# NON LINEAR SEISMOLOGY A REALITY. THE IMPLICATIONS IN ENGINEERING

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**ABSTRACT.**
Most cities and villages are located on alluvial deposits/sediments, on Quaternary layers in river valleys. 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. To see the actual influence of nonlinearity of the whole system (seismic source-path propagation-local geological structure) the authors used to study the response spectra because they are the last in this chain and are taken into account in seismic design of structures. The evidence for nonlinearity for Bucharest and extra-Carpathian area is given by a systematic relative decrease in the variability of peak ground acceleration with the increasing earthquake magnitude The spectral amplification factors for last three strong and deep Vrancea earthquakes are larger than the values given by Regulatory Guide 1.60 of the U. S. Atomic Energy Commission and IAEA Vienna-through Safety Series No.5-SG-S1.

*Keywords: nonlinear seismology, response spectra, spectral amplification factors, site effects.*

## 1.INTROUCTION

To civil engineer, soil is any uncemented or weakly cemented accumulation of mineral particles formed by the weathering of rocks, the void space between the particles containing water and/or air. This basic material characteristic shall be taken into account when we are making evaluating the seismic response of soil deposits or earth structures. The model of linear elastic response of the Earth to earthquakes has been almost universally used so far in seismology to model teleseismic, weak, and also strong earthquakes. 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 condition and this nonlinear amplification(Aki,1993). For teleseismic and weak ground motions, there is no reason to doubt that this model is acceptable, but for strong ground motions, particularly when recorded on soils, the consequences of nonlinear soil behavior have to be seriously considered. Soils exhibit a strong non-linear behavior under cyclic loading conditions. In the elastic zone, soil particles do not slide relative to each other under a small stress increment, and the stiffness is at its maximum. The stiffness begins to decrease from the linear elastic value as the applied strains or stresses increase, and the deformation moves into the nonlinear elastic zone(Fig.1). Tension and strain states are not enough to determine the mechanical behavior of soils. It is necessary, in addition, to model the relation between stresses and deformations by using specific constitutive laws to soils. Currently, there are not constitutive laws to describe all real mechanical behaviors of deformable materials like soils. Viscoelastic material behavior could be characterized using Boltzmann's formulation of the constitutive law(Borcherdt,2009). Generic name of "soils" covers a wide range of materials occurred over time as a result of rocks degradation. From mechanical behavior point of view there are two main groups of main importance: sands and clays. These soils, although have many common mechanical properties require the use of different models to describe behavior differences. Soils are simple materials with memory: sands are "*rate-independent*" type and clays are "*rate-dependent* "one, names used in mechanical deformable bodies. However the complexity of these "simple" models exceeds the possibility of solving and requires to introduce of simplifying assumptions or conditions which are restricting the loading conditions which makes additional permissible assumptions. Sands typically have low rheological properties and can be modeled with an acceptable *linear elastic model* and clays which frequently presents significant changes over time can be modeled by a *nonlinear viscoelastic model*.

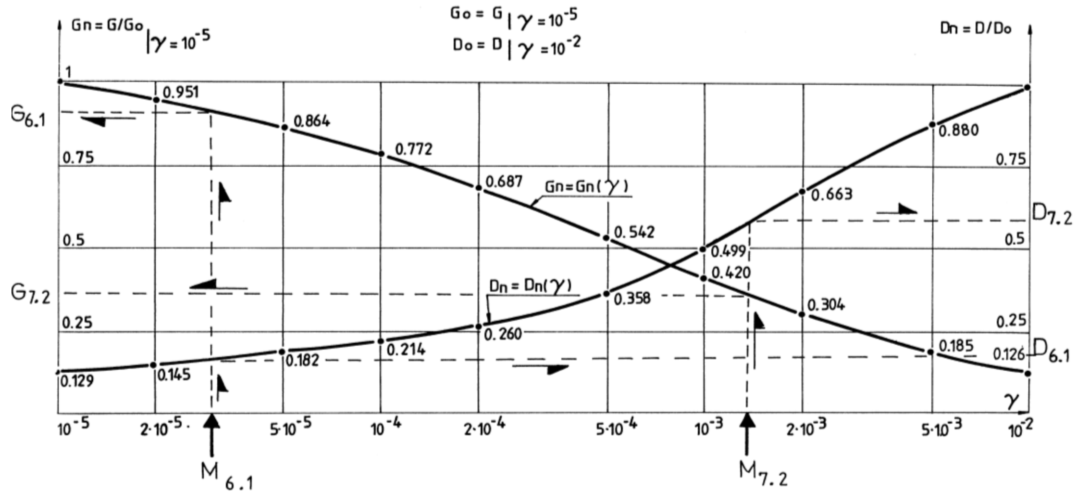


**Figure 1**.The variation of dynamic torsion modulus function (G, daN/cm$^2$) and torsion damping function(G%) of specific shear strain (γ%) for sand and gravel samples with normal humidity obtained in Hardin & Drnevich resonant columns(USA patent) from NIEP, Laboratory .of Earthquake Engineering. Normalized values (Marmureanu et al, 2005).

