STRUCTURAL DEFORMATION MONITORING ANALYSIS USING GEODETIC TECHNIQUES AFTER THE EARTHQUAKE AT BOLU PASS OF TRANS-EUROPEAN MOTORWAY

Esra TEKDAL EMNİYETİ, Rahmi Nurhan CELİK and Tevfik AYAN

Istanbul Technical University, Civil Engineering Faculty, Division of Geodesy, 34469 Maslak Istanbul, Turkey

Abstract: The Bolu viaduct I, viaduct II and the tunnel are a part of the Bolu mountain project that is located in the north central Turkey. The project which is a part of the Trans-European Motorway (TEM) aims to improve the transportation conditions in the western part of Bolu.

The crustal movements that come out as a result of earthquakes are the main cause of the deformations in engineering structures. Turkey has a long history about the earthquakes, because one of the most active faults, the North Anatolian Fault (NAF), is crossing over Turkey. Especially in 1999, the earthquakes that happened because of the movements in the NAF cause damages on many engineering structures.

The earthquake that happened in 12th November 1999, cause serious damage to the Bolu viaducts and tunnel which were under construction. The damaged viaduct, viaduct I was nearly complete and the viaduct II was in its foundation construction stage when the second earthquake (12th November earthquake) struck Turkey.

The aim of this study is to investigate the deformations (rotation, bending and torsion), occurred on structures (especially the viaduct I) of the Bolu pass of 114 km long Ankara-İstanbul motorway, after 17th August Marmara and 12th November Düzce earthquakes.

1. Introduction

In the design or the construction stage of the engineering structures, due to the environmental effects or the forces applied on the structure as a result of use, some deformations can be observed. The determination of the deformations in large engineering structures is an important subject to work, because these structures are expensive. If the deformation can be observed in the early stages, some precautions can be taken and the structure can be prevented from collapsing. Most of the deformations whether small scale or large scale is caused by earthquakes.

Turkey is located in a tectonically active zone as seen in Figure 1. The faults in the Bolu region (especially the region around the Bolu viaducts), are classified as first degree or seismically active. One of these first degree active faults is the NAF, which is the most important tectonic feature in Turkey producing lots of earthquakes in a big scale and causing loss of property and life.

The August 17, 1999 earthquake with a moment magnitude of 7.4 and, November 12, 1999 earthquake with a magnitude of 7.2 took place in the NAF. As a result of these earthquakes many engineering structures, one of which is the Viaduct 1, are seriously damaged (Ghasemi et al. 2000).

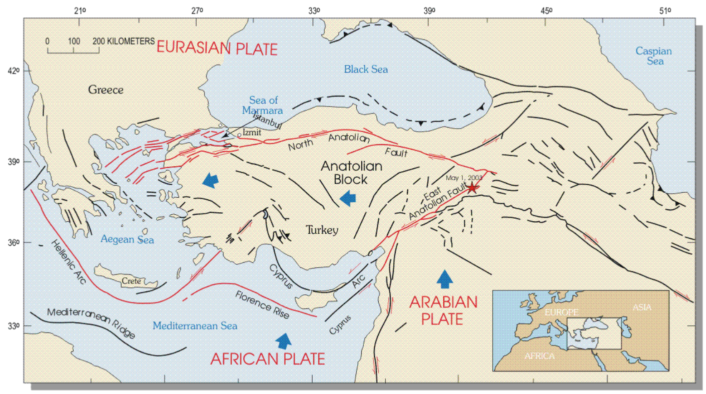

Figure 1 - The Tectonic Map of Turkey (Celik et al. 2005)

2. Bolu Pass of Ankara-İstanbul Motorway

The Bolu pass, which is composed of two viaducts, Viaduct 1 and Viaduct 2, and a tunnel, is a part of TEM’s Ankara- İstanbul Motorway. This pass starts from Kaynaslı/Bolu and ends at Elmalık/Bolu. The Viaduct 1 consists of two parallel and structurally separate viaducts that totally consist of 117 spans (59 piers supporting the northern lanes and 58 piers supporting the southern lanes). The 2.3 kilometres long span structure, was approximately 95% completed and was waiting for the installation of expansion joints for completion of the project, at the time of November 12, 1999 earthquake (Celik et al. 2004).

