13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 2444

FORENSIC ENGINEERING STUDIES ON HISTORICAL EARTHQUAKES IN ROMANIA

Emil-Sever GEORGESCU[1]

SUMMARY

The paper evaluates data on Romanian historical earthquakes, with consideration to the following aspects:

- study of the shape and size of the actual "Vrancea epicentral area", the territorial extent and damaging potential of strong intermediate earthquakes, for magnitudes around Richter 7 and intensities from VII to IX, using forensic engineering approaches for sites and situations where the historical damage contradicts zoning maps;
- study of the actual "shielding effect" of the Carpathian Mountains in Transylvania and of the "seismic shadow" combined with remote amplifications in Moldavia, vs. actual intensities;
- comparative study of damage patterns and associated intensities of greater historical motions in Romania, including the 1802 and 1838 earthquakes, the greatest in history.
- forensic engineering study of the damage and collapse mechanism of Coltzea Tower, the tallest structure in Bucharest, during the 1802 earthquake; study of damage patterns of slender towers vs. rigid structures and their correlation with the spectral content of earthquakes in Bucharest.

Results can be useful for better calibrations of new seismic zoning maps in Romania, to compensate the lack of instrumental data, since the newly introduced mean recurrence intervals of 100 and 475 years in earthquake design codes require additional data on long time periods, comparable with historical ones. A careful and interdisciplinary work for the conversion of historical data into intensities and/or PGA, EPA etc. is necessary.

INTRODUCTION

For a long period (in Romania it lasted until 1990) the engineers relied only on historians', seismologists' and geologists' data as input data for zoning maps and seismic forces in their structural calculation. The lack of local instrumental data bitterly affected the validity of engineering applications in earthquake resistant design, until 1977, when the first acccelerogram was recorded at INCERC site, leading to the first locally calibrated spectral curve in Romanian earthquake code P100-1978, Georgescu [1].

In the mean time, a lot of work was devoted in both seismological and engineering branches to improve and develop new maps and codes at European and global scale, that triggered again the concern about

[1] Ph.D., C.E., The National Institute for Building Research – INCERC, Bucharest, Romania. E-mail: ssever@cons.incerc.ro

historical earthquakes (see the last decade's Proceedings and resulting catalogues and zoning maps of ESC, UNESCO-IUGS, IASPEI, GSHAP etc.).

After a first attempt of recovering the information of the past ages, after the earthquake of March 4, 1977, the involvement of Romanian engineers in the study of historical earthquakes kept a low profile, except the work initiated since 1990 in INCERC. The need to convert past data (expressed in intensities) in new parameters as PGA, EPA, with return periods of hundreds or thousands years etc, was chalenging, and paradoxically the seismologists' team preserve some momentum in comparison with engineers, at lest in their attempt to a global view.

Under these circumstances, the intention of this paper is to point out some preliminary data that resulted from recent forensic studies on Romanian historical earthquakes.

CASE STUDIES OF MAJOR HISTORICAL VRANCEA EARTHQUAKES

Patterns of historical earthquakes in Vrancea area

The Romanian earthquake data base with I_0 over 6.0, include more that 180 events since 984 A.D, until 1900 A.D., mostly of Vrancea intermediate source; along of a thousand years, several tens of earthquakes caused epicentral intensities over VII MSK. Unfortunately, besides the some rather historical and merely classical seismological evaluations, the events of XV-th, XVI-th and XVII-th centuries have been not given attention by today's' earthquake engineers, although the damage was large and intensity over VIII MSK in some sites. [2].

Less damage data are available for the earthquakes of 1230 (M_l = 6.9, I = VIII), with reported damage in Ukraine, 1516 (M_l = 7.2 ?, I = IX ?) and 1545 (M_l = 6.7), while for August 10, 1590 (M= 6.7…6.9 ?, I_{max} = VIII-IX) there are damage reports from Transylvania.

The earthquake of November 8, 1620 (M = 6.9, I_{max} = VIII-IX) caused large damages, collapses and geological effects in Southern part of Romania, in Transylvania - Brasov, Sibiu, etc., where some important buildings were damaged and defense towers collapsed. It was an earthquake in August 9, 1679 (M_l = 6.7, I_0 = 8). The earthquake of 18 August 1681 (M_l = 6.7, M_w = 7.1, I_0 = 8) damaged a dungeon in Suceava Fortress, in Moldavia.

Concerning the XVIII-th and XIX-th centuries, we do know more even about the earthquakes of June 11, 1738 (M_s= 7.5, M_w = 7.7, I_{max}= 9.5 MSK), 1740 (I_{max}= 8.5 MSK), April 6, 1790 (M_l = 6.7, M_s= 6.8, I_{max}= 8 MSK), November 26, 1829 (M_l= 6.4….6.9, M_w = 7.3, I_{max}= 8.5 MSK), Janury 23, 1838 (M_s= 7.3, M_w = 7.5, I_{max}= 9 MSK), November 13, 1868 (M = 6.4, I_{max} = VII-VIII) etc. Some of the damage data are more detailed, but we still miss a thorough analysis to derive an improved picture of the territorial extent of intensities. Thus, only a part of the earthquake engineering data have been evaluated with today's' approaches, while the bulk of unexploited data is greater.

The 20-th century data base includes over 100 motions having magnitude over 5.0, and those of 1903, 1908, 1912, 1929, 1934, 1945 şi 1948, have been reportedly quoted with over VII MSK epicentral intensity, that must have been damaging but not studied.

One of the basic difficulties in evaluations is the difference between different catalogues and historical use of various meanings in what concerns the "macroseismic intensity", "area with felt motions", "area with damage" or " macroseismic area". As a general pattern, in the fig. 1, one can remark that the macroseismic area in this group of 10 motions reflects the general patterns attributed to all Vrancea motions, i.e. the smoothed ellipses oriented NE-SW, Moscalenko [3]. Study of the shape and size of the actual "Vrancea epicentral area" was a matter of concern for many Romanian geologists and seismologists, as well as of Russian seismologists. Several authors considered that the 1802 earthquake ellipses have a slightly different orientation, more obvious of the area with I = IX MSK, while other earthquakes obviously show “shifted ellipses” towards N-E or S-W.

