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Monitoring of micro-deformations along Idrija and Raša faults in W Slovenia

Opazovanje mikro-deformacij ob Idrijskem in Raškem prelomu v zahodni Sloveniji

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Ključne besede: tektonski premiki, aktivna tektonika, monitoring, Dinarski prelomni sistem, Idrijski prelom, Raški prelom, Slovenija

Abstract

Monitoring of tectonic movements along two active faults of Dinaric (NW-SE trending) fault system in W Slovenia using TM 71 extensiometers was set up in 2004. After two years ob measurements some clear trends of displacement were developed. The average left-lateral displacement along a crack in the inner fault zone of the Idrija fault in Učja valley is 0.38 mm/year. Short term (10 months) rates were even greater and reached the value of 0.54 mm/year. Since the Idrija fault is considered as dextral strike-slip, is the observed left-lateral displacement explained by local permutation of principle stress axis. In the Raša fault monitoring site at the foot of Vremščica Mt. at Košana the average reverse uplift of hanging wall (SW) block of 0.24 mm/years and left-lateral displacement of 0.16 mm/year were established. Short term (9 months) vertical displacements reached the value of 0.53 mm/year. The oblique sense of displacement is in agreement with geological and seismological observations. Since there were no stronger earthquakes in the vicinity and time span of monitoring, no correlations were established with seismic activity. The observed displacement rates along monitored faults of up to 0.5 mm/year are consistent with the regional deformation rate in W Slovenia established from GPS measurements which is of the order of 2 mm/year.

Izvleček

V letu 2004 smo v zahodni Sloveniji pričeli z opazovanjem tektonskih premikov ob dveh aktivnih prelomih Dinarskega prelomnega sistema z mehanskimi ekstenziometri TM 71. V dveh letih opazovanja so se razvili jasno izraženi premiki, ki omogočajo prvo interpretacijo. Na razpoki v notranji coni Idrijskega preloma v dolini Učje smo izmerili levo horizontalno zmikanje s povprečno hitrostjo 0,38 mm/leto. Hitrost premikov v krajšem obdobju (10 mesecev) je celo večja in doseže 0,54 mm/leto. Ker je Idrijski prelom sicer desno-zmičen, pojasnjujemo opazovan levi zmik z lokalno permutacijo glavne napetostne osi. Na razpoki v coni Raškega preloma v vznožju Vremščice pri Košani smo izmerili reverzno dvigovanje krovninskega bloka (SW) s povprečno hitrostjo 0,24 mm/leto in levo horizontalno zmikanje s hitrostjo 0,16 mm/leto. Hitrost vertikalnih premikov v krajšem obdobju (9 mesecev) doseže 0,53 mm/leto. Opazovan poševni zmik se ujema z geološkimi in seizmološkimi podatki. V obdobju meritev nismo ugotovili nobene korelacije med premiki in potresno aktivnostjo, vendar v bližini opazovanih prelomov v tem času tudi ni bilo močnejših potresov. Opazovane hitrosti premikov ob obeh prelomih, ki so do 0,5 mm/leto, so pričakovane glede na regionalno stopnjo deformacij, ugotovljeno z GPS meritvami, ki je reda velikosti 2 mm/leto.

Introduction

Within the COST 625 action (Stemberk et al., 2003) we set up deformation monitoring of three active faults in W Slovenia using five TM 71 extensiometers. In the first half of 2004 two TM 71 instruments were installed in Postojna cave system on the Dinaric oriented (NW–SE) fault that is situated about 1 km north from Predjama fault (Šebela et al., 2005). The third and fourth instruments were installed in November 2004 on Raša fault at the SE foot of Vremščica Mt. and on Idrija fault in Učja valley (Fig. 1). The fifth instrument TM 71 was set up in 2006 on Kneža fault which is located between Idrija and Ravne fault. After two years ob measurements some clear trends of displacement were developed.

