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Triggered creep rate on the Ismetpasa segment of the North Anatolian Fault

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Abstract. The Ismetpasa segment of the North Anatolian Fault is one of the rare places in the world where aseismic creep event has been observed. This segment was ruptured during both the 1944, M_w=7.2, Gerede and 1951, M_w=6.9, Kursunlu earthquakes. After these earthquakes, the segment has not experienced a major earthquake anymore. Starting from 1957, many studies using different technologies have been carried out to determine the creep rate of the segment. All these studies until 2002 revealed that the creep movement of the segment slowed down. The new observation campaign of the Ismetpasa geodetic network shows that the Ismetpasa segment has ceased the slowing trend and started to gain speed. This might be interpreted as an increasing earthquake risk for this segment.

1 Introduction

Ismetpasa segment, located 350 km east of Istanbul and 100 km northwest of Ankara, of the North Anatolian Fault is a rare place where aseismic fault slip (creep) has been observed. This segment was ruptured by two major earthquakes, the 1944 M_w=7.2 Gerede in its western tail and the 1951 M_w=6.9 Kursunlu in its eastern tail (KOERI, 2004); after that, the segment did not host any major earthquake.

The creep behavior of the fault was first discovered on the wall of the train station in Ismetpasa town, and the rate of the surface creep was determined 2 cm/year based on the wall observations between 1957–1969 (Ambraseys, 1970). This first result was compatible with 2.2 cm/year slip rate of the NAF (McClusky et al., 2000). After the discovery of its creep behavior, the Ismetpasa segment had been the center of interest; many studies using different surveying techniques were carried out to determine its creep rate in different periods (Ambraseys, 1970; Aytun, 1982; Altay and Sav, 1991; Cakir et al., 2005; Kutoglu and Akcin, 2006). A list of these studies and the creep rates obtained are shown in Fig. 1.

The studies until the early 1990s showed that the rate of the creep was decreased logarithmically in time from its first determination. In 1999, two major earthquakes, Golcuk (M_w=7.4) and Duzce (M_w=7.2), occurred in the near west of the Ismetpasa segment (see Fig. 2). These earthquakes were capable of changing the creep trend on this segment. Therefore, the geodetic network established on the Ismetpasa segment was observed one more time in 2002. Based on this observation campaign, the creep rate of the segment between 1992–2002 was obtained 0.7 cm/year (Kutoglu and Akcin, 2006). This result was also confirmed by the study of Cakir et al. (2005), using InSAR technique. Both studies showed that the creep trend of the segment had not been triggered by Golcuk (M_w=7.4) and Duzce (M_w=7.2) earthquakes. Whereupon, three different scenarios were delivered for the creep behavior of the segment: (1) if the fault creep started after the 1944 or 1951 earthquakes it might be transient (scenario 1) in time, (2) if the creep on the fault was already present and increased due to any of these earthquakes it might be now decreasing down to its pre-earthquake rate (scenario 2), and (3) as stated by Sylvester (1986) the long term rate of creep may vary before or after earthquakes along the creeping fault segment (scenario 3) (Kutoglu and Akcin, 2006). To understand which scenario would be valid, the Ismetpasa geodetic network was resurveyed in 2007 using GPS technique. This paper analyzes the results of this campaign.

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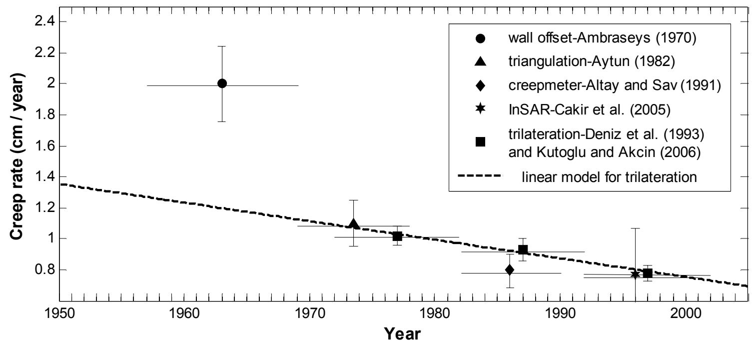

Fig. 1. Creep rates for the Ismetpasa segment obtained from different studies (adapted from Cakir et al., 2005). Horizontal bars represent the time window. Vertical bars shows the error ranges.

