Geodetic Measurements for Detecting Movements on the Structure Surface Due to Mining Activities

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SUMMARY

Underground mining activities are prone to cause movement in geological strata and also on the earth's surface leading to mining subsidence and subsidence damages. Determining mining subsidence depends upon regional subsidence parameters, underground operating speed, duration of production, production methods, geometry of the mined area (such as dimensions of opening, shape and depth).

This initiates damages on surface structures, utilities, buildings, farmlands, and also disturbs the natural balance of surface, underground water resources, natural and man-made surface drainage systems as well as engineering structures such as reinforced concrete and masonry buildings, railways and highways.

In many European countries, systematic subsidence investigations on underground coal mining productions and their subsidence effects have been widely conducted using field observations so as to reduce and control the adverse subsidence effects on urbanization since 1880.

This study focuses on the surface movement related deformations on the engineering structures in the basin such as Kozlu Seaport. For this reason subsidence monitoring points were established on this structure in the basin in a geodetic network concept, and three periods of precise leveling and static GPS observations were conducted. Analyzing these two types of geodetic observations active and residual subsidence effects were determined for Kozlu Seaport

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1. INTRODUCTION

Mining activities cause to create gaps inside the ground. The gaps withstand the load over it by vaulting inside the ground and prevent caving-in as long as they are opened deeper into ground and remain in smaller proportions as is the case in mining galleries depending upon the production length. With the mining production gaps reaching larger dimensions, however, the ground just above the gaps starts to collapse by layers breaking away and fills up the production gaps.

The movements of ground on the surface triggered by the collapse of cascading internal ground layers are termed as mining subsidence (Kratzsch, 1983; Kuşçu,1991; Perski and Jura, 2003; Deck *et al.*, 2003; Duzgun, 2005; Akçın *et al*,. 2006; Saeidi *et al.*, 2009; Can *et al.*, 2011a, 2011b). These movements cause deformations on the earth surface and in the affected ground layers and disruptions on the natural balance of ground. As a consequence of this, engineering structures inside the affected ground and on the earth surface above the subsidence region either accommodate to these deformations or sustain damages. These damages whether they occur on natural or man-made structures by means of mining subsidence are called mining damages.

Mining subsidence as a result of mine productions underneath the settlement areas, especially in Western European countries where underground coal mining is of great value, has been long a crucial mining issue with economic, social, technical and environmental aspects. In Zonguldak Kozlu Hard Coal Region, coal seams dip mostly at high angle and their thicknesses are not uniform, therefore mining subsidence problems are most likely to occur causing very serious problems with regard to urbanization.

This study details the precise leveling and Global Positioning System (GPS) monitoring results for the kozlu seaport to determine the mining induced horizontal and vertical displacements.

2. MONITORING OF MINING SUBSIDENCE

It is necessary to gather information on general and regional properties of subsidence formation and effective constituents which eventually cause damages on structures in order to mitigate mining subsidence induced issues and to provide solutions. Therefore it is of great importance that subsidence measurements and observation should be conducted on the earth surface and, if necessary, in the underground.

Even though the mining activities have been going on for 160 years in Zonguldak Hard Coal Basin there exists little or no knowledge on this, which is needed dearly today especially with the densification of settlement areas just above the old coal production galleries and mining activities continuing under new settlement areas.

The coal seams in Kozlu production region have steep inclinations as is generally the case in Zonguldak Hard Coal Basin and the subsidence occurring in this region have adverse effects on social, economic and legal aspects of life (Turer 2008). Fig 1 depicts the subsidence formation and its influence areas after mining activities in inclined coal seams in the region.