Tectonics of W Slovenia

Slovenia is situated at the NE part the Adria microplate, whose northern margin (Southern Alps-Dinarides) is highly deformed and backthrusted onto the central, less deformed part of the Adria microplate (Poljak et al., 2000). Collision of European and African plates results in predominantly N–S oriented recent principal stress direction in the region of Slovenia. This resulted in a system of conjugate strike-slip faults. In W Slovenia a right-lateral NW–SE oriented

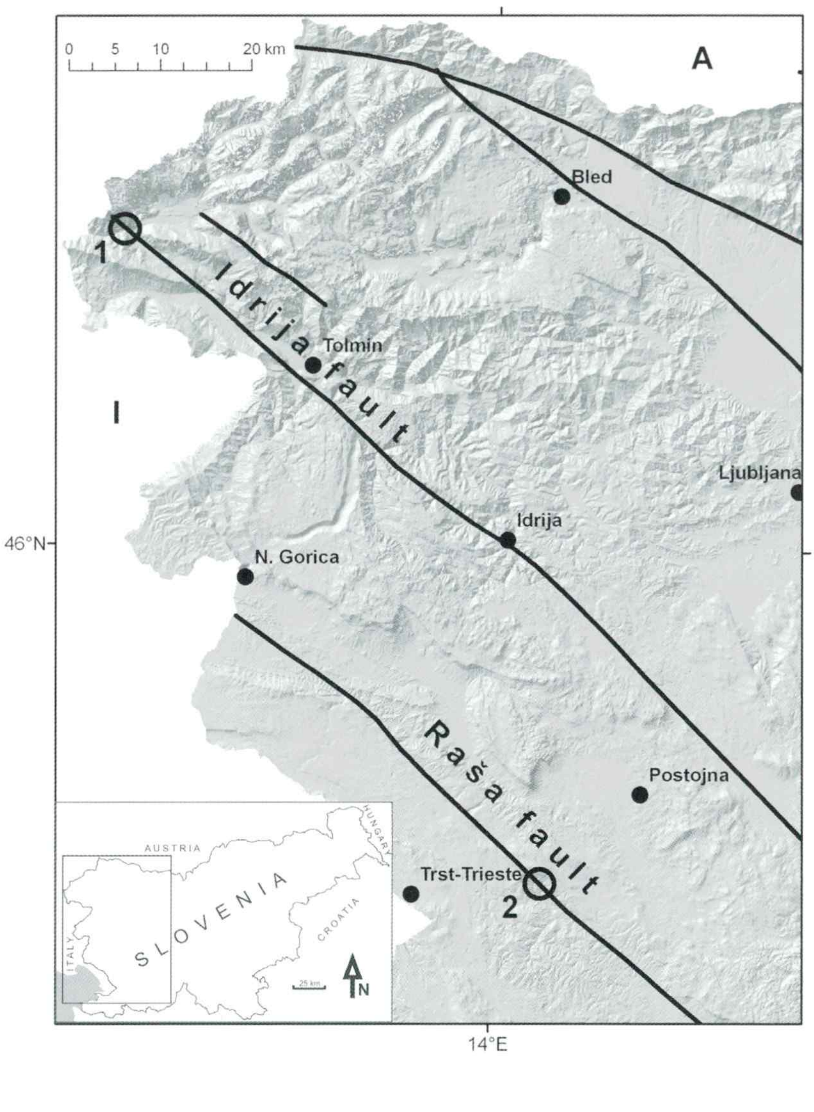

Figure 1. Micro-deformation monitoring sites equipped with TM 71 extensiometers on Idrija fault in Učja valley (1) and on Raša fault at the foot of Vremščica Mountain (2).

Slika 1. Lokacije opazovanj mikro-deformacij s TM 71 ekstenziometri na Idrijskem prelomu v dolini Učje (1) in na Raškem prelomu v vznožju Vremščice (2).

strike-slip faults prevail and in E Slovenia a left-lateral NE–SW oriented strike-slip faults. In addition there are several W–E oriented reverse faults and north verging thrusts.

Adria's major aseismic outcrop is the Istria peninsula. In northern Slovenia we observe a significant and sharp (few mm/year) dextral (and transpressive) gradient in GPS velocities along the Sava fault and Periadriatic zone, suggesting that lateral extrusion in the NE Alps is still active and being driven by the CCW rotation of Adria (Weber et al., 2006). In External Dinarides GPS observations showed N- to NNE-directed movements in the range from 0.5 to 2 mm/year (Vrabec et al., 2006).

