer monitors the distance change between points. The rod extensometer is placed inside a borehole to monitor the vertical movement of the floor. They usually consist of three stages. The lower stage is lowered to the well, up to 2 m above the tunnel ceiling. The location of other levels is determined by geological structure. The number of stages can be increased or decreased if necessary. Measurements are taken from the extensometer head mounted on the earth. The strip extensometer examines the distance change between two fixed points determined in any engineering structure. Any type of structure (tunnel, dam, road, etc.) determined by measuring fixed points can be commented on the type and amount of motion. The extensometer consists of steel strips drilled at regular intervals. For a precise measurement, the extensometer should be well tensioned (Kalkan et al., 2003).

Tunnel Intra-Convergence and Opto-Trigonometric Measurements In order to observe the relative movements of the tunnel ceiling and walls by means of strip extensometers with a precision of 0.01 mm; opto-trigonometric measurements are made to measure the absolute movements of the walls horizontally and vertically. Both types of measurement are carried out by using a total of five collecting bolts, one on the ceiling and two on the side walls. In the tunnels, measurement sections are formed on average every twenty-five meters (Kalkan et al., 2003). Fig. 7-8 are given for geotechnical measurement equipment and field applications.



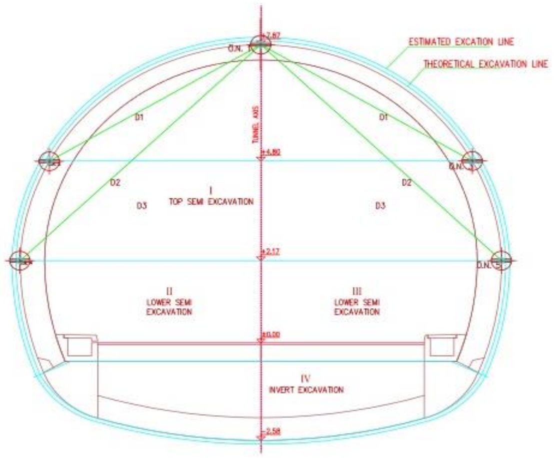


Figure 4. Tunnel deformation survey method

Figure 5. Tunnel type section

Figure 6. Tunnel deformation target.

Figure 7. Geotechnical surveying equipment.

Fig 8. Geotechnical surveying equipment

Deformation Analysis

Some regions and engineering structures on the earth and their immediate surroundings are under the influence of various factors that are temporary or permanent. These factors are as:

- Physical properties of the ground,
- Earth crust movements in the region,
- the weight of the structure and the type of material used,
- Moving external loads acting on the structure (Traffic load and wind force etc.)
- Geological and atmospheric factors and
- Dynamic pressure of water

Due to these factors, shape changes in a region, structure or its surroundings are generally called deformation (Algül 1983; Atasoy 1984). In geodesy, if this concept can be determined as Pi (t1) and Pi (t2) as a result of the measurements made in two different times such as t1 and t2, a characteristic Pi point selected on the region or the structure can be determined and if the difference between these two values can be proved that the di is statistically different from zero deformation / displacement.

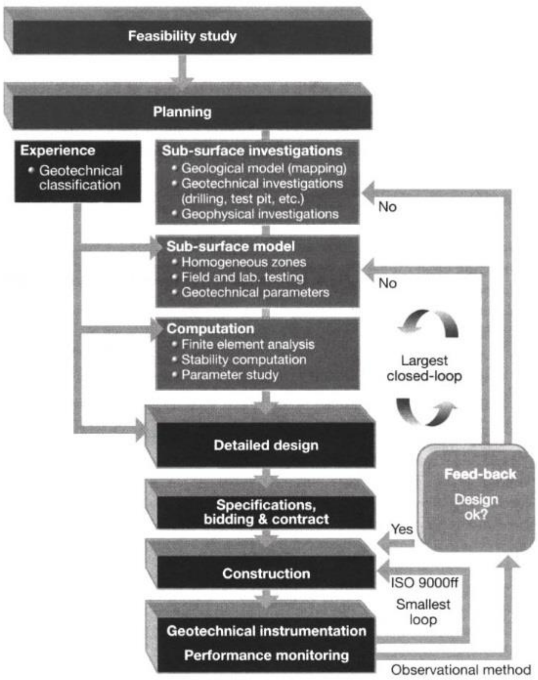


Figure 9. Flow-process Diagram.

Measurements to determine geometric shape changes in a region, structure or environment are called deformation measurements (Gama, 1996). It is called deformation analysis to determine and interpret the changes depending on the parameters of place, time and size by evaluating the measurements made with different time intervals (Erenoğlu, 2016).

