The May 22, 2012 Mw = 5.6 Pernik Earthquake – Local Effects and Seismic Impact on Sofia city

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ABSTRACT:
On May 22, 2012, a shallow earthquake of Ms=5.8 (Mw=5.6) hit Pernik region and caused damages on many buildings in the town of Pernik and near-by villages. The maximum observed intensity is of VIII degree EMS. This seismically calm area has produced the strongest Bulgarian earthquake for the latest 80 years. A short seismological insight of the source activity is followed by an engineering analysis and evaluation of the seismic impact for Sofia city, only about 20 km away. The array of recorded data by the local digital SGM Network of Sofia is exploited to obtain input characteristics, relevant to the aseismic design of structures. Processed data for some representative recording spots is extracted, submitted and discussed. Destruction and damages induced by the earthquake in the Pernik area are illustrated and the building vulnerability aspects are considered. Some inferences, conclusions and recommendations about seismic risk mitigation are made.

Keywords: earthquake magnitude and intensity, spectral analysis, impact evaluation, vulnerability of structures

1. INTRODUCTION

Pernik region covers the Pernik basin together with neighbouring horsts and it is situated only 20 km form the SW part of Sofia city, the capital of Bulgaria. Two faults, belonging to the Pernik-Belchin fault zone, separate the NE and SW borders of the basin from the horsts. These faults are not well educated and aren't known with some strong seismic manifestations in the last two centuries. On May 22, 2012, an earthquake of Ms=5.8 (Mw=5.6) hit Pernik region and caused damages on many buildings in the town of Pernik and the surrounding villages with maximum intensity of VIII degree EMS (Gruenthal, 1998). This event is the strongest Bulgarian earthquake for the last more then 80 years. The following seismic activity of Pernik area shows an abrupt increase in the amount of relatively stronger felt events. It becomes comparable to the same amount of events for most active seismic zones in Bulgaria during the last years. That is why the seismic vulnerability of the buildings in the region of interest is to be reconsidered. Effects from the response of different type of structures to this earthquake series are presented. They are illustrated with exemplifying original photos of damages induced by the earthquake. Taking into account the level of seismicity of Pernik region and the building vulnerability aspects, some conclusions and recommendations about the seismic risk reduction are made. The seismic impact on Sofia city is studied based on instrumentally recorded data by the local SGM Network. The records of the main event and aftershocks are of particular interest for our engineering community in Eeurocode-8 aspects, since this is the strongest ever instrumentally recorded earthquake to occur in the vicinity of the capital and strike its territory.

2. SEISMOLOGICAL BACKGROUND

The region of Pernik is not so very active seismic zone (Bonchev et al.,1982), but it is remarkable with one of the biggest coal deposit body in Bulgaria and the created public opinion, that the suddenly appeared strong seismicity in the last year is provoked by the consequences of the exploitation of both open pit or underground coal mines. Furthermore, there are many well known rather active deep seated landslides which are associated with the gravitational influence of numerous abandoned underground galleries or open pit coal mines. In the same time the level of the nowadays seismic activity of the Pernik region (more then 70 felt events for one year) is comparable to the same one for the most active seismic zones in Bulgaria well known with catastrophic earthquakes in the past. Historical analysis of the earthquake catalogues (Grigorova et al., 1979; Christoskov et al., 1979, Solakov & Simeonova, 1993; Botev et al., 1993-2012) shows a very small amount of weak earthquakes in the region of interest (as a rule with magnitude about or less then M=3.0) for the last 120 years – about 60 very weak earthquakes and only one relatively strong felt in town of Pernik in 1965. In that year on January 29 a single rather strongly felt earthquake with magnitude about M=4.5 and maximum intensity of VI-VII degree EMS occured.