The basic structural characteristic of the External Dinarides is a dense pattern of faults in a NW–SE direction, in addition to the thrusts with the south-westward direction of thrusting (Placer, 1981). In External Dinarides strike-slip and transpression displacement along NW–SE trending faults is present.

Seismicity of W Slovenia

The territory of Slovenia can be considered as one of moderate seismicity. No surface rupture related to an earthquake has been detected so far in Slovenia. In External Dinarides we find moderate historical and recent seismicity (Fig. 2). Data from the

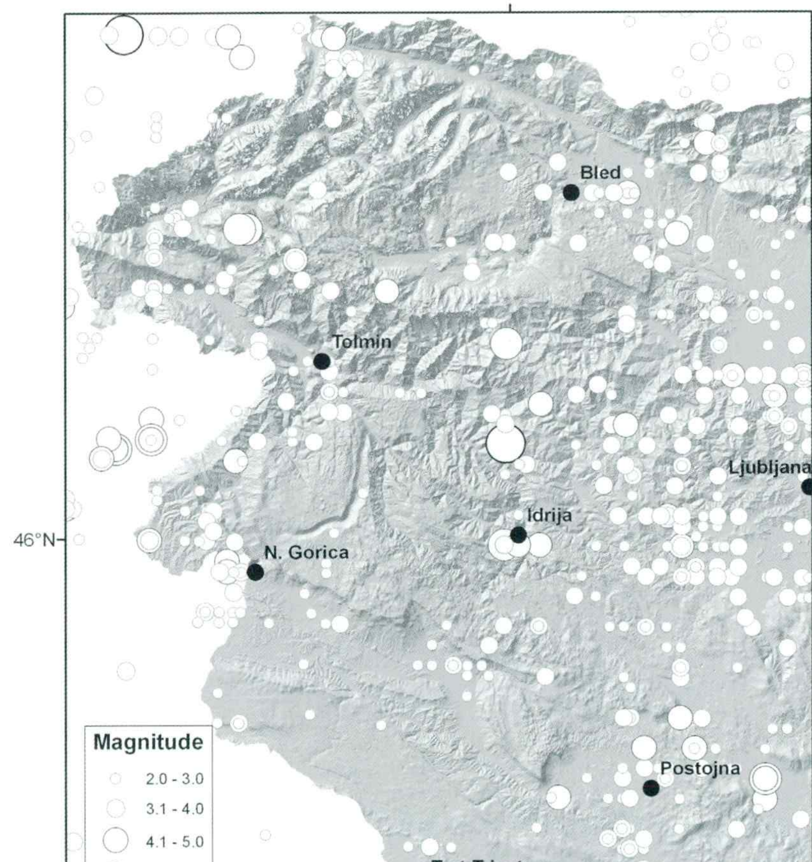

Figure 2. Seismicity map of Western Slovenia (EARS catalogue for the years 567–2004).

Slika 2. Karta seizmičnosti zahodne Slovenije (katalog ARSO za obdobje 567–2004).

last 20 years show that most earthquakes in SW Slovenia are situated along Raša and Idrija faults, delineated in NW–SE direction (Michelini et al., 1998). Focal mechanisms for the most earthquakes indicate right-lateral or reverse faults (Poljak et al., 2000). The strongest earthquake ever recorded in the Alps-Dinarides junction was the 1511 western Slovenia earthquake (M = 6.8). The exact location and mechanism of this event are still debated (Fitzko et al., 2005).

Although strike-slip and thrust-type dominate, there are also a few earthquakes with normal-type faulting. From the fault plane solutions it is evident that the governing stress in the region runs approximately in a N–S direction (Poljak et al., 2000).

The region of NW Slovenia undergoes a recent increase in seismic activity with two damaging earthquakes in the Upper Soča valley. The 12 April 1998 (Mw = 5.6) and 12 July 2004 (Mw = 5.2) earthquakes occurred on the NW–SE trending near-vertical Ravne fault in the Krn mountains at 7–9 km depth (Zupančič et al., 2001). The focal mechanisms of both earthquakes show almost pure dextral strike-slip.