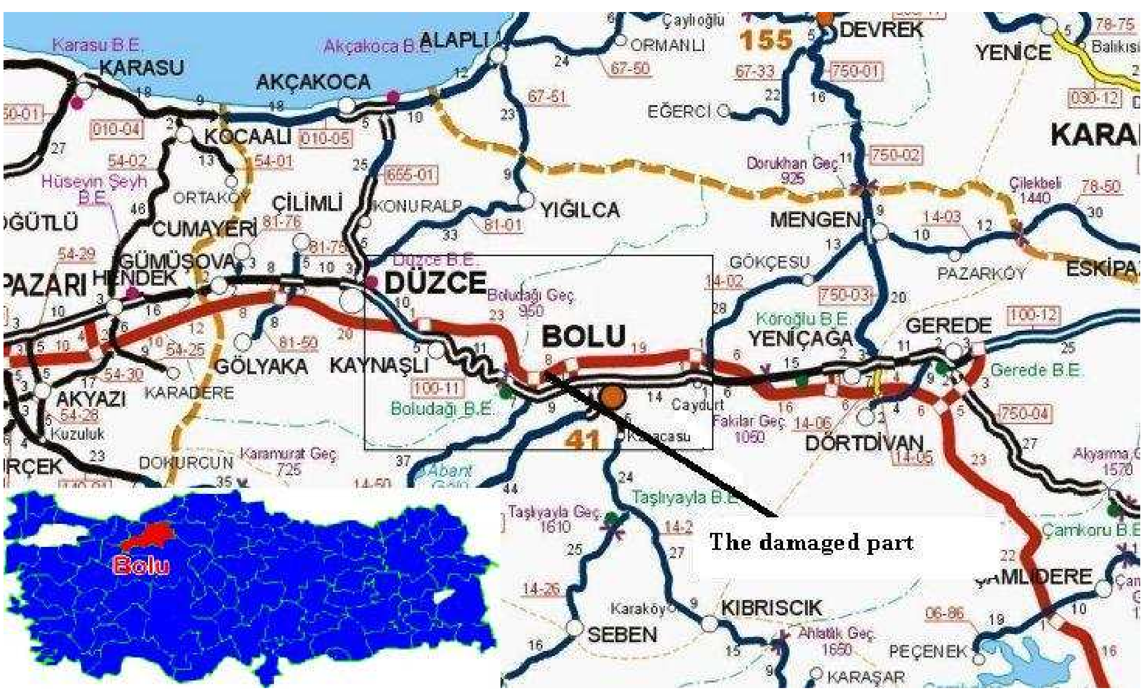

Figure 2 - Location and the damaged part of the Bolu Mountain Project

The spans of viaduct 1 are typically 39.2 m with each deck span consisting of 7 precast pretensioned U-beams with an in-situ reinforced concrete slab. The pretensioned U-beams are seated on pot bearings with a stainless steel/polytetrafluoroethylene (PTFE) slider interface. The deck slab acts continuously over 10 span segments. The deck slab is continuous across pier tops except at movement joints. Piers are up to 50 m in height and consist of single hollow rectangular reinforced concrete pier shafts with a capping beam. Foundations comprise 3 m thick pile caps with typically twelve 1.8 m diameter reinforced concrete bored cast in-situ piles up to 37.5 m long (Ghasemi et al. 2000, Barr et al. 2000).

Figure 3 - General view from the Viaduct 1

3. Geodetic Data

At the beginning of this project a geodetic network was set up in the area to apply the project in the field in 1992. Since then this network were used to carry out the project until the earthquakes happened in 1999. Those earthquakes totally changed the topography of the area, therefore it caused damage to the whole geodetic network since the fault split up the geodetic network and at least divided into two parts. Therefore all relations between the control stations are damaged. So the previous network cannot be discussed any more. As a result, new geodetic network is essential to carry out the project in future. Also the project structures existing in the field needs to be connected to the control stations of the geodetic network (Ayan and Celik, 2000).

3.1. Horizontal Geodetic Network

In Turkey, there is a national horizontal geodetic network that is used as the base of all geodetic works. The datum of this network is ED50 and its ellipsoid is International (Hayford). The coordinates of control stations of this network are provided by the governmental organisation in two types of projections: Universal Transversal Merkator (UTM) or Transversal Merkator (TM). These two projections are convertible to each other (Aksoy et al. 1999). However, the type of the coordinates should be known especially for the area where mid-longitude is common for both projections, since it is difficult to identify the projection clearly.