Laboratory tests developed in Engineering Seismology Laboratory from NIEP by using resonant columns Hardin and Drnevich consistently show consistently show the decreasing of dynamic torsion function(G, daN/cm$^2$) and increasing of torsion damping function(D%) with shear strains(γ) induced by deep strong Vrancea earthquakes; G = G(γ), respectively, D%= D%(γ) reduction in shear modulus(G) and increase in damping ratio(D) with increasing shear strain(γ),i.e, G=G(γ),respectively,

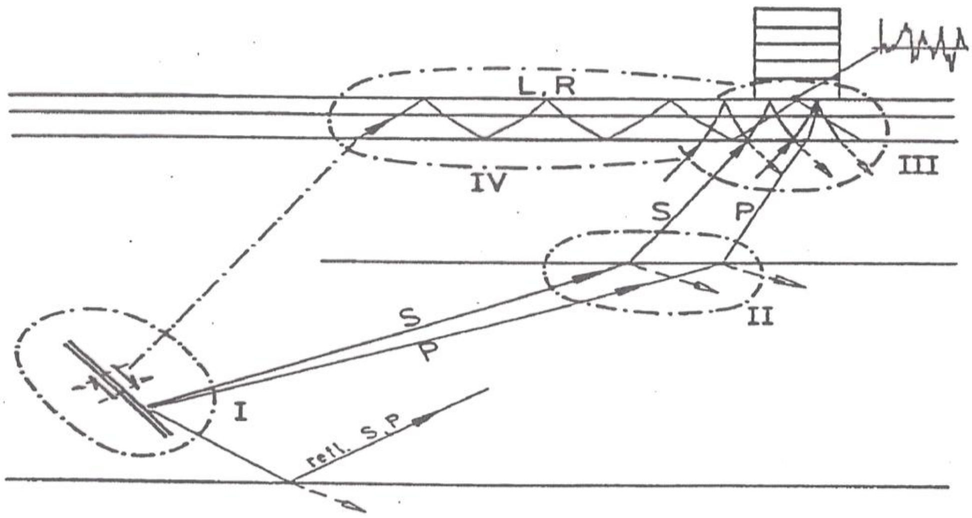


**Figure 2**.The seismic model from source to free field (Marmureanu et al,2012)

D%=D(γ)%(Fig.1). For smaller earthquakes, the strains are smaller and we are in the left-hand side of Figure 1:for strong earthquakes, the strains are larger and we are in the right-hand side of Figure 1 with large internal damping. Consequently the responses of a system of nonlinear viscoelastic materials (clays, marls, gravel with sands, sands etc.) subjected, for example to vertically traveling shear waves are far away from being linear and generating large discrepancies. On the other hand, the difficulty to seismologists in demonstrating the nonlinear site effects has been due to the effect being overshadowed by the overall patterns of shock generation and propagation(Figure 2). 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.

## 2. RECORDED DATA ON SEISMIC STATIONS FROM EXTRA-CARPATHIAN AREA

In order to find the quantitative characteristics of the nonlinear soil behavior and nonlinear site response, the authors [4-7] introduced so-called „the spectral (seismic) amplification factor"(SAF) as ratio between maximum spectral absolute acceleration (Sa), relative velocity (Sv) ,relative displacement (Sd) and peak values of acceleration(a-max), velocity (v-max) and displacement (d-max),respectively, from processed strong motion records.The theoretical support to spectral amplification factor approach is according to Marmureanu et al,2005. In Tables 1-18 are given the nonlinear effects function of Vrancea earthquake magnitude and site of seismic stations locations from Bucharest and other cities from extra-Carpathian area, that is, from Iaşi to Craiova, records obtained by NIEP and INCERC Bucharest(Marmureanu et al,1995&2005;Borcia,2008). In Tables 1-18 are given spectral amplification factors(SAF) for absolute accelerations at 5% fraction of critical damping (β=5%) at 18 seismic stations for last four Vrancea strong earthquakes: March, 4, 1977 ($M_W$=7.4); August, 30, 1986 ($M_W$=7.1); May, 30, 1990 ($M_W$=6.9) and May, 31, 1990 ($M_W$= 6.4).