Monitoring of micro-deformations with TM 71 extensiometers

Within the COST 625 action five locations for TM 71 measurements of active faults in Slovenia were selected. Monitoring started in Postojna cave system on February 2004 (Šebela et al., 2005). In November 2004 two TM 71 instruments were installed on Idrija fault (Učja) and on the Raša fault (Vremščica) (Fig. 1). The fifth instrument in Slovenia was installed on Kneža fault in November 2006 (Gosar et al., 2007).

TM 71 extensiometer

TM 71 is a mechanical extensiometer (Fig. 3) designed for installation on a narrow cracks (crack gauge) to monitor relative micro-displacements between both walls of the crack. It works on the principle of mechanical interference (Moire effect), and displacements are recorded by interference patterns of two optical grids (Košt'ák, 1991). The instrument provides three-dimensional results – displacement vector in two perpendicular planes (horizontal and vertical) and angular deviations (rotation). The sensitivity of the system is: 0.05–0.0125 mm in all three space co-ordinates, and 3.2 10^{-4} in angular deviations (Stemberk et al., 2003). The main advantages of this purely mechanical instrument are: it completely avoids the use of electrical transmission means, it furnishes good performances under severe outdoor conditions and has a long-term stability. TM 71 instrument was developed at the Institute of rocks structures and mechanics of the Czech academy of science (Košt'ák, 1991).

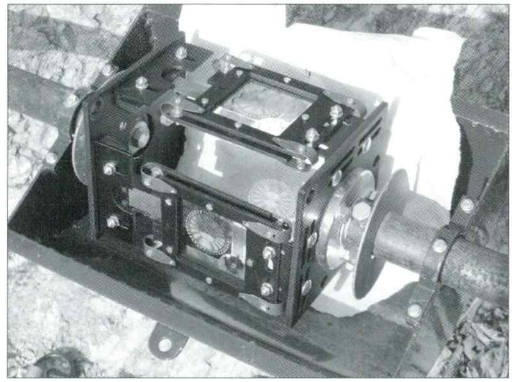

Figure 3. TM 71 instrument for monitoring micro-displacements in three-directions.

Slika 3. Inštrument TM 71 za meritve mikro-premikov v treh smereh.

Idrija fault

The best morphologically expressed fault in the region of W Slovenia is the Idrija fault, which is clearly visible in topography and in aerial or satellite images. It extends from the Italian border near Bovec to the Croatia in Gorski Kotar (N of Rijeka), having a total length of more than 120 km (Fig. 1). The strongest historical earthquake in the region, the »Idrija« earthquake in 1511 with estimated magnitude of 6.8 and max. intensity X (Fig. 2), is usually related to this fault (Ribarič, 1979), but its exact location and relation to the faults in the region is still not clear (Fitzko et al., 2005). The second strongest known event with magnitude 5.6 happened in 1926 at the SE end of the Idrija fault. However, recent seismicity in the vicinity of this fault is rather low (Poljak et al., 2000).

No terrestrial geodetic measurements of tectonic movements along Idrija fault were performed so far. In 1977 they established the geodetic network across the fault in Kanomljica valley near Idrija and performed the first measurements, but later the measurements were never repeated (Kogoj, 1997).

In November 2004 we installed the TM 71 device in the NW part of Idrija fault, where good exposure of the main fault zone was found in the Učja valley near Bovec. The whole fault zone is here more than 1 km wide and was divided in outer and inner fault zone by Čar & Pišljar (1993). The TM-71 instrument is installed on a prominent crack in the central part of the inner fault zone (Figs. 4 and 5) which cut 50 m high wall of a canyon.

In first 10 months of measurements a clear trend of horizontal displacements y = + 0.54 mm/year was developed (Fig. 6). It was followed by an outlying measurement at the beginning of 2006. It was most

Figure 4. Left: the crack in the inner zone of the Idrija fault in the Učja valley. The arrow shows the location of TM 71 instrument. Right: The exposure of the fault plane 50 m from the crack shown in the left figure with clear striations indicating subhorizontal movements.

Slika 4. Levo: razpoka v notranji prelomni coni Idrijskega preloma v dolini Učje. Puščica kaže lokacijo inštrumenta TM 71. Desno: izdanek prelomne ploskve 50 m stran od razpoke na levi sliki z izrazitimi drsami, ki kažejo na subhorizontalne premike.

