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Relaxation on the Ismetpasa segment of the North Anatolian Fault after the Golcuk $M_w = 7.4$ and Duzce $M_w = 7.2$ shocks

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Abstract. The Ismetpasa segment of the North Anatolian Fault (NAF) is a rare place where aseismic fault slip (creep) has been observed. Its creep behaviour has been monitored using different observation methods since the 1950s. The findings obtained from the studies until 1990s showed that the creep rate exponentially decreased before the major shocks in 1999, Golcuk ($M_w = 7.4$) and Duzce ($M_w = 7.2$). After these shocks, three GPS periods observation in 2002, 2007 and 2008 were carried out on the geodetic network established around the segment. The evaluations of these observations showed that the creep behaviour relaxed after the major earthquakes. This result demonstrates that the creep behaviour of the Ismetpasa segment might be a warning before future major earthquakes.

1 Introduction

The North Anatolian Fault, which runs from the border with Iran to the Marmara Sea, a length of about 1200 km, is one of the most active strike-slip faults (2.2 cm/year slip rate; McClusky et al., 2000) in the world; it has experienced 11 major earthquakes ($M_w > 6.7$) since 1939 (Stein et al., 1997) (Fig. 1). Two of these earthquakes occurred in the Ismetpasa segment, located 350 km east of Istanbul and 100 km north of Ankara (Fig. 2). These were the 1944 $M_w = 7.2$ Gerede and the 1951 $M_w = 6.9$ Kursunlu Earthquakes, which occurred in the western and the eastern tails of the segment, respectively (KOERI, 2004).

The Ismetpasa segment is a rare place where a seismic fault slip (creep) has been observed. Its creep behaviour was first discovered on the wall of the train station in the town of Ismetpasa. After this discovery, the Ismetpasa segment became the centre of interest; and many studies using different surveying techniques were carried out to determine its creep rate at different time periods (Altay and Sav, 1991; Ambraseys, 1970; Aytun, 1982; Cakir et al., 2005; Kutoglu and Akcin, 2006). A detailed discussion of these studies will be given in Sect. 2.

The studies prior to the early 1990s showed that the creep rate was decreasing exponentially over time. In Kutoglu and Akcin (2006), three different scenarios were suggested for the creep behaviour of the segment; these were (1) if the fault creep started after the 1944 or 1951 Earthquakes it might be transient in time (scenario 1), (2) if the creep on the fault was already present and increased due to any of these earthquakes it might now be decreasing to its pre-earthquake rate (scenario 2), and (3) as stated in Sylvester (1986) "the long-term rate of creep may vary before or after earthquakes along the creeping fault segment" (scenario 3).

In 2007, the possibility that the creep rate was increasing to levels similar to those in the 1970s was explored. In Kutoglu et al. (2008), this new situation was interpreted as "the long-term rate of the creep may be varying before an earthquake along the creeping fault segment". The latest observations in 2008 demonstrate this possibility, which claims the creep rate accelerated. Furthermore, the 2008 observations make a further interpretation for the creep behaviour of the Ismetpasa segment.

2 Historical observations on the Ismetpasa segment

The first observations to determine the Ismetpasa creep rate were initiated on the wall of the train station (Ambraseys, 1970). These measurements yielded an average creep rate of 2 ± 0.6 cm/year between 1957 and 1969, which is compatible with the overall NAF slip rate of 2.2 cm/year. Following this, two separate geodetic networks were established on the segment in the years of 1969 and 1971, respectively.

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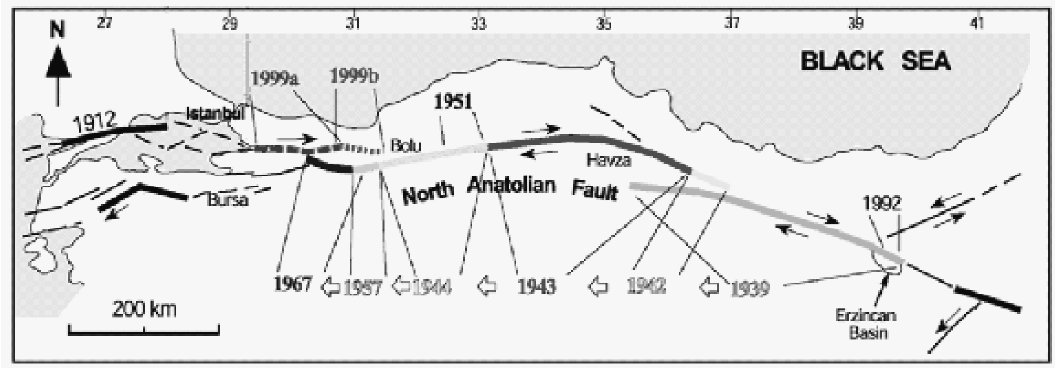