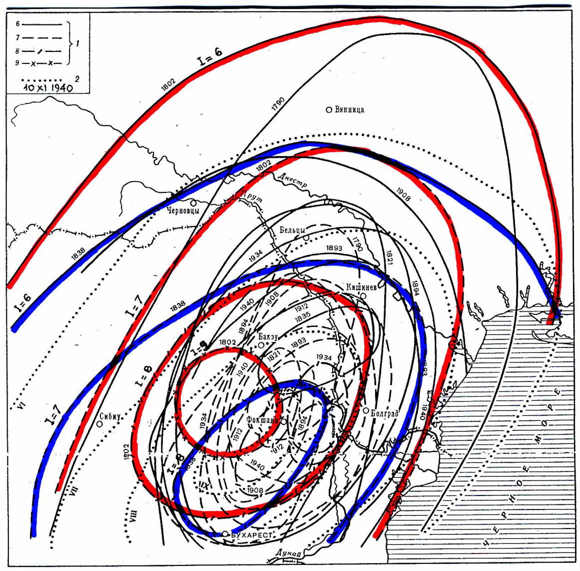

Fig. 1. Areas affected by different intensities in case of 10 Vrancea historical earthquakes. Isoseismal lines of 1802 motion (in red) and 1838 motion (in blue) are thicker (adapted after Moskalenko, 1980) [3].

The earthquake of August 29, 1471

The earthquake (M = 6.7, I_{max} = VIII) was felt as a great Vrancea motion, in all Romanian Kingdoms, with large structural damage to rather stiff buildings in Brasov, great damage in Princes’ Palace in Bucharest etc. The event is reported by some historians emotionally, without proper concern about the site of impact and damage (Suceava Princely Fortress, in Northern Moldavia). Some cronicles describes the collapse of Neboisa Defence dungeon. It should be mentioned that at that time it was the strongest citadel of the Ruling Prince Stephen the Great, the stone walls have been of some 1…1.10 m thickness, thus a strong damage or collapse could have been possible in case of an intensity over VII-VIII MSK.

The historical studies mention that the citadel was built by foreign masters in the XIV-th century, thus the local knowledge about earthquakes might have been not used. The local slopped site might have been an additional reason for damage. Te citadel was repaired and completely reinforced in 1476, after the siege of Mahomed the Second, the conqueror of Constantinople, with additional walls of 2.5 m.
Thus, since a provoked fire in 1675 damaged the citadel, the earthquake of 1679 (M_L = 6.7; I_0 = VIII) badly damaged it and it was then dismantled by Ottomans order of political reasons. It is interesting that other sources claims that the Neboisa Dungeon collapsed due to the earthquake of 18 August 1681, fact that can be explained only by previous fire damage, since the structure was very strong.

While the seismological map (SR 11100-1993) indicates VI MSK, the maps of seismic coefficient and corner periods in Earthquake design Code P100-1992 indicates an equivalent intensity of VII MSK. Thus, the remote seismic effects at some hundreds kilometers in Northern Moldavia and the possible mecahnism of transfer along the roots of Eastern Carpathians must be reevaluated, and given a scientifically established credit.

The earthquake of May 31 / June 11, 1738

The motion is considered to be of M_L = 6.9; I_0 = VIII-IX (M=7.0), M_S= 7.4..7.5, I_{MAX}= 9.5 MSK. It is peculiar in the large damage caused to many monasteries, towers and turrets, at I = VIII in Bucharest, Jassy, Brasov, South-West of Wallachia, as well as by visible faults, big stones overturning in Buzau River Walley (near Vrancea). Some collapses of 4 mosques (or minarets ?!) in Nicopole (on Danube) may indicate a long period motion (?!). All this damage was not studied and territorially correlated in due extent.

The 1802 earthquake (M = 7.5…7.8, M_w = 7.9, I_0 = IX-X MSK, I_{Buch} = VIII…IX? MSK)

The 14/26 October 1802 earthquake (data are given in two types of calendars) is considered by far the greatest in the history of Romania, called “the Great Earthquake” in chronicles and other documents, with an assessed magnitude of 7.5…7.8 Richter. The extended area of its effects or perception is very large, reaching west border of present Romania, while at European scale the macroseismic area was well more that 2 million square kilometers. (Fig. 1 and 2) [4, 5, 6].

Ludwig Heinrich Jeitteles (1860) [15], provides damage description and a map of area of effects for 1802 and 1838 earthquakes in Transylvania and Hungary. The damage was major in Brasov, Rasnov, Bod, Bretcu (ground faulting), but less powerful in Sibiu and Sighisoara. It was felt in Timisoara. Remote effects are attributed to Bucharest (Coltzea Tower, St. Nicolas Church, rumours about victims), Craiova (South of Romania, Vidin, Rusciuc, Varna (in today Bulgaria), Istanbul, Bessarabia, Kiev, Lemberg, Varsovia, Kaluga, Tula, Moskow (very strong ?!), Italy.

Romanian studies Popescu [4], suggested a rather vertical, ellipse, longer for 1802 motion, reaching in East Istanbul, Crimea Peninsula, Harkov and Moskow, in North Leningrad (Sankt Petersburg), in West Warsaw and Budapest, in South Athens; according to the author, the area of 1940 Vrancea earthquake differs in its Southern limit that is Thessaloniki.

