FREQUENCY CONTENTS OF STRONG MOTIONS FROM ROMANIAN SUBCRUSTAL EARTHQUAKES

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ABSTRACT

The earthquakes of March 1977, August 1986 and May 1990 represent the largest intermediate-depth seismic events produced in the Vrancea seismic zone in the past 70 years. Over 90 pairs of horizontal recordings were obtained during these earthquakes and their frequency contents is analysed in this paper. In addition, the characteristics of the most important strong ground motion recorded in Romania – the recording from INCERC station are discussed and evaluated, as well. The analyses of the frequency content of recorded ground motions reveal long predominant frequencies in Bucharest observed during the larger magnitude earthquakes of March 1977 and August 1986. Two definitions of the control period T_C given by Newmark and Hall (1969, 1982) and Lungu et al. (1997) are applied on the available strong ground motion database in order to evaluate the frequency content. The shape of the normalized acceleration response spectra as a function of the cycle duration and number of cycles of the ground motions are investigated using the recording from INCERC station and the recording obtained at Mexico-City SCT station during the 1985 Michoacan seismic event.

INTRODUCTION

The Vrancea seismic source, located at the Carpathian Mountains bending, is a source of subcrustal seismic activity (depths in the range 60 to 170 km), which affects more than 2/3 of the territory of Romania and an important part of the territories of Republic of Moldova, Bulgaria and Ukraine.

The ground motions recordings from the Vrancea earthquakes of March 4, 1977 (M_w = 7.5, h = 109 km), August 30, 1986 (M_w = 7.1, h = 131 km) and May 30, 1990 (M_w = 6.9, h = 91 km) show various frequency contents, from wide and/or intermediate frequency bandwidth ground motions (in hard and/or medium soil conditions) to narrow frequency band ground motions with long predominant periods (T_P = 1.4 ÷ 1.6 s) in Bucharest area or Ramnicu Sarat. The random frequency content of the recorded strong ground motions shows a clear dependence on the earthquake magnitude and local soil conditions, as well as on the epicentral distance.

The Vrancea subcrustal earthquakes of August 30, 1986 and May 30, 1990, despite of their significant magnitude, did not cause building collapses in Bucharest or in other regions of Romania, but they did produce damage to many buildings. Considering the fact that these two earthquakes came less than 15 years after the large magnitude earthquake of March 4, 1977 and that the building stock was not retrofitted, the lack of serious buildings damage in Bucharest is noticeable.

The assessment of the frequency contents of strong ground motions from Vrancea earthquakes using the power spectral density and its related indicators: the dimensionless frequency bandwidth indicators ε and q, as well as the fractile frequencies f_{10}, f_{50} and f_{90} is presented in the papers of Lungu et al. (1992, 1993).

Among the most used deterministic indicators of the frequency contents of ground motion recordings are the control periods of structural response spectra originally introduced by Newmark and Hall (1969, 1982). These control periods are very significant concepts for building codes provisions. The evolution of the definition of the control periods during the years 1978 – 2010 is shown in the paper of Pavel and Lungu (2012) and is applied to various worldwide strong ground motions. The correlation between the frequency content indicators and the peak ground velocity (PGV) is investigated in the study of Pavel and Lungu (2013). Another deterministic indicators of the frequency contents might be the mean period T_M defined in (Rathje et al., 1998) and the period at which the maximum spectral acceleration is encountered.

The study focuses mainly on: (i) the evaluation of the frequency content of strong ground motions from the largest Vrancea earthquakes which occurred in the last 30 years in Romania with emphasis on predominant period concept and (ii) the impact of the results on the most recent version of the Romanian seismic design code (P100-1/2013). The study emphasizes the dependence of the frequency contents of the strong ground motions recorded in soft soil conditions on the earthquake magnitude. Moreover, the values of the dynamic amplification factors (defined as the maximum spectral acceleration divided by the peak ground acceleration) for two representative narrow frequency band ground motions in the world – the recording of the Vrancea earthquake of 1977 from INCERC station in Bucharest and the recording of the Michoacan 1985 earthquake obtained at Mexico-City SCT station are evaluated, as well.

