Determination of Structural Deformations Caused by Earthquakes Using Geodetic Techniques

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SUMMARY

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. Deformation analysis is especially used for, the determination of crustal movements.

The crustal movements that come out as a result of earthquakes are the main cause of the deformations in engineering structures. Especially in 1999, the earthquakes that happened because of the movements in the North Anatolian Fault 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 1 was nearly complete and the the viaduct 2 was in its foundation construction stage when the second earthquake (12th November earthquake) struck Turkey.

The Bolu viaduct 1, viaduct 2 and the tunnel are a part of the Bolu mountain project that is located in the north central Turkey. The project aims to improve the transportation conditions in the western part of Bolu.

The aim of this study is to investigate the deformation occurred on structures (especially the viaduct 1) of the Bolu pass of 114 km long Ankara-İstanbul motorway, after 17th August Marmara and 12th November Düzce earthquakes by using precise 3D geodetic measurements.

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1. INTRODUCTION

Turkey is located in a critical and 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).

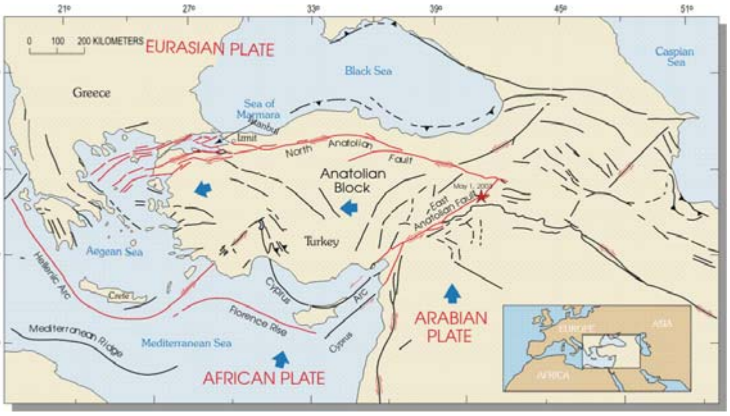

Figure 1: The Faults located in Turkey (Celik et al. 2005)

2. VIADUCT 1 AND BOLU PASS OF ANKARA-ISTANBUL MOTORWAY

The Bolu pass is a part of Trans-European Motorway (TEM) and composed of two viaducts, viaduct 1 and viaduct 2, and a tunnel. 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).

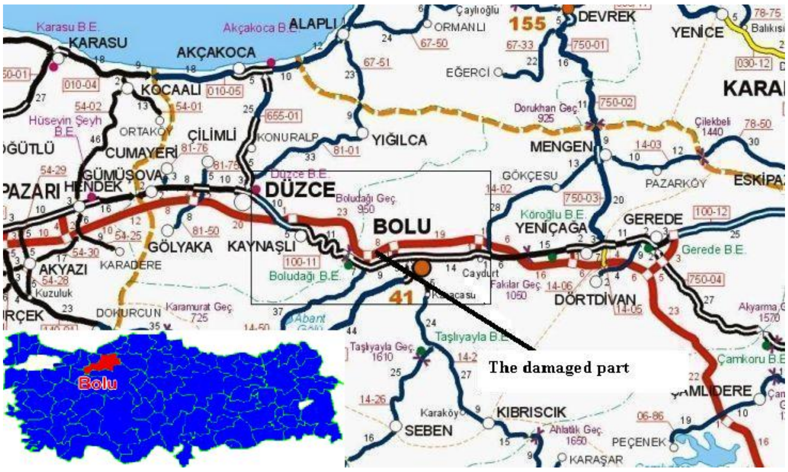

Figure 2: Location and the damaged part of the Bolu Mountain Project

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 OF THE PROJECT

In order to apply the project in the field, in 1992 at the beginning of the project a geodetic network was set up. 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, and it caused damage to the whole geodetic network since the fault split up the geodetic network (at least divided into two parts). Because of the change in topography all relations between the control stations are damaged. So the previous network cannot be used for the application of project 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. Measurements on Viaduct Piers

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. The detail points measured on piers can be seen in Figure 4.

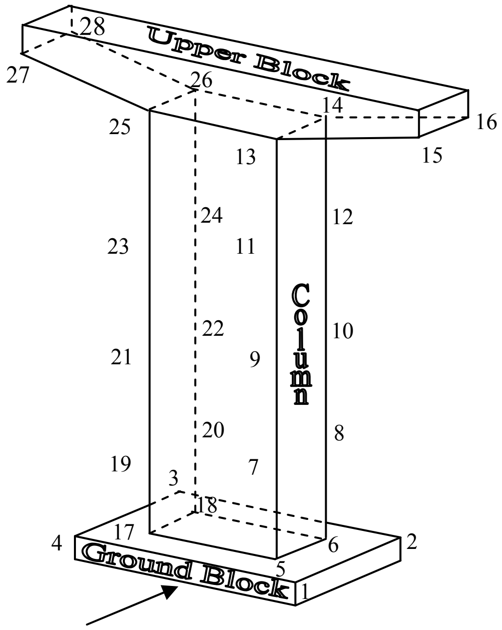

Figure 4: Measured control points on the viaduct pier

4. ANALYSING THE 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 destination of the viaduct. 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.

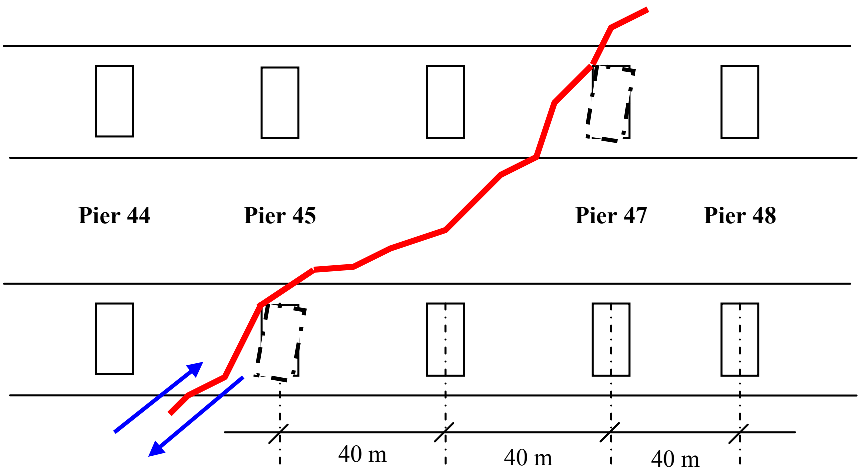

Figure 5: Fault trace at viaduct (Celik et al. 2005)

The viaduct region is divided into two parts nearby 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 49 to 57

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.

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 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. After the detailed investigation of the viaduct, some arrangements and updates should be carried on the project (Tekdal, 2007).

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.

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