**Table 1**.Bucharest-INCERC Seismic Station(E-W Comp.): $\Phi^0$ =44.442; $\lambda^0$=26.105

| Earthquake | $a_{max}$(cm/s$^2$) (recorded) | $S_a^{max}$ (β=5%) | $S_a^{max}/a_{max}$ (SAF | c | $S_a^*$(g) ( β=5%) | $a^*$ | % |
|---|---|---|---|---|---|---|---|
| 04.03,1977 | 188,4 | 440 cm/s$^2$ | 2.33 | 1,214 | 1025.2 | 228.7 | 21.4% |
| 08.30,1986 | 109.1 | 249 cm/s$^2$ | 2.28 | 1.241 | 309.0 | 135.4 | 24.1% |
| 05.30,1990 | 98,9 | 280 cm/s$^2$ | 2.83 | 1.000 | 280.0 | 98.9 | - |

**Table 2**.Bucharest-INCERC Seismic Station(N-S Comp.): $\Phi^0$ =44.442; $\lambda^0$=26.105.

| Earthquake | $a_{max}$(cm/s$^2$) (recorded) | $S_a^{max}$ (β=5%) | $S_a^{max}/a_{max}$ (SAF) | c | $S_a^*$(g) (β=5%) | $a^*$ | % |
|---|---|---|---|---|---|---|---|
| 04.03,1977 | 206,90 | 650 cm/s$^2$ | 3.14 | 1,322 | 859.3 | 273.5 | 32.2% |
| 08.30,1986 | 96.96 | 255 cm/s$^2$ | 2.62 | 1.583 | 403.6 | 153.4 | 58.3% |
| 05.30,1990 | 66,21 | 275 cm/s$^2$ | 4.15 | 1.000 | 275.0 | 66.2 | - |

**Table 3.**Bucharest-Balta Albă Seismic Station(E-W Comp.): $\Phi^0$ =44.413; $\lambda^0$=26.169

| Earthquake | $a_{max}$(cm/s$^2$) (recorded) | $S_a^{max}$ (β=5%) | $S_a^{max}/a_{max}$ (SAF) | c | $S_a^*$(g) ( β=5%) | $a^*$ | % |
|---|---|---|---|---|---|---|---|
| 08.30,1986 | 89.08 | 345 cm/s$^2$ | 3.87 | 1,217 | 419.86 | 104.41 | 21.7% |
| 05.30,1990 | 63.13 | 270 cm/s$^2$ | 4.27 | 1.103 | 297.81 | 69.63 | 10.3% |
| 05.31,1990 | 15.90 | 75 cm/s$^2$ | 4.71 | 1.000 | 75.00 | 15.90 | - |

**Table 4**.Bucharest-Bolintinu Vale Seismic Station(N155E Comp.):$\Phi^0$ =44.444;$\lambda^0$=25.757

| Earthquake | $a_{max}$ (recorded) | $S_a^{max}$ (β=5%) | $S_a^{max}/a_{max}$ (SAF) | c | $S_a^*$(g) ( β=5%) | $a^*$(g) | % |
|---|---|---|---|---|---|---|---|
| 08.30,1986 | 83.7 cm/s$^2$ | 295 cm/s$^2$ | 3.52 | 1,235 | 364.3 | 103.3 | 23.5% |
| 05.30,1990 | 215.0 cm/s$^2$ | 800 cm/s$^2$ | 3.72 | 1.169 | 935,2 | 251.3 | 16.9% |
| 05.31,1990 | 35.6 cm/s$^2$ | 155 cm/s$^2$ | 4.35 | 1.000 | 155.0 | 35.6 | - |

**Table 5**.Bucharest- Brăneşti Seismic Station(N107W Comp.): $\Phi^0$ =44.460; $\lambda^0$=26.329

| Earthquake | $a_{max}(cm/s^2)$ (recorded) | $S_a^{max}$ (β=5%) | $S_a^{max}/a_{max}$ (SAF) | c | $S_a^*(g)$ ( β=5%) | $a^*$ | % |
|---|---|---|---|---|---|---|---|
| 08.30,1986 | 89.08 | 345 $cm/s^2$ | 3.87 | 1,217 | 419.86 | 104.4 | 21.% |
| 05.30,1990 | 63.13 | 270 $cm/s^2$ | 4.27 | 1.103 | 297.81 | 69.6 | 10.% |
| 05.31,1990 | 15.90 | 75 $cm/s^2$ | 4.71 | 1.000 | 75.00 | 15.9 | - |

**Table 6**.Bucharest-Metalurgiei Seismic Station(N127W Comp.): $\Phi^0$ =44.376; $\lambda^0$=26.119

| Earthquake | $a_{max}(cm/s^2)$ (recorded) | $S_a^{max}$ (β=5%) | $S_a^{max}/a_{max}$ (SAF) | c | $S_a^*(g)$ ( β=5%) | $a^*$ | % |
|---|---|---|---|---|---|---|---|
| 08.30,1986 | 71.07 | 220 $cm/s^2$ | 3.06 | 1,483 | 326.26 | 105,39 | 48.3% |
| 05.30,1990 | 55.40 | 220 $cm/s^2$ | 3.97 | 1.143 | 251.46 | 63,32 | 14.3% |
| 05.31,1990 | 12.10 | 55 $cm/s^2$ | 4.54 | 1.000 | 55.00 | 12.10 | - |

