CRUSTAL FIELD DEFORMATION CHARACTERISTICS IN VRANCEA SEISMIC AREA FROM GPS DATA*

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The present paper aims to bring contribution to geodynamic researches by carrying out a study of the crustal deformations field in the Vrancea area, known as the most important seismic area in Romania at subcrustal level. To meet this goal a network of GPS measurement points centered on the Vrancea active area was considered, the geodetic network being developed within a large scale international project, CRC461. The sensors network have been repeatedly measured every year since 1997, aiming to make it possible to determine the points' movement velocities each year and drawing some conclusions on the characteristics of the kinematics of the crustal blocks. The measurement network, hereinafter referred to as the *"Vrancea Extended Network"* consisted of more than 50 measuring stations, of which only 26 were considered, as this group overlaps very well at surface the maximum seismic activity in Vrancea zone, covering both the subcrustal and crustal domains of earthquakes occurring in the area. As the considered network presents distinct geodynamic behaviors in the two compartments placed to the South and to the North of the Trotuș fault, regarding the vertical displacement velocities of the measurement points, the network was divided into two compartments, *North Vrancea* and *South Vrancea*, the calculations being made on the extended network as well as on several separate subnets. The present paper is carrying out a calculation of the crustal deformation vectors' field on the main components, maximum principal strain, ε_1, and the minimum principal strain, ε_2, together with their graphical representation in the form of deformation maps. All calculations were performed using specialized software, using the finite element method, and graphic representations using specialized GIS software. Some of the geodynamic maps have been prepared from all data that shows the behavior of the zone.

Key words: geodynamic researches, crustal deformation, GNSS.

1. INTRODUCTION

Romania is located from a tectonic point of view in an area affected by significant major faults: *Peceneaga – Camena*, an important transcurrent fault evidenced over the entire terrestrial crust, the *Intramoesian* and *Capidava – Ovidiu* faults, which have quasi-parallel directions. The Vrancea area of crustal seismicity is located in front of the Carpathians Arc Bend, geographically corresponding to the Focşani Depression, characterized by a thickened crust.This major seismic zone is responsible for the most important number of large intermediate earthquakes, which generates approximately 95% of the total seismic energy released per year in Romania. Such a substantial concentration of earthquakes epicenters within a relatively small area is no longer found globally except the Hindu Kush region of the Himalayas (Lister *et al.*, 2008). The massive damage caused by the Carpathian subcrustal earthquakes cannot be explained only by their high magnitude but also by the interaction between the released seismic energy, the physical and geological characteristics of the soil, its distinctive chemical composition (the natural seismic wave propagation environment) and last but not least the types and quality of the structures built-in high seismic activity areas. Over time, many authors have focused their attention on the peculiarities of this unique geodynamic area, numerous tectonic models, some of them with a high degree of novelty and spectacularity being developed. Among the most important tectonic models, one can refer to those elaborated by Sperner *et al.*, 2001; Wortel *et al.*, 2004; Cloetingh *et al.*, 2005; Knapp *et al.*, 2005; Martin *et al.*, 2006.

The researchers attention has also focused on monitoring of the Vrancea seismic region by the aid of an extensive GPS observatories network, in order to highlight the land's movements in the

* Paper presented at the 5th GEOSCIENCE Symposium of the Romanian Society of Applied Geophysics, November 20–22, 2020, Bucharest, Romania.

range of the investigated area and to provide, as far as possible clear evidence of any observed anomalies. At the same time, an attempt was made to determine the crustal parameters based on data exclusively obtained from satellite measurements using GPS technology. Considering that the analyses carried out to achieve this main goal have incorporated a huge working volume, resulting in a comprehensive written material, in the present paper, the results of the first part of the study will only be presented, particularly the calculation of strain parameters.

2. VRANCEA 2000 GEODETIC NETWORK AND ITS SUBNETS – GENERAL CONSIDERATIONS

In 1997 the designed geodetic network was "centered" on the Vrancea seismic area; it has originally consisted of 25 points (Mateciuc, Bălă, 2020), which for reasons easy to understand, has also covered some of the neighboring regions of the concerning zone.