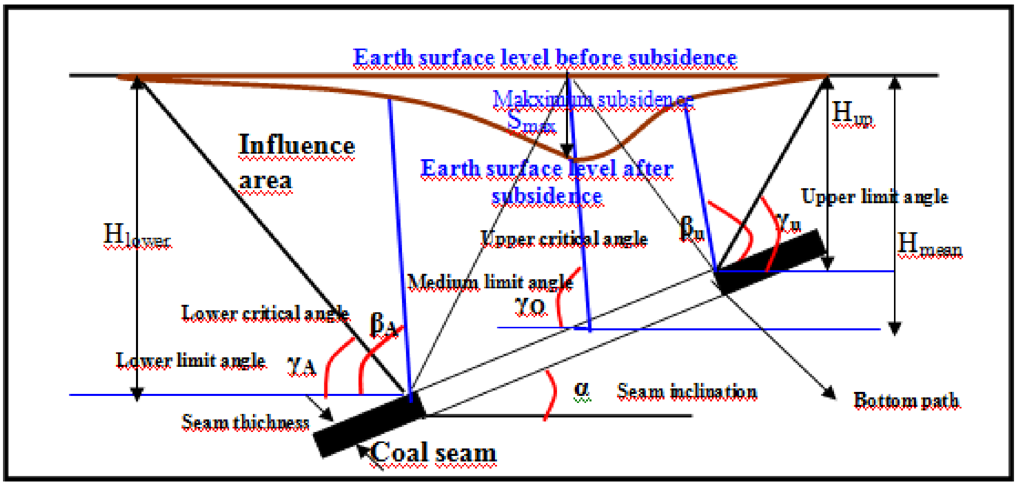


Figure 1. Subsidence tub forming after production in inclined coal seams and the other related definitions (Kratzsch, 1983).

In times when the main source of energy was coal in a region, much of the effort was spent on obtaining coal reserves under the settlement areas with less production losses and subsidence damages as much as possible.

This naturally gave way to important work and research for maintaining this purpose and then to the birth of a discipline called subsidence engineering which is specialized in five topics as follows (Kuscu,1991)

- Subsidence measurements,
- Subsidence estimations,
- Subsidence damages,
- Subsidence control,
- Subsidence related laws and regulations.

In order to determine the subsidence occurring due to mining activities in an underground mine production region, subsidence measurements are utilized to ascertain:

- Subsidence parameters (critical and limit angles, displacement values etc.),
- Relationship between subsidence and geology, tectonics and topography,
- Relationship between subsidence and production speed and time,
- Relationship between subsidence and production method,

3. FEATURES OF KOZLU COAL PRODUCTION REGION

Kozlu-Zonguldak Hard Coal Basin is a formation of the Late Plaeozoic–Mesozoic Age, consisting of various faults and topographic irregularities along the North Anatolian Mountain Range. The town of Kozlu within the Zonguldak Hard Coal Basin was established in 1941 and has a coal production rate of 780,000 ton per year along with 3.3 million ton per year in the whole basin (URL1 2011; URL 2 2011).

Kozlu is located in the Western Black Sea Region of Turkey at latitudes 41°–27′ N and longitudes 31°–49′ E (Citiroglu and Baysal, 2011). It borders city of Zonguldak to the northeast, Eregli to the southwest, Caycuma to the east and Devrek to the southeast. The coastline forms the north–northwest boundary of the study area (Figure 2a and 2b).

Kozlu is divided into 7 districts, namely Merkez, Tasbaca, Ihsaniye, Kilic, 19 Mayis, Güney and Fatih. The settlement of Kozlu is completely surrounded by mountainous areas. The streams within the study area include Kozlu Stream and its branch Kilic Stream (Ekinci, 2005). Zonguldak-Kozlu-Kandilli (West Hard Coal Basin) is situated to the west of the Filyos River. The Carboniferous clastic sequence of Zonguldak basin contains several coal seams that have been mined since 1848 by underground methods.