**Table 7**.Bucharest-Panduri Seismic Station(N131E Component): $\Phi^0$ =44.426; $\lambda^0$=26.065

| Earthquake | $a_{max}(cm/s^2)$ (recorded) | $S_a^{max}$ (β=5%) | $S_a^{max}/a_{max}$ (SAF) | c | $S_a^*(g)$ ( β=5%) | $a^*$ | % |
|---|---|---|---|---|---|---|---|
| 08.30,1986 | 89.4 | 295 $cm/s^2$ | 3.29 | 1,513 | 446.33 | 135.26 | 51.3% |
| 05.30,1990 | 131.3 | 590 $cm/s^2$ | 4.49 | 1.109 | 654.31 | 145.61 | 10.9% |
| 05.31,1990 | 33.0 | 160 $cm/s^2$ | 4.98 | 1.000 | 160.00 | 33.00 | - |

**Table 8.**Bucharest-Titulescu Seismic Station(N145W Component): $\Phi^0$ =44.452; $\lambda^0$=26.080

| Earthquake | $a_{max}(cm/s^2)$ (recorded) | $S_a^{max}$ (β=5%) | $S_a^{max}/a_{max}$ (SAF) | c | $S_a^*(g)$ ( β=5%) | $a^*$ | % |
|---|---|---|---|---|---|---|---|
| 08.30,1986 | 87.54 | 395 $cm/s^2$ | 4.51 | 1,142 | 451.09 | 99.97 | 14.2% |
| 05.30,1990 | 56.80 | 210 $cm/s^2$ | 3.69 | 1.395 | 292,95 | 78.91 | 39.5% |
| 05.31,1990 | 10.67 | 55 $cm/s^2$ | 5.15 | 1.000 | 55.00 | 10.67 | - |

**Table 9**.Bucharest-Carlton Seismic Station(N75E Comp.): $\Phi^0$ =44.436; $\lambda^0$=26.102

| Earthquake | $a_{max}(cm/s^2)$ (recorded) | $S_a^{max}$ (β=5%) | $S_a^{max}/a_{max}$ (SAF) | c | $S_a^*(g)$ ( β=5%) | $a^*$ | % |
|---|---|---|---|---|---|---|---|
| 08.30,1986 | 79.60 | 240 $cm/s^2$ | 3.015 | 1,276 | 306.24 | 101.64 | 27.6% |
| 05.30,1990 | 114.7 | 305 $cm/s^2$ | 2.659 | 1.447 | 210.78 | 165.97 | 44.7% |
| 05.31,1990 | 19.48 | 75 $cm/s^2$ | 3.850 | 1.000 | 75.00 | 19.48 | - |

**Table 10**.Galaţi-IPJ(GLT2)Seismic Station(N97WE Comp.):$\Phi^0$ =45.430; $\lambda^0$=28.058

| Earthquake | $a_{max}(cm/s^2)$ (recorded) | $S_a^{max}$ (β=5%) | $S_a^{max}/a_{max}$ (SAF) | c | $S_a^*(g)$ ( β=5%) | $a^*$ | % |
|---|---|---|---|---|---|---|---|
| 08.30,1986 | 69.10 | 220 $cm/s^2$ | 3.183 | 1,334 | 293.48 | 92.17 | 33.4% |
| 05.30,1990 | 74.23 | 250 $cm/s^2$ | 3.368 | 1.260 | 315.00 | 93.53 | 26.0% |
| 05.31,1990 | 47.11 | 200 $cm/s^2$ | 4.245 | 1.000 | 200.00 | 47.11 | - |

**Tabel 11.**Iaşi-Centru(IAS2)Seismic Station(N-S Comp.):$\Phi^0$ =47.160; $\lambda^0$=27.570

| Earthquake | $a_{max}(cm/s^2)$ (recorded) | $S_a^{max}$ (β=5%) | $S_a^{max}/a_{max}$ (SAF) | c | $S_a^*(g)$ ( β=5%) | $a^*$ | % |
|---|---|---|---|---|---|---|---|
| 08.30,1986 | 64.10 | 190$cm/s^2$ | 2.964 | 1.363 | 563.16 | 87.36 | 36.3% |
| 05.30,1990 | 109.5 | 390$cm/s^2$ | 3.561 | 1.135 | 442.65 | 124.28 | 13.5% |
| 05.31,1990 | 45.76 | 185$cm/s^2$ | 4.042 | 1.000 | 185.00 | 45.76 | - |