The network configuration includes five special points belonging to the CEGRN European network (Zoran *et al.*, 2008), points measured from 1995 in the framework of the CERGOP International Project at whose achievement Romania has also participated. The situation of the installed GPS observation points in the Vrancea 2000 network, in its extensive variant, as it will be analysed in this paper, is presented in Table 1 and Fig. 1. We must notice that only some of the 35 GPS observatories of the Vrancea 2000 geodetic network have been presented in Table 1, points which will be subject to the main further analysis.

Table 1

The GPS measurement points which will be further used in *Northern*, *Southern* and *extended Vrancea 2000* geodetic networks

No.	Code	Label	Location	No.	Code	Label	Location
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	[1] **TOPA**	*Toplița*	**Eastern Carpathians** *Neogene volcanic formations*	16	[16] **GARO**	*Garoafa*	**Eastern Carpathians** *Carpathian Foredeep*
2	[2] **POTO**	*Potoci*	**Eastern Carpathians** *Tarcău Fold*	17	[17] **BALT**	*Balta Albă*	**Eastern Carpathians** *Carpathian Foredeep*
3	[3] **BABU**	*Băbușa*	**Eastern Carpathians** *Carpathian Foredeep*	18	[18] **MIHA**	*Mihăilești*	**Eastern Carpathians** *Carpathian Foredeep*
4	[4] **POGA**	*Pogana*	**North Dobrudja Promontory**	19	[19] **CHEI**	*Cheia*	**Eastern Carpathians** *Ceahlău Fold*
5	[5] **BERE**	*Berești*	**North Dobrudja Promontory**	20	[20] **LUPS**	*Lupșa*	**Transilvanian Depression**
6	[6] **INDE**	*Independența*	**North Dobrudja Promontory**	21	[21] **ODOR**	*Odorhei*	**Transilvanian Depression**
7	[7] **IAZU**	*Iazu*	**Moesian Platform**	22	[22] **VOSL**	*Voșlobeni*	**Eastern Carpathians** *Neogene volcanic formations*
8	[8] **GRUI**	*Gruiu Căldărușani*	**Moesian Platform**	23	[23] **MOIN**	*Moinești*	**Eastern Carpathians** *Subcarpathic Fold*
9	[9] **CATE**	*Căteasca*	**Getic Depression**	24	[24] **MANA**	*Mănăstirea Cașin*	**Eastern Carpathians** *Subcarpathic Fold*
10	[10] **TUTA**	*Tutana*	**Getic Depression**	25	[25] **VRAN**	*Vrâncioaia*	**Eastern Carpathians** *Subcarpathic Fold*
11	[11] **CIRT**	*Cârțișoara*	**Southern Carpathians**	26	[26] **GURA**	*Gura Văii*	**Eastern Carpathians** *Subcarpathic Fold*
12	[12] **NADE**	*Nadeș*	**Transilvanian Depression**	27	[27] **ZABA**	*Zăbala*	**Sfântu Gheorghe Depression**
13	[13] **TAZL**	*Tazlău*	**Eastern Carpathians** *Subcarpathic Fold*	28	[28] **TUSN**	*Tușnad*	**Eastern Carpathians** *Neogene volcanic formations*
14	[14] **CLEJ**	*Cleja*	**Eastern Carpathians** *Carpathian Foredeep*	–	[-] **FUND**	*Fundata*	**Southern Carpathians**
15	[15] **FELD**	*Feldioara*	**North Dobrudja Promontory**	–	[-] **MACI**	*Măcin*	**North Dobrudja Orogen**