Figure 2a. Town of Kozlu

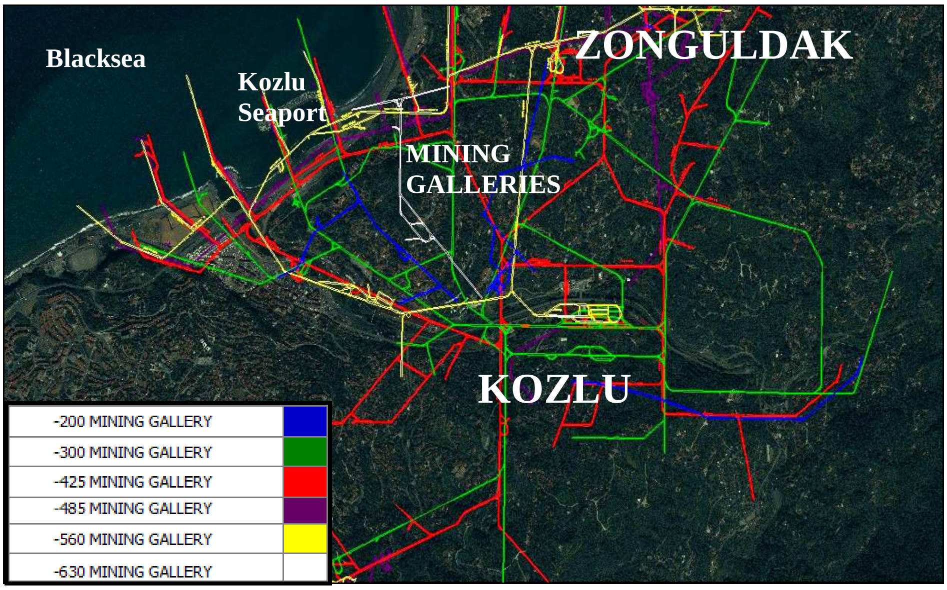


Figure 2b. Mining galleries and Kozlu Seaport (Study Area) in the Kozlu coal production region

Coal seams are located in a Namurian to Westfalian D progradational delta and fluid plain sequence that is approximately 3500 m thick (Karacan and Okandan, 2000). These units are affected by Hercynian orogenic movements. Related tectonism and uplift led to a widespread erosion.

4. GEOMETRICAL PROPERTIES OF MINING PANELS AFFECTING KOZLU SEAPORT

The coal seams under the engineering structures focused on in this study have steep inclination angles, and they house production panels working on longwall method. Figures 3 demonstrate Ikonos satellite images containing old and new production panels just under

Kozlu Seaport with active and residual subsidence effects.

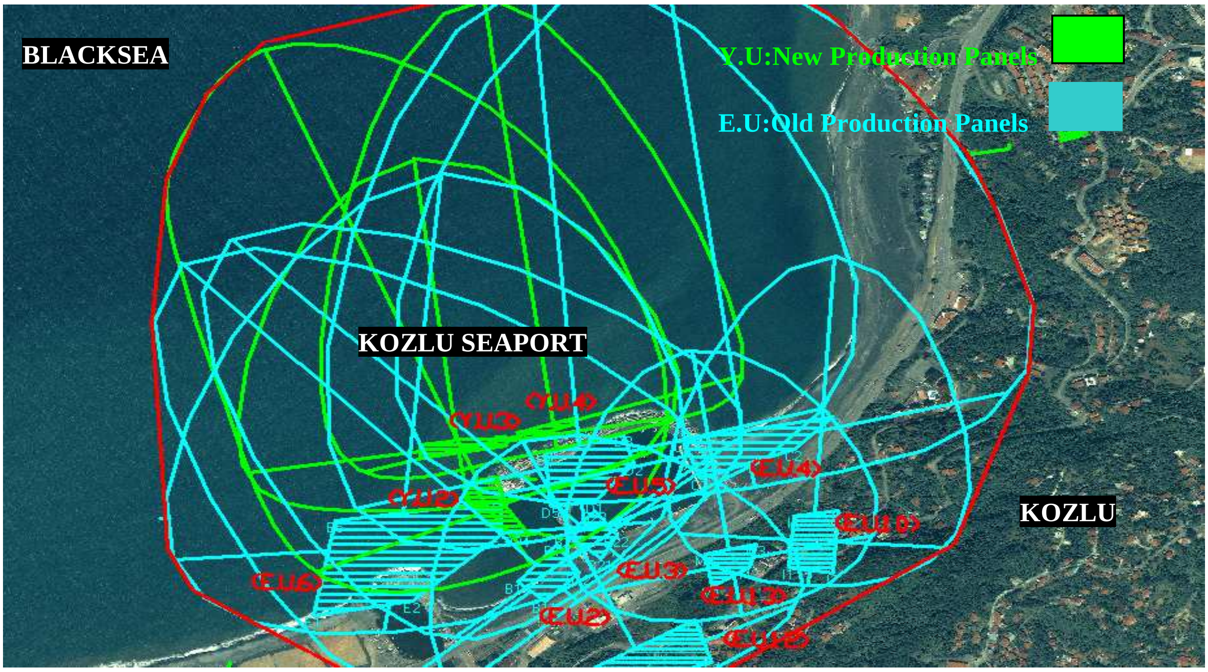


Figure 3 Influence areas of old and new production panels in Kozlu Seaport under active and residual subsidence influences.