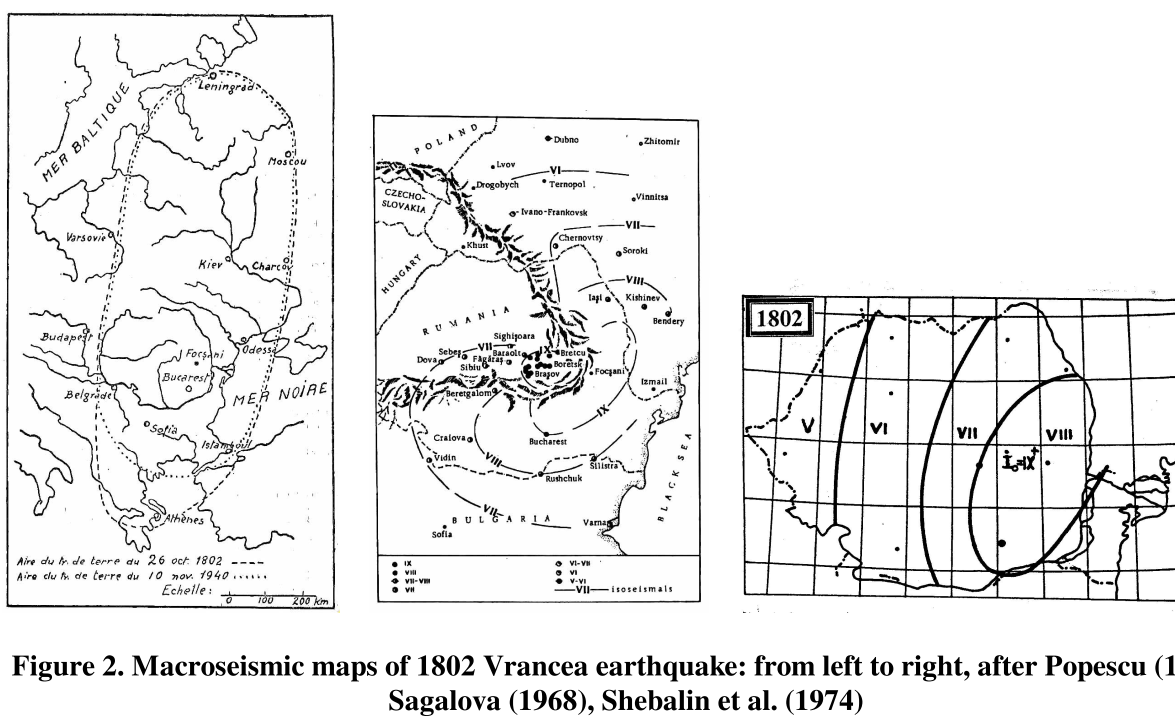

Figure 2. Macroseismic maps of 1802 Vrancea earthquake: from left to right, after Popescu (1941), Sagalova (1968), Shebalin et al. (1974)

Russian studies, E. A. Sagalova, 1964, quoted in Medvedev, 1968; 1976 [5], analyzed Russian and Romanian data, and drafted isoseismal ellipses that include Bucharest in the intensity IX, as for epicenter, while in Brasov area some Western extension of the IX intensity is given; the other areas of VIII intensity reached in South Craiova, at Danube, at Russe and Silistra, In North-East reached Jassy and Chisinau (VIII-IX), the VII intensity reached in West, Deva, Sebes, and Sighisoara, in South Vidin and Varna, while in North it passed over Cernautzi and Soroca. The author considered that 1802 effects overwhelmed the 1940 ones, while in 1802 the epicentral intensity of Vrancea zone was higher that in any other earthquake. Another well known source, N.V. Shebalin et al., 1974 [6], considered that 1802 earthquake was of M=7.4 Richter or M_s=7.5, epicentral intensity I=IX$^+$ MSK, with ellipses oriented much more towards North than in case of other Vrancea earthquakes; its ellipse of intensity VIII reaches Danube, including Bucharest, then arrives quite at Jassy and Chisinau; Sibiu and Cernauti are in VII MSK, Kiev in I=VI MSK, Moskow in I=IV-V MSK, Istanbul in I=V-VI MSK. Tatevosian and Mokrushina [7] evaluated numerous sources about 1802 earthquake and derived a table of 81 data points from the available isoseismal maps, many graded as 8-9 intensity, in the Transylvanian sites. On the other hand, they concluded that some reports of damage in Moskow and Istanbul were wrong.

The forensic research about a unique structure behavior during the Great 1802 Earthquake

The collapse of Coltzea Tower during the 1802 earthquake is the main issue of all diplomatic reports, news and correspondence of that age and later on. The Austrian Consul Merkelius in Bucharest promptly reported the generalized earthquake effects, with only few death cases and the collapse of Coltzea Tower, next day after.

As we miss a scientific analysis of the causes and patterns of this contradictory pattern of damage and collapse of Coltzea Tower at Vrancea earthquakes, the forensic research has the following objectives and phases [8, 9]

- gathering of historical and seismic data: recovery of the general tower characteristics; alternative/comparative, multicriterial structural-architectural hypotheses;
- recovery of historical and seismological data on 1802 motion and damage, as well as about other towers behavior in earthquakes;
- study of damage patterns of slender towers vs. rigid structures and their correlation with the spectral content of earthquakes;
- study of the actual “shielding effect” of the Carpathian Mountains in Transylvania and of the “seismic shadow” in other areas;
- correlative evaluation of patterns and size of 1802 motion:
    - assessment of the 1802 earthquake patterns in Bucharest central area;
    - the correlation of the damage data with the local site conditions of the central area, possibly about the motions with a spectral content able to affect slender structures.
- evaluation of the dynamic model and damage mechanism of Coltzea Tower during 1802 earthquake:
    - alternative, detailed dimensional and materials characteristics;
    - select and evaluate dynamic models and damage mechanisms during earthquake;
    - derive conclusions about the characteristics of 1802 earthquake, useful for microzonation and earthquake protection of tall buildings.
- feasibility study and project for a possible reconstruction of the Coltzea Tower / model.

The Coltzea Tower

This architectural and historical master piece of Middle-Age heritage in Romania (whose Southern part was the Kingdom of Wallachia), the Coltzea Tower of Bucharest, was built in the period 1710-1715 by order of the Great Landlord and High Army Commander, (“Spatar”) Mihai Cantacuzino.

The main data on structure can be found in the drawing published by Oteteleseanu, 1838 [8, 9], as it was “initially” built (Fig.3, left). Besides Doussault engravings, Angerer in 1856 and Szathmary in 1869-1870 left us some photographs (Fig. 3, center and right), while Niculescu got images before the tower was demolished (1887 -1888). The Coltzea Tower was a main gate and bell tower of the Coltzea Monastery. It was the first building of this kind and height in European / Germanic style, in the Kingdoms of Wallachia and Moldavia. The thick walls were made of masonry, the strong foundation walls of raw stone. The entrance gate was on the ground floor, under a large vault, having buttresses at corners. [8, 9, 10]

Figure 3. The Coltzea Tower between 1715 and 1802, (Drawing by N. Oteteleseanu 1838), (to the left) and the damaged Tower, repaired after 1847, with additional timber stories for firetower, as seen from the East side (middle photo) and West side (right photo) (Photos around 1869, by Carol Popp de Szathmary) [8, 9]

The intermediate floors were presumably on timber beams. The mid-height floors decreased in width and included a room with sculptured door frames leading to an open terrace supported by stone cantilevers with lion heads/gargoyles. The roof was very sloped, with four small corner lanterns and covered with tiles. There was a watchtower at the top, under a conical roof, two quite spherical additions covered with tin and a large cross. The total height was believed to reach ca. 54 m [Panait, 1970] [11]. The foundations were built in stone and bricks, as a rough rectangle on an area of 10.50 m by 9 m, with the depth of 1.6 m, a double H plan, of some 100 m^2, with a current width of Tower of ca. 7 m of East and West facades and of ca. 7.5 – 8.5 m on North and South facades. Archaeological excavations Panait [11], proved the vernacular building techniques and materials, at lest for underground remnants. Unfortunately, the foundations were partly destroyed in the 1980's, by the subway tunnel trench.

