STATISTICAL EVALUATION OF THE 3D MONITORING OF DISPLACEMENTS OF DINARIC FAULT ZONE IN POSTOJNA CAVE, SLOVENIA

Stanka ŠEBELA [1)]*, Janez TURK [1)], Janez MULEC [1)], Blahoslav KOŠŤÁK [2)] and Josef STEMBERK [2)]

[1)] *Karst Research Institute SRC SASA, Titov trg 2, 6230 Postojna, Slovenia*
[2)] *Institute of Rock Structure and Mechanics, Academy of Sciences of the Czech Republic, v.v.i., V Holešovičkách 41, 182 09 Prague, Czech Republic*
**Corresponding author's e-mail:* sebela@zrc-sazu.si

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ABSTRACT

The results obtained by four years long TM 71 extensometer monitoring of 3D micro-tectonic displacements of Dinaric Fault Zone on two sites, being 260 m apart in Postojna Cave, were statistically evaluated with different methods (Kolmogorov-Smirnov test, comparison between relative displacement and earthquakes, linear regression, Kruskal-Wallis one-way analysis of variance, histograms and correlation coefficients). Responses to stress changes regarding *x*, *y* and *z*-axes are not the same on two monitoring sites even if we are monitoring the same fault zone. Kolmogorov-Smirnov test for comparing the two curves is applicable only for three axes combination (Postojna 1 *z* - Postojna 2 *z*, Postojna 2 *y* - Postojna 1 *z*, and Postojna 2 *z* - Postojna 2 *y*). Kruskal-Wallis analysis is most representative for *z*-axes. Some sharp peaks coincide with earthquake occurrences (Krn M=5.2, Cerkno M=4.0, Ilirska Bistrica M=3.9, Brežice M=2.9 and Krško M=3.1). Generally we detect very small tectonic deformations, dextral horizontal movement of 0.05 mm in 4 years for Postojna 1 and extension of 0.03 mm in 4 years for Postojna 2. Discrepancies between two sites can be attributed to complex geological structure and by the fact that studied fault zone is cut by cross-Dinaric fault zone.

KEYWORDS: micro-tectonic displacements, 3D monitoring of displacements, TM 71 extensometer, statistical evaluation, Postojna Cave, Slovenia

INTRODUCTION

In Postojna Cave the regular monthly monitoring of micro-tectonic movements with TM 71 extensometers is going on from 2004 (Šebela and Gosar, 2005; Šebela, 2005; Šebela et al., 2005; Gosar et al., 2007; Šebela et al., 2008). Two instruments are installed on Dinaric oriented (NW-SE) fault zone (Figure 1). The studied fault zone is situated about 1 km north from regionally important Dinaric oriented Predjama Fault and about 5 km south from Idrija Fault. With regular monitoring of displacements we wanted to ascertain if the fault zone is still tectonically active and in what scale are the movements. Detalied structural geological data of both sites were reported in previous articles (Šebela et al., 2005; Gosar et al., 2007; Šebela et al., 2008). In this article we want to point at statistical comparison between two data sets.

Monitoring of tectonic deformations, as well as landslide movements and stability of mine walls with TM 71 extensometers is experienced for more than 30 years (Košťák, 1969; 1977; 1991; 1998; 2002; Košťák et al., 2007). Especially karst caves and artificial tunnels are very suitable for TM 71 installation due to the stable temperature conditions. Such study cases are in Czech Republic (Stemberk et al., 2008a), Poland (Kontny et al., 2005), Slovakia (Briestenský et al., 2007) and Slovenia (Šebela and Gosar, 2005; Šebela, 2005; Šebela et al., 2005; Gosar et al., 2007; Šebela et al., 2008). In Germany (Stemberk et al., 2003; Stemberk et al., 2008b) and in Slovakia the instruments are also placed in an artificial tunnel. On the Gargano peninsula TM 71 is situated in the basement between the wall and Mattinata fault plane (Borre et al., 2003).

TM 71 detects micro displacements with accuracy of up to 0.01 mm on active tectonic structures, which can be seismic or aseismic. Being a mechanical and optical instrument, the TM 71 measures the displacements in three dimensions (*x*, *y* and *z*). The measurement works on the principle of Moiré optical effect, which changes when two transparent plates move (Košťák, 1977; 1991).

The results obtained by four years long monitoring on two sites Postojna 1 (Velika gora) and Postojna 2 (Lepe jame) were statistically evaluated with different statistical methods (Kolmogorov-Smirnov test, comparison between relative displacement and earthquakes, linear regression, Kruskal-Wallis one-way analysis of variance,

