ESSENTIAL TOOLS TO MITIGATE VRANCEA STRONG EARTHQUAKES EFFECTS ON MOLDAVIAN URBAN ENVIRONMENT

Gheorghe Marmureanu*, Alexandru Marmureanu, Carmen Ortanza Cioflan, Constantin Ionescu

National Institute for Earth Physics, Bucharest, Romania (NIEP)
12 Calugareni St, POBox MG-2, Magurele, Ilfov, Romania

Abstract

In a world of uncertainty, the only constant is change and rapid change produces a multitude of diverse facts. Risk is an integral part of life. While no country in the world is entirely safe, the lack of capacity to limit the impact of hazards remains a major burden for all countries and while the world has witnessed an exponential increase in human and material losses due to natural disasters, there is a need to reverse trends in vulnerability to earthquakes. Available data prove that natural disasters from earthquakes can cause considerable damages, with potentially severe effects to urban environment. Earthquakes cascade as chaotic chain reactions through the natural and built environments; therefore, seismic hazard and risk are time-dependent quantities. On the other hand, environmental degradation increases the intensity of natural disasters, and is often the factor that transforms natural hazards, into a disaster. In World, earthquakes are responsible for 15% of total number of events, and 30% of the total damages (Freeman, 2000). Last strong Vrancea earthquake on March 4, 1977 (Mw=7.4, h=95 km): 1578 dead and 11,321 injured, 36 ruined/destroyed blocks in Bucharest, 32,900 houses collapsed or severely damaged; 35,000 families homeless, tens of thousands (64,000) of buildings damaged from Iaşi and Bacău to Craiova, many other damages and destructions in the industry and economy; the downtown of Bacău was completely damaged etc. The goal of the paper is to enhance our capability to decrease the effects of strong and deep Vrancea earthquakes on urban and built environment, especially in Moldavian area. The practical goal is to enable new geo-technologies for reducing risk and improving community resilience. Specific fundamental and applied researches were developed last years by National Institute for Earth Physics sustained by national legislation and regulations as well as European Programs: FP-7, Cross-Border etc. The priority of protecting the environment is emphasized. This knowledge can be very fruitfully used by civil engineers in the design of new seismic resistant constructions and in the reinforcement of the existing built environment, and, therefore, supply a particularly powerful tool for the prevention aspects of Civil Defense.

Key words: early warning system, earthquake, urban environment

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1. Introduction

Strong and deep Vrancea earthquakes proceed as chain reactions across multiple scales and primary effects induce secondary effects like landslides, liquefaction, lateral spreading etc. These cascades propagate from natural environment into built environment (buildings, industry, infrastructure etc.), setting off tertiary destructive processes fires, structural collapse, radiation leakage etc. Poverty and vulnerability to earthquake disasters are closely linked. Disaster risk management is essential to fight against poverty, because the poor are disproportionately affected by disaster.

The seismic risk is the uncertainty of loss which is the reduction in value of an asset due to damage. Risk or „loss estimation” is the quantification of the earthquake loss, and is a basic first step in managing risk (Cavaliere et al., 2011; Rotaru and Kolev, 2010).

Rapid urbanization of cities has caused unbearable environmental problems primary in cities
and countries with high seismic risk (Champion and Liel, 2012; Erbil et al., 2012). Natural risks such as earthquakes are largely beyond human control. Seismic risk management can only be successful when it is fully integrated in global management. This is what is referred to as integrated safety by using innovative and integrated techniques and methods to the further development of community risk management policy (Gavrilescu and Manta, 2011; Tilio et al., 2012). In general, safety management should not be limited to technical prevention, mitigation or preparedness, but must be part of the general trend toward efficiency, effectiveness and quality improvement of environment.

2. The state of art on Vrancea earthquakes

Vrancea seismogenic zone in Romania denotes a peculiar source of seismic hazard, which represents a major concern in Europe, especially to neighboring regions from Bulgaria, Serbia, Republic of Moldova etc. The strong seismic events originating from Vrancea area can generate the most destructive effects experienced in Romania, and may seriously affect high risk man-made structures such as nuclear power plants (Cernavoda, Kozloduj etc.), chemical plants, large dams, and pipelines located within a wide area from Central Europe to Moscow. In plan view, the earthquakes are localized to a restricted area in the bending zone between the Eastern and Southern Carpathians at least three units in contact: the East European plate, Intra-Alpine and Moesia sub-plates (Cioflan et al., 2009). In Fig. 1 we have the recent stress and strain pattern in the central Mediterranean and the strain transfer from the active Adriatic, Aegean and Vrancea deformation fronts through the ALCADI-Pannonian System (Cloetingh et al., 2007; Marmureanu et al., 2010a).