Forensic engineering study of the damage and collapse mechanism of Coltzea Tower, the tallest structure in Bucharest, during the 1802 earthquake

The "History of Bucharest", Ionnescu-Gion, 1899 [12], mentions that in 1802 the upper part collapsed, falling towards North – East, confirming the general direction of isoseismal ellipses caused by great Vrancea earthquakes. The remaining part showed corner damage towards N- E, below the former level of the clock, as represented in the drawings of Doussault in 1843 and in other photographs in 1856, 1870 and 1887. After the collapse, of the upper part in the 1802 earthquake, the remaining part withstood until 1888, when it was demolished for urban planning purposes. For all these reasons, the Coltzea Tower was for more than 170 years the highest, the most known, and quoted building, an urban mark and symbol of the Bucharest City.

The present forensic analysis of all images pointed out that that the lower part of the Tower was not even cracked even after almost 170 years of existence, despite being subject to at least 18 large Vrancea earthquakes (magnitude over M_s= 6, intensity over MSK= 7). Out of these, the Coltzea Tower resisted the earthquakes of 1738, 1740, and 1790. The remained part resisted some other large earthquakes, as that of 1829 and 1838 etc. Since many other buildings have been entirely destroyed by these earthquakes, the behavior of the Tower can be considered as a proof of a Local Seismic Culture.

Multicriterial forensic analysis to explain seismic behavior of Coltzea Tower [8, 9].

For a long time, this beautiful and impressive, although unusual building, was considered by the popular tradition and belief of many historians, to have been built by some Swedish soldiers, or even by King Charles XIIth, after the Poltava battle of 1709. Some travelers of the age have compared the Coltzea Tower with the San Marco Tower of Venice or with St. Stephan Tower of Vienna. Different sources of inspiration may explain the unusual aspect and architectural patterns and earthquake behavior of Coltzea Tower, Georgescu [8,9]. In order to evaluate the alternatives, we used several criteria:

- historical criterion: the source to have been built long enough before 1715, in order to have time to enter in the architectural practice as a model;
- criterion of distance: the source to be in a zone where the builder usually traveled;
- criterion of relevance: the borrowed patterns to be enough similar to the originals;
- seismic criterion: which are the patterns that may provide earthquake resistance.

Concerning the possible sources from Europe, some influence of San Marco Campanile can be accepted. The addition of the upper terrace gives some similarity with the campanile of Palazzo Vecchio in Firenze, Palazzo Pubblico in Siena, while the four small corner towers of bell tower of Duomo in Siena may prove another source. In case we shall consider this type of campanile “imported“ from Italy, we may understand that shallow earthquakes produce short period motions and for slender structures the resonance do not occur [8, 9].

In countries with Germanic culture heritage, the very common towers of Gothic age have most of Coltzea Tower patterns in closer countries as Austria, Hungary, Slovakia or distanced territories as Germany, Switzerland, France, Holland, Denmark, England, Sweden, Norway, etc, mostly in non-seismic zones or from countries of Germanic civilization, where earthquakes are not frequent.

Concerning the alleged Swedish sources, some engravings present bell towers at the Cathedral of Strängnäs (1631 and 1723), Riddarholmskyrkan Cathedral in Stockholm, Katarina Kyrka of Stockholm, tower Jäders Kyrka, Södermanland; the modern architecture of the City Hall Tower - Stadhuset, 1911, Stockholm) continued that pattern. Anyway, the way of an allegedly Swedish involvement is not yet proved; reference authors, Sulzer, 1781 [13], Cernovodeanu, 1966 [10], admitted at most that some soldiers could have been barely engaged in some final works, as masters, workers, or even painters. Although there was no time for a direct involvement of King Charles XIIth in all works and he did not pass in 1714 through Bucharest, other officials from his staff did and they visited the plundered Castle of Brancoveanu at Mogosoaia. [8, 9].

The strength of the legend and the reported painting of Swedish soldiers on gate buttresses in an engraving by Pappasoglu [14], concerning the height, functions and appearance of the upper part could have been transmitted to Cantacuzinos by some secret messengers or Swedish soldiers in disarray. A German / Transylvanian master of works could have been required at least for the installation of clock and bells manufactured in Wien [8, 9].

Concerning the possible sources from Romanian Kingdoms, the bell towers of a Wallachian and Moldavian type are squat and stiff, Romanic patterns, preserved during history due to seismic conditions and their defense role. [8, 9]. There is a certain architectural and conceptual influence from the Transylvanian area of German colonists burgs (Siebenbürgen). Such tall towers built before centuries XVI-XVII still exist, a lot have a slender shape and preserves many basic patterns as Coltzea Tower had, as follows:

- in Sibiu (Hermannstadt), the belfry of Evangelical Church – 73 m, damaged by earthquake in 1586 ;
- Sighisoara (Schässburg), the bell tower with clock – 64 m;
- Turda (Thorda), the tower of Reformed Church – 60 m, having clock and turrets;
- Medias (Mediasch), tower of 70 m and Saschiz stiffer defense tower;
- Brasov (Krönstadt), the 58 m height tower of Burg Council is depicted in 1646 as very similar to Coltzea Tower, while later on some reconstructions changed a little bit the features, apparently decreasing its height, probably because of repeated Vrancea earthquakes.

Other slender or squat towers still exist in peasants' fortresses or German colonists' settlements as Cisnadie, Cincu (Grosschenk), Harman, Bod, Codlea (Zeiden), Feldioara (Marienburg), Rotbav (Rohrbach), Sanpetru, Prejmer (Tartlau), Biertan (Birthälm). In Bistrita, quite far from Vrancea seismic zone, there is a very slender tower with a perimetral balcony, rebuilt by Petro de Lugano in XVI-th century. Some Romanian bell towers in Maramures, in North, have a similar appearance, but are made in wood.

Therefore the Coltzea Tower can be seen a combination of a local materials, techniques and type of tower in the lower part, with an Italian open terrace with rich ornaments and Germanic or Gothic patterns in the upper part (clock and roof). The mixture of structural and architectural patterns taken from seismic and non-seismic zones may explain the weakness of the upper part in comparison with the lower part.