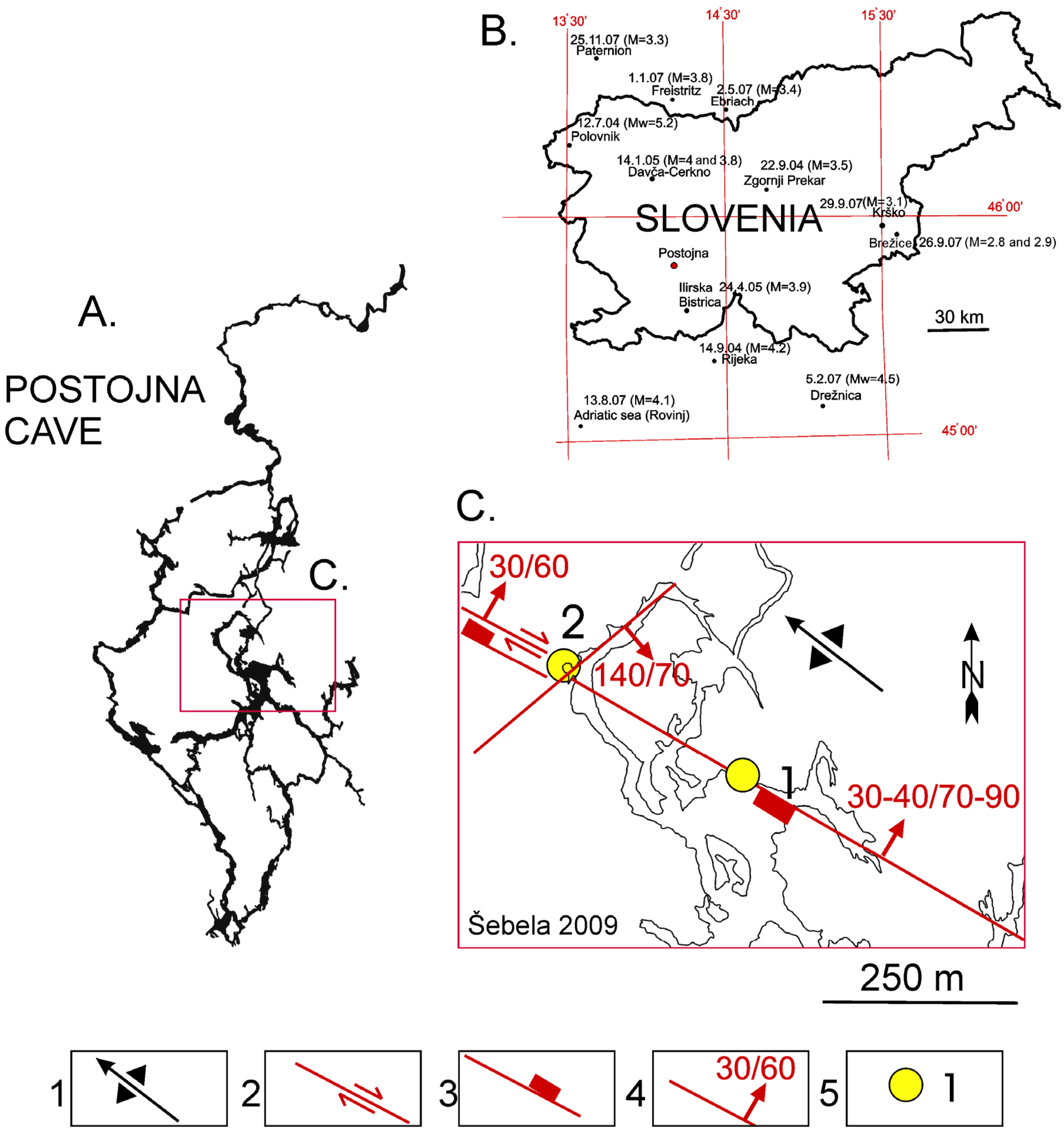


Fig. 1 A-Ground-plan of Postojna Cave, B-Position of stronger earthquakes with magnitude, C-Geological position of monitoring sites Postojna 1 and 2, 1-Postojna anticline, 2-dextral horizontal movement of fault, 3-vertical movement of fault, 4-strike and dip direction of fault, 5-monitoring site Postojna 1.

histograms and correlation coefficients). The curves and the peaks were compared between two monitoring sites being 260 m apart, but situated in the same fault zone. With statistical methods we want to point out the differences and similarities in the 3D displacements between two monitoring sites, because previous papers related to Postojna Cave mostly represented general visual comparison between relative displacement and earthquakes (Šebela and Gosar, 2005; Šebela, 2005; Gosar et al., 2007; Šebela et al., 2008). In the example of Polish Sudeten similar study analyzed time series of data of selected TM 71 crack gauges (Kontny et al., 2005) by linear trend analysis of relative displacements, periodicity analysis, temperature dependency analysis, detection of and analysis of episodic data disturbances.

Regarding the stable cave environment (temperature 9-11 °C, no active karst subsidences, monitoring sites are sufficiently distant from active underground water flow), more 10 years long monitoring experiences with TM 71 in other countries (Košťák et al., 2007; Kontny et al., 2005) and regarding the data obtained from Postojna Cave (Šebela et al., 2008), we expect to monitor micro-

Table 1 KS-test of data distribution of Postojna 1 (*x*, *y*, *z*-axes) and Postojna 2 (*x*, *y*, *z*-axes). sdev=standard deviation.

Axis	MEAN	sdev	KS-TEST	Normal distribution Mean	Normal distribution sdev
1x	8.148	10.3	it is unlikely this data is normally distributed	12.8	9.837
2x	18.42	19.5	it is unlikely this data is normally distributed	23.51	16.68
1y	21.68	25.4	it is unlikely this data is normally distributed	28.96	21.260
2y	4.977	8.29	it is unlikely this data is normally distributed	10.26	8.633
1z	4.932	7.23	it is unlikely this data is normally distributed	9.551	7.898
2z	5.261	7.86	it is unlikely this data is normally distributed	12.43	11.44

tectonic deformations of Dinaric oriented (NW-SE) fault zone, transmitting the changes in stress/strain conditions that can coincide with stronger earthquakes.

The monitoring of micro-deformations started within the COST 625 projec t (3D monitoring of active tectonic structures) and is continuing within Slovenia-Czech bilateral projects (BI-CZ/06-07-011 and BI-CZ/08-09-015).

3D MONITORING OF DINARIC FAULT ZONE IN POSTOJNA CAVE

The monitoring of micro-tectonic movements with TM 71 started on 26th May 2004 (Postojna 1) and on 26th February 2004 (Postojna 2). The data are generally taken once a month. The decision for installation of TM 71 instruments in Postojna Cave was taken due to updated and detailed geological cave maps, broad speleological data and due to the general recognition as one of the best-known show caves in the world.

The studied area is part of Adria microplate South from Periadriatic Fault and belongs to External Dinarides that are characterized by moderate historic and recent seismicity. The recent seismicity of Idrija Fault, that is rather low, is of the right-lateral strike-slip type. The last strongest event (Cerknica earthquake) was in 1926 with the magnitude 5.6 (Poljak et al., 2000). The cave is situated about 10 km, West from the epicenter.

STATISTICAL METHODS

In order to compare the results of 3D micro-displacements obtained from two, 260 m distant, monitoring sites various statistical methods were applied. Although the movements are small, we got some interesting peaks (maximum for –0.08 mm on Postojna 1 *y*) and very stable periods with almost no movements (Postojna 1 and 2 *y* from the end of 2005 during 2006) what supports our hypothesis of monitoring the real tectonic deformations, excluding influence of seasonal changes and influence of karst water oscillations.

Representative results in comparing two data sets (Postojna 1 and 2) were analysed by Kolmogorov-Smirnov test, comparison between relative displacement and earthquakes, linear regression, Kruskal-Wallis one-way analysis of variance, histograms and correlation coefficients.

KOLMOGOROV-SMIRNOV TEST (KS-TEST)

Kolmogorov-Smirnov test (KS-test) tries to determine if two datasets differ significantly. It is a non-parametric and distribution free test. One of the advantages of the KS-test is that it leads to a graphical presentation of the data, which enables the user to detect normal distributions. The KS-test is a robust test that cares only about the relative distribution of the data (www.physics.csbsju.edu/stats/KS-test.html).

The Kolmogorov-Smirnov test (KS-test) is a goodness of fit test used to determine whether two underlying one-dimensional probability distributions differ. The two-sample KS-test is one of the most useful and general nonparametric methods for comparing two samples, as it is sensitive to differences in both location and shape of the empirical cumulative distribution functions of the two samples (http://en.wikipedia.org/wiki/Kolmogorov-Smirnov_test).

The Kolmogorov-Smirnov (KS) test was performed on-line (www.physics.csbsju.edu/stats/KS-test.n.plot_form.html) for 15 axes combination calculating 88 data points for each axis. We observed significant difference between two datasets if the *P* value is small. Table 1 shows KS-test definition of normal or non-normal distribution for all three axes on two monitoring sites and Table 2 shows *D* (the maximum difference between the cumulative distributions with corresponding *P* (the value that reports if the numbers differ significantly) values for each of 15 axes combination. Our results show the non-normal distribution of the data (Table 1).

Many things in nature are not normally distributed. Much of what is not normally distributed would be normally distributed if you took the logarithm of each data item (www.physics.csbsju.edu/stats/descriptive2.html).

In our case it was not possible to use a log scale because some of the data are zero and negative, since the logarithm of negative numbers and even zero is undefined.

Table 2 KS-test of comparison similarities of different axes of Postojna 1 and 2. Highlighted correlations are significant.
D=the maximum difference between the cumulative distributions with corresponding *P*
P=the value that reports if the numbers differ significantly. Reject the null hypothesis if *P* is "small".