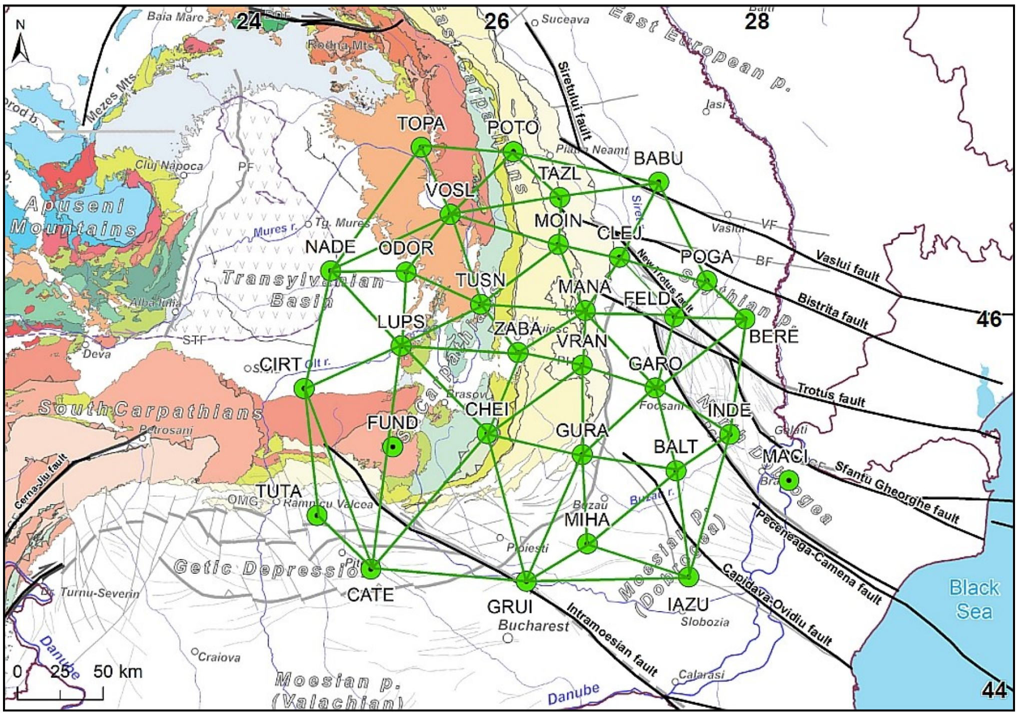


Fig. 1 – The *Vrancea GNSS network*, ● , GPS observatory belonging to Vrancea network; —— ,major faults; —— **,** finite elements mesh; ○ , towns.

3. RESULTS AND DISCUSSIONS

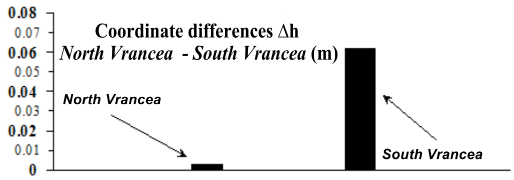
As it has been pointed out in a previous study (Mateciuc, 2010), the vertical movement field, subject to that investigation, is not uniform at all. So, it might be divided into two distinct sectors, separated by the Trotuș Fault:

- *the Northern sector*, materialized in the *Northern Vrancea subnet*, in which Băbuşa (**BABU** – 3), Tazlău (**TAZL** – 13), Moineşti (**MOIN** – 23), Pogana (**POGA** – 4), Vatra Dornei (**VTRA**, not included in this network, due to the destruction of the main marker), Feldioara (**FELD** – 15), Bereşti (**BERE** – 5), and Potoci (**POTO** – 2) observatories, characterized by small to very small vertical movements, in the range of 0.9 mm/yr, can be included in this subnet;
- *the Southern sector*, materialized in the *Southern Vrancea subnet*, which consists of Zăbala (**ZABA** – 27), Cheia (**CHEI** – 19), Independența (**INDE** – 6), Mănăstirea Cașin (**MANA** – 24), Vrâncioaia (**VRAN** – 25), Mihăileşti (**MIHA** – 18), Măcin (**MACI** – not included in this network due to the destruction of the main benchmark), Voşlobeni (**VOSL** – 22), Cleja (**CLEJ** – 14), Garoafa (**GARO** – 16), Tuşnad (**TUSN** – 28), Gura Văii (**GURA** – 26), Balta Albă (**BALT** – 17), Iazu (**IAZU** – 7), and Fundata (**FUND** – not included in this network due to the destruction of the main benchmark) GPS observatories, where vertical movements are much higher than in the North, in this case being included both the local and the regional components of the vertical movements (Table 2).