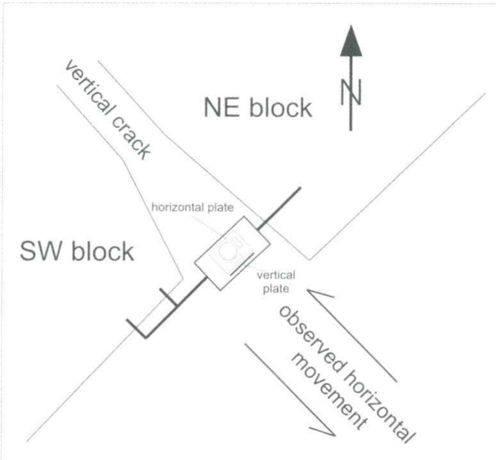

Figure 5. The sketch of TM 71 instalation on the crack in the Idrija fault zone with indication of observed displacement.

Slika 5. Skica namestitve TM 71 na razpoki v Idrijski prelomni coni z označenim ugotovljenim premikom.

probably caused by a mechanical impact on the instrument (fallen rock or ice), because later the same trend continued. The average displacement rate for the first two years of measurements is + 0.38 mm/year. In the same period no clear trend in angular deviation was developed in both planes. Relative movement between blocks shows left-lateral horizontal displacement (Fig. 5). This is unexpected result, because Idrija fault is considered as a dextral strike slip fault (Čar & Pišljar, 1993). There are clear geological evidences of dextral displacement for the geological history (Placer, 1982), but for recent times no direct proofs are available. Therefore the dextral strike slip movement was mainly inferred from the orientation of principal stress axis, which has N–S direction and from the fault plane solutions of two stronger earthquakes that occurred on parallel Ravne fault. Observed left-lateral displacement should be therefore explained by local permutation of stress direction inside very complex fault zone (Kavčič, 2006).

In any case longer observations and detailed tectonic mapping of complex Idrija fault cross-section in the Učja valley are necessary to understand the relations between different cracks observed in outer and inner fault zone. X-axis (opening or closing the crack) shows clear seasonal effects, which are in good corre-

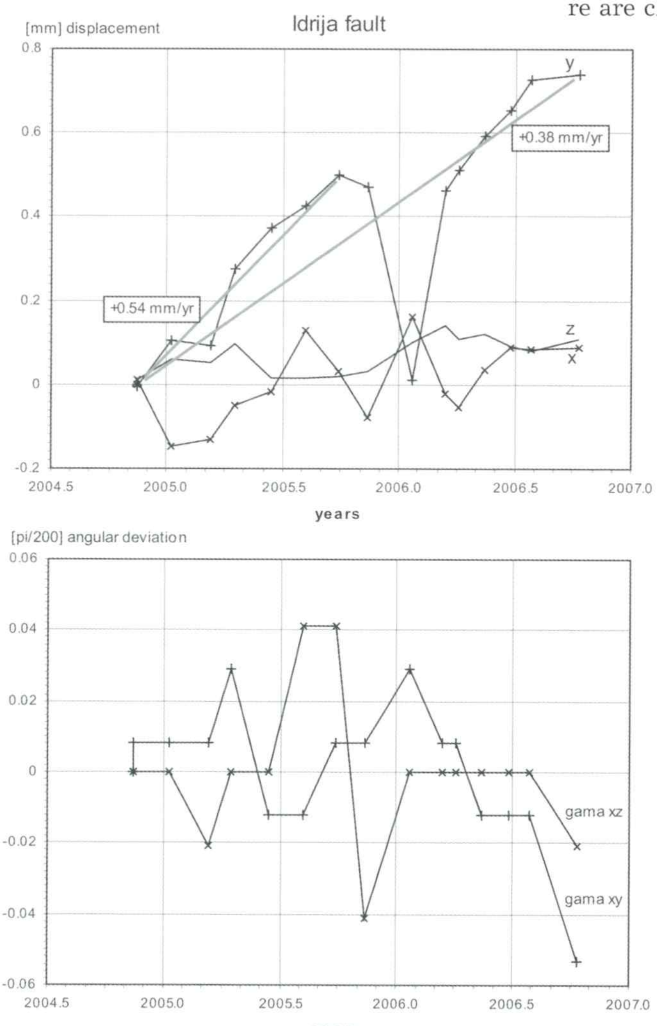

Figure 6. Displacements and angular deviations recorded with TM 71 at the monitoring site Učja on the Idrija fault. +x represents closing of crack, +y horizontal left-lateral slip, +z downslope slip of SW block.