After earthquake all topography in the area has been changed, since the North Anatolian Fault is a long fault and pre-analysis show that it has moved from East to West at about 2 to 4 meters. Therefore previous network established for the project was deformed. As a result all control stations in this network have been remeasured using GPS techniques.

Even though GPS provide 3D positions for the control stations, 2D coordinates have been considered to examine the differences from the previous network, since the previous network was set up as 2D conventional network connecting to national network. However it should be accepted that previous network is seriously damaged due to earthquake, so the new GPS network should take the place of the previous one. If this is the case, it is advisable that GPS network should be considered in 3D. Moreover this should not be ignored that GPS has its own datum and ellipsoid. Therefore additional measurements for this geodetic network or connections to it have to made or reduced to this system rather then national system (Ayan and Celik 2000).

In the new geodetic network, there are totally 73 control stations with 27 3D monitoring stations. 13 of these are common with the previous geodetic network and 32 of these have been established as the new control stations.

3.2. Viaduct Measurements

Viaduct I measurements have been carried out using high-tech reflector-less total station. Using these total stations, detail points can be measured up to 100 meters without using a reflector. Therefore that technology provides speed and precision for such a difficult measurement. By using this technology, 28 detail points have been measured on each of the pier. Number of these points is more than sufficient amount to investigate the displacements of a pier. However in case of the measurement errors all available points on piers have been measured.

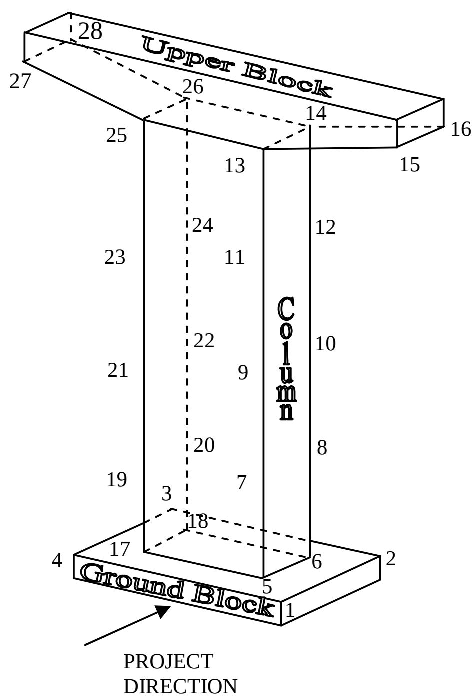

Figure 4 - Measured control points on the viaduct pier

4. Analysis of Geodetic Data

In order to obtain relations between the previous and the new GPS networks, all common stations have been taken into 2D-transformation processes. The result of that transformation has shown that northern part and southern has no consistency. Therefore, different strategy has been set up, as transforming the coordinates from East to West and then West to East. First transformation process started from Bolu side to Düzce side (East to West). An iterative strategy has been used, so that transformation has been started taking the first 3 control stations from Bolu side. If the consistency achieved another common station has been taken into transformation account and the new transformation result has been obtained. This process has been carried out until no consistent station left from Bolu to Düzce direction.

The result of this transformation process has shown that the common geodetic network stations are consistent up to the region where one of the North Anatolian Fault cracks crosses the stretch of the viaduct. Same transformation strategy has been used from Düzce to Bolu direction. In this transformation, common points have also lost the consistency at the same region that the crack crossing the viaduct stretch. The results of both transformations process are given in Table1.

Transformation from Bolu to Düzce				**Transformation from Düzce to Bolu**			
Parameter	**Value**	**r.m.s**	**Dim**	**Parameter**	**Value**	**r.m.s**	**Dim**
Shift dX	-187.667	0.083	m	Shift dX	-186.720	0.026	m
Shift dY	-35.007	0.083	m	Shift dY	-32.753	0.026	m
Rotation about Z	-19.441	1.900	[’’]	Rotation about Z	-25.227	1.694	[’’]

Table1 - Transformation parameters

When the transformation parameter is examined it is seen that in East-West direction there is about 2 meters horizontal displacement. However in North-South direction there is less than half a meter horizontal displacements. There is a significant scale problem that might occur due to earthquake or natural distortion of the national geodetic network or the previous geodetic network processing strategy. There might be projection type confusion, like TM or UTM since mid-longitude of both projections are common for the region.