Earthquakes in the Carpathian-Pannonia region are confined to the crust, except the Vrancea zone, where earthquakes with focal depth down to 200 km occur. For example the last strong Vrancea earthquakes were: (i)-November 10, 1940, $M_W = 7.7$; h=145 km depth; (ii)-March 4, 1977, $M_W = 7.4$; h=85 km; (iii)-August 30, 1986, $M_W = 7.1$; h=133 km; (iv)-May 30, 1990, $M_W = 6.9$; h=90 km and, (V)-May 31, 1990, $M_W = 6.4$ and h=79 km. The depth interval between 110 km and 130 km remains not ruptured since 1802, October 26, when it was the strongest earthquake occurred in this part of Central Europe. The magnitude is assumed to be $M_W = 7.7 - 7.8$ and this depth interval is a natural candidate for the next strong Vrancea event (Report, 2007).

![Figure 1](image1.png)

**Fig. 1.** Strain transfer from the active Adriatic, Aegean and Vrancea deformation fronts through the ALCADI-Pannonian System (Cloetingh et al., 2007)

![Figure 2](image2.png)

**Fig. 2.** Observed distribution of macroseismic intensity during the large Vrancea Earthquakes (November 10, 1940, $M_W = 7.7$ and March 4, 1977, $M_W = 7.4$) (Bonjer, 2007)
The maximum intensity for strong deep Vrancea earthquakes is function of earthquake depth. In 1977 strong earthquake (Mw =7.4 and h=95 km) at its epicenter, in the Vrancea region, the estimated intensity was only VII/2 (MMI scale), while some 170 km away in the capital city of Bucharest, the estimated maximum intensity was IX - IX½ (MMI), but in 1940, the large effects were in Focșani, on all Moldova territory, Republic of Moldova and Ukraine (Odessa) (Marmureanu et al., 2010a). An interesting characteristic is the intensity deforming Vrancea zone, shows a quite enigmatic seismic pattern (Fig. 2) (Bonjer, 2007). The complexity of the geology of the extra-Carpathian region is obvious.

The geology of main cities from this area, like Iasi, Bacau, Buzau, Bucharest and Craiova is complex. The scientific problems regarding the waves propagation on source-crystalline fundament - free field path taking into account the nonlinear behavior are the most recent researches conducted the NIEP in this domain. Bacău City is located on the sedimentary filling of the external „Neocene fore-deep” limit and Tornquist-Teisseyre (TT) Zone (Fig. 3), built by normal stratigraphic succession of: marls and sandstones formations, clayey-sandy deposits, sands, clays and sandstones, gravels, sands and clays, quaternary gravels and sands with loess intercalations. Total thickness of them is between 20 m and 40 m.

The influences of the seismic sources in the „MS (Modal Summation)-Shake method”, used by authors are taken into account by calculating the seismic input through MS technique which takes not only the seismic source parameters (location, depth, fault plane solutions), but also the characteristics of geological structures from source to the site and can model any lateral discontinuities which can meet on relatively large epicenter distances, such as Vrancea to Bacau City.

3. The realistic modeling of the ground motion in (neo)deterministic analysis applied to Bacau city

This innovative modeling technique takes into account source, propagation and local site effects. The realistic modeling of the ground motion is a very important base of knowledge for the preparation of ground shaking scenarios that represent a valid and economic tool for the seismic microzonation. Seismic input MS-SH (horizontal component of shear waves) method takes into account all these variables which in other approaches are unknown (half-space linear elastic bedrock modeling) (Cioflan et al., 2009; 2011; Marmureanu et al., 2010a; Report, 2008).

A self-impose condition in our approach is the spectral completeness of the seismic signal computed with MS, needed since SH techniques are maintaining constant the spectral content of the seismic accelerograms and modifying only the signal amplitudes and duration computed at surface, in free field. For the sake of mathematical rigor and also on reason that seismic energy is mostly carried out by transverse waves (or their coupling surface layers-Love waves), the method used in this paper was applied on SH waves which represents transverse component of seismic motion (Freeman, 2000).

The method could be applied to other components of the seismic motion, even if their contribution is less important in terms of seismic engineering.