**Table 12.**Iaşi-Copou(IAS2)Seismic Station(N-S Comp.):$\Phi^0$ =47.193; $\lambda^0$=27.562

| Earthquake | $a_{max}(cm/s^2)$ (recorded) | $S_a^{max}$ (β=5%) | $S_a^{max}/a_{max}$ (SAF) | c | $S_a^*(g)$ ( β=5%) | $a^*$ | % |
|---|---|---|---|---|---|---|---|
| 08.30,1986 | 68.18 | 225 $cm/s^2$ | 3.300 | 1.293 | 290.92 | 88.15 | 29.3% |
| 05.30,1990 | 97.22 | 395 $cm/s^2$ | 4.063 | 1.050 | 414.75 | 102,08 | 13.5% |
| 05.31,1990 | 49.44 | 211 $cm/s^2$ | 4.267 | 1.000 | 211.00 | 49.44 | - |

Table 13.Bucharest-Măgurele Seismic Station(E-W Comp.):$\Phi^0$ =47.347; $\lambda^0$=26.030

| Earthquake | $a_{max}$(cm/s$^2$) (recorded) | $S_a^{max}$ (β=5%) | $S_a^{max}/a_{max}$ (SAF) | c | $S_a^*$(g) (β=5%) | $a^*$ | % |
|---|---|---|---|---|---|---|---|
| 08.30,1986 | 113.80 | 307 cm/s$^2$ | 2.6982 | 1.329 | 408.6 | 151.46 | 32.9% |
| 05.30,1990 | 90.25 | 324 cm/s$^2$ | 3.5869 | 1.000 | 324.0 | 90.25 | - |

**Table 14.** Ploieşti-(PLS)Seismic Station(N100E Comp.):$\Phi^0$ =44.930; $\lambda^0$=26.020

| Earthquake | $a_{max}$(cm/s$^2$) (recorded) | $S_a^{max}$ (β=5%) | $S_a^{max}/a_{max}$ (SAF) | c | $S_a^*$(g) (β=5%) | $a^*$ | % |
|---|---|---|---|---|---|---|---|
| 08.30,1986 | 207.2 | 730 cm/s$^2$ | 3.523 | 1.124 | 820.5 | 232.89 | 12.4% |
| 05.30,1990 | 72.6 | 235 cm/s$^2$ | 3.236 | 1.224 | 287.6 | 88.86 | 22.4% |
| 05.31,1990 | 16.4 | 65 cm/s$^2$ | 3.963 | 1.000 | 65.00 | 16.40 | - |

**Table 15.** Bacău-(BAC2)Seismic Station( E-W Comp.):$\Phi^0$ =46.567; $\lambda^0$=26.900

| Earthquake | $a_{max}$(cm/s$^2$) (recorded) | $S_a^{max}$ (β=5%) | $S_a^{max}/a_{max}$ (SAF) | c | $S_a^*$(g) ( β=5%) | $a^*$ | % |
|---|---|---|---|---|---|---|---|
| 08.30,1986 | 72.20 | 292 cm/s$^2$ | 4.0443 | 1.457 | 425.44 | 105.19 | 45.7% |
| 05.30,1990 | 132.43 | 684 cm/s$^2$ | 5.1649 | 1.141 | 780.44 | 151.10 | 24.1% |
| 05.31,1990 | 63.07 | 372 cm/s$^2$ | 5.8942 | 1.000 | 372.00 | 63.07 | - |

**Table 16.** Cernavoda -(CVD2)Seismic Station(E-W Comp.):$\Phi^0$ =44.340; $\lambda^0$=28.030

| Earthquake | $a_{max}$(cm/s$^2$) (recorded) | $S_a^{max}$ (β=5%) | $S_a^{max}/a_{max}$ (SAF) | c | $S_a^*$(g) ( β=5%) | $a^*$ | % |
|---|---|---|---|---|---|---|---|
| 08.30,1986 | 62.78 | 256 cm/s$^2$ | 4.0777 | 1.420 | 363.52 | 89.14 | 42.0% |
| 05.30,1990 | 100.06 | 475 cm/s$^2$ | 4.7471 | 1.219 | 579.02 | 121.97 | 21.9% |
| 05.31,1990 | 49.73 | 288 cm/s$^2$ | 5.7912 | 1.000 | 288.00 | 49.73 | - |

**Table 17.** Craiova-(CRV) Seismic Station (N05E Comp.):$\Phi^0$ =47.321; $\lambda^0$=23.798

| Earthquake | $a_{max}$(cm/s$^2$) (recorded) | $S_a^{max}$ (β=5%) | $S_a^{max}/a_{max}$ (SAF) | c | $S_a^*$(g) ( β=5%) | $a^*$ | % |
|---|---|---|---|---|---|---|---|
| 08.30,1986 | 140.70 | 690 cm/s$^2$ | 4.9040 | 1.1435 | 789.01 | 160.89 | 14.4% |
| 05.30,1990 | 62.41 | 350 cm/s$^2$ | 5.6080 | 1.000 | 350.00 | 62.41 | - |