STRONG GROUND MOTION DATABASE

The strong ground motion database used in the current study consists of 185 horizontal recordings obtained during the three Vrancea subcrustal earthquakes of March 1977 (4 recordings), August 1986 (78 recordings) and May 1990 (103 recordings). The first strong ground motion in Romania was recorded at INCERC seismic station in Bucharest during the Vrancea earthquake of 4 March 1977 on a Japanese SMAC-B type accelerograph. Unfortunately, this represents the single free-field recording of the strongest earthquake produced in the Vrancea subcrustal seismic source in the past 70 years. The subsequent earthquakes of August 1986 and May 1990 produced around 100 pairs of horizontal recordings obtained on analog SMA-1 accelerographs. 75 such instruments were donated to Romania by the United States after the March 1977 earthquake.

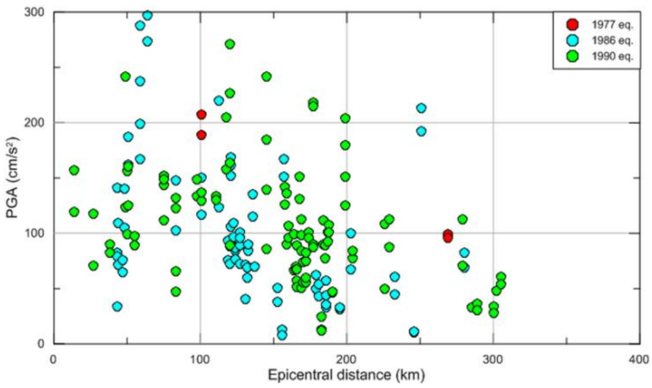

Figure 1. Distribution of peak ground acceleration (PGA) with the epicentral distance of the recording seismic station

Since all the recordings from the three above-mentioned seismic events were obtained on analog type instruments no processing was performed by the authors. Originally the ground motion processing was done using an Ormsby band pass filter with cut-off frequencies of 0.15 - 0.25 Hz and 25 - 28 Hz. The analyzed recordings come from three different seismic networks: INFP (National Institute for Earth Physics), INCERC (Building Research Institute) and GEOTEC (Institute for Geotechnical and Geophysical Studies).

The distribution of the peak ground acceleration (PGA) and peak ground velocity (PGV) with the epicentral distance of the recording seismic station is shown in Fig. 1 and Fig. 2.

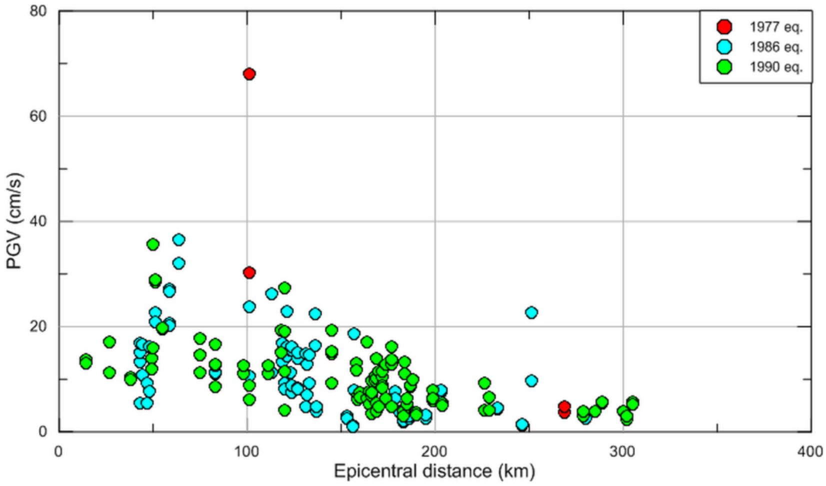

Figure 2. Distribution of peak ground velocity (PGV) with the epicentral distance of the recording seismic station

One can notice from Fig. 1 and Fig. 2 the very high peak ground velocity recorded at INCERC station (PGV ≈ 70 cm/s) and the corresponding peak ground acceleration which is around 0.2 g.