On 22 May 2012, the strongest Bulgarian earthquake (Ms=5.8), in the course of a very long relatively quite period after the catastrophic 1928, occurred in the region of Pernik. It was generated in the frames of the Pernik-Belchin fault zone (Bonchev, 1971; Karagjuleva et al., 1973), north-western section, in the vicinity of Pernik town. Macroseismic study was done through inquiries accumulated via internet or by hand as well as by telephone interviews. Mobile groups of NIGGG of BAS for field investigations after strong events visited the site for the post earthquake activity investigation and data collection. The digital network of the National Operative Telemetric System for Seismological Information (NOTSSI) allowed for providing reliable detection, fast location and precise determination of all parameters of the earthquake that caused many damages in Pernik region and was felt almost on the whole territory of Bulgaria. The earthquake was recorded very well by 25 stations (15 permanent seismic stations and three local networks) of NOTSSI.

The maximum realized magnitude of this earthquake is Ms=5.8 (Mw=5.6), the depth is 9 km and the geographical coordinates are 23.00 eastern longitude and 42.58 northern latitude. According to the rapid evaluations of the Bulgarian seismic network the earthquake occurred about 20 km SW from the capital Sofia causing moderate damages in a wide area including the regional town. The seismic history of Bulgaria evidences that the epicentre of the shock is in an area which is relatively quiet at least for the last 200 years. This is the Bulgarian earthquake with highest magnitude for the last 80 years. However this strongest Bulgarian event for the last eight decades caused consequently not so strong macroseismic effects – the maximum intensity of VIII degree of EMS were observed very rarely in the villages near Pernik.

Fault plane solutions for the main earthquake with magnitude Ms = 5.8 (Mw=5.6) were obtained by various world networks as a results of analysis of 88 world seismic station records (http://www.emsc-csem.org/). Twenty three first motion polarities data from seismological stations in Bulgaria and surrounding area are included in the double - couple focal mechanism solution of NIGGG (Botev et al., 1993-2012). All polarities are check as waveforms, the strike, dip and rake are determined with accuracy up to 10 degree. The earthquake is characterized as a normal faulting, with very small strike-slip component. All fault plane solutions are conformed to each other and most of the focal mechanism parameters are within close values. According to these parameters it is clear that the main earthquake is a jerk normal fault movement caused by extensional regional tectonic stresses with northeast – southwestern orientation. The fault line run along the north-eastern borders of the Pernik basin and at average has strike = 124°, dip = 49°, and rake = -104°.

During the first day the main shock is followed by more then 30 events with maximum M=4.7, causing moderate damages in a wide area. The relatively short duration and low frequency of the aftershock sequence of this event does not increase significantly the relatively low number of all seismic events in Bulgarian territory during whole 2012. The strongest of the secondary shocks is with magnitude M=4.7 (Fig.4), the events with M > 4.0 are only four, with M > 3.0 – 15 events only and all the rest events are microearthquakes with magnitude M <3.0 – about 130. There are many smaller events (about 400) which are recorded by only one seismic station, whose coordinates are not located. Regardless of the low energy level more then 70 of these events were felt in the region of Pernik – most of them are with magnitude less than M=3.0. Some aftershocks caused additional damage on the building stock in the area.

The seismicity map shows better the active strip with NW-SE oriented epicentre alignments in the Pernik region. This orientation coincides with the strike of Pernik - Belchin fault lineament mentioned above. This fault line had been hardly identified as seismogenic structures in the pass because of their insignificant previous seismic activity. Now, regardless of the fact that earthquakes are generated rarely, the considered northeastern section of Pernik-Belchin fault zone obviously demonstrates the presence of seismogenic potential.