Coordinate difference between two periods:

$$d=x_1-x_2 \quad \text{(Eq. 1)}$$

The weight coefficients matrix is as:

$$Q_d=Q_{x1x1}-Q_{x2x2} \quad \text{(Eq. 2)}$$

Geodetic and geotechnical data obtained from the field in the direction of the flow diagram used in the study (Fig. 9) were analyzed and classified.

Mathematical Modelling

Using the theory of elasticity a set of expressions relating the displacements u, v with normal strains e_r , e_q for a bi-dimensional state of strain in polar coordinates with radius r are (Benham and Warnock, 1973):

$$e_r = \frac{\partial u}{\partial r} \qquad e_q = \frac{u}{r} \quad \text{(Eq. 3)}$$

As the strain gages measure the hoop strain e_q its relation with the radial displacement u may be obtained by the expression:

$$e_q = \frac{u}{r-u} \quad \text{(Eq. 4)}$$

so the radial displacement is given by:

$$u = \frac{re}{1+e} \quad \text{(Eq. 5)}$$

Results

The obtained data are integrated into the deformation analysis model and analyzed. The results obtained from the analysis are subjected to statistical tests and it is examined whether the obtained data is meaningful. The deformation results obtained by extensometer, strain guage and geodetic data collected in the study are presented in the Tables 2 and 3, respectively. Note that the stations with significant deformation from deformation analysis are show by yellow highlight. According to the extensometer results, significant movement was observed at 32nd, 33rd, 36th and 37th stations. In addition, the results of the strain gauge confirm this because significant deformation is detected at 32nd, 33rd, 34th, 36th and 37th stations.

Table 2. The results of deformation analysis obtained by extensometer and geodetic measurements

No	Gauge	Mileage	Deformation (mm) 32.Station (11+064)	33.Station (11+073)	34.Station (11+082)	35.Station (11+091)	36. Station (11+100)	37.Station (11+109)	Test Results Sensor 1 (mm)	Sensor 2 (mm)	Sensor 3 (mm)
1	Ekstensometre 01	11+105,95	13 67 -68	-19 -74 -211	-45 -309 -360	-123 -288 -438	-141 -324 -477	-26 -15 -52	-3.2	-1.9	-4.1
2	Ekstensometre 02	11+105,95	-31 -11 -150	-34 -2 -212	-8 -12 -276	-54 -27 -276	-31 52 -211	-26 -11 -119	-1.1	0.2	0.4
3	Ekstensometre 03	11+105,95	-14 -23 -97	-22 -21 -156	-34 23 -241	-32 56 -275	-20 86 -298	25 36 -206	-6.2	-6.1	-6.1
4	Ekstensometre 04	11+068,80	-14 -23 -97	-22 -21 -156	-34 23 -241	-32 56 -275	-20 86 -298	25 36 -206	17.2	3.6	15.9

Table 3. The results of deformation analysis obtained by strain meter and geodetic measurements

No	Gauge	Mileage	Deformation (mm) 32.Station (11+064)	33.Station (11+073)	34.Station (11+082)	35.Station (11+091)	36. Station (11+100)	37.Station (11+109)	Test Results Strain (Δμε)	Deform. (mm)	Stres (Mpa)
21	StrainGuage 01	11+105,95	13 67 -68	-19 -74 -211	-45 -309 -360	-123 -288 -438	-141 -324 -477	-26 -15 -52	6.17	-0.143	260.00
22	StrainGuage 02	11+105,95	13 67 -68	-19 -74 -211	-45 -309 -360	-123 -288 -438	-141 -324 -477	-26 -15 -52	6.77	-0.157	280.20
23	StrainGuage 03	11+106,95	-31 -11 -150	-34 -2 -212	-8 -12 -276	-54 -27 -276	-31 52 -211	-26 -11 -119	7.07	-0.164	279.33
24	StrainGuage 04	11+106,95	-31 -11 -150	-34 -2 -212	-8 -12 -276	-54 -27 -276	-31 52 -211	-26 -11 -119	3.66	-0.085	214.99
25	StrainGuage 05	11+105,95	-14 -23 -97	-22 -21 -156	-34 23 -241	-32 56 -275	-20 86 -298	25 36 -206	5.93	-0.137	260.01
26	StrainGuage 06	11+105,95	-14 -23 -97	-22 -21 -156	-34 23 -241	-32 56 -275	-20 86 -298	25 36 -206	0.76	-0.018	148.36
27	StrainGuage 07	11+069,80	-14 -23 -97	-22 -21 -156	-34 23 -241	-32 56 -275	-20 86 -298	25 36 -206	11.39	-0.264	387.80
28	StrainGuage 08	11+069,80	-14 -23 -97	-22 -21 -156	-34 23 -241	-32 56 -275	-20 86 -298	25 36 -206	12.28	-0.284	331.96
29	StrainGuage 09	11+074,80	13 67 -68	-19 -74 -211	-45 -309 -360	-123 -288 -438	-141 -324 -477	-26 -15 -52	7.79	-0.181	288.87
30	StrainGuage 10	11+074,80	13 67 -68	-19 -74 -211	-45 -309 -360	-123 -288 -438	-141 -324 -477	-26 -15 -52	14.28	-0.331	428.85