EVALUATION OF THE FREQUENCY CONTENT OF GROUND MOTIONS

The currently enforced Romanian seismic design code P100-1/2013, as well as its previous versions takes into account the soil conditions through three values of the control period T_C = 0.7 s, 1.0 s and 1.6 s. The definition for the control period T_C is given by Lungu et al. (1997). Table 1 summarized the definitions for the control periods given by Lungu et al. (1997). The design response spectrum from the seismic code P100-1/2013 is also characterized by a control period $T_B = 0.2\ T_C$, a control period T_D which has two values 2.0 s and 3.0 s (depending on T_C) and a maximum dynamic amplification factor of 2.5.

Eurocode 8 (EN 1998-1) accounts for the influence of the site effects through the use of different spectral shapes and of soil factors S for each soil class. The soil classes (from A to E, S1 and S2) are categorized according to the values of $v_{s,30}$ - the average shear wave velocity in the upper 30 m of soil deposits.

Table 1. Definitions of control periods T_C and T_D of the structural response spectra (Lungu et al, 1997)

<table>
<tr><td colspan="2">Control period</td></tr>
<tr><td>$T_C = 2\pi \frac{EPV}{EPA}$</td><td>$T_D = 2\pi \frac{EPD}{EPV}$</td></tr>
<tr><td colspan="2">$EPV = \frac{\max \overline{SV}_{0.4}}{2.5}$ $EPD = \frac{\max \overline{SD}_{0.4}}{2.5}$ $EPA = \frac{\max \overline{SA}_{0.4}}{2.5}$</td></tr>
<tr><td colspan="2">EPA – effective peak acceleration
EPV – effective peak velocity
EPD – effective peak displacement</td></tr>
</table>

The definitions given in Table 1 for T_C and T_D are based on a mobile period window (of 0.4 s width) for obtaining the maximum effective values of acceleration, velocity and displacement: EPA, EPV and EPD. Fig. 3 shows the distribution of the control period T_C computed using the relation given by Lungu et al. (1997) with the epicentral distance of the recording seismic station.

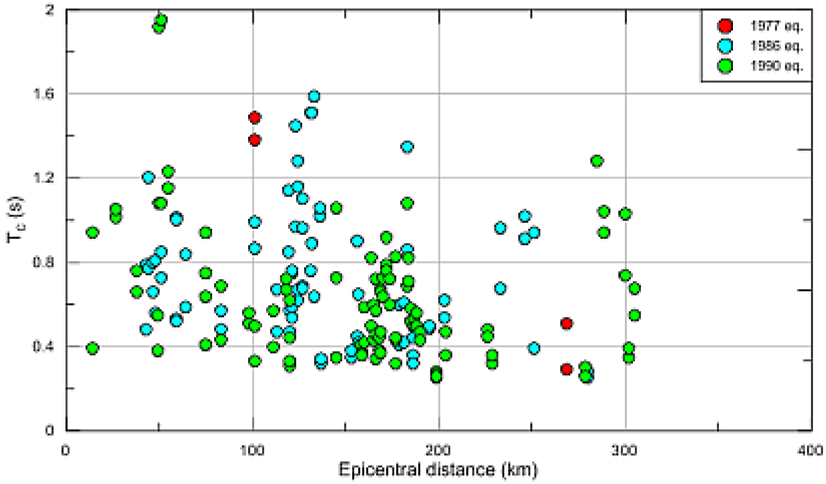

Figure 3. Distribution of control period (T_C) with the epicentral distance of the recording seismic station

The mean control period T_C for the Vrancea 1986 earthquake is 0.74 s, while in the case of the 1990 seismic event the mean T_C is 0.62 s. In the case of Bucharest, the mean control period T_C is 0.96 s for the Vrancea 1986 earthquake and 0.56 s for the earthquake of 1990.

Subsequently, the control period T_C is computed for all the strong ground motion recordings in the database using also the definition given by Newmark and Hall (1969, 1982). The relation between the two definitions for the control period T_C - Newmark and Hall (1969, 1982) and Lungu et al. (1997) is plotted in Fig. 4. One can notice from Fig. 4 that the relation between the two definitions of the control period T_C is linear and the coefficient of correlation has a value of 0.70. The difference between the two definitions is small for short T_C values, however for longer control periods (T_C larger than 0.8 s), the difference between the two definitions is quite large.