Concerning the extent of Vrancea earthquakes in Transylvania, and the alleged shielding effect of Carpathian Mountains, the German chronicles wrote about the collapses and repairs or reconstruction of churches or bell towers in Sebes (Mühlbach), Sibiu (Hermannstadt), Brasov (Krönstadt) etc. [8, 9]. The masters of Transylvanian important buildings were often invited from central and Western Europe, and we shall stress out that in the less seismic areas, the European builders could have not been aware about the likely seismic resonance effects in case of slender structures.

The height and slenderness of Germanic towers in Transylvania decreases, as well as ratio of openings in walls, when they are closer to Vrancea seismic source. On the other hand, in the initial architecture, some bell towers were independent, but later on they were incorporated and connected to the main nave building, thus the free part being rigid and less vulnerable to Vrancea motions (see the Evangelical Church in Sibiu).

For local masters, there was a learning process along the historical time, as the local seismicity of Transylvania (given by Vrancea source) has shown the patterns, and the structural types taken from the Western Europe, a less sesimic area, became adapted gradually to the local conditions.

Concerning the correlation between historical damage and the collapse of tall and slender buildings during earthquakes in Bucharest, such as in 1940 (M = 7.4) and 1977 (M = 7.2), the first accelerogram useful for engineering purposes was obtained in Romania in March 4, 1977 earthquake at INCERC Bucharest site. The long period spectral content was obvious and the damage of slender structures was very spread. The Carlton Building (14 stories, the tallest reinforced concrete structure in Bucharest), that collapsed due to the November 10, 1940 (M=7.4) earthquake, is located close to the Coltzea area, fact to be associated with the remark that Vrancea earthquakes of 1940 (M= 7.4) and 1977 (M= 7.2) were more damaging for tall buildings.

Thus, the 1802, 1940 and 1977 earthquakes may represent successive warnings about the risk of using slender structures under the specific site conditions of Bucharest, Georgescu [8, 9].

The 1838 Vrancea earthquake ($M = 6.7…6.9$, $M_s = 7.3$, $M_w = 7.5$, I_{max} = VIII…IX MSK)

The Catalogue of the Romanian seismologist C. Radu assessed the magnitude as Gutenberg-Richter 6.7, the Catalog Kondorskaya and Shebalin indicates 6.9, the catalog Constantinescu-Mârza indicate $M_s = 7,3$, while Moldoveanu and Panza give $M_w = 7,5$. Epicentral intensity I_0 was evaluated as 8 by Radu, and 9 by Constantinescu-Mârza. An isoseimal map of Medvedev (1968), fig. 1, compared the 1838 and 1940 earthquakes for the east of Romania, the 1940 one being considered as larger.

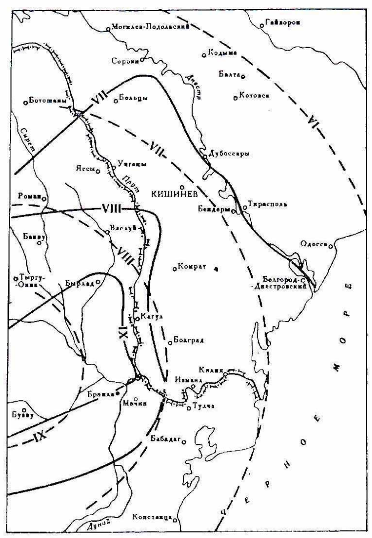

Fig. 4. Macroseismic intensities of 1838 and 1940 earthquakes in East of Romania, Bessarabia and Russia. Full lines are for November 10, 1940, while dotted lines are for 11/23 January 1838 earthquake (Medvedev, 1968)

The macroseismic area and associated intensities have been historically assessed by Ludwig Heinrich Jeitteles (1860), Perrey (1846), Medvedev (1968), Moskalenko, (1980); these sources confirm a large European area, but reduced in comparison to 1802. Ludwig Heinrich Jeitteles (1860) [15], provides damage description and a map of area of effects for 1838 earthquake in Transylvania, Hungary, Russia, Turkey, Italy, Poland. He quotes 12 deaths and 40 wounded in Bucharest in 1838. The Vrancea epicentral deformed ellipse is limited to Carpathian curvature, but the impact in Transylvania seems to be greater that in other cases, reaching the West and North -Western areas, as Cluj, Timisoara etc. Memories of Perrey, relates the seismic perception in Istanbul, Odessa, Sibiu, Brasov, Orsova.

Forensic data about the 1838 disaster in Bucharest

The most circulated image of this eartqhuake is a wood engraving with a text in German: „The terrible earthquake of the Bucharest town in Wallachia, of January 23, 1838”. The pair of drawings in this image have been considered since then as a „true” report of disaster reported in the text, but the reality seems to be different. As it was the case of other engravings, they were most probably manufactured somewhere in the Germanic culture area of Europe, showing some stereotype patterns. [16, 17].

Thus, the church structure is not a local type one, the collapse of entire „block” masonry building is not possible, although there is no snow, there is a sledge with horses and pasengers, seems to be just catched under it quite artificially…The collapse mechanism of chimneys and towers is unrealistic but similar to the „Nuremberg style” of the ages…

The text itself seems to originate from a foreigner that lived in Bucharest, it contains some actual and other possibly less realistic data, as the damage to masonry buildings, to St. George Monastery are confirmed, but official data indicated quite few victims. Thus, the number of fires deaths by suffocation, as well as the woolfs entrance in town can be a rumor or fantasy

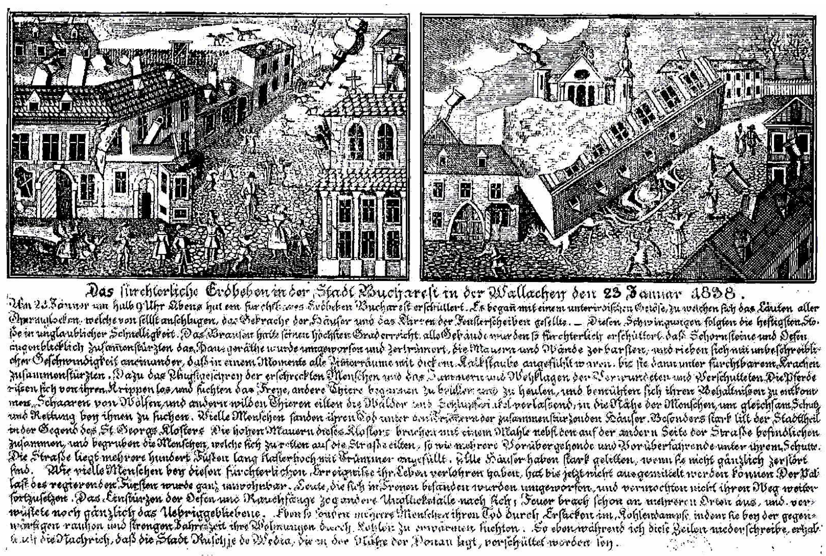

Fig. 5. Earthquake of January 23, 1838, in Bucharest.
(Wood Engraving, Romanian Academy Collection)
After A. Corbu, Bucurestii vechi – Documente iconografice, Bucuresti, 1936. [16]
See also Kozak Collection, NISEE, Berkeley, USA [17]

The damage and the public perception of 1838 earthquake

This event is often compared in size with the 1802 one, being quoted immediately in the local and foreign media. The officialy reported losses were: 8 deaths, 14 injuries, 36 collapsed buildings, some 4 churches collapsed and 50 badly damaged including the Princely Palace, in Bucharest. Later on, less credible memories quoted that in Bucharest the death toll could have been of 600 persons and 600 injured, as well as many out of mind people, rumours!