Some results obtained by applying the MS-SH method to assess local effects of site in the Bacău City (Report, 2008) are shown in Figs. 4 for last 3 strong Vrancea earthquakes: (i)-August 30, 1986 (VR86, Mw=7.1; h=133 km); (ii)-May 30, 1990 (VR901, Mw=6.9; h=90 km) and, (iii)-May 31, 1990 (Mw=6.4; h=79 km). Local structure of Bacău site is consisting of thin relatively thin layers of sand with gravel in various combinations and it was modeled as equivalent layer of sand with gravel of 40 m with average parameters: \( \rho =1700 \) m/s; \( V_p=694.54 \) m/s; \( p=1.26 \) g/cm^3 on a thick of „shale fat” layer of 500 m with \( V_p=2300 \) m/s; \( V_s=940 \) m/s; \( p=2.1 \) g/cm^3.The speed structure of the region has high values at depths more than 600 m \( \text{Vr}=2600 \) m/s; \( \text{Vs}=1080 \) m/s; \( \rho=2.2 \) g/cm^3.The range of frequencies used in our analysis was between 0.05 and 1.0 Hz.

The variation of dynamic torsion modulus function (G, daN/cm^2) and torsion damping function (G%) of specific strain (\( \gamma \)) for diluvial clay, sand and gravel and shale fat samples obtained in Hardin & Drnevich resonant columns (USA patent) from NIEP are given in Figs. 5-7 with absolute or normalized values (Marmureanu et al., 2010a).

Even with this simplified modeling local structure, applying MS-SH method it was obtained a realistic correlation between surface acceleration and response spectrum computed for the event VR901 (Mw=6.9 and h=90 km) to recorded one, rotated and filtered recursively by using a Butterworth filter in the range of 0.05-1 Hz: 16 cm/s^2 from synthetic one to 17.23 cm/s^2 filtered record.
From transfer function shown in Fig. 4, large amplifications can be observed in seismic signal (approx. 12) values that are expected for local structures of "soft" materials. Note that local seismic amplification and maximum response is obtained for VR902 which is the smallest magnitude of simulated events, which is a direct consequence of the nonlinear behavior of land during strong earthquakes.

This knowledge can be very fruitfully used by civil engineers in the design of new seismic resistant constructions and in the reinforcement of the existing built environment, and, therefore, supply a particularly powerful tool for the prevention aspects of Civil Defense.

Fig. 4. Acceleration response spectra for 10% damping (leftside and spectral amplification function (Report, 2008)
Essential tools to mitigate Vrancea strong earthquakes effects on Moldavian urban environment

Fig. 5. The variation of dynamic torsion modulus function (G, daN/cm\(^2\)) and torsion damping function (G\%) of specific strain (γ %) for diluvial clay samples obtained in Hardin & Drnevich resonant columns (USA patent) from NIEP, Lab. of Engineering Seismology. Absolute values (Marmureanu et al., 2010a)

Fig. 6. The variation of dynamic torsion modulus function (G, daN/cm\(^2\)) and torsion damping function (G\%) of specific strain (γ %) for sand and gravel samples obtained in Hardin & Drnevich resonant columns (USA patent) from NIEP, Lab. of Earthquake Engineering. Normalized values (Marmureanu et al., 2010a)

Fig. 7. The variation of dynamic torsion modulus function (G, daN/cm\(^2\)) and torsion damping function (G\%) of specific strain (γ %) for shale fat samples obtained in Hardin & Drnevich resonant columns (USA patent) from NIEP, Lab. of Earthquake Engineering. Absolute values (Marmureanu et al., 2010a)
4. The recorded data on Bacau city and the nonlinear effects developed during of last earthquakes

Soils exhibit a strong non-linear behavior under cyclic loading conditions. This basic material characteristic shall be taken into account when we are making evaluating the seismic response of soil deposits or earth structures.

Nonlinear effects in ground motion during of large earthquakes have long been a controversial issue between seismologists and engineers. Aki wrote in 1993: "Nonlinear amplification at sediments sites appears to be more pervasive than seismologists used to think. Any attempt at seismic zonation must take into account the local site conditions and this nonlinear amplification" (Aki, 1993; Marmureanu et al., 2004).

In other words, the seismological detection of the nonlinear site effects requires a simultaneous understanding of the effects of earthquake source, propagation path and local geological site conditions. The difficulty for seismologists in demonstrating the nonlinear site effects has been due to the effect being overshadowed by the overall patterns of shock generation and propagation.

We can see the struggle for seismologists to find nonlinear effects in site lies in the difficulty of separating the effects of source of propagation from source to bedrock and from this fundament to surface area (free field).