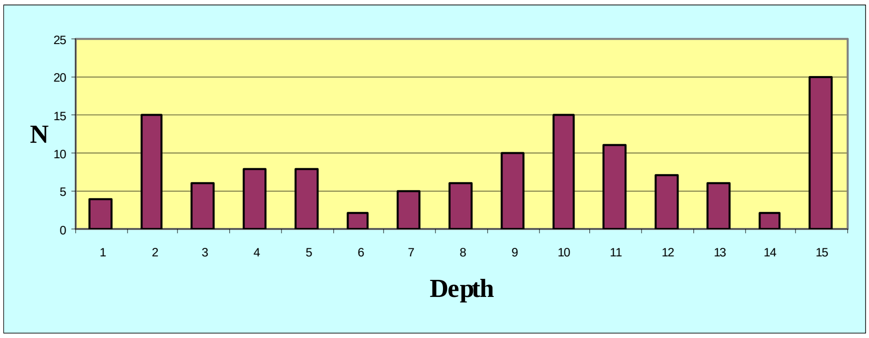


Fig. 2.1. Depth distributions of the aftershocks

The ordinary depth distribution (Fig.5) of the earthquakes shows that all the events occur down to 15 km depth. Decreasing of the number of the events with the increasing of depth, which is a natural phenomenon for the intraplate seismicity, is not observed in the case of Pernik region. Many hypocenters of the earthquakes are concentrated in the layer of 9-11 km, which is the depth of the main shock. It is not to be neglected the seismogenic potential of the underlying kilometers between 12 and 15. Finally, so many cases of a small magnitude at a 15 km depth show some boundary effect, but may be this is some implication about deeper hidden seismogenic layer in Pernik region. The magnitude-depth distribution of this earthquake series delineates some privileged seismogenic depth layer for the relatively stronger events – they were realized within 8-12 km depth.

3. ANALYSIS OF THE PROCESED INSTRUMENTAL DATA

The May 22, 2012 main event and the following stronger aftershocks were recorded by most of the stations around the country belonging to the National SGM Network and by all accelograph units of Sofia local SGM Network. The seismic risk in densely populated urban areas situated near earthquake sources is very high. Therefore concentrating the SGM monitoring in such areas is a precondition for acquiring actual data of the true input and response of structures and subsequently work out adequate solution of EE design/construction problems and effective prevention policy.

The seismic impact of this earthquake on Sofia city was evaluated after processing and analysis of the recorded data array. Representative information about the main earthquake magnitude and energy distribution within the municipality is submitted bellow. The data acquired from 3 selected stations speak about the power of this earthquake within the city framework. These are: Vitosha mountain station - coded VTS (19 km away from the epicentre); SGL1 station in the heart of the city (26 km away from the epicentre); and SGFI station (about 30 km away from the epicentre) in the E-SE part of Sofia – within the main campus of Bulgarian Academy of Sciences. The time domain and spectral characteristics of their records are illustrated in tables and figures bellow and then discussed.