It is strongly advisable that new coordinate system of the project should be taken as ITRF96. However, when the national coordinates are necessary, the 2D transformation parameters given in Table 2 should be used to convert the GPS coordinates to national coordinate system. This transformation has been processed using well-distributed 4 common control stations in the region. However all these are in the southern part of the North Anatolian Fault.

Transformation Parameters			
Parameter	**Value**	**r.m.s**	**Dim**
Shift dX	-187.198	0.284	m
Shift dY	-35.823	0.284	m
Rotation about Z	-4.422	4.201	[’’]

Table 2 - Recommended transformation parameters from ITRF96 to National Geodetic System

As is mentioned above, there is no alternative to examine the viaduct previous position within a global system, since the viaducts have been seriously damaged by 3 individual cracks of the North Anatolian Fault. Therefore, the damages on the viaduct piers and stretch have been investigated in two parts. First part is, from Düzce to Bolu direction up to crossing crack and the second part is from Bolu to Düzce up to crossing crack. The fault trace at viaduct is demonstrated detailed in Figure 5.

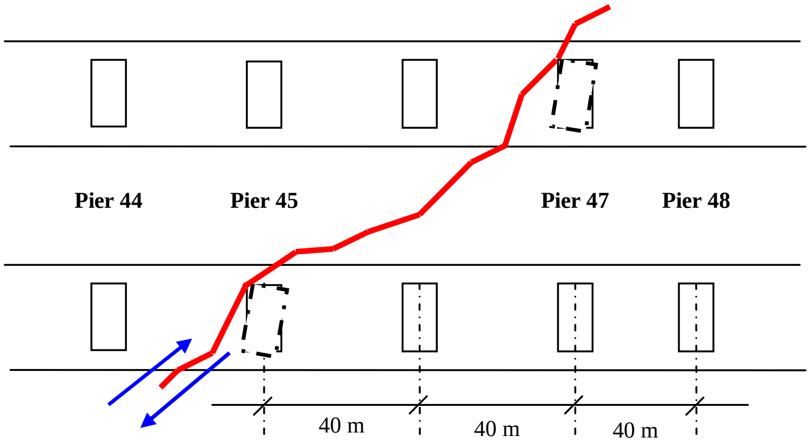

Figure 5 - Fault trace at viaduct (Celik et al. 2005)

The viaduct region is divided into two parts near by pier 47. Therefore, analyses from two directions have been examined up to pier 48 from Düzce and up to pier 46 from Bolu. The overlapping region has been evaluated to see the effects of regional passing.

Firstly Düzce to Bolu part have been considered, no transformation effects carried from the geodetic network, viaduct piers have been transformed from the points that are on viaducts themselves. Therefore that was a local investigation just for the viaduct. The main goal of that investigation is to identify the relative positional movements of the piers with respect to each other. In order to analyze this, piers by piers transformation have been executed. For this transformation mainly the project and the measured coordinates of points at the bottom corner of the piers, number 5,6,17,18 are used, see Figure 4. When these points are not available, the points whose numbers are 1, 2, 3 and 4 are used. This transformation started from pier 1 left and right and continued taking following piers in the analyzing direction. Results of the transformations are given in Table 3 and Table 4.

Transformation from Düzce to Bolu Pier 1 to 35			
Parameter	**Value**	**r.m.s**	**Dim**
Shift dX	-187.711	0.004	m
Shift dY	-33.123	0.004	m
Rotation about Z	-14.630	0.465	[’’]

Table 3 - Transformation parameters from pier 1 to 35

Transformation from Bolu to Düzce Pier 57 to 49			
Parameter	**Value**	**r.m.s**	**Dim**
Shift dX	-186.901	0.024	m
Shift dY	-35.142	0.024	m
Rotation about Z	-29.722	2.275	[’’]

Table 4 - Transformation parameters from pier 47 to 49

In order to see whole scenario of the piers positional movements, the other piers which are not taken into account in the transformation process have been transformed to new GPS coordinate system with the transformation parameters in Table 3 and Table 4. Transformation parameters given in Table 3 used to transform the coordinates of the piers from 1 to 48 and transformation parameters given in Table 4 is used for piers 58 to 46.

4.1. Analysis of Deformations

The deformation analysis, which is carried out for the region the fault crosses the viaduct, includes the determination of rotation, bending and torsion.