To see the actual influence of nonlinearity of the whole system (seismic source-path propagation-free surface of geological structure of the site), the authors are using, in last years, the spectral response, which are last in this chain (Marmureanu et al., 2004; 2005; 2010a; 2012a; 2012b) and, of course, they are used in seismic design of structures. In each response spectra we have fundamental period, spectral values for accelerations, velocities and displacements and all of them are used as design data in any seismic area.

Romanian National Institute for Earth Physics developed, in last years, the concept of "Nonlinear seismology-The Seismology of the XXI Century" (Marmureanu et al., 2005; 2012a; 2012b). In order to make a quantitative evidence of nonlinear effects, the authors are using the spectral amplification factor (SAF) as a ratio between maximum spectral absolute acceleration (Sa), relative velocity (Sv), relative displacement (Sd) and peak value of acceleration (a-max), velocity (v-max) and displacement (d-max), respectively, from processed strong motion records.

In Figs. 8, 9 and 10 there are last recorded data for Bacau City, recorded by NIEP and INCERC during last deep Vrancea earthquakes: August 30, 1986 (Mw=7.1; h=133km); May 30, 1990 (Mw=6.9; h=90 km) and May 31, 1990 (Mw=6.4; h=79 km). The values of peak ground acceleration (PGA), peak ground velocity (PGV) and peak ground displacement (PGD) for the same events are presented in Table 1.

5. The nonlinear effects of Bacau city local soil structure and the influence to build environment

For smaller earthquakes (Mw ≤ 6.4), the strains are smaller and we are in the left-hand side of the Fig. 11, for strong earthquakes (Mw ≥ 7.2), the strains are larger and we are in the right-hand side of the Fig. 11. Consequently the responses of the system of nonlinear viscoelastic materials (clays, marls, sands etc.) subjected, for example, to vertically traveling shear waves are far away from being linear. In this case, the wave equation is given by (1) (Marmureanu et al., 2010a):

\[ G \frac{\partial^2 U_2(x_1,t)}{\partial x_1^2} + \eta \frac{\partial^3 U_2(x_1,t)}{\partial t \partial x_1^2} = \rho \frac{\partial^2 U_2(x_1,t)}{\partial t^2} \]

where: \( G = G(\eta, \omega, \sigma; \ h, \ldots) \); \( \eta = \eta(\gamma); \ D\% = (\omega, \sigma; \ h, \ldots) \), \( \omega_{tr} = 2GD; \ \rho = \rho(\gamma, p, \omega, \sigma; \ h, \ldots) \); \( G(\text{daN/cm}^2) \) is the dynamic torsion modulus function and \( \text{D\%} \) is the torsion damping function; both of them are functions of shear strains \( (\gamma) \) induced by strong earthquakes, frequency \( (\omega) \), pre-existing stationary (\( \sigma \)) stress, depth \( (h) \); density \( (\rho) \); viscosity \( (\eta) \) etc.

In Tables 2 and 3 are given spectral amplification factors \( (S_a, \text{cm/s}^2) \) for absolute accelerations and 5% fraction of critical damping \( (\xi=5\%) \) at Bacău seismic station (gravel, loess, sand etc.; 20-40 m) for last three Vrancea strong earthquakes: August 30, 1986 \( (M_w=7.1) \); May 30, 1990 \( (M_w=6.9) \) and May 31, 1990 \( (M_w=6.4) \) with data processed by NIEP and INCERC Bucharest.

As we can see from Tables 2 and 3, in the same seismic station from Bacau (sedimentary deposit), the nonlinearity effects are very large. For \( \xi = 5\% \) internal damping, in the response spectra, spectral amplification factor for accelerations is \( 4.0443 \) for August 30, 1986 earthquake \( (M_w=7.1) \) on moment seismic scale; \( 5.1649 \) for May 30, 1900 earthquake \( (M_w=6.9) \) and \( 5.8982 \) for May 31, 1990 Vrancea earthquake \( (M_w=6.4) \), that is 45.8 % bigger that first one. If we maintain the same amplification factor \( \text{SAF} = 5.8922 \) from Table 1 as for relatively strong earthquake on May 31.1999 \( (M_w = 6.9) \), considered to be still in elastic range, on May 31, then at Bacau station for earthquake on May 30, 1990 \( (M_w=6.9) \) the peak acceleration has to be \( a_{\text{max}} = 151.23 \text{cm/s}^2 (14.2\%) \) and the actual recorded was only \( a_{\text{max}} = 132.43 \text{cm/s}^2 \). Also, for Vrancea earthquake on August 30, 1986, the peak acceleration has to be \( a_{\text{max}} = 105.26 \text{cm/s}^2 (45.8\%) \) instead of real value of 72.20 cm/s² recorded at Bacau seismic station. The same effects are presented in Table 3.
This means that the actual acceleration recorded on August 30, 1986 was with 45.8% smaller if it were elastic behavior of soil (Marmureanu et al., 2005; 2010a; 2012b).