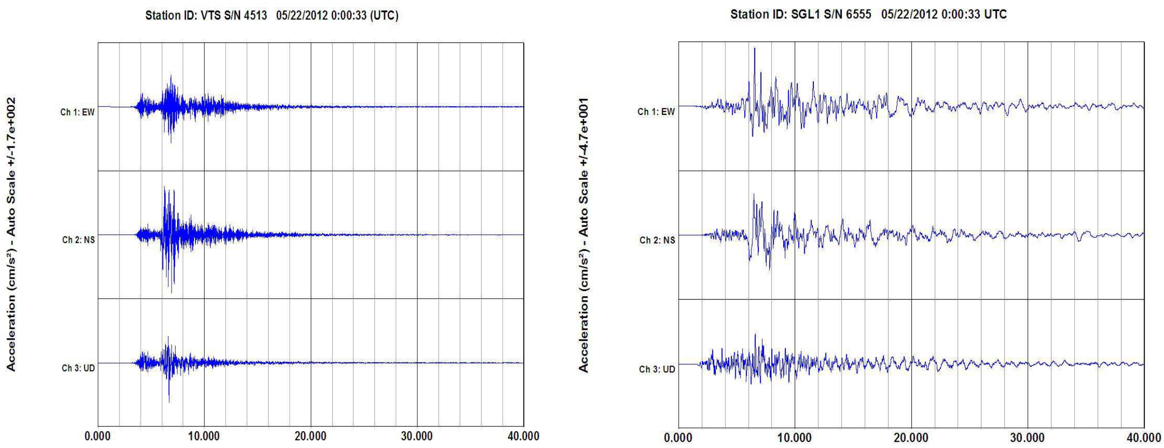


Fig. 3.1. Corrected accelerograms of VTS and SGFI stations

The time domain acceleration traces for the VTS and SGFI records may be seen in Fig. 3.1. The two stations are at different epicentral distance (19 km for VTS and 29.60 km for SGFI). Note that the scales are not the same, so that the difference in amplitude patterns may be clearly observed. The VTS record is with defined higher amplitudes (about 2.5 to 6 times higher) and higher frequency content as compared to the SGFI record, see Table 3.1. The duration of the significant part of these accelerograms is about 20 sec. The previously strongest EQ recorded by Sofia stations was with M = 3.8 /epicentre in the Vitosha Fault structure - southern boundary of the city of Sofia in November, 2008/. The respective duration of these accelerograms was about 5 sec (Hadjiyski & Simeonov 2010).

Each record has incorporated the influence of the specific seismic waves' travel paths and local soil conditions. The predominant frequencies for VTS record are much higher (1.3 ÷ 8.3) Hz in comparison with those for SGFI record (0.4 ÷ 1.1) Hz. The tangible reduction of the higher frequencies energy for the SGFI record compared to the VTS one is due to its dissipation by the geological structures along the longer travel path from the epicenter of the EQ to SGFI site and the softer soil deposit underneath the SGFI site. That "absorption" of energy is further confirmed by the PSD level of SGFI record. The VTS PSD is of order higher ($1.\ 10^{-4}$) g2/Hz in comparison with the PSD of SGFI record ($1.\ 10^{-5}$) – see Fig. 3.2.

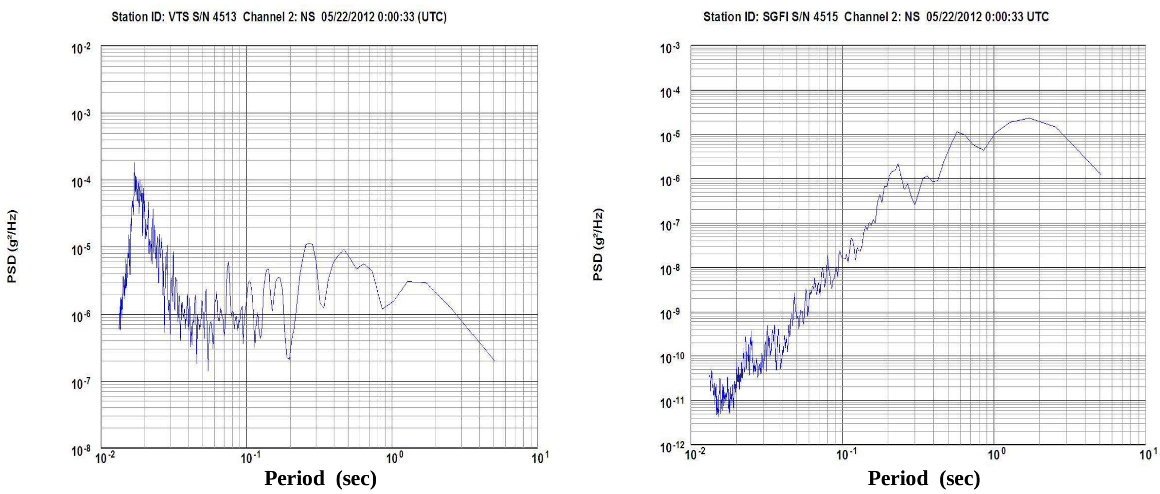


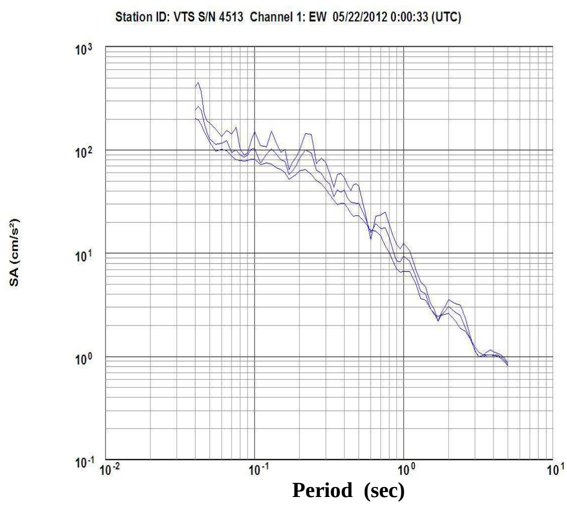
Fig. 3.2. Power spectral desnsity of VTS and SGFI records