Axes combination	D	P	POSITION
1x-2x	0.4318	0	
1x-1z	0.25	0.007	5
1x-2y	0.2159	0.028	4
1x-2z	0.25	0.007	5
1y-2y	0.4091	0	
1y-2z	0.4205	0	
1y-1z	0.4091	0	
1y-1x	0.4091	0	
2y-2x	0.4545	0	
2z-2x	0.4773	0	
2z-2y	0.1477	0.27	3
1z-2z	**0.0795**	**0.934**	1
2x-1y	0.2955	0.001	6
2x-1z	0.4659	0	
2y-1z	**0.1023**	**0.724**	2

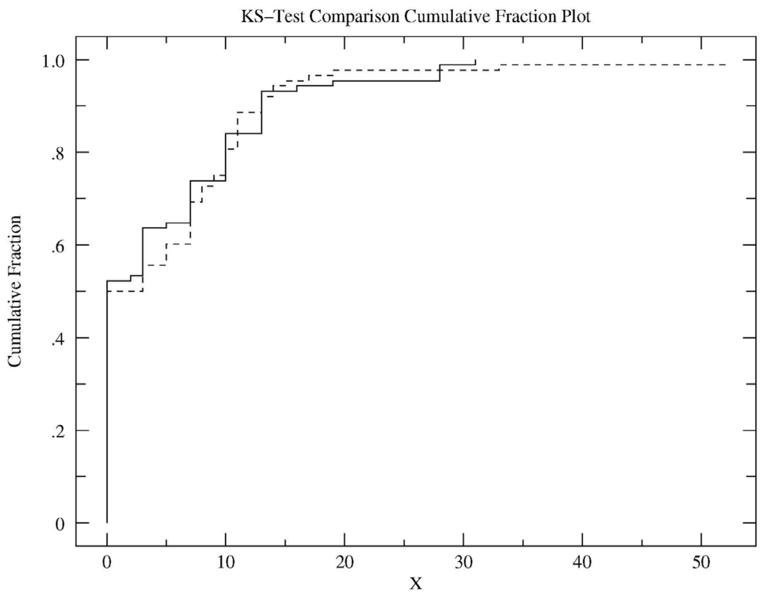


Fig. 2 KS-test of Postojna 1 *z* and Postojna 2 *z* (*D*=0.0795, *P*=0.934). 1 *z* – solid line, 2 *z* – dashed line.

We did not apply *t*-test, because if you run the *t*-test to non-normal data, you are probably increasing the risk of error. Highly non-normal datasets can cause the *t*-test to produce fallible results, even for large N datasets. Beside this the *t*-test is not robust enough to handle the highly non-normal data with *N*=80 (www.physics.csbsju.edu/stats/KS-test.html).

Even if the data of each data set are non-normally distributed, the KS-test can give good correlation between two data sets. This is shown in Table 2.

Regarding the Table 2, the smallest vertical deviation between the two curves (Postojna 1 z and Postojna 2 z) is *D*=0.0795 with corresponding *P*=0.934 suggesting almost no significant difference (Figure 2). The second good correlation is between Postojna 2 y and Postojna 1 z with *D*=0.1023 and corresponding *P*=0.724 (Figure 3). The third case

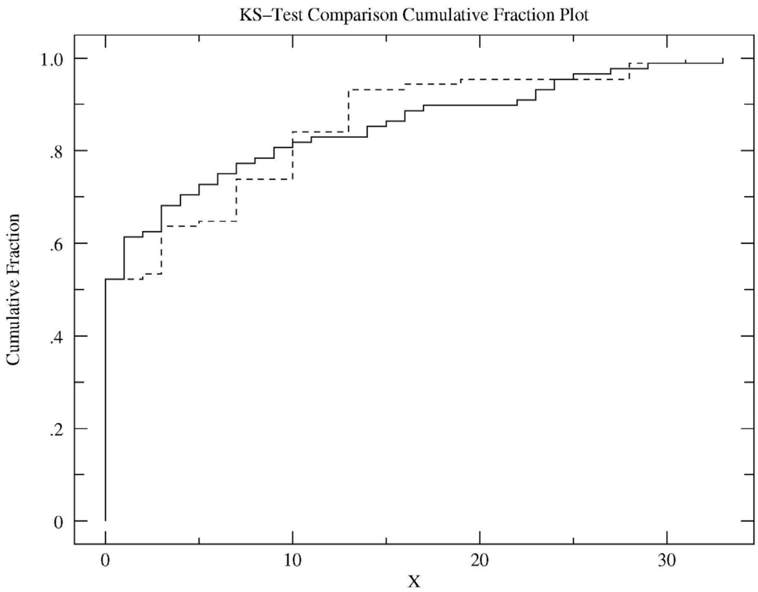


Fig. 3 KS-test of Postojna 2 *y* and Postojna 1 *z* (*D*=0.1023, *P*=0.724). 2 *y* – solid line, 1 *z* – dashed line.

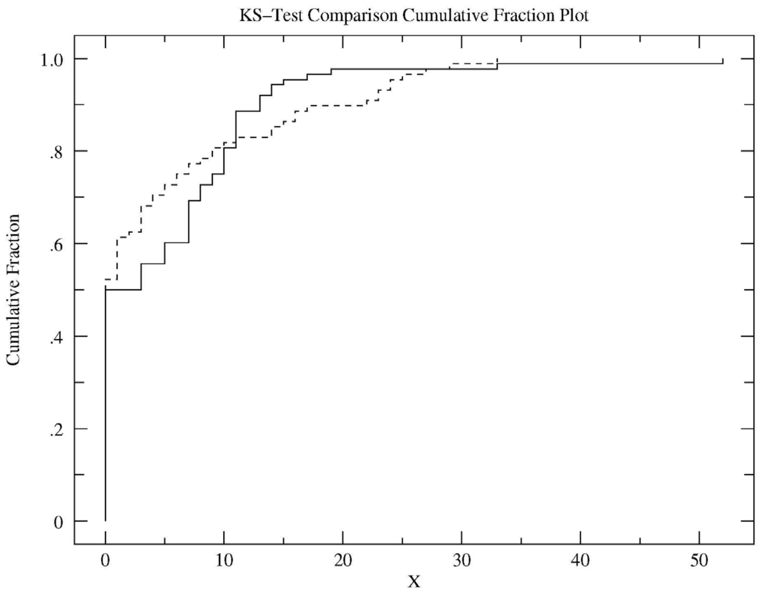


Fig. 4 KS-test of Postojna 2 *z* – *y* (*D*=0.1477, *P*=0.27). 2 *z* – solid line, 2 *y* – dashed line.

shows medium to small correlation being *D*=0.1477 with corresponding *P*=0.27 for Postojna 2 z – y (Figure 4). Other correlations are regarding KS-test very low.

RELATIVE DISPLACEMENT AND EARTHQUAKES

The relative displacements detected with TM 71 extensometers are shown for *x* axes for Postojna 1 and 2 sites, for y axes (Postojna 1 and 2) and for z axes (Postojna 1 and 2). Stronger and closer earthquakes (Table 3) are marked by magnitude (Figure 1B).

Figure 5 shows the results of monitoring of tectonic movements for the site Postojna 1 with significant earthquakes that were reported during well-expressed movement peaks. The results are representing the movements in three axes *x, y* and *z*, where +*x* represents compression of the observed fault, +*y* represents sinistral horizontal movement and +*z* vertical movement (NE block dropped down and SW rose up).

The visual comparison between two curves (Figure 5) is the best for *z* axes. The curves for *x* and *y*

Table 3 Stronger earthquakes with magnitudes (www.arso.gov.si, www.emsc-csem.org).