The rotations in the viaduct are obtained by calculating the differences between the azimuths calculated according to a reference coordinate (Tekdal, 2007). In the figures below 'a' represents the ground block on the pier, 'b' represents the upper block and finally 'c' represents the column. As seen in Figure 6 there is an approximately 3^{o} rotation in pier 45R.

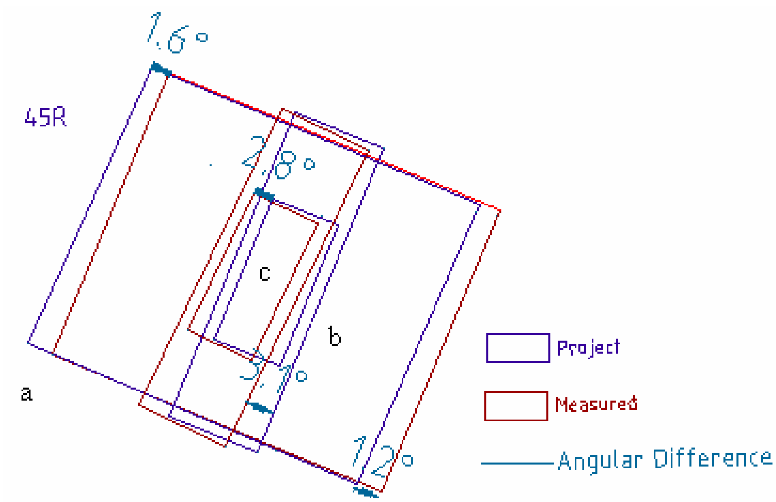

Figure 6 - The angular displacements in pier 45R (Tekdal, 2007)

It is clearly seen in Figure 7 that the pier 46R did not performed a rotation, just moved parallel compared to the position before the earthquake.

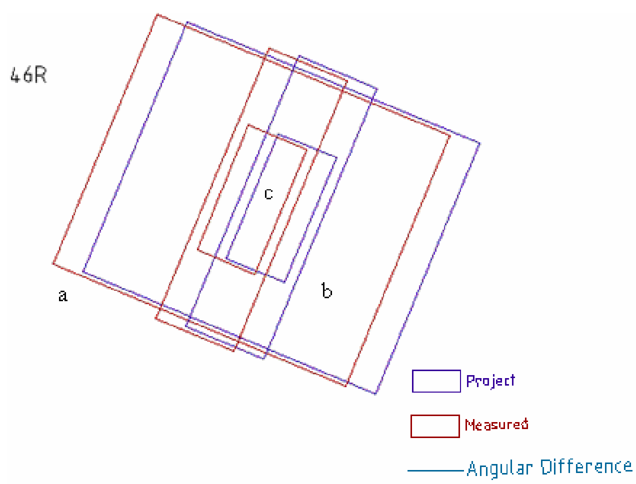

Figure 7 - The angular displacements in pier 46R

An approximate 4° of rotation achieved by pier 47L can be seen in Figure 8.

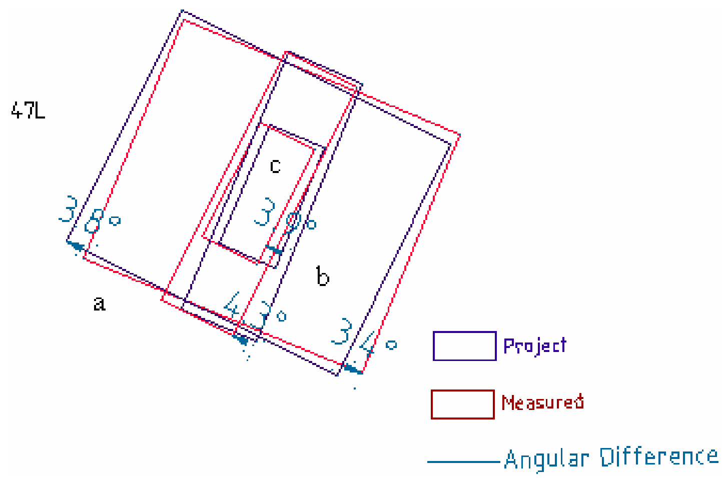

Figure 8 - The angular displacements in pier 47L

In order to say there is torsion, the bottom and the upper part or the structures of the piers should perform different rotation angles at the same time. If we look at piers 45R in Figure 6 and 47L in Figure 8, lower and upper part has a different rotation value. So it can be said that the piers 45R and 47L has performed torsion (Tekdal, 2007).