The two sectors of the Vrancea 2000 network are very different from the geodynamic behavior point of view. This may be easily observed by analyzing Table 2, where one can notice important differences between the vertical displacements in the two subnets. In Figs. 2 (a, b), 3 (a, b), 4 and 5, the two subnets *Northern* and *Southern Vrancea* are presented, and in Fig. 6, the entire *Vrancea 2000 network* is shown. This extended network sums all the GNSS observatories that form the two above mentioned subnets.

Table 2

Vertical velocities (mm/an) for *Northern* and *Southern* Vrancea GPS networks

Northern Vrancea Subnet				**Southern Vrancea Subnet**			
GPS location			**Δh (m)**	**GPS location**			**Δh (m)**
BABU	Δx = 0,0280 m	Δy = 0,0345 m	-0.0072	**ZABA**	Δx = 0,0310 m	Δy = 0,0323 m	0.0274
TAZL			-0.0054	**CHEI**			0.0245
MOIN			-0.0024	**INDE**			0.0076
POGA			0.0025	**MANA**			0.0253
VTRA			0.0054	**VRAN**			0.0256
FELD			0.0095	**MIHA**			0.0112
BERE			0.0081	**MACI**			0.0089
POTO			-0.0035	**VOSL**			0.0361
NORTH			**0.0009**	**CLEJ**			0.0289
				**GARO**			0.0207
				TUSN			0.0311
				GURA			0.0188
				BALT			0.0143
				IAZU			0.0052
				FUND			0.0238
				SOUTH			**0.0206**

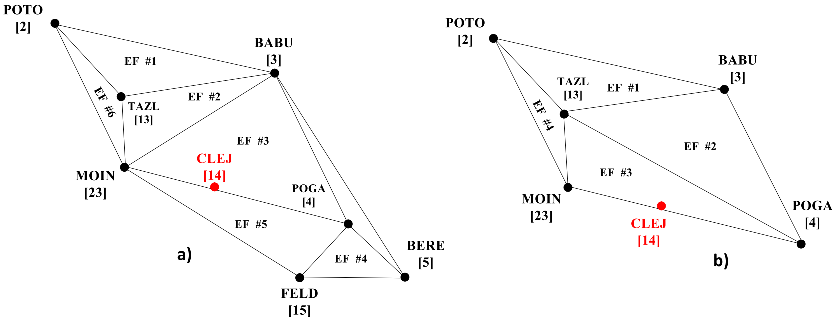


Fig. 2 – The *Northern Vrancea subnet*: a) the **original** finite element draft obtained from the meshing process; b) the **final** finite element draft obtained from the meshing process.

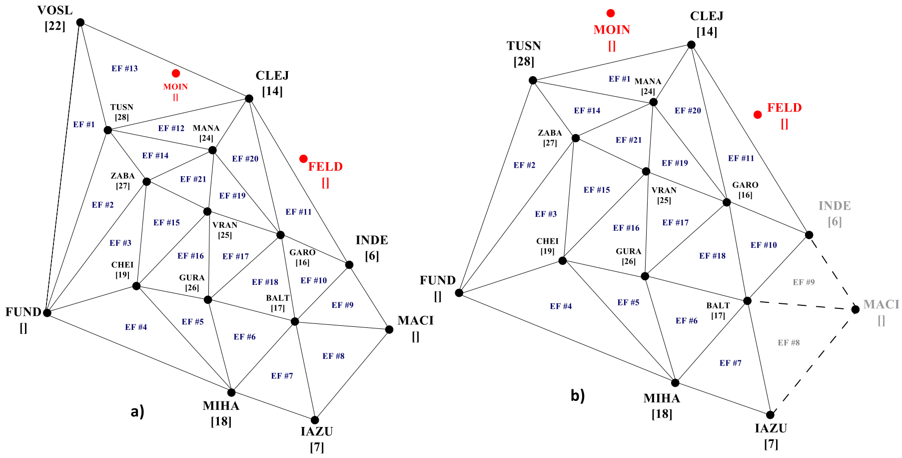


Fig. 3 – The *Southern Vrancea Subnet*, a) the **original** finite element draft obtained from the meshing process; b) the **final** finite element draft obtained from the meshing process.