Number	Date (dd/mm/yy)	Depth (km)	M_L	Location	Air distance from Postojna
1	12.7.2004	13	M_w=5.2	Krn	70 km NW
2	14.9.2004	8.9 (?)	4.2	Fužine-Rijeka (Croatia)	50 km south
3	22.9.2004	16	3.5	Zgornji Prekar	70 km NE
4	14.1.2005	20	4	Cerkno	45 km NW
4	14.1.2004	20	3.8	Cerkno	45 km NW
5	24.4.2005	17	3.9	Ilirska Bistrica	25 km SE
6	30.8.2005	18	2.8	Medvode	45 km NE
7	24.11.2005	16	2.5	Postojna	5-10 km W
8	12.12.2005	19	2.9	Žiri	30 km NW
9	30.1.2006	12	2.1	Prestranek	10-15 km south
10	21.6.2006	16	2.8	Gorski Kotar (Croatia)	70 km SE
11	30.8.2006	22	2.4	Škofja Loka	45 km north
12	3.9.2006	13	2	Podnanos	22 km W
13	24.9.2006	15	2.2	Podnanos	22 km W
14	1.1.2007	16	3.8	Freistritz/Bistrica v Rožu (Austria)	80 km north
15	5.2.2007	10	M_w=4.5	Drežnica (Croatia)	90 km south
16	2.5.2007	16	3.4	Ebriach/Obirsko (Austria)	80 km NE
17	13.8.2007	27	4.1	Adriatic sea, near Rovinj (Croatia)	95 km SW
18	26.9.2007	3	2.8	Brežice	115 km E
18	26.9.2007	5	2.9	Brežice	115 km E
19	29.9.2007	10	3.1	Krško (Raka)	105 km E

M_L = local magnitude

Mw = moment magnitude

axes show differences in movement size. The *x* axis on Postojna 1 generally shows smaller movements than *x* axis on Postojna 2, but *y* axis on Postojna 1 demonstrates bigger movements than the same axis on Postojna 2.

On Postojna 1 *y* curve (Figure 5) indicates the biggest movement (November 10, 2004 to December 15, 2004), which was of –0.08 mm (dextral horizontal movement). And on Postojna 2 *z* axis (January 26, 2005 to March 22, 2005) there was a vertical movement of –0.05 mm (Šebela et al., 2008).

Some ideas in paralleling well-expressed micro-movements detected by TM 71 with earthquakes have been described by several authors (Košťák et al., 2007; Stemberk et al., 2008a; Briestenský et al., 2007; Kontny et al., 2005). According to the Košťák's hypothesis a strong earthquake would respond to temporary changes in the Earth's crust stress field detectable in the readings of sensitive extensometer instruments (Košťák, 1998; 2002).

In the case of Postojna Cave we observed very small tectonic deformations (general dextral horizontal movement of 0.05 mm in 4 years for Postojna 1 and extension of 0.03 mm in 4 years for Postojna 2) and in this sense it is difficult to find some very good coincidences between earthquakes and tectonic movements. However, some sharp peaks coincide with earthquake occurrences. The best examples are (Figure 5 and Table 3):

- Krn earthquake M=5.2 (Šebela et al., 2005)
- Cerkno earthquake M=4.0 (Postojna 2 x and z, Postojna 1 y)
- Ilirska Bistrica earthquake M=3.9 (Postojna 2 x and z)
- Brežice M=2.9 and Krško M=3.1 earthquakes (Postojna 2 x).

It is interesting to compare the highest peaks and earthquakes (Figure 5). On Postojna 2 *x*-axis the extension is followed by compression, at the end of which (Krn, Cerkno, Ilirska Bistrica, Brežice and Krško) earthquakes occurred. On Postojna 2 *z*-axis Krn, Cerkno and Ilirska Bistrica earthquakes coincide with highest peaks. On Postojna 1 and 2 *y*-axes dextral horizontal movement is followed by sinistral movement at the end of which there is partially good coincidence with Krn, Cerkno and Ilirska Bistrica earthquakes.

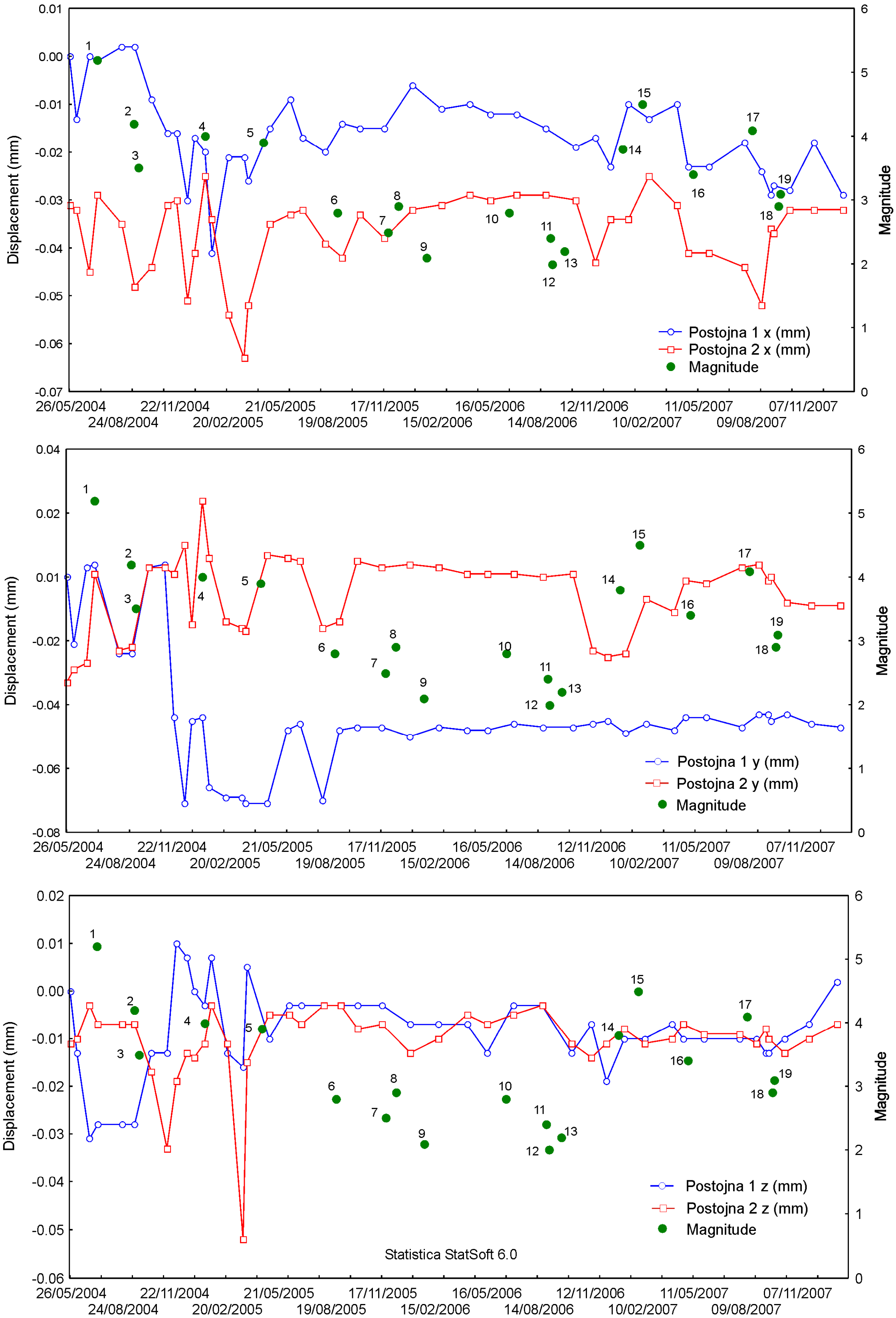


Fig. 5 Relative displacements and earthquakes of Postojna 1 z – Postojna 2 z, Postojna 1 x – Postojna 2 x, Postojna 1 y – Postojna 2 y. Important earthquakes:1-Krn M=5.2, 4-Cerkno M=4.0, 5-Ilirska Bistrica M=3.9, 18-Brežice M=2.9 and 19-Krško M=3.1.