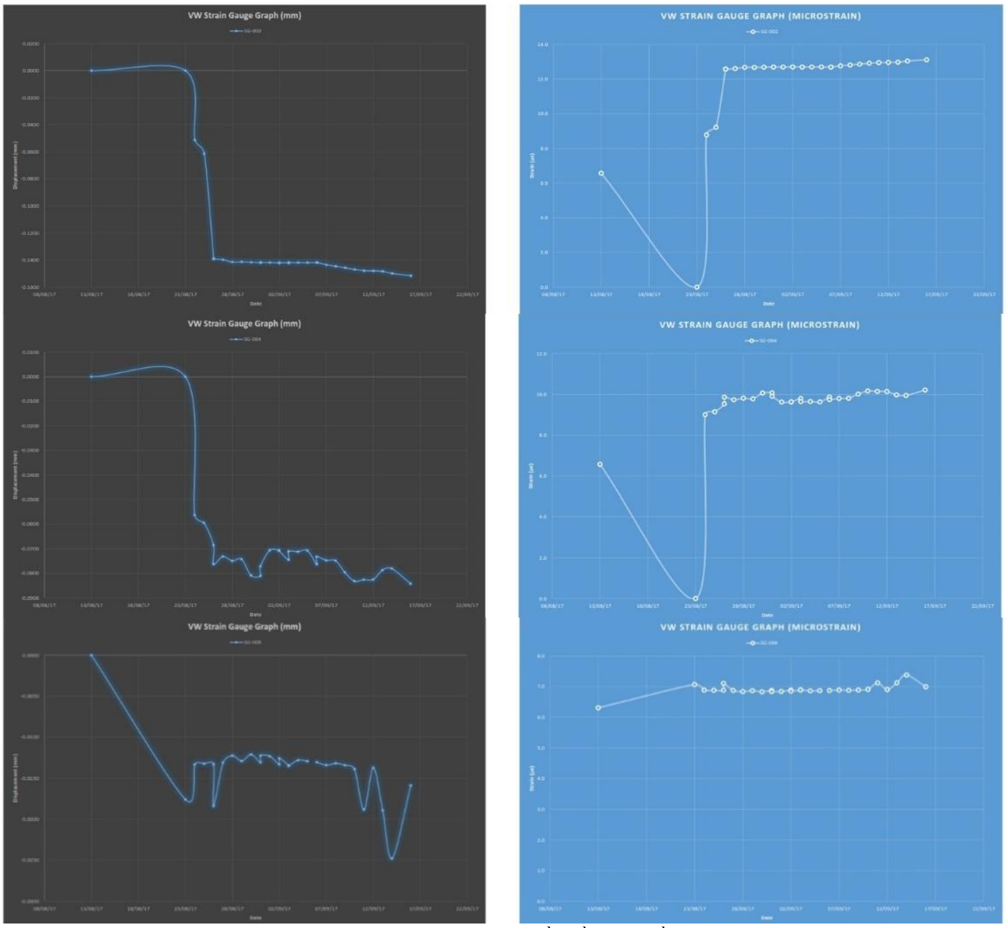


Figure 10. The strain and deformation results at the 2nd, 4th and 6th strain guage.