Fig. 1. Major earthquakes experienced on the NAF (adapted from Stein et al., 1997). In the figure, the rupture 1944 identifies the Ismetpasa segment.

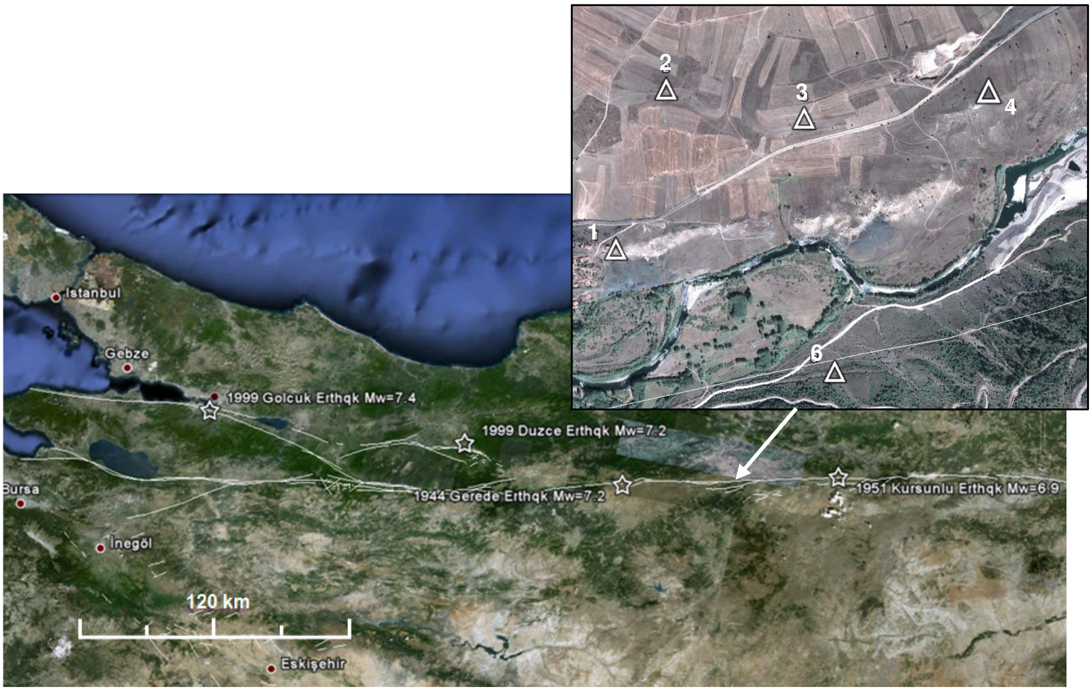

Fig. 2. Ismetpasa location and Ismetpasa geodetic network. The solid white lines are the segments of the NAF. The stars locate the major earthquakes that occurred in the last century (The satellite image obtained from Google Earth).

The first network, observed using triangulation techniques between 1969 and 1978, resulted in an average slip rate of 1.1 ± 0.4 cm/year (Aytun, 1982). The second network (Fig. 2) observed using trilateration techniques in the years of 1972, 1973, 1982 and 1992 (Ugur, 1974; Deniz et al., 1993). Comparisons of the observation pairs gave significant displacement rates, 1.0 ± 0.1 cm/year and 0.9 ± 0.1 cm/year, respectively, for the periods of 1972–1982 and 1982–1992.