Tables 1a lists the geometrical properties of panels in Kozlu Seaport region such as opening year, inclination, thickness and width, and Table 1b the maximum possible subsidence magnitudes and parameters computed in accordance with the Subsidence Engineering Handbook of National Coal Board (NCB).

Table 1a. Geometrical properties of production panels under Kozlu Seaport

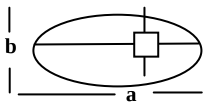
Panel name	Year	Inclination	Thickness	Width	H_{mean}
E.U.2 (old)	1988	40^o	3m	60m	-456m
E.U.3 (old)	1990	40^o	3m	60m	-434m
E.U.4 (old)	2004	58^o	3m	50m	-510m
E.U.5 (old)	2006	32^o	2m	110m	-508m
E.U.6 (old)	1989	26^o	1.5m	190m	-400m
E.U. 10 (old)	1987	28^o	3m	120m	-283m
E.U.12 (old)	1990	27^o	3m	80m	-256m
E.U.13 (old)	1990	17^o	3m	60m	-321m
Y.U.2 (new)	2009	29^o	2.5m	130m	-510m
Y.U.3 (new)	2009	20^o	2m	30m	-445m
Y.U.4(new)	2009	44^o	2m	20m	-450m

Table 1b. The maximum possible subsidence magnitudes and parameters computed in accordance with the NCB in Kozlu Seaport region.

Panel name	**S_{max} (vertical)**	**Subsidence type**	γ_{lower}	γ_{medium}	γ_{upper}
E.U.2 (old)	0.4cm	Residual	28^o	55^o	85^o
E.U.3 (old)	0.2cm	Residual	28^o	55^o	85^o
E.U.4 (old)	1.1cm	Residual	29^o	55^o	84^o
E.U.5 (old)	1.3cm	Residual	29^o	55^o	83^o
E.U.6 (old)	9.5cm	Residual	32^o	55^o	81^o
E.U. 10 (old)	1.9cm	Residual	30^o	55^o	83^o
E.U.12 (old)	5.9cm	Residual	30^o	55^o	82^o
E.U.13 (old)	0.6cm	Residual	38^o	55^o	75^o
Y.U.2 (new)	3cm	Active	30^o	55^o	82^o
Y.U.3 (new)	1cm	Active	37^o	55^o	76^o
Y.U.4(new)	0.3cm	Active	27^o	55^o	85^o

Table 3a lists the computed semi-major and –minor axes values of an ellipse enveloping possible subsidence affected areas of old and new production panels in Kozlu Seaport under residual and active subsidence effects for plotting purposes

Table 3a. Elliptic parameters for possible subsidence influence areas of old and new production panels in Kozlu Seaport region

Panel name	 **Semi-major and –minor axes of subsidenceinfluence areas**		
	a(m)	**b(m)**	**Area (km^2)**
E.U.2 (old)	1002m	748m	0.59 km^2
E.U.3 (old)	961m	668m	0.50 km^2
E.U.4 (old)	1091m	994m	0.85 km^2
E.U.5 (old)	1147m	870m	0.78 km^2
E.U.6 (old)	1052m	750m	0.62 km^2
E.U. 10 (old)	693m	476m	0.26 km^2
E.U.12 (old)	591m	588m	0.27 km^2
E.U.13 (old)	565m	558m	0.24 km^2
Y.U.2 (new)	1142m	784m	0.70 km^2
Y.U.3 (new)	736m	652m	0.38 km^2
Y.U.4(new)	959m	720m	0.54 km^2

5. PRECISE LEVELING AND GPS MEASUREMENTS IN KOZLU SEAPORT

In order to determine subsidence magnitudes in the aforementioned region just under the engineering structures three periods of precise leveling and GPS measurements were conducted in August 2009, May 2010 and November 2010. The one hour static GPS data were collected at the subsidence monitoring points with an observation epoch of 2009.58 in the first period, 2010.40 in the second period and 2010.90 in the third period avoiding any multipath creating surroundings (Mekik and Can 2010). This study focuses on the subsidence monitoring measurements carried out only in Kozlu Seaport sections of an extensive research enveloping the whole region (Can, 2011a,b). Table 4 lists horizontal displacement vectors of subsidence monitoring points T34, T35, T36, T37, T38, T39 and T40 in Kozlu Seaport.

Table 4. Horizontal displacement vectors of subsidence monitoring points in Kozlu Seaport with their RMSE values for the period pairs.