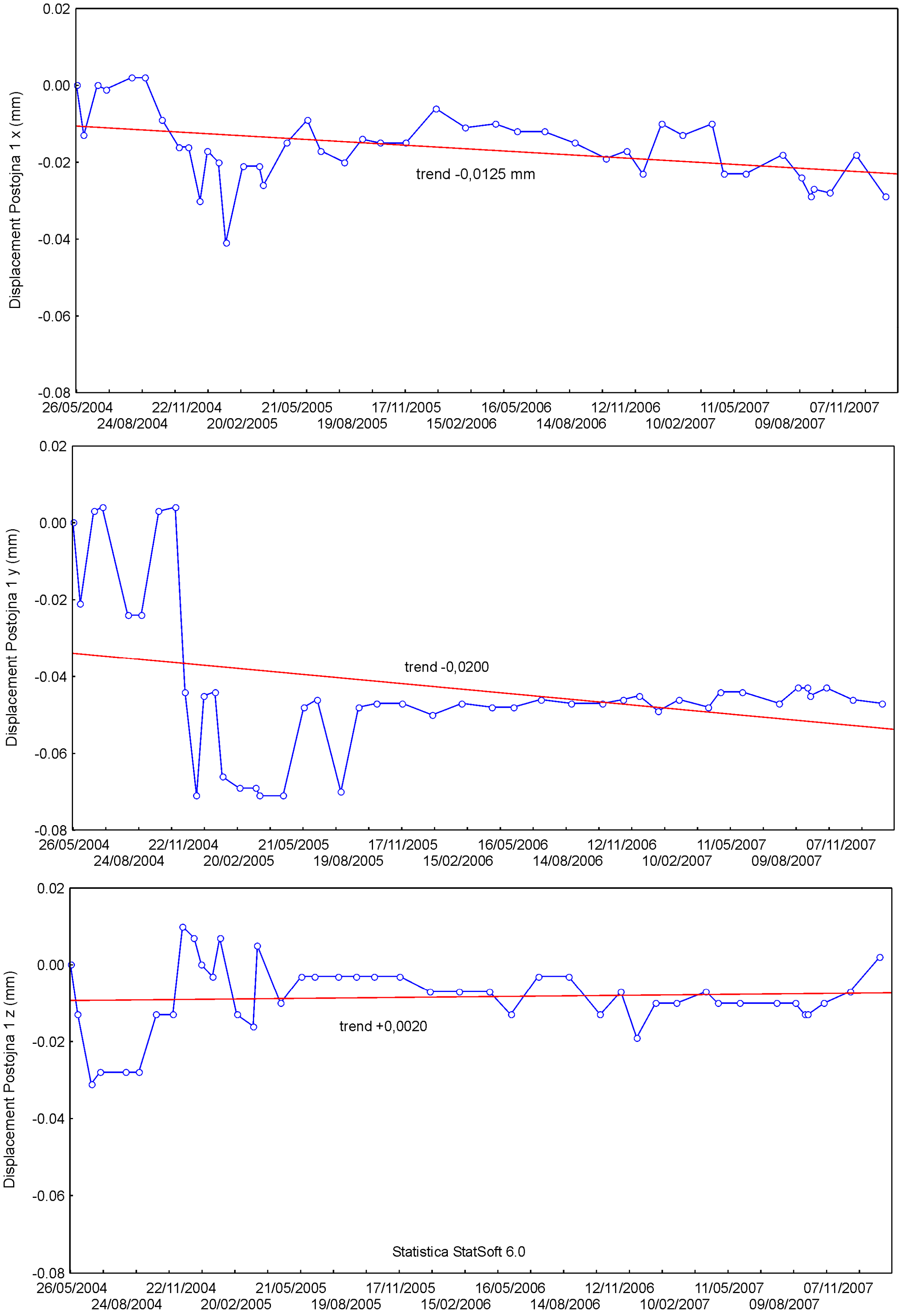


Fig. 6 Linear regression of Postojna 1 (*x*, *y*, *z*-axes).