In 1999, two major earthquakes, Golcuk $M_\mathrm{w} = 7.4$ and Duzce $M_\mathrm{w} = 7.2$, occurred in the Marmara Region. Detailed studies on coseismic and postseismic deformations of these earthquakes were carried out by Barka (1999), Reilinger et al. (2000), Cakir et al. (2003) and Ergintav et al. (2009). These studies showed that the deformation effects of both the earthquakes extended 230 km from Golcuk; however, the deformation did not reach the Ismetpasa segment, which is 90 km away from Duzce (see Figs. 1 and 2). After these earthquakes, the 1971 network was resurveyed a further times in 2002 and 2007 using GPS techniques, and the creep rates of 0.7 ± 0.1 cm/year and 1.2 ± 0.1 cm/year were obtained, respectively, for the periods of 1992–2002 and 2002–2007 (Kutoglu and Akcin, 2006; Kutoglu et al., 2008). Meanwhile, an InSAR study by Cakir et al. (2005), covering a time period of 1992–2000, arrived at a creep rate of 0.8 ± 0.3 cm/year.

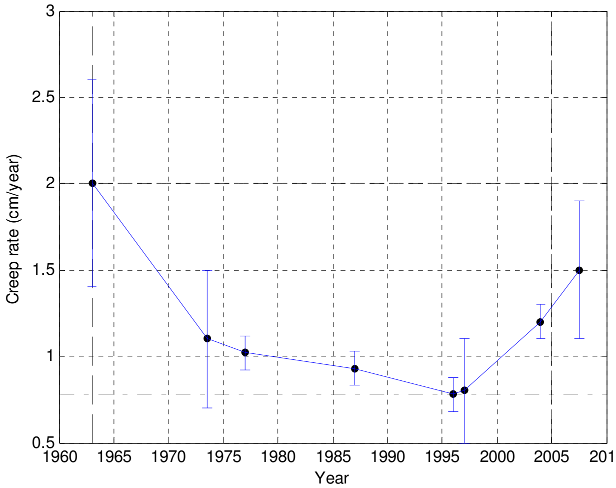

Fig. 3. Average creep rates determined at Ismetpasa. The blue vertical lines at data points are error bars.

3 2007–2008 creep rate from GPS observations of the 1971 network

The aim of the 2007 GPS campaign was to monitor the site displacements of the 1971 geodetic network from the 2002 observations. A global network connection was not intended due to a lack of financial support. Therefore, one hour site occupations in static mode of relative positioning were regarded adequate for the observation of the network baselines having a maximum length <914 m. The GPS observations were processed by Leica Geo Office Software, where the pre-adjustment baselines have internal precision estimates of between 1.7 mm to 2.6 mm (Table 1).

In 2008, a new GPS campaign was planned for the segment. The observations were carried out also by using static mode of relative positioning methods, but this time the sites were occupied for eight hours a day over four days. The reason for the longer occupations is to make a global network connection in order to obtain absolute displacements at the network points for future creep analysis. As seen from Table 1, the baseline precision estimates vary between 1.9 mm and 2.1 mm, and are comparable with the ones measured in 2007.

The baseline vectors obtained from both the periods were adjusted using a minimum constraint adjustment. The three points (points 2, 3 and 4) of the network are located on the Eurasian plate, one point (point 1) is very close to the fault line and one point (point 6) is on the Anatolian block. Given that the aim was to monitor displacements on the Eurasian plate, which included the majority of the network points, point 6 (located on the Anatolian block), was held fixed. Any other (object) point was given a different name (point number) corresponding to each observation epoch. Hence, two separate coordinate sets for each point were estimated for the two observation periods. Thus, there is a total of eight station positions estimated in the adjustment, resulted in residuals ranging between 0.05 mm – 6.53 mm. The accuracies for the estimated coordinates varied between 2 mm – 4 mm. The other details of the adjustment can be seen in Table 2.

Table 1. Baselines measured in 2007 and 2008.

From_to	Slope distance (m)	
	2007	2008
1_2	467.019 ± 2.2	467.013 ± 2.1
1_3	636.090 ± 2.3	636.097 ± 2.0
1_6	697.321 ± 2.6	697.303 ± 2.1
2_3	394.657 ± 2.3	394.656 ± 2.1
2_4	849.529 ± 2.6	849.527 ± 1.9
2_6	914.143 ± 2.6	914.135 ± 2.0
3_4	464.421 ± 1.7	464.421 ± 2.1
6_3	703.465 ± 2.1	703.456 ± 2.0
6_4	827.169 ± 2.2	827.172 ± 2.1

Table 2. Adjustment summary.