The 1838 earthquake was officially investigated in Bucharest and all counties. It resulted that villages and towns located on walleyes suffered more damage, but one should know that some villages were newly located in such places. The damage was larger in case of landlords' manors, churches, bell towers, gambles etc., possibly because of the cumulative effects of earthquakes of 1802, 1812, 1821, 1829, 1831 and 1835. All these effects may lead in 1838 to an intensity of VII-VIII MSK on large areas in South of Romania. Some witnsesses quoted that „the duration of 1838 motion was shorter than the 1802 one but the speed greater"; this remark can be related to the spectral content (?!) and needs further study

The Schüller Report

The most relevant engineering report of 1838 is the field trip and investigation in the sub-Carpathians and epicentral area, done by the Dr. Gustav Schüller [Gustave Schueler], Counselor for Mining to the Grand Duke of Saxonia, in charge with making the geological map, mining, water resources and supply of Wallachia. Besides the text in German, there are reports' editions in French and Romanian republished in 1882 and 1883.[18].

Schüller describes the ground faulting and failures in different sites or villages, dejections of sand, crude oil etc. For buildings' behavior it is very significant a drawing with geological profiles, faulting types, included in the French edition. On this print there are 3 rural houses, x - cracked, damaged but still standing, although there is a fault beneath them !!! (Fig. 6).

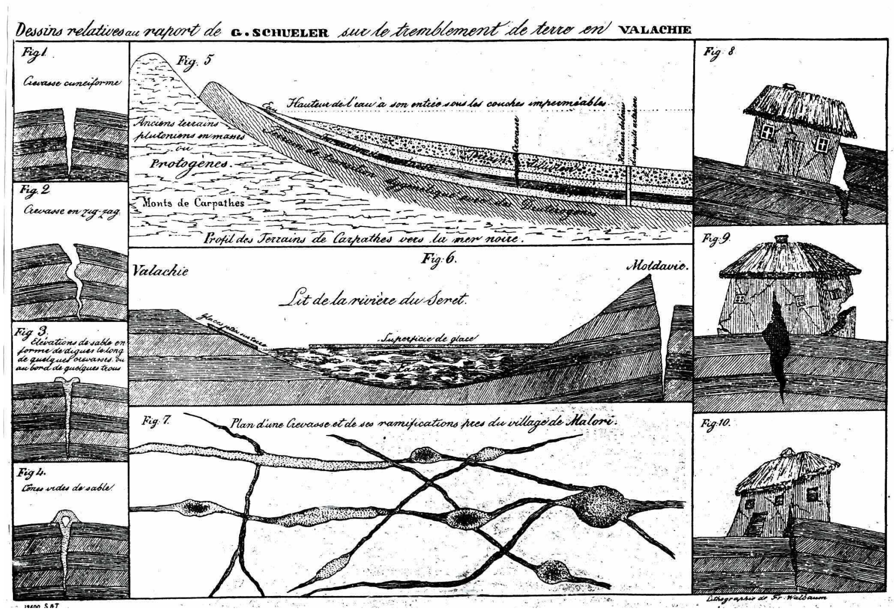

Fig. 6. Drawing with geological data and sketches of Romanian peasants damaged houses. Although damaged, located over faults and ground ruptures, these houses survived and saved the life of owners at 11/23 January 1838 earthquake (The Report of Dr. Gustave Schueler, French edition).

The report relates that „in the visited areas all massive buildings, made of stone heavily suffered and many of them, mainly churches, cannot be used". On the contrary, „the peasants' houses, as well as all structures made in timber, have been able to deflect since they were flexible, so they suffered less…" This apparent miracle (proved by other earthquakes in the Romanian space, too) is the proof of a „local seismic culture", since the people that lived for thousand years in areas exposed to Vrancea motions reached a satisfactory level of performance, at least in what concerns the life safety. Taking into account the 1838 earthquake effects, the large affected area and the geological effects is south of Romania, this event is among the greatest Vrancea earthquakes, and the 1802, 1940 and 1977 earthquakes proved the same patterns in many sites.

Study of remote amplifications in Transylvania and Moldavia, vs. actual intensities

The effects of 1838 earthquake have been considerable in Transylvania and Moldavia. Some Romanian sources claim that the Red Lake (Lacul Rosu, Gyilkostó) in the Eastern Carpathians at the border of Transylvania to Moldavia was created by a strong slide of rocks over a river. Other Hungarian sources claim that the slide was triggered in advance, in 1837. If the Romanian variant is true, the propagation of such powerful effects at a distance of some hundreds kilometers may have important implications about the attenuation laws, as well as about the zonation, since in the seismological map SR 11 100/1-93 the Red Lake site is zoned in VI MSK.

THE USE OF FORENSIC DATA FOR SEISMIC ZONATION

Romanian seismic zonation and associated seismic coefficients and spectral curves prove a bitter history. [1]. The first map in official MLP Instructions of 1942 and 1945 was very simple, referring to the South and East of the country. A zonation standard map was introduced in 1952. In accordance with this, the isoseismal line of what delimited the VIII intensity zone extended towards South (near Targoviste), the Bucharest City was considered as the VIII intensity local zone, the VII intensity zone spread towards North-East, nearby Jassy and it included the North part of Dobrogea. The VI intensity zone was limited, at North, by Suceava and, at South-West by Orsova; excepting some zones above Oradea and at Halmeu, the VII grade, included Bucharest city, that was in 8 grade after 1945 and 1952 revisions; the rest of territory was not considered seismic.