The final control is the bending check. To observe the bending in piers, upper and lower midpoints of piers are used. The lower and upper midpoint coordinates are calculated from the coordinates 1,2,3,4 and 13,14,25,26 respectively. The distance between project coordinates and measured coordinates are calculated (Tekdal, 2007). The results of these calculations can be seen in Table 5. According to the results, bending can be observed on piers 45R as 8 cm, 47R as 8 cm and finally 47L as 12 cm.

	Project(m)		Measured(m)			
Pier No	Y	X	Y	X	Dist(cm)	Diff(cm)
45R(Bottom)	615595.169	4515812.452	615594.020	4515812.495	115.0	
45R(Top)	615595.169	4515812.097	615593.970	4515812.385	123.3	8
46R(Bottom)	615631.368	4515797.050	615629.623	4515797.530	180.9	
46R(Top)	615631.368	4515797.050	615629.620	4515797.527	181.1	0
47R(Bottom)	615667.655	4515782.004	615665.933	4515782.293	174.7	
47R(Top)	615667.655	4515782.004	615665.858	4515782.345	183.0	8
47L(Bottom)	615675.605	4515801.360	615674.888	4515801.570	74.7	
47L(Top)	615675.680	4515801.360	615674.830	4515801.550	87.1	12

Table 5 - Bending on viaduct piers

5. Results and Recommendations

Results of this study show that due to the close proximity of fault rupture, the structures of Viaduct 1 and national network are seriously damaged. However, using the measurements, data, etc. that is obtained before and after the earthquake, the project coordinate system can be transformed to ITRF96. This transformation will provide some advantages, such as working directly by 3D coordinates using GPS or other conventional techniques.

Deformations like rotation, bending and torsion in viaduct piers, especially the ones (45, 46, 47) located near the fault trace can be observed. Although the damages in piers are obvious it is advised to observe the critical piers by techniques other than the geodetic methods in detail.

In conclusion, Bolu Mountain Project is located at a critical region about the tectonic movements. So the structures in the area should be continuously monitored against all possible deformations.

References

Aksoy, A., Ayan, T., Celik, R. N., Demirel, H., Deniz, R. and Gurkan, O. (1999). Güncel gelişmeler ışığında mekansal bilgi sistemleri için altyapı ve problemler., *Harita Kadastro Mühendisleri Odası Istanbul Şubesi, Eğitim serisi 2 (in Turkish)*, Istanbul, Turkey, 1999.

Ayan, T. and Celik, R. N. (2000). *Gumusova Gerede Motorway Measurement and Analysis Report*, Istanbul Technical University, Civil Engineering Faculty Geodesy Division, Volume 1-2-3, İstanbul, Turkey

Barr, J., Sanders, P., and Davey, S. (2000). *Effect of the 1999 earthquakes on seismically isolated viaducts on the Istanbul to Ankara motorway, Turkey.* Report of High-Point Rendel.

Celik, R. N., Acar, M., Kaplan, M. O. and Ayan, T. (2004). Investigation of displacements in engineering structures after earthquakes using both conventional and satellite geodetic techniques, *Proceedings of International Symposium "Modern Technologies, Education and Professional Practice in Geodesy and Related Fields"*, Sofia, Bulgaria, Nov 4-5, 2004.

Celik, R. N., Acar, M., Kaplan, M. O. and Ayan, T. (2005). Benefits of using geodetic approaches for determining earthquake damages on large structures, *Proceedings of International Symposium "Modern Technologies, Education and Professional Practice in Geodesy and Related Fields"*, Sofia, Bulgaria, Nov 3-4, 2005.

Ghasemi, H., Cooper, J. D., Imbsen, R., Piskin, H., Inal, F. and Tiras, A. (2000). *The November 1999 Duzce Earthquake: Post-Earthquake Investigation of the Structures on TEM,* Publication No. FHWA-RD-00-146, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.

Tekdal, E. (2007). Deprem sonrasında meydana gelen deformasyonların jeodezik yöntemlerle belirlenmesi (Determination of structural deformations caused by earthquakes using geodetic techniques), Istanbul Technical University Institute of Science and technology, Istanbul, Turkey, 2007.

Corresponding author contacts

Esra TEKDAL EMNİYETİ
tekdale@itu.edu.tr
Istanbul Technical University, Civil Engineering Faculty, Division of Geodesy, 34469 Maslak Istanbul
Turkey