For the linear case, the response spectrum is larger than that for the nonlinear one. Also, we found that there is a strong nonlinear dependence of the spectral amplification factors of earthquake magnitude (M) and strong earthquakes are considered as key for development actions in Moldavian urban environment.

This new research direction and its implication on real time seismology and engineering seismology in all sites where thick Quaternary sediments exist will be developed and it will open up a new challenge for researchers and any attempt at seismic hazard must take into account this nonlinear amplification (Aki, 1993).

6. Specific actions developed by NIEP to mitigate Vrancea strong earthquakes effects on Moldavian urban environment

Main courses for specific actions to mitigate the seismic risks given by strong and deep Vrancea earthquakes are considered as key for development actions in Moldavian urban environment:

- Early warning system for industrial facilities and other installations of national interest at strong Vrancea earthquakes (GD, 2004). EWS is a device for shutting down of the dangerous industrial processes.
before strong earthquakes arrives, a decision support system to European environment assessment (Ionescu et al., 2007; Marmureanu et al., 2008; 2009; 2010b; 2011a).

**Innovative content.** EWS (Fig. 12) is the first European system for real-time early detection and warning of the seismic waves in case of strong Vrancea earthquakes. Its development, made in collaboration with Karlsruhe University is based on new concepts and models of risks caused by seismic phenomena.

**What does it do?** EWS uses the time interval (28-34 seconds) between the moment when earthquake is detected by the borehole seismometers in the epicenter (Vrâncioaia) and the time of the wave arrival to deliver timely integrated information in order to enable actions to be taken before a main destructive shaking takes place.

**What is its use?** EWS automatically triggers: gas distribution nets, shutting down of computers, stopping critical operations in airports, nuclear power plants, refineries, stopping trains and elevators in a safe position, alerting of hospital surgery rooms and starting of emergency generators etc.

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**Fig. 9.** Recorded accelerograms, NS & EW components and response spectra (ζ=5%), in Bacău City during of May 30, 1990 earthquake (Mw=6.9 and h=90 km)
For whom? The destination of the EWS includes large category of users for many industrial processes and finally, to save life of people. It was included already in the user’s infrastructure: (i)-Nuclear irradiator installation from Horia Hulubei National Institute of Physics and Nuclear Engineering; (ii)-Nuclear Reactor from Pitesti; (iii)-Heavy Water Factory from Turnu Severin; (iv)- NPP Cernavoda etc. It is on way the project for: (i)- alerting of all hospital surgery rooms from extra-Carpathian area from Iasi to Craiova and starting of emergency generators; (iii)-for gas distribution system there is our Patent No.117731/2002.

![Figure 10](image)

**Fig. 10.** Recorded accelerograms, N-S & E-W components and response spectra (\(\xi=5\%\)), in Bacău City during of May 31, 1990 earthquake (\(M_w=6.9\) and \(h=79\) km) (Cioflan et al., 2009; Marmureanu et al., 1995)

Table 1. PGA, PGV and PGD recorded in Bacau City during of last Vrancea Earthquakes (Cioflan et al., 2009; Marmureanu et al., 1995)

<table>
<thead>
<tr>
<th>Code</th>
<th>August 30, 1986 ((M_w=7.1))</th>
<th>May 30, 1986 ((M_w=6.9))</th>
<th>May 31, 1986 ((M_w=6.4))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PGA (cm/s(^2))</td>
<td>PGV (cm/s)</td>
<td>PGD (cm)</td>
</tr>
<tr>
<td>NS</td>
<td>88.4</td>
<td>9.1</td>
<td>2.2</td>
</tr>
<tr>
<td>EW</td>
<td>72.6</td>
<td>8.2</td>
<td>2.1</td>
</tr>
<tr>
<td>V</td>
<td>24.9</td>
<td>1.8</td>
<td>0.9</td>
</tr>
</tbody>
</table>
Fig. 11. The variation of dynamic torsion modulus function \(G, \text{daN/cm}^2\) and torsion damping function \(G\%\) of specific strain \(\gamma\%\) for sand and gravel samples with normal humidity obtained in Hardin & Drnevich resonant columns (USA patent) from NIEP, Laboratory of Earthquake Engineering. Normalized values (Marmureanu et al., 2010a).