Slika 6. Premiki in kotne deformacije izmerjeni s TM 71 na lokaciji opazovanja Učja na Idrijskem prelomu. +x predstavlja stiskanje razpoke, +y levo horizontalno zmikanje, +z spuščanje SW bloka.

lation with recorded temperatures. On the other hand no trend was developed yet on z-axes.

Raša fault

The second important fault located approximately 25 km SW from the Idrija fault is the Raša fault (Placer, 1981), which can be clearly traced in a length of 50 km from Anhovo (N of Nova Gorica) in the Soča valley to the Snežnik thrust at Ilirska Bistrica (Fig. 1). Main features related to this fault are: almost straight valley of the Raša river between Kobdilj and Štorje and its clear expression in topography around Vremščica Mountain. A cross-section of this fault is well exposed near Senožeče where the highway crosses the fault trace. Otherwise there are only few good exposures of the fault. The seismicity in the vicinity of the Raša fault is concentrated mainly in the Snežnik Mt. area at its SE termination (Fig. 2). Hypocenters of the earthquakes in this area define a steeply NE dipping fault plane (Michelini et al., 1998).

We explored the whole trace of the Raša fault to find a suitable location for installation of TM 71 extensiometer. In spite of its clear expression in the topography we recognized that there are very few good exposures. The best location was found at the foot of Vremščica Mt., on its SE side, near Košana (Fig. 7). There are two abandoned quarries in the Upper Cretaceous limestone situated exactly at the fault trace. There is a plan to put the upper quarry again in operation, but the lower one is abandoned for more than 15 years and will remain closed. Therefore, it provides a suitable place for crack gauge measurements. The contact between Upper Cretaceous limestone to the NE and Palaeocene Kozina limestone to the SE (Buser et al., 1967) is exposed in this quarry, separated by the main fault zone, which is approximately 10 m wide. Therefore, it was not possible to install the instrument in the main fault plane, but we selected a parallel crack (Figs. 7 and 8) in the exposed wall of the quarry built of Cretaceous limestone. The measurements started in November 2004.

In two years of observations the average reverse uplift of hanging wall (SW) block

Figure 7. The quarry at the foot of Vremščica Mt. near Košana on Raša fault zone with location of TM 71 instrument.

Slika 7. Kamnolom v vznožju Vremščice pri Košani v coni Raškega preloma z lokacijo inštrumenta TM 71.

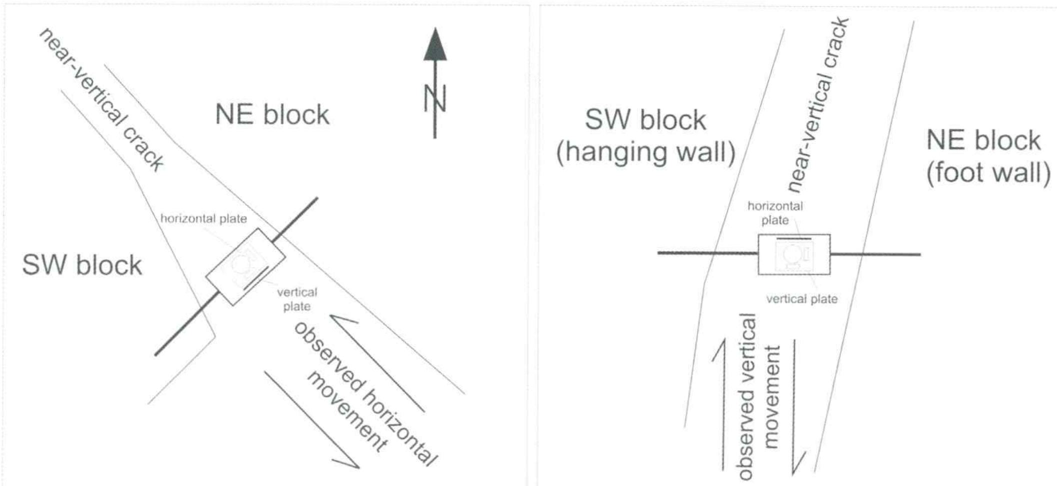

Figure 8. The sketch of TM 71 instalation on the crack in the Raša fault zone with indication of observed displacement. Horizontal plane (left) and vertical plane (right).