The basic characteristics derived from VTS, SGL1 and SGFI records after being processed are listed in Table 3.1, to provide information as follows: the record number; station code and condition; distance of the recording spot to EQ epicenter; the axis codes; with the respective peak accelerations (extracted from the corrected accelerograms); and the maximum peak spectral acceleration for the three components of every record (based on the Acceleration Response spectra for 5% damping); the predominant frequency intervals; and the order of the PSD.

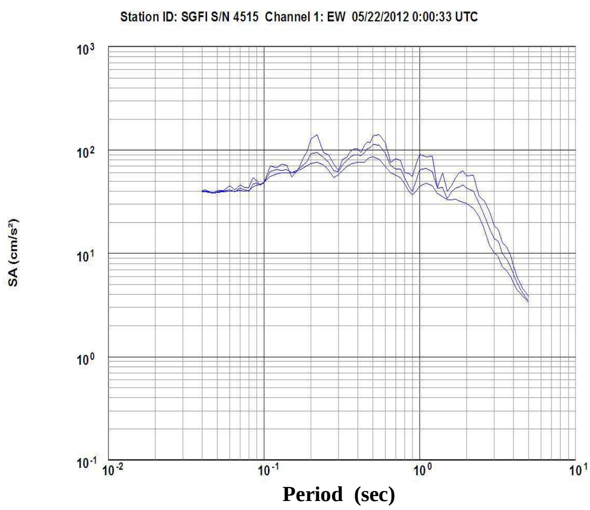
Table 3.1. Earthquake engineering relevant characteristics evaluated at Sofia stations for the seismic impact of May 22, 2012 Pernik earthquake

Record	Station		Epicenter distance	Axis code	A max	SAmax (β = 5%)	Predom. Freq.	Order of PSD
#	Code	Cond.	[km]		[cm/s^2]	[cm/s^2]	[Hz]	[g^2/Hz]
1	VTS	rock	19.00	EW NS V	- 96.22 - 156.47 - 105.97	98.67 190.24 210.30	2.0 ÷ 5.2 1.3 ÷ 4.2 2.4 ÷ 8.3	< 1. 10^{-4}
2	SGL1	base-ment	26.00	EW NS V	42.62 30.26 21.94	103.6 81.8 66.3	0.5 ÷ 0.8 0.4 ÷ 0.8 0.8 ÷ 1.8	< 3. 10^{-5}
3	SGFI	base-ment	29.60	EW NS V	38.33 - 29.91 - 17.81	112.7 114.1 53.3	0.4 ÷ 0.8 0.4 ÷ 0.9 0.5 ÷ 1.1	< 4. 10^{-5}

Let us compare the computed Acceleration Response Spectra for the EW (Fig.3.3) and NS (Fig.3.4) components of VTS and SGFI records of May 22, 2012 earthquake. It may be observed that there is a shift in maximum response to the longer periods with increasing distance of the recording site to epicentre. The maximum spectral accelerations for a SDF system at VTS site is for periods of (0.2 ÷ 0.3) sec, while for SGFI site the maximum response is for (0.5 ÷ 0.6) sec. Note that the maximum dynamic amplification is 3.8 times (5 % damping) at 0.6 sec for the NS component of the remotest site of SGFI, see Table 3.1.