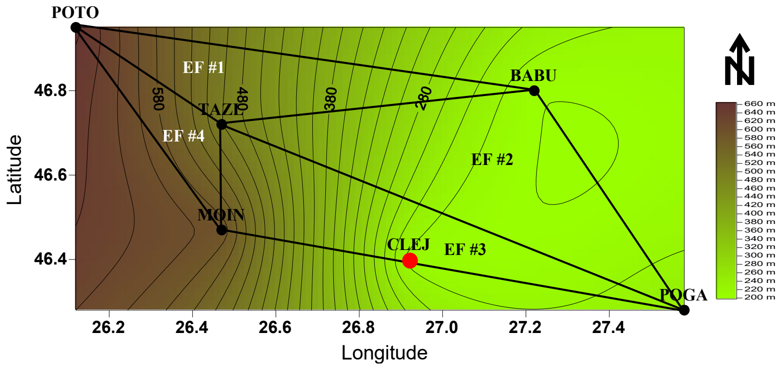


Fig. 4 – The *Northern Vrancea GPS network* map, the finite elements mesh which will be further used to compute the strain parameters, ● Northern Vrancea network nodes, ● **CLEJ** GPS measurement point which is part of Southern Vrancea network.

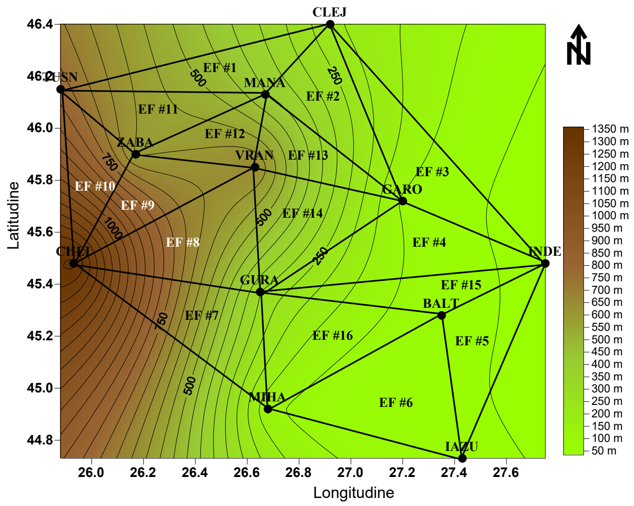


Fig. 5 – The *Southern Vrancea GPS network* map, the finite elements mesh, which will be further used to compute the strain parameters. ● Southern Vrancea network nodes.

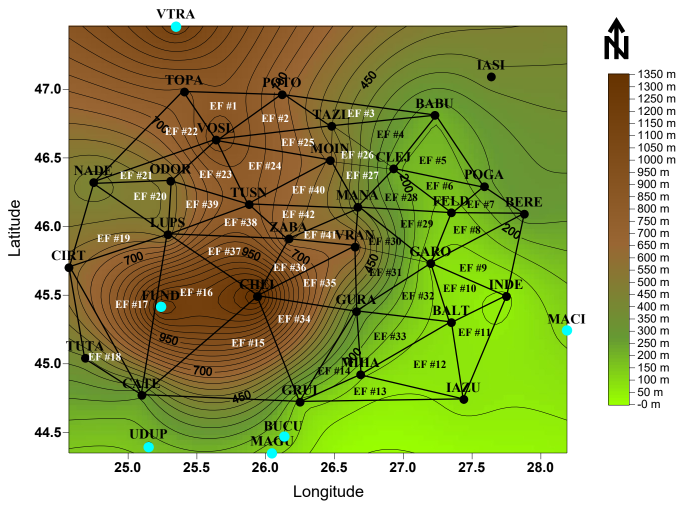


Fig. 6 – The *Extended Vrancea 2000* GPS network map, the finite elements mesh, which will be further used to compute the strain parameters. ● *Extended Vrancea 2000* network nodes.