**Table 18**. Râmnicu Sărat -(RMS2)Seismic Station(N55E Comp.):$\Phi^0$ =45.380; $\lambda^0$=27.040

| Earthquake | $a_{max}$(cm/s$^2$) (recorded) | $S_a^{max}$ (β=5%) | $S_a^{max}/a_{max}$ (SAF) | c | $S_a^*$(g) (β=5%) | $a^*$ | % |
|---|---|---|---|---|---|---|---|
| 08.30,1986 | 140.3 | 400 cm/s$^2$ | 2.8510 | 1.215 | 486.0 | 170.46 | 21.5% |
| 05.31,1990 | 66.4 | 230 cm/s$^2$ | 3.4638 | 1.000 | 230.0 | 66.40 | - |

At the same seismic station, for example at Bucharest-Panduri Seismic Station (Table 7) and Figure 3, close to borehole 172, for horizontal components and β=5% damping, the values of the SAF for accelerations are: 3.29 for August 30,1986 Vrancea earthquake ($M_W$=7.1); 4.49 for May 30, 1990 ($M_W$=6.9) and 4.98 for May 31, 1990 ($M_W$ =6.4). Vrancea earthquake on May 31,1990 ($M_W$=6.4) could be assumed that the response is still in elastic domain and then we have the possibility to compare to it. On the other hand, from Tables 1-19 and Figure 4 we can see that there is a strong nonlinear dependence of the spectral amplification factors on earthquake magnitude (Marmureanu et al,1995,2005) for other seismic stations on Romanian territory on extra-Carpathian area (Iasi, Bacau, Focsani, Bucharest-NIEP, NPPCernavoda,Bucharest-INCERC etc.).

**Table 19**. Median values of (SAF) for last three strong Vrancea earthquakes (Marmureanu et al,2005,2010)

| Damping | August 30, 1986 ($M_S$=7.0; $M_w$=7.1) | | May 30,1990 ($M_S$=6.7 ; $M_w$ =6.9) | | May 31,1990 ($M_S$=6.2; $M_w$ =6.4) | |
|---|---|---|---|---|---|---|
| ξ% | $S_a^{max}/a_{max}$ | $S_v^{max}/v_{max}$ | $S_a^{max}/a_{max}$ | $S_v^{max}/v_{max}$ | $S_a^{max}/a_{max}$ | $S_v^{max}/v_{mav}$ |
| 2% | 4.74 | 3.61 | 5.58 | 3.72 | 6.22 | 4.84 |
| 5% | 3.26 | 2.69 | 3.63 | 2,95 | 4.16 | 3.48 |
| 10% | 2.43 | 1.99 | 2.56 | 2,14 | 2.92 | 2.69 |
| 20% | 1.78 | 1.50 | 1.82 | 1,58 | 2.13 | 1.86 |

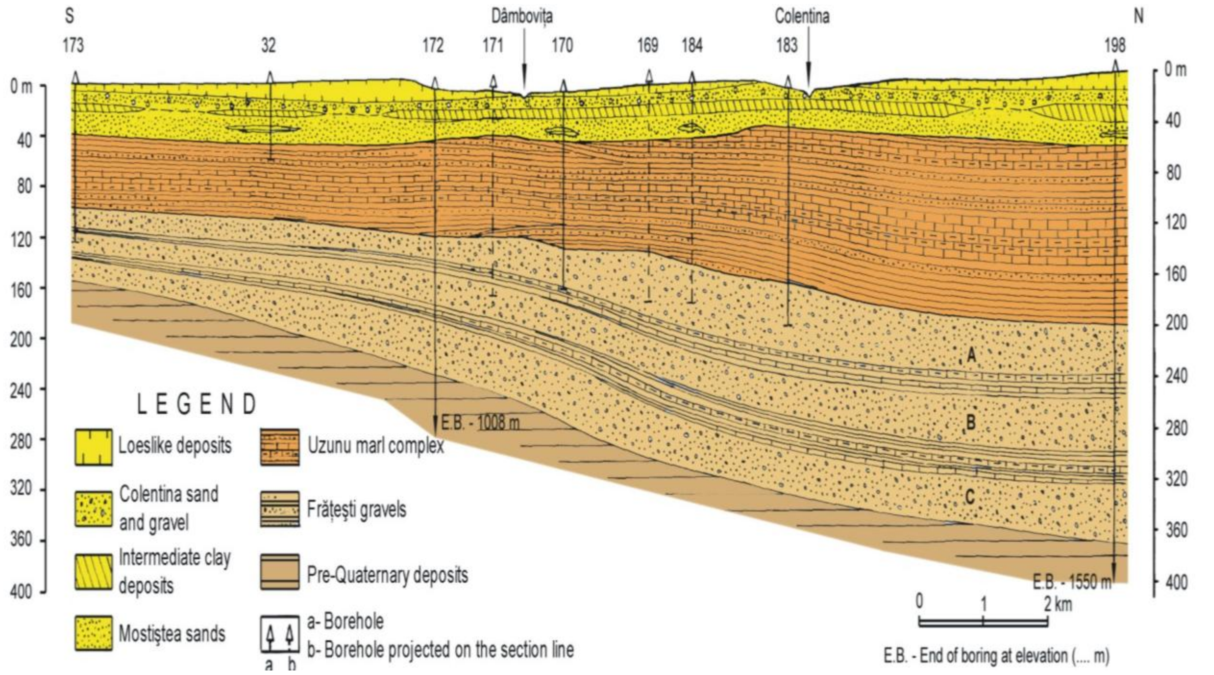


Figure 3.The geological structure under Bucharest. Isobars are generally oriented East-West with slope of 8‰ down from South to North. In the same direction , the thickness of layers becomes larger(Marmureanu et al, 2010).