Slika 8. Skica namestitve TM 71 na razpoki v Raški prelomni coni z označenim ugotovljenim premikom. Vodoravna ravnina (desno) in navpična ravnina (desno).

of – 0.24 mm/years and left-lateral displacement of + 0.16 mm/year were established (Figs. 8 and 9). Short term vertical displacements reached the value of – 0.53 mm/year (Fig. 9). The oblique sense of displacement is in agreement with geological and seismological observations. Focal mechanisms of some stronger earthquakes in the active zone of Snežnik Mt., SE of the monitoring site, indicate strike slip and reverse character. X-axis (opening or closing the crack) shows clear seasonal effects, which are in good correlation with recorded temperatures. No trend in angular deviation was developed in both planes so far.

Conclusions

The observed displacement rates of up to 0.5 mm/year at both monitored active faults are consistent with the regional GPS deformation rate in W Slovenia established from GPS measurements which is of the order of 2 mm/year (Vrabec et al., 2006). Since there were no stronger earthquakes in the vicinity and time span of monitoring, no correlations were established with seismic activity.

In addition to described monitoring sites in W Slovenia another one was set up in November 2006 at Kneža fault near Tolmin (Zadlaz-Čadrg).

Acknowledgments

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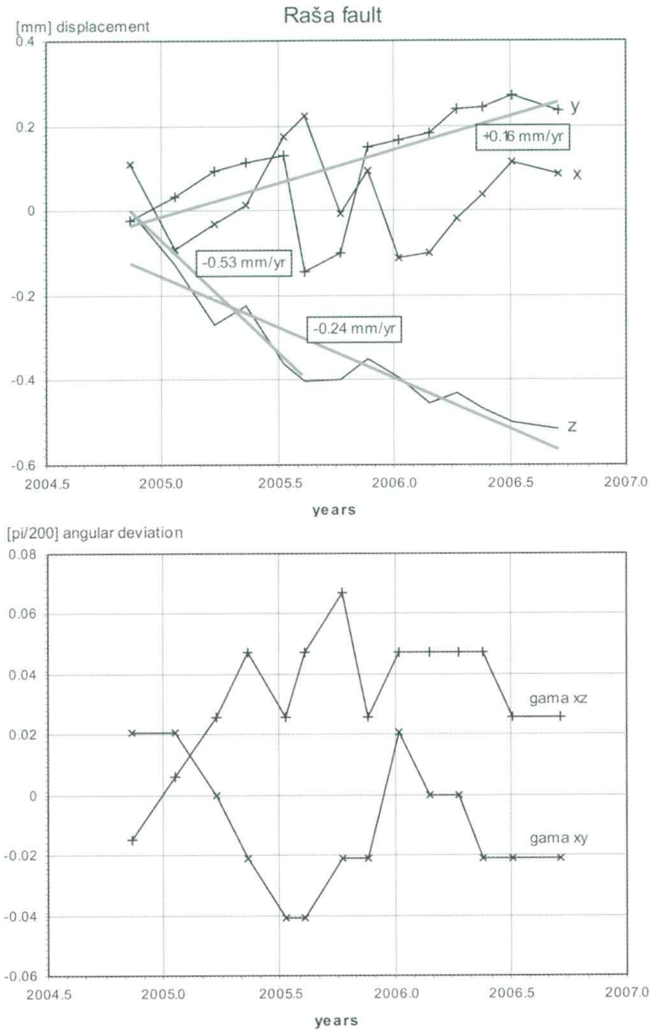

Figure 9. Displacements and angular deviations recorded with TM 71 at the monitoring site Vremščica on the Raša fault. +x represents closing of crack, +y horizontal left-lateral slip, +z downslope slip of SW block.

Slika 9. Premiki in kotne deformacije izmerjeni s TM 71 na lokaciji Vremščica na Raškem prelomu. +x predstavlja stiskanje razpoke, +y levo horizontalno zmikanje, +z spuščanje SW bloka.

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