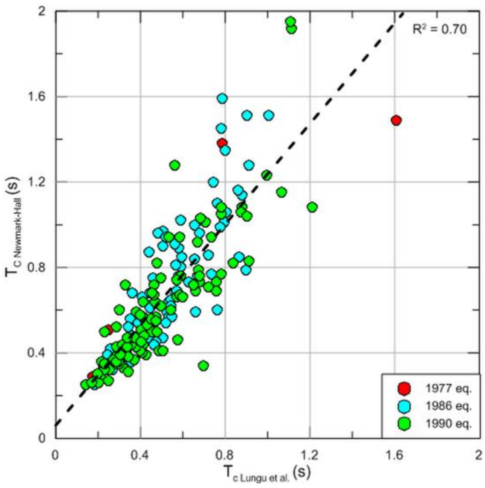

Figure 4. Relation between the definition of the control period T_C given by Newmark and Hall (1969, 1982) and Lungu et al. (1997)

In Fig. 5 the ratio between the same two T_C definitions - Newmark and Hall (1969, 1982) and Lungu et al. (1997) is plotted as a function of the epicentral distance of the recording seismic station. One can observe that the ratio is generally below one meaning that the definition of Newmark and Hall (1969, 1982) provides smaller values as compared to the definition of Lungu et al. (1997). It appears that there is a trend of decreasing values of the ratio between the two T_C definitions with the epicentral distance, however an increased database of strong ground motions should be used in order to confirm this finding.

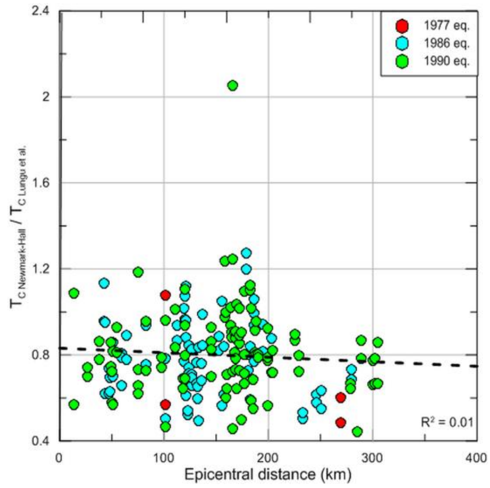

Figure 5. Relation between the definition of the control period T_C given by Newmark and Hall (1969, 1982) and Lungu et al. (1997)

The median normalized acceleration response spectra obtained using all the strong ground motions recorded in Bucharest area are shown in Fig. 6 and are compared with the normalized acceleration response spectrum from the current Romanian seismic design code P100-1/2013.

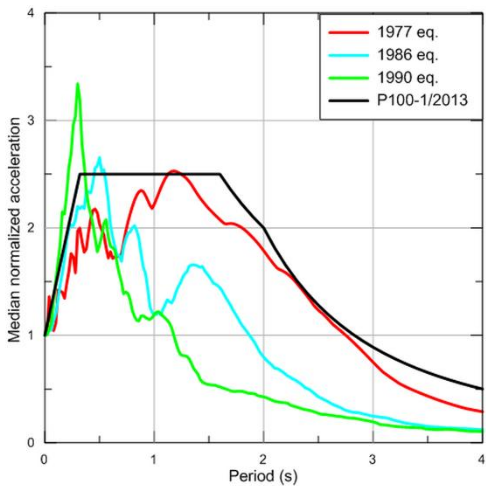

Figure 6. Comparison of median normalized acceleration response spectra from the three earthquakes with the code response spectrum for Bucharest

From Fig. 6 one can notice that the frequency content for the strong ground motions recorded in Bucharest area during the three earthquakes is quite different. It appears that the long-period spectral ordinates are significant only in the case of larger magnitude seismic events – the earthquakes of March 1977 and August 1986. In the case of the Vrancea 1990 earthquake, only the short-period spectral ordinates are noticeable from the median normalized response spectra. Moreover, the code normalized acceleration response spectrum appears to follow the normalized acceleration of the March 1977 recording from INCERC station for periods in excess of 1.5 s. The median dynamic amplification is around 2.5 for the seismic events of 1977 and 1986 and above 3 for the smaller magnitude 1990 earthquake.