DIFFERENCES BETWEEN PERIODS I AND II (August 2009-May 2010)					
Point #	**Point #**	**Y (Easting) (m)**	**X (Northing) (m)**	**Horizontal Disp. Vector (m)**	**RMSE (±) (m)**
T.34	**T.34**	-0.063	0.014	0.065	0.0042
T.35	**T.35**	-0.069	0.008	0.070	0.0045
T.36	**T.36**	-0.056	-0.013	0.058	0.0058
T.37	**T.37**	-0.051	0.005	0.051	0.0063
T.38	**T.38**	-0.070	0.027	0.075	0.0037
T.39	**T.39**	-0.068	0.037	0.077	0.0036
T.40	**T.40**	-0.073	0.051	0.089	0.0054
DIFFERENCES BETWEEN PERIODS II AND III (May 2010-November 2010)					
Point #	**Point #**	**Y (Easting) (m)**	**X (Northing) (m)**	**Horizontal Disp. Vector (m)**	**RMSE (±) (m)**
T.34	**T.34**	-0.021	0.012	0.024	0.0040
T.35	**T.35**	-0.016	0.025	0.029	0.0031
T.36	**T.36**	-0.022	-0.004	0.022	0.0037
T.37	**T.37**	-0.028	0.004	0.029	0.0028
T.38	**T.38**	-0.017	0.002	0.017	0.0036
T.39	**T.39**	-0.017	0.028	0.033	0.0035
T.40	**T.40**	-0.051	0.039	0.064	0.0034
DIFFERENCES BETWEEN PERIODS I AND III (August 2009-November 2010)					
Point #	**Point #**	**Y (Easting) (m)**	**X (Northing) (m)**	**Horizontal Disp. Vector (m)**	**RMSE (±) (m)**
T.34	**T.34**	-0.085	0.026	0.089	0.0043
T.35	**T.35**	-0.085	0.033	0.091	0.0050
T.36	**T.36**	-0.078	-0.017	0.080	0.0054
T.37	**T.37**	-0.080	0.009	0.080	0.0063
T.38	**T.38**	-0.087	0.029	0.092	0.0043
T.39	**T.39**	-0.085	0.065	0.107	0.0039
T.40	**T.40**	-0.124	0.089	0.153	0.0052
Influencing production panels: Old Panels:E.U.2,3,4,5,6,10,12,13; New Panels:Y.U.2,3,4					

Figures 4 depict Ikonos satellite images containing horizontal displacement vectors obtained using the three periods of GPS measurements on the subsidence monitoring points in Kozlu Seaport.

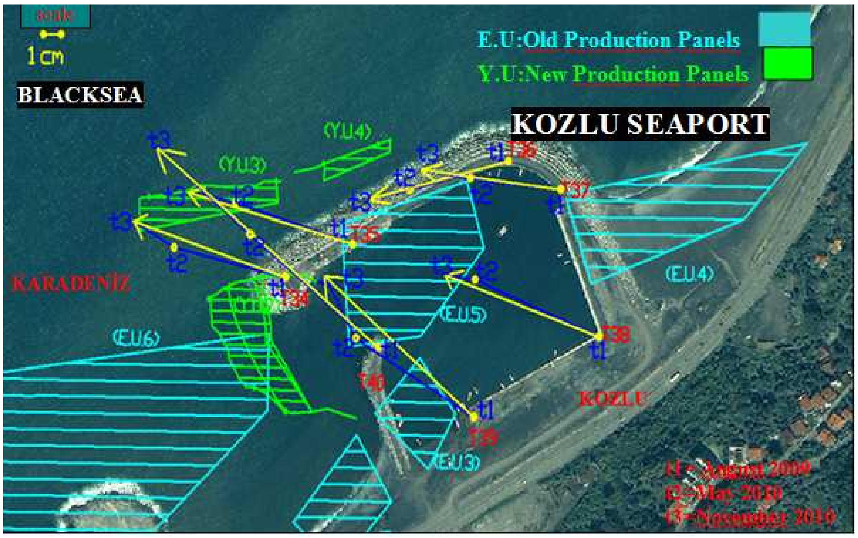


Figure 4 Horizontal displacement vectors obtained from GPS measurements in Kozlu Seaport.