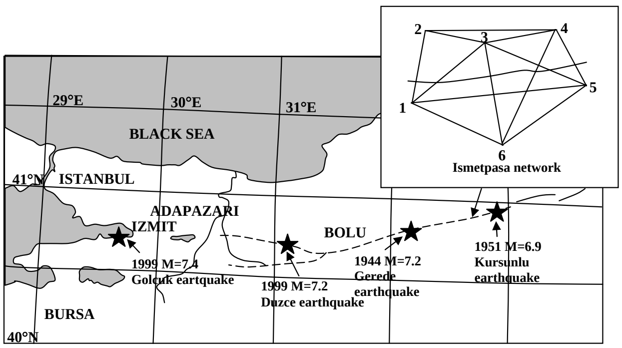

Fig. 2. Map of the NAF around the Marmara and the Northern Black Sea region (adapted from Deniz et al., 1993). The inset map shows the Ismetpasa geodetic network. As for the scale of the inset map, the distance between the points 1 and 5 represents 1.2 km in field. The dashed line is the trace of the NAF. The stars locate the major earthquakes that occurred in the last century.

2 Periodical observations of the Ismetpasa geodetic network

Ismetpasa geodetic network was originally designed as a micro-geodetic network with six points, three on Eurasian plate side and three on Anatolian plate side of the NAF, to monitor horizontal offsets across the Ismetpasa segment of the NAF (Fig. 2). The first observation of this network was carried out in 1972 using Electromagnetic Distance Measurement (EDM) technique. In the second campaign of 1982, the network was observed by Doppler technique. When the network was resurveyed in 1992 by EDM technique again the five points were available on the ground; the point 5 had been destroyed in the elapsed time between 1982 and 1992. In those campaigns, the observations were always slope distances between the network points. In accordance with the theory of deformation analysis, the observations of each campaign were adjusted by the same strategy; the approximate coordinates of the network points were referenced to a local coordinate system defined on Gauss-Krüger projection plane; before the adjustments, the slope distances were reduced onto Gauss-Krüger projection plane using the point heights gathered by altimeter; the reduced baselines were weighted by the function $p_i=1/s_i^2$ (p_i=weight of i^{th} observation, s_i=distance in kilometers), which is the most common function for the trilateration networks; the points on the Eurasian plate were used as the reference points during the adjustments with the aim of monitoring the relative offsets at the points on the Anatolian block to the Eurasian plate (Deniz et al., 1993).

Table 1. Slope distances from GPS campaign of 2007.

From_to	Slope distance in meters	Precision in milimeters
1_2	467.019	2.2
1_3	636.090	2.3
1_6	697.321	2.6
2_3	394.657	2.3
2_4	849.529	2.6
2_6	914.143	2.6
3_4	464.421	1.7
6_3	703.465	2.1
6_4	827.169	2.2

After the Golcuk and Duzce earthquakes, the network was observed one more time by Global Positioning System (GPS) technique to determine whether the creep rate of the segment had changed, or not. For the comparison of the GPS-derived results with the previous ones, the GPS observations had to be evaluated in the same strategy as applied for the previous periods. For that reason, the slope distances between the points were derived by preprocessing the GPS observations so that it was possible to conduct the adjustment with respect to the principle of the trilateration networks defined above.

The last campaign in 2007 was carried out by GPS technique again as it is done in 2002. Since the baselines are

Table 2. Local coordinates obtained from the periodical observations.

Points on the Eurasian plate						
	2		3		4	
Period	$y \pm m_y$ [m]±[mm]	$x \pm m_x$ [m]±[mm]	$y \pm m_y$ [m]±[mm]	$x \pm m_x$ [m]±[mm]	$y \pm m_y$ [m]±[mm]	$x \pm m_x$ [m]±[mm]
1972	1457.098±1	905.474±1	1568.853±2	1283.825±2	1825.609±1	1670.274±2
1982	1457.098±1	905.474±1	1568.852±2	1283.823±2	1825.605±1	1670.266±2
1992	1457.098±2	905.474±2	1568.854±3	1283.825±3	1825.609±3	1670.274±3
2002	1457.100±1	905.473±1	1568.850±1	1283.827±1	1825.610±1	1670.273±1
2007	1457.099±1	905.473±1	1568.852±1	1283.827±1	1825.609±1	1670.273±1

Points on the Anatolian block				
	1		6	
Period	$y \pm m_y$ [m]±[mm]	$x \pm m_x$ [m]±[mm]	$y \pm m_y$ [m]±[mm]	$x \pm m_x$ [m]±[mm]
1972	999.936±2	1000.007±3	999.937±2	1697.193±2
1982	999.870±4	999.926±4	999.879±3	1697.102±3
1992	999.811±3	999.858±4	999.821±3	1697.041±4
2002	999.763±1	999.804±3	999.778±2	1696.999±2
2007	999.735±1	999.750±2	999.738±2	1696.954±2