Table 2. Bacău-(BAC2) Seismic Station (E-W Comp.): \(\Phi^0=46.567; \lambda^0=26.900\). NIEP Data (Marmureanu et al., 1995; 2005; 2010a).

<table>
<thead>
<tr>
<th>Earthquake</th>
<th>(a_{\text{max}}\text{(cm/s}^2\text{)}) (recorded)</th>
<th>(S_{a,\text{max}}\text{((\xi=5%))})</th>
<th>(S_{a,\text{max}}/a_{\text{max}}) (SAF)</th>
<th>(c)</th>
<th>(S_{a}(\text{((\xi=5%))}\text{)})</th>
<th>(a^*(\text{g}))</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>08.30.1986</td>
<td>72.20</td>
<td>292cm/s(^2)</td>
<td>4.0443</td>
<td>1.458</td>
<td>425.74</td>
<td>105.26</td>
<td>45.8%</td>
</tr>
<tr>
<td>05.30.1990</td>
<td>132.43</td>
<td>684cm/s(^2)</td>
<td>5.1649</td>
<td>1.142</td>
<td>781.13</td>
<td>151.23</td>
<td>14.2%</td>
</tr>
<tr>
<td>05.31.1990</td>
<td>63.07</td>
<td>372cm/s(^2)</td>
<td>5.8982</td>
<td>1.000</td>
<td>372.00</td>
<td>63.07</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 3. Bacău-(BAC2) Seismic Station (E-W Comp.): \(\Phi^0=46.567; \lambda^0=26.900\). INCERC Data (Cioflan et al., 2009; Marmureanu et al., 2012b).

<table>
<thead>
<tr>
<th>Earthquake</th>
<th>(a_{\text{max}}\text{(cm/s}^2\text{)}) (recorded)</th>
<th>(S_{a,\text{max}}\text{((\xi=5%))})</th>
<th>(S_{a,\text{max}}/a_{\text{max}}) (SAF)</th>
<th>(c)</th>
<th>(S_{a}(\text{((\xi=5%))}\text{)})</th>
<th>(a^*(\text{g}))</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>08.30.1986</td>
<td>72.60</td>
<td>310cm/s(^2)</td>
<td>4.269</td>
<td>1.443</td>
<td>447.33</td>
<td>104.76</td>
<td>44.3%</td>
</tr>
<tr>
<td>05.30.1990</td>
<td>122.7</td>
<td>555 cm/s(^2)</td>
<td>4.5232</td>
<td>1.361</td>
<td>755.35</td>
<td>166.99</td>
<td>36.1%</td>
</tr>
<tr>
<td>05.31.1990</td>
<td>63.0</td>
<td>388 cm/s(^2)</td>
<td>6.1587</td>
<td>1.000</td>
<td>388.00</td>
<td>63.00</td>
<td>-</td>
</tr>
</tbody>
</table>

Fig. 12. Early Warning System for strong Vrancea earthquakes (EWS): (Ionescu et al., 2007; Marmureanu et al., 2009; 2010b; 2011a; Report, 2007)

Early Warning System (EWS) for strong Vrancea earthquakes is winner of “2006 IST (Information Society Technology)-Prize” of the European Commission (http://www.ist-prize.org). Early warning system developed by NIEP together with Karlsruhe University should be viewed as part of an
European real-time information system that provide rapid information, about an earthquake impeding hazard, to the public and disaster relief organizations before (early warning) and after a strong earthquake (shake maps).

New seismic hazard map in intensities for Romania by using probabilistic and (neo) deterministic analyses (Fig. 13) (Marmureanu et al., 2011b; Report, 2009). The seismicity of Romania comes from the energy that is released by crustal earthquakes (also called normal ones), which have a depth not more than 40 km, and by the intermediate earthquakes coming from Vrancea region (unique case in Europe) with a depth between 60 and 200 km. The real evaluation of seismic hazard in intensities is the crucial step in the reduction of seismic risk and in build environment. In order to make a complete analysis of the seismic hazard generated by crustal and intermediate depth seismic sources, authors used probabilistic, deterministic and (neo) deterministic approaches. If the knowledge regarding earthquakes and earth motion would be complete, the deterministic approach would be the best method for maximum magnitude earthquake estimation. If the scientific knowledge is limited, but we have a good perception of uncertainties, the probabilistic approach is the right method. Unfortunately, none of these situations is completely true. In the deterministic analysis there are determined the etalon or controlling earthquake effects at the site.