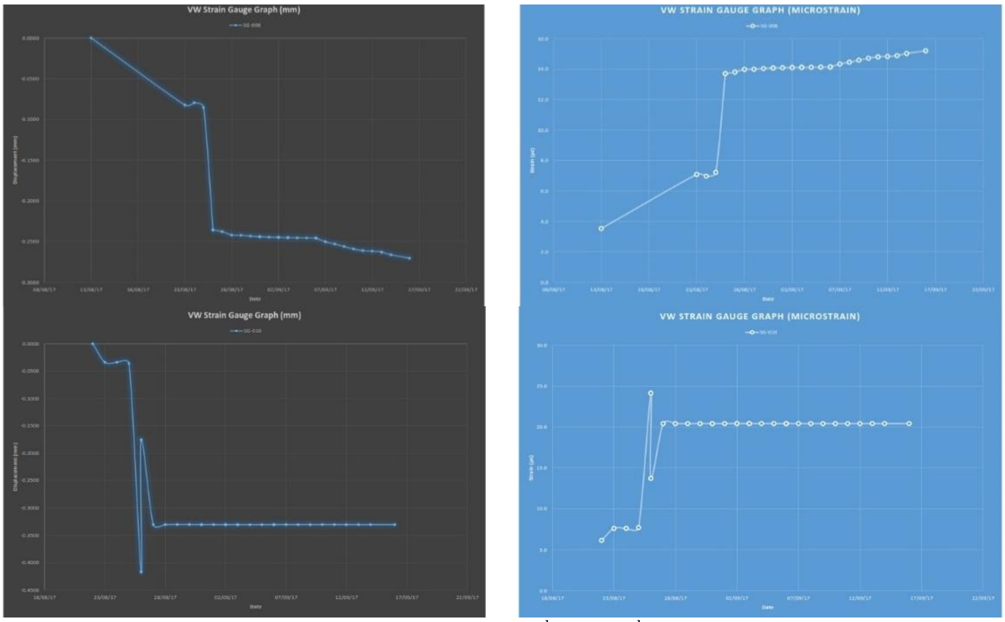


Figure 10. The strain and deformation results at the 8th and 10th strain guage.

When the results presented in Fig. 10 are examined, it is seen that the results of the strain and deformation of these stations are quite significant especially in August 2017. In these charts, where the temporal monitoring has been presented, it is clear that the movement trend is observed at the 2nd, 4th, 6th, 8th and 10th monitoring points until the beginning of September. Morever, the results of the statistical deformation in Table 3 confirm this trend. It is determined that the movement trend has been diminished in September 2017 after the efforts to control and stop the ongoing movement. Finally, the results of the analysis with the help of these extensometer data are presented in Fig.s 11, 12, 13 and 14, respectively.

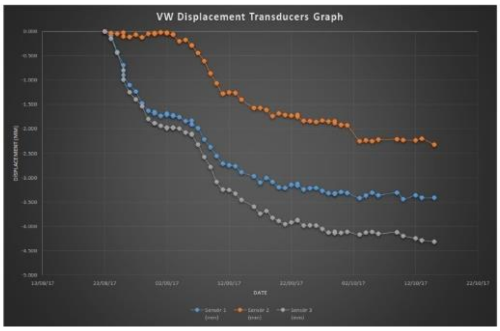


Figure 11. Deformation graphs obtained by Extensometer-1 data

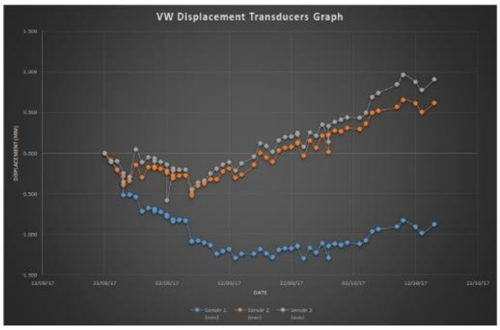


Figure 12. Deformation graphs obtained by Extensometer-2 data

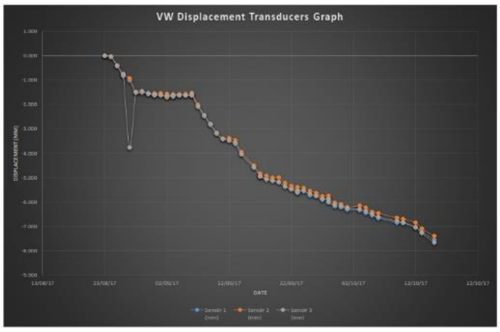


Figure 13. Deformation graphs obtained by Extensometer-3 data

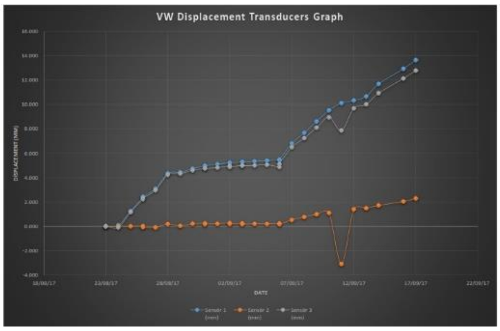


Figure 14. Deformation graphs obtained by Extensometer-4 data

In addition to the deformations presented in Table 2 and determined statistically significant, it should be focused on the displacements in level of the millimeter detected by 3 different sensors for each extensometer. For example, in Fig. 11 for the Ekstantometre-1, it is clear that there are 3 different sensors in similar trend but in different sizes. However, the same cannot be said for the sensors in Fig. 12 for the Extensometer-2. In contrast, the results of the Extensometer-3 in Fig. 13 indicate that all sensors are subject to the same amount of collapse movement. According to the Extensometer-4 results presented in Fig. 14, it is determined that Sensor 1 and Sensor 3 have similar arising trend but in Sensor 2, there is independently a lower arising movement.