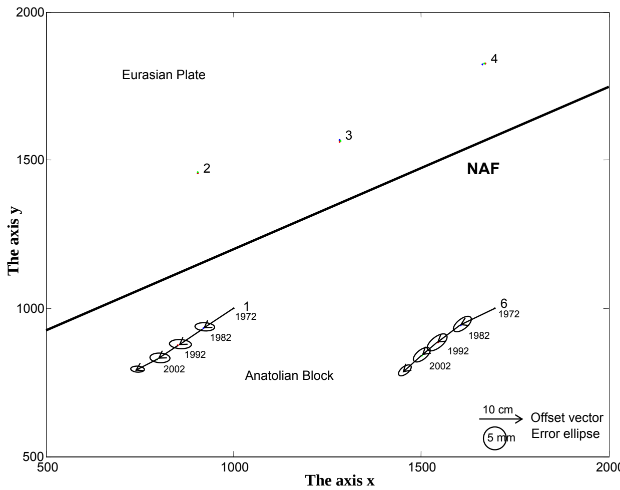

Fig. 3. Surface displacements at points 1 and 6 relative to Eurasian plate since 1972. The axes are plotted on the Gauss-Krüger projection plane. The arrows and ellipses are the offsets and the error ellipses of the offsets, respectively. Their scales are shown at the right lower corner. The solid line is the NAF.

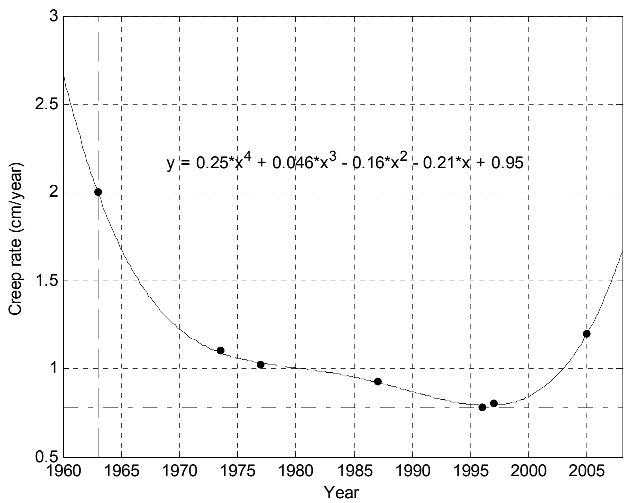

Fig. 4. Creep rates determined at Ismetpasa and their prediction. Creepmeter resolution in 1986 is not used for the prediction because it seems to be outlier in the creep history.

short, one hour site occupation in static mode of relative positioning was regarded adequate to obtain sufficient precision in order to monitor the offsets of five years. The baselines obtained in this way and their precisions are shown in Table 1. As seen from the table, the precisions ranging from 1.7 mm to 2.2 mm are considerably homogenous and adequate for the purposes of deformation monitoring. These baselines have been evaluated by the same way as done in the former observation periods. The coordinates obtained from this evaluation are displayed in Table 2 together with those determined in the previous periods. The accuracies of the coordinates achieved in the last determination vary between 1 mm and 4 mm. These values are quite accurate to compare the coordinates of 2007 with the previous ones.

Table 3. Offsets at the network points on the Anatolian Block.

Periods	Point No	$dy\pm m_{dy}$ [cm]	$dx\pm m_{dx}$ [cm]	$d=\sqrt{dy^2+dx^2}$ [cm]	d(cm/yr)	Average d (cm/yr)
1972–1982	1	−6.6±0.5	−8.1±0.5	10.4±0.5	1.04±0.16	1.06±0.11
	6	−5.8±0.4	−9.1±0.4	10.8±0.4	1.08±0.13	
1982–1992	1	−5.9±0.5	−6.8±0.6	9.0±0.6	0.90±0.19	0.87±0.13
	6	−5.8±0.4	−6.1±0.5	8.4±0.5	0.84±0.16	
1992-2002	1	−4.8±0.3	−5.4±0.5	7.2±0.4	0.72±0.13	0.67±0.11
	6	−4.3±0.4	−4.2±0.5	6.1±0.5	0.61±0.16	
2002-2007	1	−2.8±0.1	−5.3±0.4	6.0±0.4	1.2±0.13	1.20±0.08
	6	−4.0±0.3	−4.5±0.3	6.0±0.3	1.2±0.09	