The mapping was carried out by using probabilistic approach and a complex hybrid wave-form modeling method which combines the modal summation technique with finite-difference one to describe the seismic waves propagation through an inelastic space from source to free field surface. The result is a new seismic map in intensities (Fig. 13) by using probabilistic and deterministic approaches, linear and nonlinear seismology and developing the concept of control earthquake to obtain the banana shape of the attenuations curves of the macroseismic intensity along the directions defined by azimuths (Marmureanu et al., 2011b; Report, 2009). The novelty and complexity degree comes from the fact that for the first time a seismic hazard map for Romania were made by using probabilistic and deterministic methods, including a development of the nonlinear seismology concept, necessary to deterministic analysis; the mathematical approach is a very laborious and complex one, but can be verified (Marmureanu et al., 2011b). Boundary conditions and computing algorithms were used at global scale. It is the first map scientifically made, using the last researches in the nonlinear seismology field. The result is obtained by a consortium composed by NIEP, Faculty of Geology and Geophysics-University of Bucharest, INCERC Bucharest, Mathematics Faculty-Iasi from University A. I. Cuza and Solid Mechanics Institute from Romanian Academy (Report, 2009).

Seismic microzonation of large populated areas. At local level it is asked to any city to make microzonning seismic maps (local hazards maps) to put into evidence the differences which occurs during a strong earthquake (Marmureanu et al., 2010a; Marmureanu and Cioflan, 2010; Trendafiloski et al., 2009; Report, 2008). The realistic modeling of the ground motion is a very important base of knowledge for the preparation of ground shaking scenarios that represent a valid and economic tool for the seismic microzonation. The sustainable design of structures asks a local hazard map (microzonation map). If we refer to the specific objectives of this field regarding the Earth physics research, the natural disasters and the environment, the evaluation, prognosis and monitoring methods of the earth phenomena, in Romania there are at this time a governmental decision no. 372/2004 – National Program of the Seismic Risk Management, where is specified (in point p.5) the objective number 10, named “Macrozoning of the Romanian territory and seismic hazard zoning in densely populated urban cities” (GD, 2004). First local hazard map (microzonation map) by using probabilistic and deterministic approaches was made by NIEP for city of Bucharest for maximum possible earthquake in Romania (Mw =7.8) – Fig. 14, in intensities (MMI), peak ground accelerations (cm/s²) and fundamental periods (T,s). Also, there are constructed maps for Baia Mare, Timișoara, Sibiu, Banat, Ploiești, Galati, Tulcea, Moldova, Dobrogea etc. by using probabilistic analysis. Also, for Baia Mare and Crișana-Maramureș microzonning maps we used “Fuzzy Set Theory Concept” (Marmureanu and Cioflan, 2010).

Fig. 13. The isoseismal map (intensities) of the maximum credible Vrancea earthquake or maximum probable Vrancea earthquake (Mw =7.8) with MMI intensities of IX½ in epicenter area (Focsani and surroundings) and Bucharest (Fig. 14) (Marmureanu et al., 2011b; Report, 2009)

Advanced studies were made on local seismic hazard (microzonation) for important cities located outside of the Carpathians Belt, which are: Iasi, Bacau, Buzău and Craiova and the local hazard maps (microzonation) will be finished in short time. The novelty and complexity degree is based on the fact that local hazard maps (microzonation) will be developed for the four considered densely populated
cities located in Extra-Carpathian region for which local geological conditions are different to the city of Bucharest. The deterministic analysis will play a determinant role, compensated the lack of instrumental data for the certain cities.

Shake/Quake Map. The shake map constructed automatically for each earthquake is part of the Government Decision 372/2004-Seismic Risk National Management Program, at page 8 there is the objective “Seismic Map of Earthquake Real Time Developing-Shake/Quake Map” (GD, 2004). A shake/quake map is a representation in intensities of ground shaking produced by an event and it is generated automatically following moderate and large Vrancea earthquakes (Marmureanu et al., 2008; 2010b). The map allows us to rapidly portray the extent of shaking in a simplified form suitable for immediate post-earthquake decision-making. Shake. This map enables decisions makers at central or regional level, to take the most appropriate decisions, during and after strong earthquake. For example, if it is a strong Vrancea earthquake, then from Iasi, Bacau to Craiova on this map will show in real time the disaster areas and then the policymakers will send forces of intervention to save in time, lives and material goods. The effects of soil nonlinearity are quantified in such site response maps since a majority of ground motions were recorded at low levels of input motion, and these nonlinear effects could be important at the strong motion levels for which we anticipate Shake Map will be most useful.