The results obtained in the light of these data show that extensometer data contributes to geodetic methods for deformation tracking. In the tension meter data, it is observed that the results obtained are in a linear relationship with deformation and stress data and there is an inverse relationship between them. As can be seen in the graphs, the increase in the tension value creates a stress on the tunnel supporting systems and this increase causes deformation / displacement.

Recently, it brings great solutions to the increasing transportation problems of tunnels. In this direction, important budgets are allocated by attaching serious importance to tunnel projects. In this direction, deformation tracking in tunnels is of great importance. Geodetic and geotechnical methods are more expensive than geodetic methods for geotechnical measurement equipment. However, as the lithology for the tunnels, which are the major engineering projects, is irregular and the seismicity of the T1 tunnels is high, the use of these studies in the regions where the seismicity is preferable will result in a significant increase in the construction of more healthy, more economical and long-lasting structures. In this direction, it is recommended that the productions will be made healthier.

Discussion and Conclusion

According to the data obtained from the study, the results were consistent with each other. Based on these results, major changes have been made to the existing tunnel supporting systems currently used. In addition to the presence of the zone in the earthquake zone, the long-lasting use of the structure was taken into consideration by changing the supporting system which was used by taking into consideration the deformation results obtained. Thus, it has been ensured that manufacturing has a rigid structure within itself and it is less affected by external factors. With the help of geodetic and geotechnical deformation monitoring methods used in this study, the ongoing project has been ensured to be longer lasting and socioeconomic.

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References

Avşar, E.O., Bozkurtoğlu, E., Aydar, U., Şeker, D.Z., Kaya, Ş., Gazioğlu, C. (2016). Determining roughness angle of limestone using optical laser scanner. *Internatonal Journal of Environment and Geoinformatics (IJEGEO)*, 3(3), 57-75.

Benham, P., Warnock, F. (1973) *Mechanics of Solids and Structures*, Pitman, London.

Çepni, M. S., Arslan, O. (2017). A gis approach to evaluate infrastructure variables influencing the occurence of traffic accidents in urban roads. *Internatonal Journal of Environment and Geoinformatics (IJEGEO)*, 4 (1), 17-24.

Dinis G.C. (2004) A method for continuous monitoring of tunnel deformations during construction and service phases, *EUROCK'2004* – Salzburg, Austria.

Erenoğlu, R.C. (2016) *Deformation Analysis Lecture Notes.* In Turkish.

Gama, C.D. (1996) Correlation between rock mass classes, convergence rates and support densities for underground coal mine excavations.*Eurock'96,*Torino, 825-830.

Jimeno, C.L. (1997*) Manual of tunnels and underground workings* (in Spanish). Madrid

Martisek, D., Prochazkova, J. (2018). The Analysis of Rock Surface Asperities, *MENDEL*, 24(1), 135-142.

Michael J.K. (2003) Monitoring and Modelling Ground Deformations During Tunnelling, *11th FIG Symposium on Deformation Measurements*, Santorini, Greece.

Öztürk, B., Serkendiz, H. (2018). Location Selection forWind Turbines in Balıkesir, NW Turkey, Using GIS, *Internatonal Journal of Environment and Geoinformatics (IJEGEO), 5*(3), 284-295.

URL-1, http://www.leica-geosystems.com corporate/en/products/levels/lgs_4457.htm 10 Feb 2019.

URL-2, http://www.leica-geosystems.com/ hds/en/lgs_5210.htm, 10 Feb 2019.

URL-3, http://www.leica-geosystems.com/ corporate/en/solutions/other/lgs_2957.htm, 10 Feb 2019.

Yakar, M., Ulvi, A., Toprak, A.S. (2015). The Problems and Solution Offers, Faced During The 3d Modeling Process Of Sekiliyurt Underground Shelters With Terrestrial Laser Scanning Method, *Internatonal Journal of Environment and Geoinformatics (IJEGEO), 2*(2), 39-45.

Yiğit O. (2012) A prospective sector in the Tethyan Metallogenic Belt: Geology and geochronology of mineral deposits in the Biga Peninsula, NW Turkey. *Ore Geology Reviews* (46) 118-148.