What can be immediately observed in the case of the Northern Vrancea subnet is the relatively small number of GNSS observatories which it is composed of. This would not be still troubling if the subnet's geometry would be proper for the finite element method approach in strain parameters determination. Unfortunately, as it can be easily seen in Fig. 2a, the *Northern Vrancea subnet* geometry is unsatisfactory, meaning that one of the basic and most important conditions required in Delaunay triangulation theory, namely that the finite elements should be as close as possible to an equilateral triangle shape is not complied with, especially in the case of finite elements #5 and #6. Also, in Fig. 2a it was represented by a dotted line another connecting possibility, with the formation of a new finite element, **BABU – POGA – BERE**. In this case, the new finite element does not comply at all with the above theoretical constraint and was considered totally unsatisfactory and removed from the mesh. Another observation might be made in relation to the position of the Cleja GPS measurement point (**CLEJ**), which, although it belongs to the Southern Vrancea subnet, taking into account the vertical velocity movements recorded in this point, is physically located within the Northern Vrancea subnet, at North of the Southern Trotuş fault, considered as being the boundary between the two subnets. In order to get rid of this significant inconvenience, the only possibility left is to remove all the SE part of the subnet, that means Feldioara (**FELD**) and Bereşti (**BERE**) GPS observatories, so, the Northern Vrancea subnet now consisting only of 5 measurement points and 4 finite elements, as it is illustrated in Fig. 2b, which, although it is far from being optimal, has at least the most important advantage of a "stranger" observation point removal. Fig. 2b shows the discretization scheme, which will be further used.

Figs. 4, 5, 6 illustrate maps of the Northern Vrancea subnet, Southern Vrancea subnet, and Extended Vrancea 2000 network, highlighting the measurement points' heights. All the results obtained after calculating the components of the deformation tensor have been synthesized in data tables, and all data obtained from individual FE tables were systematized into a single database table, so the deformation maps shown in Figs. 7, 8 were built.

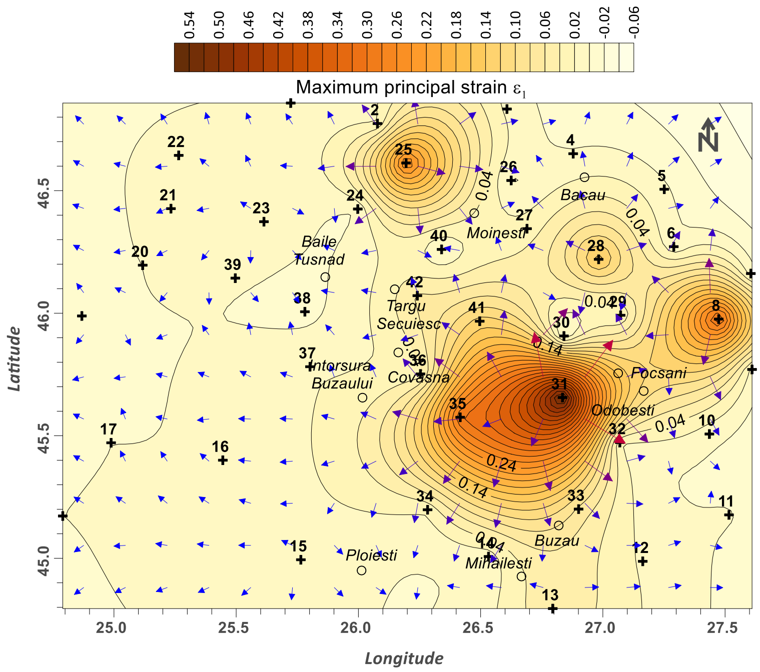


Fig. 7 – *Extended Vrancea Network*, ε_1 field map (μstrain) × 10^5;
→ , ε_1 vector; + , FE weight centre; ○ major cities.