It is hard to imply that horizontal displacements have caused any visual deformations or functional defects in the seaport during the three periods of GPS and precise leveling measurements in the region. As for the vertical displacements Tables 5 list the findings obtained from the three period pairs of precise leveling measurements for Kozlu Seaport

Table 5. Vertical displacement vectors of subsidence monitoring points in Kozlu Seaport with their RMSE values for the period pairs

	Vertical Displacements (m)					
Point #	**Period pair I-II (Aug 09-May 10)**	RMSE (m)	**Period pair II-III (May 10-Nov 10)**	RMSE (m)	**Period pair I-III (Aug 09-Nov 10)**	RMSE (m)
T34	-0.067	0.003	-0.027	0.003	-0.094	0.004
T35	-0.065	0.003	-0.026	0.003	-0.091	0.004
T36	-0.045	0.003	-0.020	0.003	-0.065	0.004
T37	-0.042	0.003	-0.019	0.003	-0.061	0.004
T38	-0.045	0.003	-0.015	0.003	-0.060	0.004
T39	-0.045	0.003	-0.019	0.003	-0.064	0.004
T40	-0.066	0.003	-0.031	0.003	-0.097	0.004

Figures 5 depicts Ikonos satellite images containing vertical displacement vectors obtained using the three periods of precise leveling measurements on the subsidence monitoring points in Kozlu Seaport

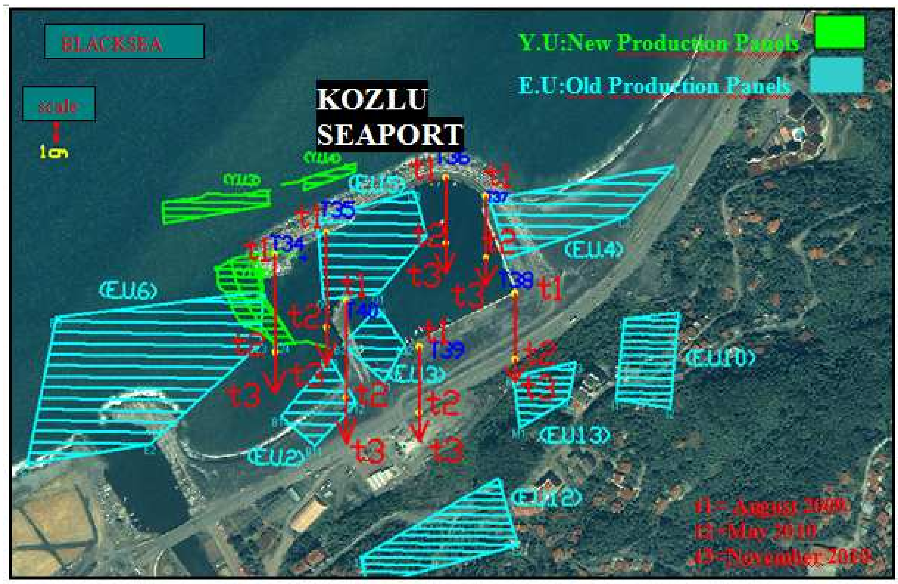


Figure 5. Vertical displacement vectors obtained from the precise leveling measurements in Kozlu Seaport.

Similar to horizontal displacements, it has not been observed that the vertical displacements resulted from residual and active subsidence effects have caused any visual deformations or functional defects in the seaport during the three periods of precise leveling measurements in the region.

6.CONCLUSIONS

Kozlu mining production region with extensive mining activities houses, many crucial engineering structures such as Kozlu Seaport which are the core of this study and there are plans for new constructions on even daily basis in the region. In order to maintain the mining operations along with urban developments in a healthy way, the subsidence monitoring measurements and observations play important role in mitigating or even preventing the damages that possibly will occur in future and in giving way to desired urban development in the region. In the study it has been determined that the horizontal displacements in Kozlu Seaport vary from 8.0cm to 15.3cm with their rmse values of 3.9mm to 6.3mm, respectively, obtained from the GPS measurements between the periods of I (Aug 2009) and III (Nov 2010). On the other hand, the vertical displacements obtained from the three periods of precise leveling measurements have been found to deviate from 6.0cm to 9.7cm in the seaport region with 3.0 and 4.0mm rmse values. Since the mining operations under Kozlu Seaport and Road will also be active in future, in the lights of findings obtained from this study it is suggested that an extensive subsidence monitoring measurements with longer periods should be carried out to mitigate and even prevent functional problems that may arise in these engineering structures in future.

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