Adjustment type	Minimum constraint
Reference point	Number 6
Number of object points	8
Number of unknowns	24
Number of measurements	60
Degree of freedom	36
Apriori standard deviation(m_o)	1
Aposteriori standard deviation (s_o)	1.064
Model test $F = s_o^2/m_o^2 < T_{r,f,0.95}$	1.13 < 2.97 model valid

Comparisons of the two separate coordinate sets for the object points obtained for the periods 2007 and 2008 yields deformation components from −0.34 cm to −1.05 cm in the northern direction which represents a contraction of the network towards the Anatolian Block. The eastern component varies between 1.07 cm and 1.57 cm, which is consistent with the motion of the NAF. The total (horizontal) displacement rate is between 1.29 ± 0.88 cm and 1.65 ± 0.78 cm towards the SE (Table 3).

The surface creep rate of the Ismetpasa segment from the geodetic network is calculated as 1.51 ± 0.41 cm/year based on the average of the total displacement rates. This result shows that the increase in the creep rate is still remaining after the period of 2002–2007.

Figure 3 shows how the Ismetpasa creep rate has changed since the first determination made over in the period 1957–1969. The creep rate trend is decreasing before the 1999 earthquakes. The two separate studies by Cakir et al. (2005) and Kutoglu and Akcin (2006) consistently demonstrated

Table 3. Horizontal components of the estimated coordinates and displacements.

Point No_Year	Latitude (° ′ ″)	Longitude (° ′ ″)	Displacement rate (cm)		
			North	East	Total
1_2007 1_2008	40 52 15.29875 ± 2 mm 40 52 15.29841 ± 1 mm	32 39 6.81234 ± 2 mm 32 39 6.81280 ± 1 mm	−1.05	1.07	1.29 ± 0.88
2_2007 2_2008	40 52 29.71614 ± 2 mm 40 52 29.71597 ± 1 mm	32 39 12.88205 ± 2 mm 32 39 12.88272 ± 1 mm	−0.53	1.57	1.60 ± 0.79
3_2007 3_2008	40 52 26.85792 ± 2 mm 40 52 26.85772 ± 1 mm	32 39 29.30162 ± 2 mm 32 39 29.30225 ± 1 mm	−0.62	1.47	1.65 ± 0.78
4_2007 4_2008	40 52 27.96585 ± 2 mm 40 52 27.96574 ± 1 mm	32 39 49.05934 ± 2 mm 32 39 49.05987 ± 1 mm	−0.34	1.24	1.51 ± 0.81

that the creep rate reached a lower limit during the periods 1992–2000 and 1992–2002. The creep rates obtained from these studies correspond to the epochs of 1996.0 and 1997.0 before the major earthquakes. After that, an acceleration was reported for the epoch 2004.5 in Kutoglu et al. (2008). Lastly, this study has demonstrated an increasing level of creep continuing in epoch 2007.5.

4 Conclusions

As a result of this latest study, it has been shown that the Ismetpasa creep rate decreased to its lowest rate prior to the 1999 earthquake events (Fig. 3). Following the 1999 earthquakes, the rate has increased significantly. In this respect, it can be said that the interpretation by Kutoglu et al. (2008) is incomplete. According to the results obtained, the most valid scenario for the Ismetpasa creep is the scenario 3. This means the creep rate decreased over the thirty years before the earthquake, and then increased after the earthquake.

The 1999 Golcuk ($M_\mathrm{w} = 7.4$) and Duzce ($M_\mathrm{w} = 7.2$) shocks were the most destructive earthquakes produced by the NAF; they deeply affected human life in Turkey. Presently, more than 20 million people who live around Marmara Region in the western part of Turkey are terrified of the possibility of further major earthquakes $<7\ M_\mathrm{w}$. The analyses in this study imply the Ismetpasa segment gave us the signals of the Golcuk and Duzce earthquakes since thirty years, but could not be interpreted before the destructions.

Unfortunately, we do not know how the segment behaved before the 1944 Gerede and 1951 Kursunlu events. If it exhibited a similar behaviour as shown in Fig. 3, the Ismetpasa segment might be the stress indicator for the possible earthquakes in the western part of the NAF. If so, the Ismetpasa segment of the NAF can be utilized as an early warning before an earthquake in the western section of the NAF.

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