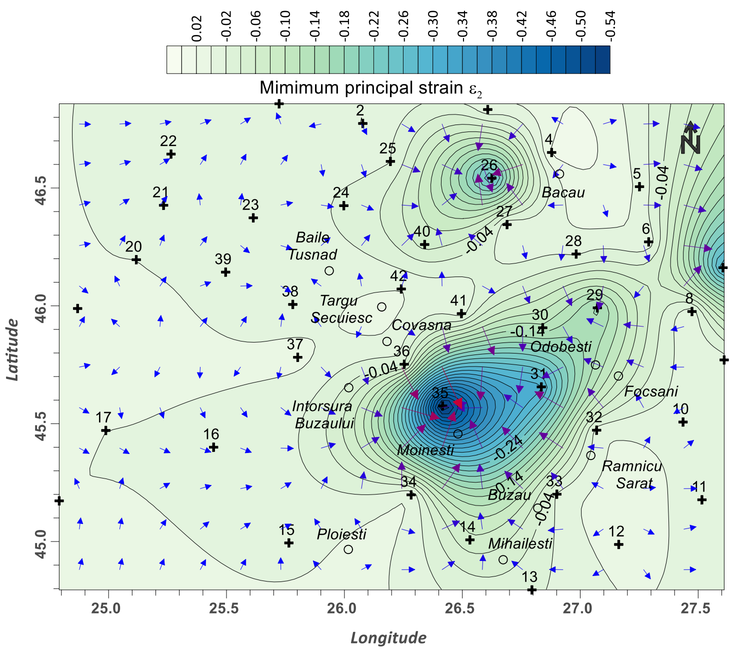


Fig. 8 – *Extended Vrancea Network*, ε_2 field map (μstrain) x 10^5; →, ε_2 vector; + , FE weight centre; ○ major cities.

4. CONCLUSIONS

A first conclusion that can be drawn by analyzing the values of the principal strain ε_1 and ε_2 (Figs. 7, 8) is related to their relatively modest size. In this way, we can say that in the analyzed region, nothing spectacular happens, as a visible effect on the land' surface.

There are no large movements, in the order of centimeters per year, even more, characteristic of other areas with very important seismicity.

An argument of the low values of the calculated strain parameters may be explained by the short time interval between the sets of measurements, only two years, which led to very small displacements, also reflected in the size of the specific deformations, but also by the very small GPS points velocities, located somewhere to the error limit of the method. Another fundamental observation that can be deduced from the preliminary study of the deformation parameters is related to the existence of a pair of compression – extension values for the vast majority of the finite elements of the network. Thus, it can be easily noticed that in a proportion of about 90% (34 of the 38 values taken into account) the values of the maximum principal strain ε_1 are positive; on the other hand, the values of the minimum principal strain ε_2 are negative in the same proportion of about 90% (34 of the 38 values taken into account). In addition to the "normal" behavior of the deformations within the finite elements with positive and negative pairs for the components ε_1 and ε_2, there are different behaviors, without being able to speak of anomalies, in which both values are positive, in the situation of the finite elements #2, #4, #12, #37 or both negative for finite elements #26, #30, #38, #40. In neither of the two atypical situations presented, one cannot speak of the existence of any demonstrable correlation with specific geological structures.

However, a series of observations can be made from the analysis of the results. First, it should be noted that, as expected, the perfect correlation between the area with maximum seismic crust activity (finite elements #29, #31, #32, #33, #35) and the strong anomalies in the field of crustal deformations, whose overlap is almost exact. If the crustal seismic activity inside the finite element #31 is well-highlighted, the same for finite element #32, the same cannot be said in the case of the finite element #36, where the seismic crustal activity is almost absent. However, there are subcrustal earthquakes, but from this simple finding until to generalize and to admit a significant influence of the subcrustal seismic activity to the surface is a long way. In the NE part of the analyzed area, within finite elements #7, #8, #28, there is a moderate disturbance of the minimum principal strain field, which may be somewhat related to the crust activity, although here the number of surface earthquakes is relatively low, located exclusively within the finite element #8, the other finite elements being practically aseismic.

Acknowledgments: This paper was carried out within "*Nucleu Program MULTIRISC*", supported by MEC – Romania, project no. PN19080201 and Project no. 18PCCDI/2018, supported by UEFISCDI – Romania.

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Received: November 25, 2020
Accepted for publication: December 10, 2020