The NS component of the ground acceleration recorded at INCERC seismic station from Bucharest during the Vrancea 1977 earthquake is shown in Fig. 7. As previously mentioned, this recording is the only one obtained during this earthquake, which represents the largest magnitude seismic event which has occurred in the Vrancea subcrustal seismic source in the past 75 years. The strong part of the ground motion which is represented by a single large amplitude pulse and has a duration of about 1.6 s is also highlighted in the plot.

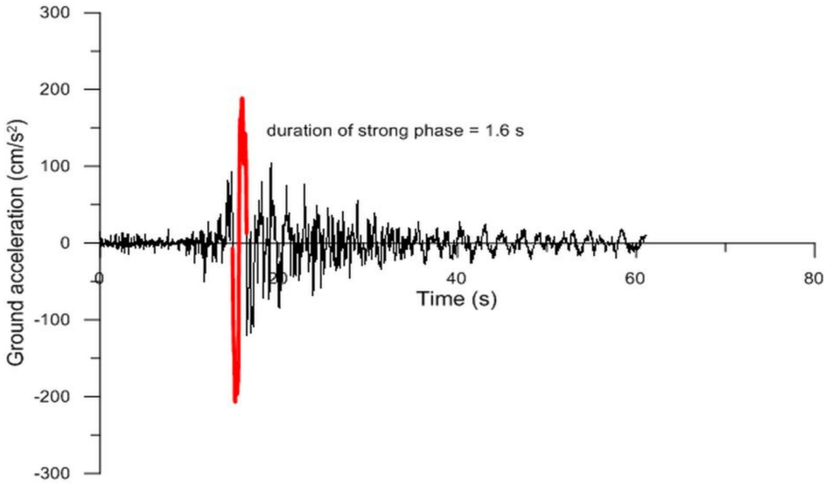

Figure 7. NS component of the ground acceleration recorded at INCERC station during the Vrancea 1977 earthquake

In Fig. 8 the influence of the duration of the strong phase on the shape of the normalized acceleration response spectra is evaluated. Three normalized acceleration response spectra are depicted in Fig. 8: the normalized acceleration response spectrum of the original strong round motion recording and two other response spectra corresponding to a duration of the strong phase double of the original one (3.2 s) and half of the original one (0.8 s), respectively. One can notice from Fig. 8 that the duration of the strong phase influences to a great extent the shape of the normalized acceleration response spectra: the predominant period increases from 1.5 s to 2.5 s for a double duration of the strong phase, while in the case of reducing the duration to half the predominant period decreases from 1.5 s to 0.7 s.

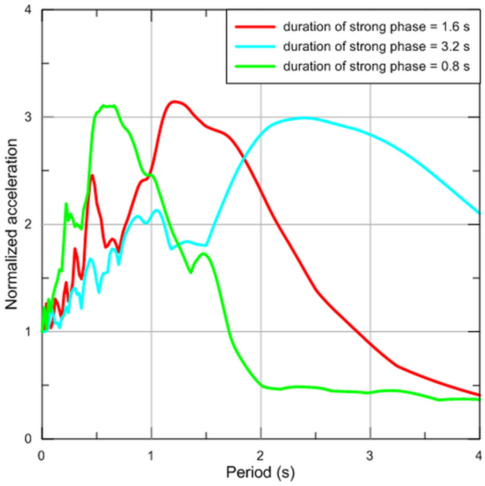

Figure 8. Comparison of median normalized acceleration response spectra from the three earthquakes with the code response spectrum for Bucharest

Another well-known strong ground motion recording was obtained at Mexico-City SCT station during the Michoacan earthquake in 1985. This strong ground motion recording, despite a limited PGA of 0.17 g, is also characterized by a very large amplification around the period of 2.0 s. The time-history of the ground acceleration is shown in Fig. 9 for the EW component of this recording. One can observe from Fig. 9 the significant number of large amplitude ground motion cycles and the very long duration of the ground motion recording – almost three minutes, as well.