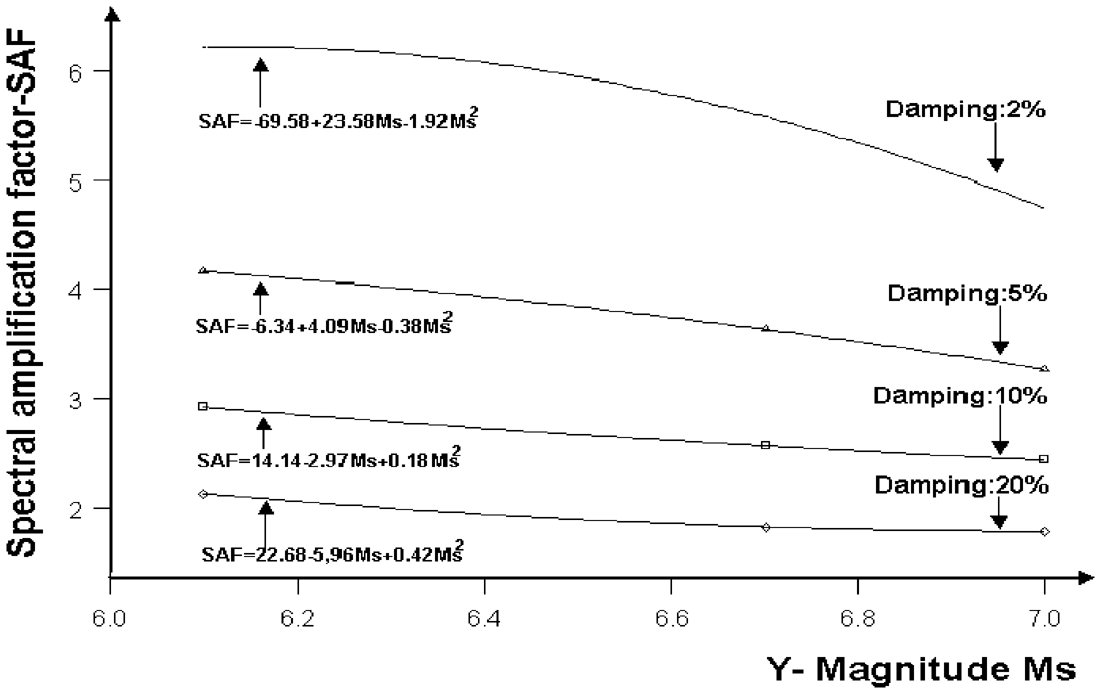


**Figure 4**.Strong nonlinear dependence of spectral amplification factors (SAF) of Vrancea earthquake magnitude on extra-Carpathian area. Magnitude $M_S$ is Richter scale (Marmureanu et al,2005,2010).

**Table 20.**Values of spectrum amplification factors for control points: A, B, C, D from R.G 1.60[21 ]

| Percent of critical damping, ζ (%) | Amplification factors for control points | | | |
|---|---|---|---|---|
| | Acceleration | | | Displacement |
| | A(33 Hz) | B(9 Hz) | C(2.5 Hz) | D(0.25 Hz) |
| 0.5 | 1.0 | 4.96 | 5.95 | 3.20 |
| 2.0 | 1.0 | 3.54 | 4.25 | 2.50 |

| | | | | |
|---|---|---|---|---|
| 5.0 | 1.0 | 2.61 | *3.13* | 2.05 |
| 7.0 | 1.0 | 2.27 | 2.72 | 1.88 |
| 10.0 | 1.0 | 1.90 | 2.28 | 1.70 |