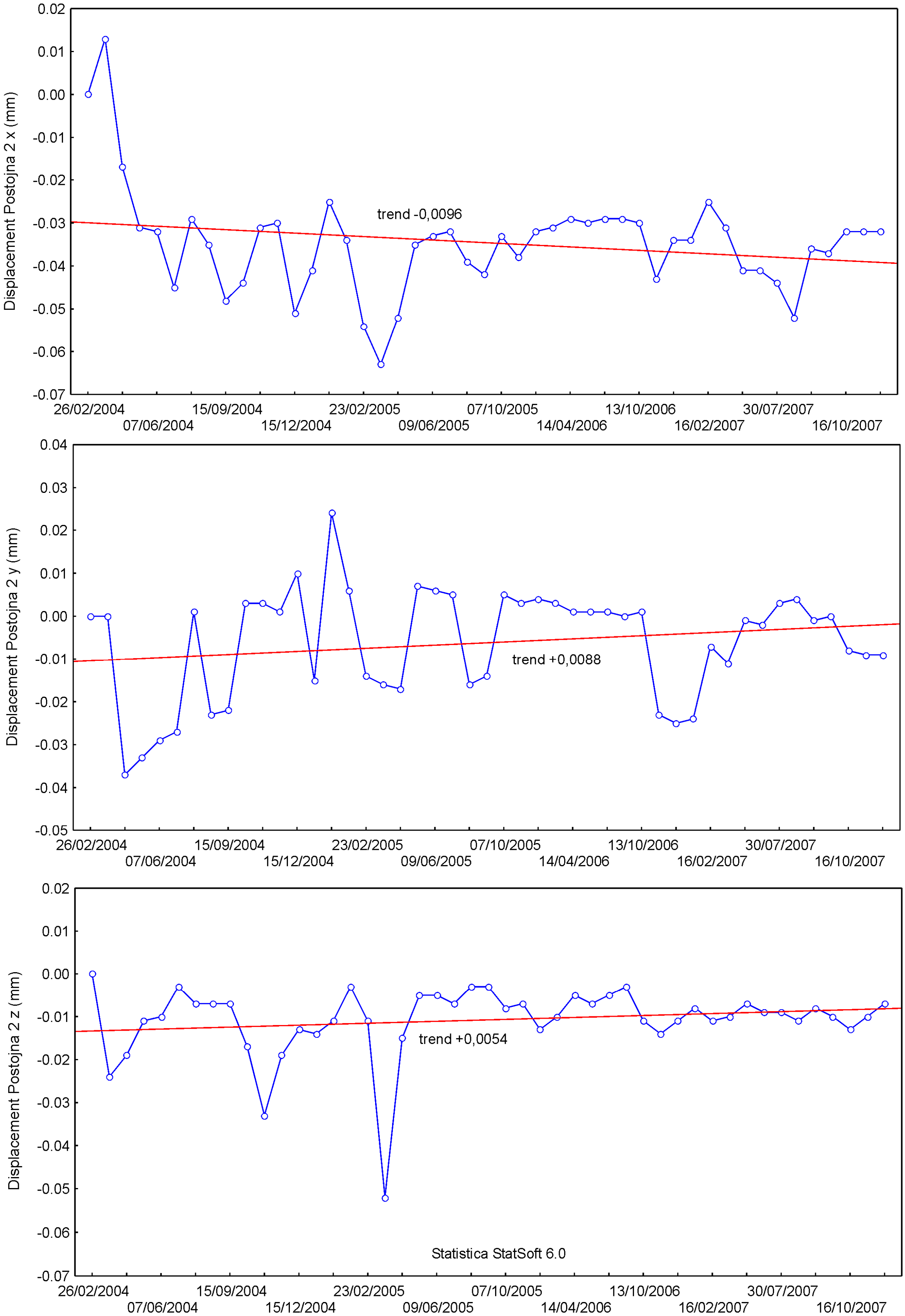


Fig. 7 Linear regression of Postojna 2 (x, y, z-axes).

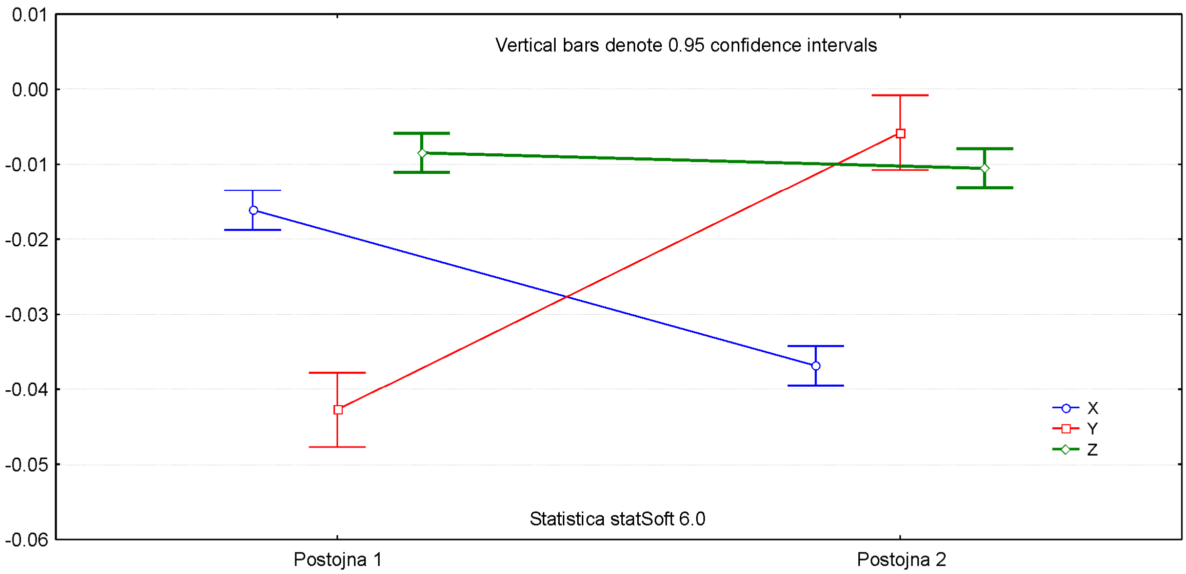


Fig. 8 Kruskal-Wallis one-way analysis of variance of Postojna 1 (*x*, *y*, *z*-axes) and Postojna 2 (*x*, *y*, *z*-axes).

LINEAR REGRESSION

Simple linear regression applies two variables: independent (x) and dependent (y), where independent variable (x) is used to describe, predict or explain the variation in the dependent variable (y) (Baxter, 2003).

Figures 6 and 7 are representing linear regression for Postojna 1 and 2. Linear regression shows trends of displacement in studied time period (almost four years, 47.5 months respectively). The most expressive trend, with displacement of -0.0200 in studied period, represents *y*-axis on Postojna 1. Other displacements are -0.0125 mm (*x*-axis on Postojna 1), -0.0096 (*x*-axis on Postojna 2), +0.0088 (*y*-axis on Postojna 2), +0.0054 (*z*-axis on Postojna 2) and +0.0020 (*z*-axis on Postojna 1).

Three regressions represent trends with positive displacements and three with negative. However, displacements are relatively low in four years period hence some trends may alter in longer time period, which would give more representative results.

KRUSKAL-WALLIS ONE-WAY ANALYSIS OF VARIANCE

The Kruskal-Wallis test is a nonparametric method of testing the hypothesis that several populations have the same continuous distribution versus the alternative that measurements tend to be higher in one or more of the populations (http://www.wku.edu/~david.neal/statistics/nonparametric/kruskal.html).

The Kruskal-Wallis test is an alternative to one-way (between-groups) ANOVA. The Kruskal-Wallis test is based on ranks, while ANOVA on means (http://www.babylon.com/definition/Kruskall-Wallis_test/English).

The Kruskal-Wallis statistic is:

$$H = [12 / (N (N + 1))] * \text{Sum } [R_i^2 / n_i] - 3(N + 1).$$

N – number of observations across all groups
n_i – the number of observations in group i
R_i – the sum of ranks of the n_i observations in the i^{th} sample

When H is large, creating a small right-tail probability (p-value), then we reject the null hypothesis that all populations have the same distribution. (http://www.wku.edu/~david.neal/statistics/nonparametric/kruskal.html).

The Kruskal-Wallis test for *x*, *y* and *z*-axes:

x - axis: KW-H(1.88) = 58.3799605, $p = 0.0000$

y - axis: KW-H(1.89) = 42.1133279, $p = 0.0000$

z - axis: KW-H(1.89) = 0.950368063, $p = 0.3296$

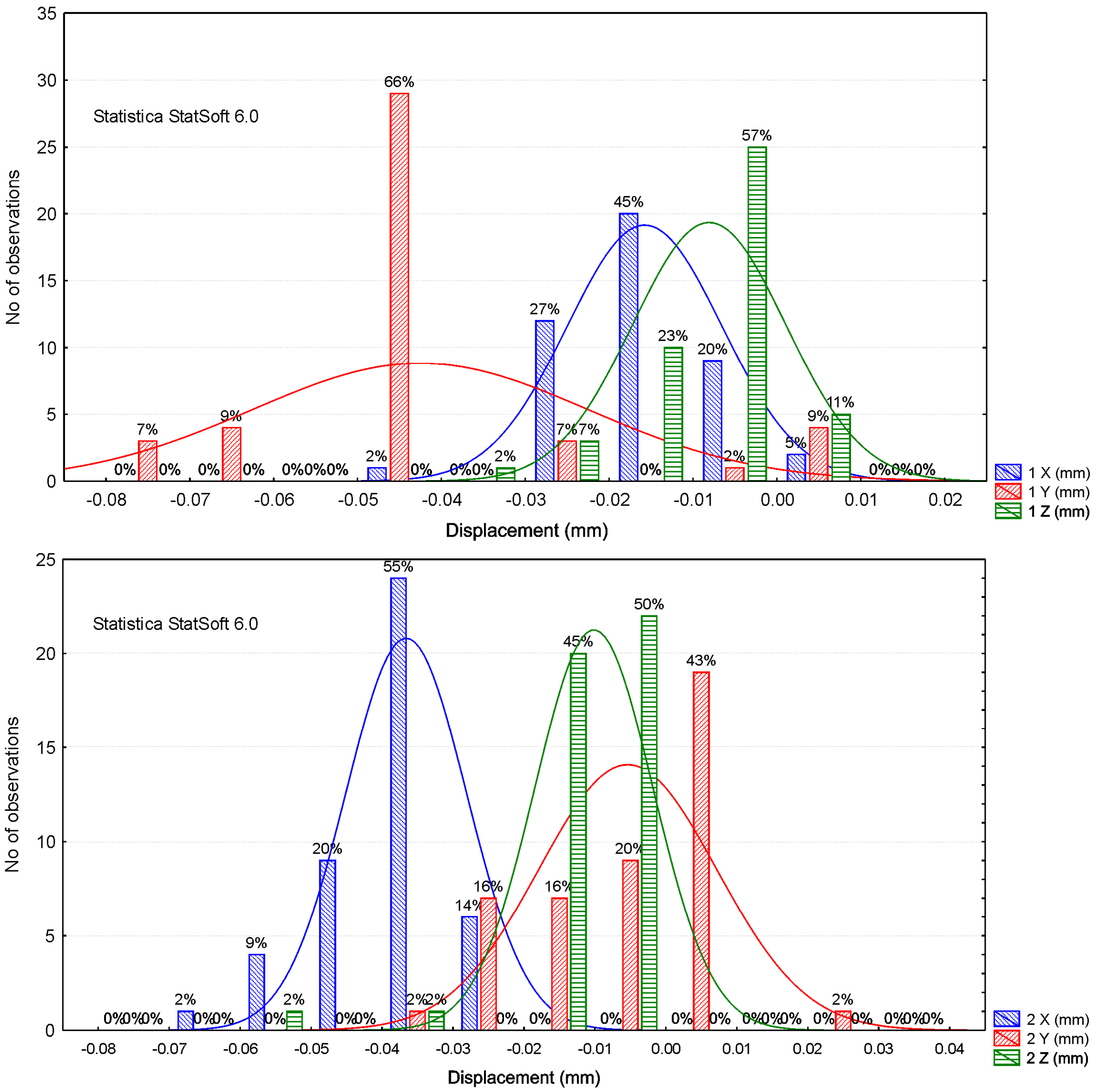
H is large fore *x* and *y*-axis, hence the null hypothesis that all populations have the same distribution is rejected. Populations have the same distribution for *z*-axis only (H is small being 0.95 and $p > 0.05$).

Similar results may be seen from Figure 8, which represents ANOVA test graphically.

HISTOGRAMS

Histograms have advantage of showing exactly which ranges are highly populated and which are not (www.physics.csbsju.edu/stats/display.distribution.html). Histograms were applied to show ranges for all axis at both measuring places.

A



B

Fig. 9 A - histograms of Postojna 1 (*x*, *y*, *z*-axes), B - histograms of Postojna 2 (*x*, *y*, *z*-axes).

Figure 9A is showing the data for Postojna 1 (*x*, *y* and *z* axes) and Figure 9B for Postojna 2 (*x*, *y* and *z* axes). The normal fits for Postojna 1 *x* and *z* have similar shapes. However more distinctive movements are on *x* axis. For Postojna 1 *y* axis, 66 % of all data has the movement between –0.04 and 0.05 corresponding to dextral horizontal movement. For Postojna 2 *y* (Figure 9B) 43 % of all data is between 0 and +0.01 mm corresponding to sinistral horizintal movement. Shapes of the normal fits for Postojna 2 *x* and *z* are similar, but *x* axis has a bigger movements (55 % at –0.04 mm).

On Figure 10 histograms comparing same axes between Postojna 1 and 2 sites are presented. Normal fit shows the best similarity for *z* axes. The comparison for *x* axes shows bigger movements for Postojna 2 than for Postojna 1.

CORRELATION COEFFICIENT

The correlation coefficient is a number between 0 and 1 or -1. It tells us what is the relationship between the predicted values and the actual values. If the correlation coefficient is 0 or very low it indicates no or low relationship. A perfect fit gives a coefficient of 1 (or -1). Thus the higher is the coefficient the better is correlation.

The correlation coefficient above 0.8 (under –0.8) and approaching the value of 1 (or -1) indicates significant or very high dependence. However interpretation of a correlation coefficient depends on