Later on, the P.13-1963 Code, P.13-1970 respectively and which used seismic zoning maps (STAS 2923-63). In the P13-63 Code the design spectrum β had a constant value from 0 to 0.3 s threshold, with β = 1/T formula, limited between 0.6 and 3, with a decrease until T_r = 1.5 s, and with a possible increase of 25-50% to take into account the soil conditions. This was based on a Californian-type spectrum. Microzonation maps have been indicated as an alternative to the soil conditions characterization.

The MSK seismic zones and K_s factors corresponded at that time to a value of 0.025 in 7th grade, 0.05 in 8th grade and 0.1 in 9th grade. On the zonation map of 1963, the intensity of Bucharest city was decreased with one grade, I = VII, the intensity of Focsani zone was increased by one grade, I = IX, but the map took into account the possible effects of the other local sources too (the South of Dobrogea that was not considered seismic in 1952 was re-estimated at VII intensity); the South-West of Banat was reconsidered (Timisoara, Oravita, Moldova Noua I = VII); in the West and North of Transilvania the following intensities were introduced: Valea lui Mihai – I = VII, Halmeu – I = VII and the other zones were characterized by VI intensity.

The link between design spectrum and foundation soil and especially with “weak or soft soil” was based on limited parameters from usual geology and geotechnical conditions and even when shear wave propagation data were used, only superficial layers have been considered (on some meters or some tens of meters), at the water table depth, with “Medvedev concept” being considered in microzonation maps for some cities too. Thus, in Bucharest the most affected area had to be the one on the river meadow and right bank of Dambovita River.

In the new edition of the P13-1970 Code, the spectral β curve had a flat branch from zero to 0.4 s threshold with a $\beta = 0.8/T_r$ formula, limited between 0.6-2 s, with a decreasing until T_r=1.33 s, with reductions of 20% and increasing of 50% corresponding to foundation soil; seismic forces were increased for the 7 grade zone and diminished for the 9 grade zone, the global seismic coefficients increased or diminished on some construction categories, with the well known and blamed 2% minimum limit of base shear force. It was recommended the use of rigid structures, avoiding soft ground floor, while the choice of extending the flexible zone on more levels was limited too.

The March 4-th 1977 earthquake radically modified for a while the options and actions of specialists and authorities in civil engineering and construction industry. The seismic coefficients k_s, corresponding to the zones and degrees in the map proved to be unrealistic, being wrongly estimated from ancient studies.
As a consequence, the spectral curve (the dynamic coefficient β_r), from the P13-1970 Code (which became P100-78), as well as the seismic zonation map of Romanian Standard STAS 2923-63 have been radically changed.

Immediately after the March 4, 1977 earthquake, by Decree no. 66/1977, in the seismic zonation map the VII intensity zone was extended towards western Oltenia, around the towns of Alexandria, Zimnicea and Craiova provided zones of VIII and VII ½ intensity, respectively, were the VII intensity zone of Timisoara was slightly modified, for Bucharest the VIII ½ intensity was introduced and for the Southern Dobrogea there was a zone of VIII intensity over a small area. Later on, in the zonation map of STAS 11100/1-77, some modifications were made such as:

- refinement and spread of the IX MSK intensity zone to Focsani area, the reduction of the VII intensity zone in western Oltenia and of the northern boundary of the VIII intensity zone;
- reduction by ½ degree of the intensity for Bucharest (VIII), by 1 degree of intensity for Alexandria and by ½ degree for Zimnicea, as well as introduction of the VII ½ intensity for Turnu Magurele and of new, local, VII intensity zones (Copsa Mica, Sighet, Radauti); the increase of the intensity by ½ degree for Jassy (VII ½);
- splitting Dobrogea into VI intensity zones (east of Tulcea and north of Constanta) and VII intensity zones elsewhere; the adjustment of the intensity for north-western Transylvania (Valea lui Mihai – Carei, detailed to include zones with I = VIII).

It is significant that the microzonation maps (STAS 8879 series) have been taken out of use, because they did not reflect at all realistic correlations with possible attenuations or amplifications of the Vrancea-type seismic motions, especially for the ground conditions of the Romanian Plain in South.
The main adjustments of the P13-70 design code (which became P100-78) regarded the new values for k_s (from 0.07 for degree 6 up to 0.32 for degree 8), which were better correlated with the ground accelerations, passing to values for ψ smaller than unity (from 0.15 to 0.35). The β spectral curve had now a branch from zero to the threshold of 1.5 sec, with the formula $\beta=3/T_r$, bounded by 0.75 and 2, with a decreasing to T_r=4.0 sec, with 20% reductions and 30% increases, function of the ground conditions.

Presently, the seismic zoning maps of Romania are bipolar:

- maps with MSK intensities, with associated indices of mean return periods (index 1-minimum 50 years, index 2-minimum 100 years), according to the standard SR 11 100/1-1993, of general use, mostly for seismologists;
- maps with basic k_s (seismic design coefficients) and T_c (corner periods values of the design spectrum), according to Earthquake Design Code P. 100-1992 ; in these maps, the return periods are of some 50 years for zones where Vrancea activity prevails and of 100 years or more for zones affected by other foci. The Code P.100-1992 provides a table of conversion between k_s, T_c and MSK intensities, but locally there are differences between these MSK intensities and those given by SR 11 100/1-1993; only P.100 Code maps are officially used for engineering design and risk reduction planning.

A new couple of zoning maps expressed in PGA and corner periods shall be introduced after 2004, in the new Romanian Earthquake Design Code P100.

The gathered forensic data can be used for:

- the checking and calibration of the new Romanian zoning maps to avoid the zonations' shortcomings of the past;
- selection of extreme scenario events; in case of Vrancea source, they should correspond to a magnitude of around 7.6 (like, probably, that of the "Great Earthquake of 1802"); in such cases, there is a greater potential of catastrophic losses, directly on half of territory and indirectly in the remaining part.

Some of the curent myths that strongly influenced the to date seismic zonation maps are clearly contradicted by the historical data, as:

- the actual extent of Vrancea epicentral area and the real the area of damage in case of motions below 7 Richter is larger than presumed;
- the shielding effect of Carpathian on Transylvanian area is limited and there are reports of effects in remote Western zones;

- the so called effect of „seismic shadow" up to Prut River is doubtful, while extent of effects in Northern Moldavia is larger that in some zoning maps;
- the repeatability of orientation, symmetry and forms of ellipses in case of great earthquakes is not valid in all cases and this fact has implications in selection of scenario earthquakes for the „most credible event".