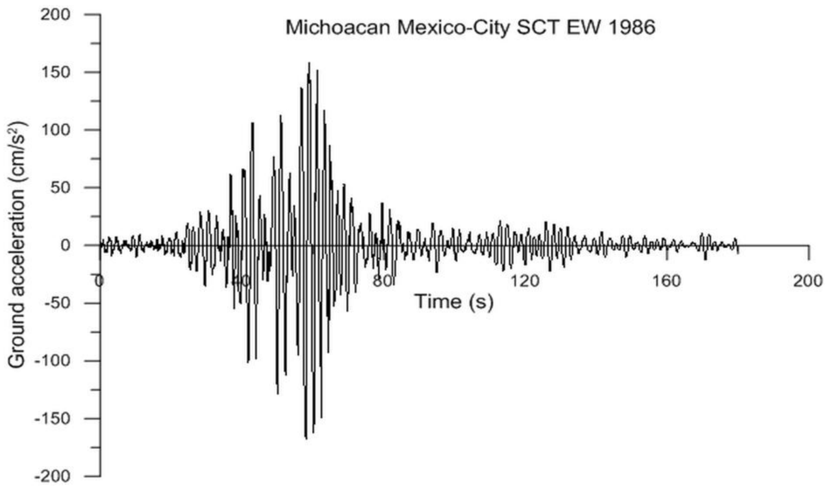

Figure 9. EW component of the ground acceleration recorded at Mexico-City SCT station during the Michoacan 1985 earthquake

The shape of the normalized acceleration response spectra as a function of the number of considered ground motion cycles is analysed in Fig. 10. One can observed that the amplification at around 2.0 s is present even when we consider only two cycles of the recorded ground motion. However, when we consider six cycles of the recorded ground motion, the amplification at the spectral period of 2.0 s increases from five to six and an additional significant amplification is noticeable for a spectral period of 2.5 s.

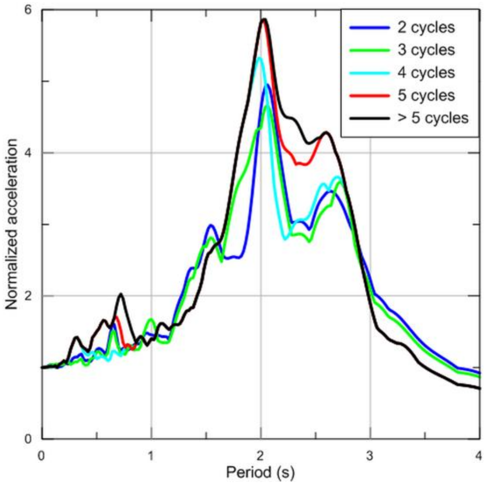

Figure 10. Influence of the number of cycles of the strong ground motion on the shape of the normalized acceleration response spectra for the Mexico-City SCT EW recording

CONCLUSIONS

The analysis of the frequency content of the strong ground motions recorded during the most important earthquakes produced in the Vrancea subcrustal seismic zone reveals that longer predominant periods are observed during the larger magnitude earthquakes of 1977 and 1986. In addition, in Bucharest the long-period spectral ordinates are significant only in the case of larger magnitude seismic events – the earthquakes of March 1977 and August 1986. In the case of the smaller magnitude May 1990 seismic event, the long period spectral ordinated are insignificant in the case of Bucharest. The control period T_C is computed using two definitions given in the literature – Newmark and Hall (1969, 1982) and Lungu et al. (1997). The analyses show that generally the definition of Lungu et al. (1997) provides larger values and in addition it appears that there is a trend of increased difference between the two definitions as the epicentral distance of the recording seismic station increases. The influence of the duration of the ground motion cycles on the shape of the normalized acceleration response spectra is highlighted with emphasis on the recording of the Vrancea 1977 earthquake from INCERC seismic station. In addition, the number of cycles of the ground motion has a significant impact on the levels of dynamic amplification as shown by the analysis performed on the Mexico-City SCT recording of the Michoacan 1985 earthquake.

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