Standard response spectrum for structures like nuclear power plants,dams,large bridges etc. is scaled up to the value of graund acceleration,velocity and displacement by using relative values of *spectrum amplification factors(SAF)* for control points(Table 20) and all of them are considering linear behavior of soils from each layer between baserock and surface free field. This standard/design response spectrum is scaled up to the value of ground acceleration, velocity and displacement specific to each site by using so called spectral amplification factors(Table 20) (IAEA, 2002a; U.S.;R.G.1.60).Values of spectrum amplification factors for control points: A, B, C, D for different frequencies are given in Table 20,values given by Regulatory Guide 1.69 of the U. S. Atomic Energy Commission and accepted by IAEA Vienna. From Tables 1-18 & 19 for median values we can see that there is a strong nonlinear dependence of the spectral amplification factors(SAF) on earthquake magnitude(Marmureanu et al,2005,2010,2012;Cioflan et al,2011) for all records made on extra-Carpathian area for last strong Vrancea earthquakes. The amplification factors are decreasing with increasing the magnitudes of deep strong Vrancea earthquakes and this values are far of that given in Table 20 by Regulatory Guide 1.60 of the U. S. Atomic Energy Commission**.** The spectral amplification factors(SAF) and, in fact, the nonlinearity, are functions of Vrancea earthquake magnitude. The amplification factors decrease as the magnitude increases**.**

## 4. DISCUSIONS AND CONCLUSIONS

1. In last book written by Peter M. Shearer, Professor of Geophysics at the Scripps Institution of Oceanography, University of California, San Diego(Shearer,2009) we can find, in total, only 12 rows about non-linear seismology(page 176).Among others are the following conclusions :(i)-Strong ground accelerations from large earthquakes can produce a non-linear response in shallow soils; (ii)-When a non-linear site response is present, then the shaking from large earthquakes cannot be predicted by simple scaling of records from small earthquakes; (iii)-This is an active area of research in strong motion and engineering seismology.
2.The central question of the discussion was in last time whether soil amplification is function of earthquake amplitude dependent. The dependence of soil response on strain amplitude become a standard assumption in the geotechnical field , in earthquake engineering and engineering seismology. Figure 1 shows a typical stiffness degradation curve ,in term of G modulus and increasing of damping along with strain levels developed during strong earthquakes. In other words, a variation of dynamic torsion modulus function (G, daN/cm$^2$) and torsion damping function (G%) of specific shear strain (γ%).The strain at the onset of the nonlinear elastic zone ranges from less than 5x10$^{-4}$ percent for non-plastic soils at low confining pressure conditions to greater than 5x10$^{-2}$ percent at high confining pressure or in soils with high plasticity.
3. To see the actual influence of nonlinearity of the whole system (seismic source-path propagation-local geological structure) the authors used to study the response spectra .The response spectra are the last in this chain and, of course, that they are the ones who are taken into account in seismic design of all structures.
4. From Tables 1-18 and 19 for median values, we can see that there is a strong nonlinear dependence of the spectral amplification factors(SAF) for absolute accelerations on earthquake magnitude for all records made on extra-Carpathian area from Iasi to Craiova for last strong Vrancea earthquakes.
5. There is a strong dependence of the spectral amplification factors of earthquake magnitude. At the same seismic station, for example at NPP Cernavoda Seismic Station, horizontal components and 5% damping, the values of the SAF for accelerations are: 4.07 for August 30,1986 Vrancea earthquake ($M_W$=7.1); 4.74 for May 30, 1990 ($M_W$=6.9) and 5.79 for May 31, 1990 ($M_W$ =6.4). The geophysical profile for NPP Cernavoda site is as follows: first 5.00 m of fractured limestone with shear modulus $G^{max}$=7,000 daN/cm$^2$, internal damping, $D_{min}$=3.7% and density, ρ=2.3t/m$^3$; next 7.00 m of fractured limestone with clay with $G^{max}$=6,000 daN/cm$^2$,$D_{min}$=3.6% and ρ=2.1t/m$^3$; next 34.00 m of marl with $G^{max}$ = 4.470 daN/cm$^2$, $D_{min}$ =4.2% and density ρ=2.1t/m$^3$.The marl is going down more than 250 m.

5. The amplification factors decrease as the strength/earthquake magnitude increases. This is consistent with data from Tables 1 to 19,which confirm that the ground accelerations tends to decrease as earthquake magnitude increases. As the excitation level increases, the response spectrum is larger for the linear case than that for the nonlinear one.
6. The amplification factors decrease with increasing the magnitudes of deep strong Vrancea earthquakes and this values are far of that given by Regulatory Guide 1.60 of the U. S. Atomic Energy Commission and accepted also by IAEA Vienna.
7. These knowledge's 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. Most cities and villages are located on large alluvial deposits/sediments, on Quaternary layers in river valleys etc. The question is: how many cities, villages, metropolitan areas etc. in seismic regions are constructed on rock sites?

ACKNOWLEDGEMENT
This work is performed in the frame of the National Plan for Research, Development and Innovation, NII, Partnership Program; Project "Bridging the gap between seismology and earthquake engineering. From the seismicity of Romania towards refined implementation of seismic action of European Norm EN 1998-1 in earthquake resistant design of buildings(BIGSEES), Contract nr.72/2012-2015.

**ACKNOWLEDGEMENT**
This work was supported partially by CNCSIS-UEFISCDI PNII-Human resources, project code PD.187, contract No. 128/29.07.2010-2013.

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