It is worth mentioning that recent studies, based on advanced processing of instrumental data from Vrancea earthquakes of 1986 and 1990 [19], confirm some of these historical data based on damage reports. From the study of radiation of seismic motions, directionality of attenuation and azimuthal variation of intensities it was revealed that:
- shape of "ellipses"is rather iregulate;
- dominant radiation azimuth for these motions is strongly different;
- attenuation is slower in the North-West direction.

Thus, these results may explain, in principle, the advance of motion impact and rather strong damage at long distances in Transylvania, behind Carpathians and perhaps towards Northern Moldavia

CONCLUSIONS

The recovery and forensic engineering interpretation of data on historical earthquakes provided a new insight in the general pattern of Romanian territory exposure to Vrancea strong motions useful for seismic zonation and earthquake scenarios. The events of 1471, 1738, 1802 and 1838 earthquakes have been only few of available strong motions that require forensic studies.

The paper revealed alternative patterns concerning the shape and size of the actual "Vrancea epicentral area", as it differs from the classical one, the territorial extent and damaging potential of strong intermediate earthquakes, using forensic engineering approaches to sites and situations where the historical damage contradicts zoning maps. There are sufficient data proving that some great Vrancea motions historically have other forms of isoseismal lines than ellipses, while the long period spectral content can be remarked even behind Carpathians'(!!!), being able to afect tall and slender structures.

The European Seismological Commission edited in 2003 the European-Mediterranean Seismic Hazard Map, expressed in PGA for 475 years return period, at national scale, with some classical type of ellipses for Vrancea source and this can be useful as a general, „harmonised" image of hazard.
In order to corelate and detaliate the European map as national map, using mean recurrence intervals of 100 and 475 years, the conversion of historical data into intensities and/or PGA, EPA, corner period values, requires in this context a careful additional work, with a similar understanding of facts by engineers and seismologists.

The problem of validity of present catalogues and of many attenuation laws highly relies on the truth of conversions of some historical damage data in data about magnitudes and intensities, as they were derived in the past, sometimes neglecting the spectral content, not taken into account before the 1977 Vrancea earthquake. The reevaluation of historical data using todate forensic engineering approaches may compensate for the lack of instrumental data; it seems more reasonable to relate the damage directly to a parameter like PGA than to magnitude and this work be done with the tools of a structural engineer.

In Romania the drafting of the new zoning maps for engineering purposes (Code P100-2003/2004 – in final draft) resulted presently in a map for 100 years return period. The forensic earthquake engineering is able to recover existing knowledge from the documents of the German and Hungarian communities in Transylvania, in order to draft the zonation maps for longer return periods.

REFERENCES

1. Georgescu, E.S. “Earthquake Engineering Development before and after the March 4, 1977, Vrancea, Romania Earthquake”, Symposium “25 years of Research in Earth Physics”, National Institute for Earth Physics, 25-27 September 2002, Bucharest, 2002
2. Balan St., Cristescu V. and Cornea I., (coordinators). “The Romania Earthquake of 4 March 1977 “ (in Romanian). Editura Academiei, Bucharest, 1982.
3. Moskalenko. T. P. – “Kartî izoseist zemliatriasenii Karpatskovo regiona”. pp. 86-105 in: Karpatskoe Zemletriasenie 4 Marta 1977 g. i evo posledstvia. Akademia Nauk SSSR, Izdatelstvo Nauka, Moskva, 1980
4. Popescu, I.G. – «Etude comparative sur quelques tremblements de terre de Roumanie, du type du celui du 10 novembre 1940». Comptes Rendus des Seances de L’Academie des Sciences de Roumanie, Tome V, Numero 3, Mai-Juin 1941, Ed. Cartea Romaneasca, Bucuresti
5. Sagalova, E.A. - quoted in Medvedev, S.V. – Seismic Zoning of the USSR, 1968, in Russian; English Edition, Israel, 1976)
6. Shebalin, N.V. et. al – “Catalogue of earthquakes”, UNESCO, Skopje, 1974
7. Tatevossian, R., Mokrushina, N., “The 1802, October 26, 10:55, Vrancea deep earthquake”. ESC, European Project Historical Seismicity. 1998
8. Georgescu, Emil-Sever –“Towards a recovery of a city mark: The Coltzea Tower of Bucharest.” The 5-th International Congress on Restoration of Architectural Heritage, 17 – 24 September 2000, Firenze, Italy, 2000
9. Georgescu E.S.- “The partial collapse of Coltzea Tower during the Vrancea earthquake of 14/26 october 1802: the historical warning of long-period ground motions site effects in Bucharest” International Conference Earthquake Loss Estimation and Risk Reduction, October 24-26, 2002, Bucharest, Romania
10. Cernovodeanu, Paul – “The History of Coltzea Tower in contemporary documents”. Journal of Museums, III, 5, pp. 392-396, (in Romanian), 1966.
11. Panait, Panait I.– “Research concerning the Coltzea Tower of Bucharest”. Bulletin of Historical Monuments, 3, pp. 3-8, (in Romanian) 1970
12. Ionnescu-Gion, G.I.–“The History of Bucharest.” I.V. SOCECU Editor, Bucharest, (in Romanian), 1899.
13. Sulzer, Franz Joseph – “Geschichte des Transalpinischen Daciens” , vol. I, pp. 292-294, Wien, 1781
14. Pappasoglu Dimitrie – “The History of Founding the City of Bucharest”, 1891 (in Romanian: Istoria Fondării Orasului Bucuresti.). New Edition, Fundatia Culturala Gheorghe Marin Speteanu, Bucuresti, 2000
15. Jeitelles, H.L. “The most important points of departure and epicenters of earthquakes in Hungary and Transilvania”. (in Hungarian) A Kir. M. tud. Társ közlönyo, I, II, 1860
16. Corbu, A., “Bucurestii vechi – Documente iconografice“, Bucuresti, 1936.
17. Kozak, Jan T. Collection, http: nisee. Berkeley.edu/kozak.com
18. Schueller G. – “Notice sur les crevasses et autres effects du tremblement de terre du 11/23 Janvier 1838 accompagnée d’un essai servant à éclarcir ces phénomenes.“ Imprimerie de Frédéric Walbaum, Boucarest, 1838. Reprinted in Buletin - Societatea Geografica Romana, Anul IV, pp. 22-45, Bucharest, 1883.
19. Sandi, H., Borcia, I.S., Stancu, M. “Analysis of attenuation for recent Vrancea intermediate depth earthquakes”. Proc. 13-th WCEE, Vancouver, BC, Canada, August 1-6, 2004