The NIEP National Seismic Network after an earthquake is sending, in real time, this Shake Map to authorities and the NIEP System is connected to National Center from Ciolpani - Ilfov County. In fact, there is a system of systems for all extra-Carpathian area from Iasi to Craiova. The overall mapping philosophy used by NIEP was to combine the early warning system (EWS) and Shake Map data, in real time, from individual stations, geology (representing site amplification), and the distance to the center to create the best composite map (Marmureanu et al., 2010b). The procedure should produce reasonable estimates at grid points located far from available data, while preserving the detailed shaking information available for regions where there are stations nearby. In Fig. 15 we can see off-line intensities distribution (I. MSK) for last significant Vrancea earthquake (Mw=6.0) (Bonjer, 2007; Report, 2007). The place of EWS and shake/quake map and disaster map in the seismic risk management is given in Fig. 16.
earthquakes one of the most damaging natural phenomena in Romania.

7. Conclusions

Available data are pointing out that natural disasters from strong and deep Vrancea earthquakes can cause considerable damages, with potentially severe effects to urban and built environment. On the other hand, environmental degradation increases the intensity of natural disasters and is often the factor that transforms natural hazards to disaster.

Environmental disasters cause loss of lives and injuries as well as damage to property. Last strong Vrancea earthquake on March 4, 1977 (Mw=7.4) generated: 1578 dead and 11,321 injured; 36 blocks in Bucharest, fell to the ground, 32,900 houses collapsed or severely damaged, 35,000 families homeless, tens of thousands of buildings damaged, many other damage and destruction in the industry and economy; downtown of Bacău City was completely damaged etc.

Natural risks such as strong and deep Vrancea earthquakes are largely beyond human control. In paper is developed the concept that seismic risk management can only be successful when it is fully integrated in global management. This is what is referred to as integrated safety by using innovative and integrated techniques and methods to the further development of community risk management policy for extra-Carpathian area.

In general, safety management should not be limited to technical prevention, mitigation or preparedness, but must be part of the general trend toward efficiency, effectiveness and quality improvement of environment. Seismic hazard map for Romania in intensities and local seismic hazard maps (microzonation) in accelerations, fundamental periods and intensities for large populated areas provide a secure design of structures to future strong Vrancea earthquakes. These maps are the results of large fundamental researches in earth physics developed by NIEP and applying them correctly and realistic to civil structures and industrial building design will mitigate the seismic risk on Romanian territory.

The recorded data on Bacau, Iasi etc. and the evidence of nonlinear effects, of nonlinear amplification at sediments sites developed by last strong Vrancea earthquakes leads to the conclusion that „any attempt at seismic zonation must take into account the local site condition and this nonlinear amplification“. As can see from Tables 2 & 3, in the same seismic station from Bacau (sedimentary deposit), the nonlinearity effects are very large.

The actual acceleration recorded on August 30, 1986 with magnitude Mw=7.1, was with 45.8% lower if it were linear behavior of soil as that considered to be on May 31, 1990 earthquake, Mw=6.4. In other words, the peak ground acceleration on August 30, 1986 strong Vrancea earthquake with magnitude, Mw=7.1 should be 105.26 cm.s², if we had a linear behavior of the soil, but it was only 72.2 cm².

From the same records made for example in Bacau City and from absolute acceleration spectra for critical damping ζ=5%, the fundamental period of soil recorded during of last strong Vrancea earthquake was 0.25 seconds and the next period is about 0.5 seconds. These periods are used in structure design to avoid the resonance between soil and structure.

Most cities and villages (95%) are located on alluvial deposits/sediments, on Quaternary layers in river valleys. Laboratory tests made by using Hardin or Drnevich resonant columns consistently show the decreasing of dynamic torsion function (G) and increasing of torsion damping function (D%) with shear strains (γ%) induced by deep strong Vrancea earthquakes; G = G(γ), respectively, D%=D(γ), therefore nonlinear viscoelastic constitutive laws are required. The strong dependence of response on strain amplitude, that is, on earthquake magnitude, become a standard assumption in evaluation of Vrancea strong earthquake effects on urban environment.

Main courses for specific actions developed so far by NIEP to mitigate the seismic risks given by strong and deep Vrancea earthquakes are considered as key for development actions in built environment. Early Warning System (EWS) and Shake/Quake Map (Marmureanu et al., 2012b), in real time, are part of prevention plan of local and central public authorities about the damaging action of strong Vrancea earthquakes. Early warning system should be viewed as part of an European real-time information system that provide rapid information about an earthquake impeding hazard, to the public and disaster relief organizations before (early warning) and after a strong earthquake (shake map).

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