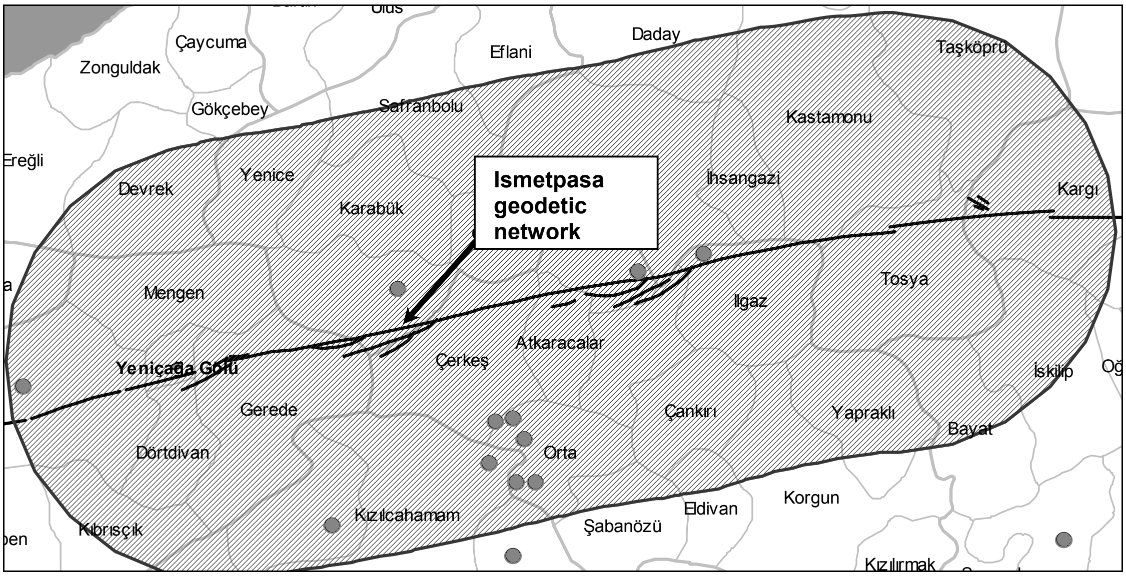

Fig. 5. Earthquakes with the magnitude of 4 and over occurred in the 50 km near zone of the Ismetpasa segment after 2002. The dashed area shows the 50 km zone. The solid circles are the earthquakes (adapted from Sayisal Grafik, 2008).

3 Conclusions

Based on the coordinates in Table 2, the points on the Anatolian block suffered significant offsets during each observation periods. The yearly rates of the offsets are 1.06±0.11 cm/year, 0.87±0.13 cm/year, 0.67±0.11 cm/year, 1.20±0.11 cm/year, respectively between 1972–1982, 1982–1992, 1992–2002, 2002–2007 (Table 3). There must be noted that the offsets had a steadily decreasing trend between the period of 1972–2002. That decrease in the rates was such that it could be approximated by a linear model at the level of %99 (see Fig. 1). However, the results from the last observation campaign show that this trend ceased during the period 2002–2007; according to this campaign, both points displaced 6.0 cm with the accuracies of ±0.4 cm for the point 1 and ±0.3 cm for the point 6 between 2002–2007. This means that the yearly rates during this period are 1.2 cm/year for each point with the accuracies of ±0.13 cm and 0.09 cm respectively. Those rates are two times bigger than the ones obtained from the previous period, and it is obvious that they are not consistent with the trend determined before (see Fig. 3 for the point offsets).

The creep rates of the Ismetpasa segment obtained from the studies between 1957–2007 are illustrated in Fig. 4. This process of the creep can be predicted by the 4th degree polynomials shown in the figure. Based on the last solution, the surface creep on the Ismetpasa segment has ceased its decreasing trend after fifty years and accelerated between 2002–2007. The yearly rate of 1.2 cm for the period of 2002–2007 is two times bigger than the one obtained from the previous period 1992–2002, and seems to have turned back at its levels of early 1970s.

After the 2002 observation campaign, eleven earthquakes of M_w>=4 have been occurred within the 50 km near zone of the Ismetpasa segment (Fig. 5). As seen from Fig. 5 the four of these earthquakes happened within a few kilometers zone across the fault. It is considered that the increase in the creep rate could be triggered by these earthquakes. Whether these earthquakes triggered or not, it is the fact that the creep rate dramatically increased after 2002. Under this circumstance, the scenario 1 and 2, stated for the segment in Introduction, are invalidated while the scenario 3 remains only to explain the behavior of the changing in the creep rate. As it is explained above the scenario 3 expresses that the long term rate of the creep may be varying before an earthquake along the creeping fault segment. According to this scenario, the Ismetpasa segment of the NAF is under a risk of earthquake. The fact that the segment has not been experienced any earthquake since 1951 Kursunlu event also reinforce this argument.

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