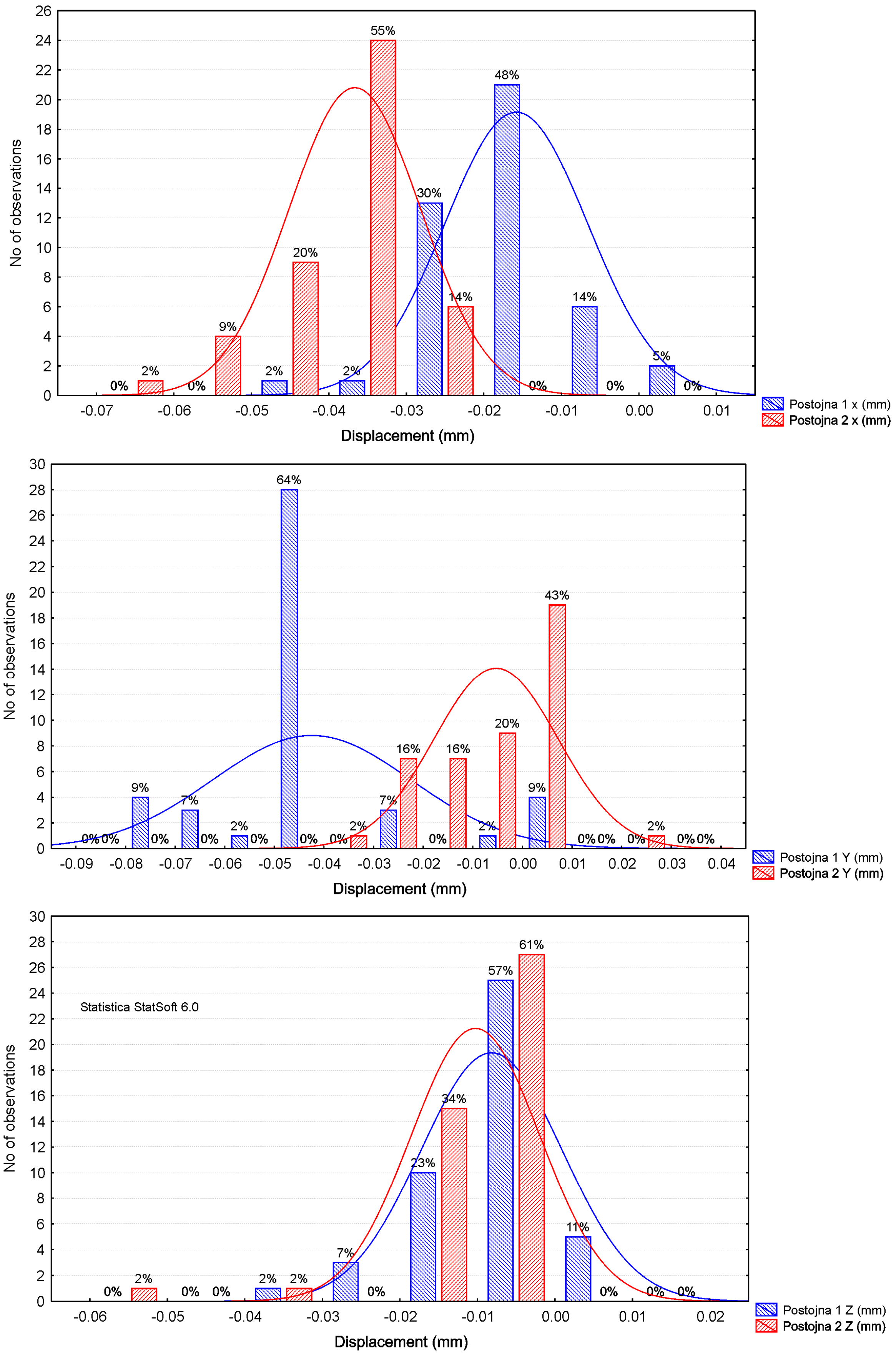


Fig. 10 Histograms comparing same axes between Postojna 1 and 2 monitoring sites.

Table 4 Correlation coefficients of 15 axes combination. Highlighted correlations are significant, due the fact that $p<0.05$.

Axes combination	Correlation coefficient	*p* value
1x-2x	0.1977	0.204
1x-1z	**-0.5302**	**0.000**
1x-2y	**-0.3173**	**0.038**
1x-2z	0.1174	0.453
1y-2y	-0.2202	0.156
1y-2z	-0.0237	0.880
1y-1z	**-0.5382**	**0.000**
1y-1x	**0.5922**	**0.000**
2y-2x	0.2460	0.112
2z-2x	**0.4232**	**0.005**
2z-2y	0.0716	0.648
2z-1z	0.0952	0.544
2x-1y	0.2385	0.123
2x-1z	0.0903	0.565
2y-1z	**0.3248**	**0.034**

the context and purposes, hence correlation with coefficient r above 0.5 (under –0.5) may be also considered as a high. Coefficient of less than 0.3 (higher than -0.3) in every case signifies low dependence or even lack of such a relationship (http://en.wikipedia.org/wiki/Correlation). Negative value of the coefficient points to an inverse relationship. Negative value means that general trends of the displacement are opposite. *i.e.* one has negative trend and other positive.

The relationship between *x, y* and *z*-axes on both monitoring sites are given by 15 correlation coefficients and *p* values calculated for these data.

Correlation coefficients of all possible combinations are relatively low (the highest one is 0.59; 1 *x* – 1 *y*). All correlations at $p<0.05$ are statistically significant. We established correlations for the following pairs: 1 *x* – 1 *y*, 1 *x* -2 *y*, 1 *x* – 1 *z*, 2 *x* – 2 *z*, 1 *y* – 1 *z* and 2 *y* – 1 *z*. However only correlations with r above 0.5 may be potentially considered as relatively good (1 *y* -1 *z*, 1 *x* – 1 *y* and 1 *x* – 1 *z*). The axis 2 *z* is the one, which has relatively the lowest correlations with other axis.

The fact is that the monitoring site Postojna 1 shows higher correlation coefficients (all three above 0.5) than Postojna 2 (the highest 0.39). The *p* values are significant (at $p<0.05$) for all three combinations at Postojna 1 and for only one combination at Postojna 2 (Table 4).

DISCUSSION AND CONCLUSIONS

In Postojna Cave we detect very small tectonic deformations, general dextral horizontal movement of 0.05 mm in 4 years at Postojna 1 and extension of 0.03 mm in 4 years at Postojna 2.

KS-test reports that it is unlikely that the data are normally distributed (Table 1). Our results show the non-normal distribution of all data from Postojna Cave.

But KS-test for different axes combination (Table 2) showed that the smallest vertical deviation between the two curves is for Postojna 1 *z* and Postojna 2 *z* (*D*=0.0795 with corresponding *P*=0.934), suggesting almost no significant difference between two curves (Figure 2). The second well-expressed correlation is between Postojna 2 *y* and Postojna 1 *z* (*D*=0.1023 with corresponding *P*=0.724 (Figure 3)). The third case shows medium to small correlation being *D*=0.1477 with corresponding *P*=0.27 for Postojna 2 *z* – *y* (Figure 4). Other correlations between axes are according to KS-test very low.

The visual comparison between two curves (Figure 5) is the best for *z* axes, as was already confirmed with KS-test. On Postojna 1 *y* curve the biggest movement peak (November 10, 2004 to December 15, 2004) was of –0.08 mm (dextral horizontal movement), and on Postojna 2 *z* axis (January 26, 2005 to March 22, 2005) a vertical movement peak of –0.05 mm (Šebela et al., 2008).

Linear regression represents the highest movement for *y* axis on Postojna 1 (-0.0200 mm, Figure 6), the second is for *x* axis on Postojna 2 (-0.0125 mm, Figure 7).

Kruskal-Wallis one-way analysis of variance (Figure 8) for all three axes for Postojna 1 and Postojna 2 sites demonstrates the best correlation for *z* axes.

Correlation coefficients are given for 15 axes combinations (Table 4). Three examples (Postojna 1 *y-x*, Postojna 1 *y-z*, Postojna 1 *x-z*) show relatively clear dependance between calculated axes combinations.

Responses to stress changes are not the same on two monitoring sites even if we are monitoring the same fault zone. KS-test for comparing the two curves is good only for three axes combinations (Postojna 1 *z* and Postojna 2 *z*, Postojna 2 *y* and Postojna 1 *z*, and Postojna 2 *z* and Postojna 2 *y*). Some sharp peaks coincide with stronger earthquake occurrences (Krn, Cerkno, Ilirska Bistrica, Brežice and Krško earthquakes (Figure 5 and Table 3)).

General view on KS-test and Kruskal-Wallis analysis shows that the best correlated are Postojna 1 *z*-axis, Postojna 2 *z*-axis and Postojna 2 *y*-axis. If we compare the graphs visually (Figure 5) we see that these are in fact the axes with the smallest displacements and small number of peaks.

Due to some different behavior between Postojna 1 and 2 monitoring sites we assume that the monitoring shows local deformations. This is in accordance with Kontny et al. (2005) who described probable movement of a particular rock-block at monitoring sites in Polish Sudeten. But on the other hand at least one axis, although different, is comparable between two monitoring sites in Postojna Cave. Additionally we envisage the detection of general displacements due to changes in regional stress regime, as was described by Stemberk et al. (2008b) in Upper Rheingraben during longer period.

Differences in displacements between two monitoring sites of Postojna Cave can be explained due to complex geological structure of the cave. Postojna 1 is situated in the biggest collapse chamber in the cave and Postojna 2 is situated in artificially enlarged opened fissure. Between both sites the studied Dinaric Fault Zone is cut by cross-Dinaric Fault Zone (Figure 1C) that might transmit some deformations causing differences between Postojna 1 and 2 sites (Gosar et al., 2007).

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