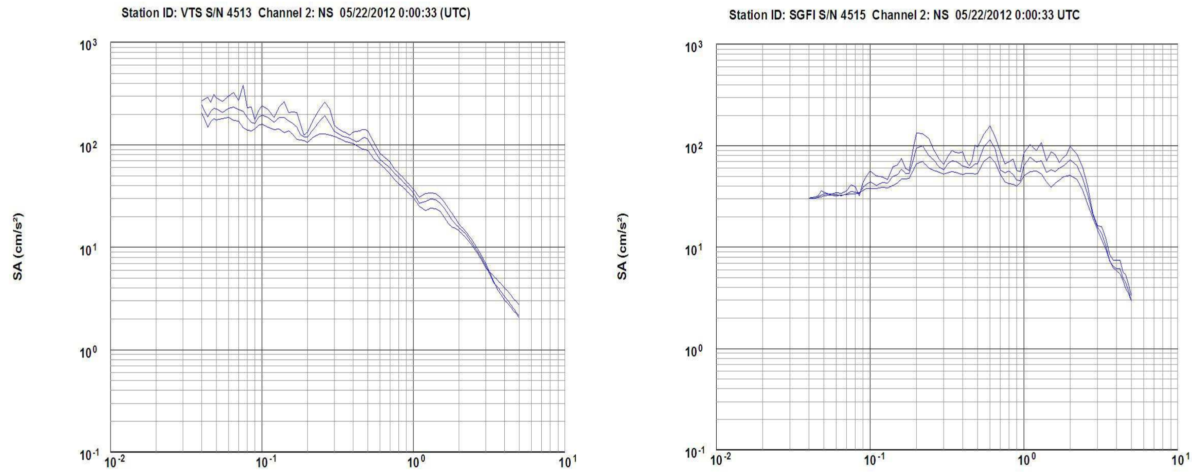


VTS (19 km away) EW component



SGFI (29.60 km away) EW component

Fig. 3.3. Acceleration Spectra for 2, 5 and 10% damping



Period (sec)
VTS (19 km away) NS component

Period (sec)
SGFI (29.60 km away) NS component

Fig. 3.4. Acceleration Spectra for 2, 5 and 10% damping

Particular attention deserves the shape of the NS acceleration response spectra at SGFI station – on the right side of Fig. 3.4. The response is almost one and the same for all SDF systems in a broad interval of periods – from 0.2 sec to 2.0 sec, corresponding to frequency interval from 0.5 Hz to 5 Hz. That means that a large variety structures with different natural periods would undergo similar seismic forces.

4. DAMAGE AND VULNERABILITY OF THE BUILDING STOCK

The on-site inspection of the earthquake's aftermaths on buildings was carried out by seismologists, geologist and structural engineers related to Academy of sciences and other institutions. The intensity of this earthquake may be defined as damaging. Most people in Pernik region and the western part of Sofia city were frightened by the main event and tried to run outdoors. The strong aftershock series caused panic among the Pernik local communities and made them live/stay outdoors for weeks. Rumours were spread about pending peril of breakdown in the wall of a dam close to Pernik. Fortunately there were no victims after the main event and the aftershock series, only slight injuries. Damages were caused in many buildings mainly in the surrounding villages of Pernik with maximum intensity of VIII (EMS). The maximum degree VII-VIII degree was observed in the village Divotino, several kilometers NE from Pernik. There were many damages corresponding to VII degree in the other villages situated NE from Pernik along the northern brunch of the line Rudarcy – Divotino - Viskyar, which is most probably a northern satellite of Pernik-Belchin fault zone. The relatively high degree of the felt intensity in those villages is explained by the specific peculiarities and orientation of the fault plane, which becomes shallow to NE of Pernik, where certain very small surface manifestations are observed in some localities along the mentioned above line.

No structural damage was observed in properly designed and constructed buildings, see Fig. 4.1. Many ordinary buildings suffer moderate damages such as: small to medium cracks in the walls (Fig. 4.2), Fracture at the roof line (Fig. 4.3), fall of plaster, many chimneys fall down. Some older buildings showed large cracks in walls and failure of infill walls (Fig. 4.4), Only a few relatively new buildings suffer serious damages, but rather due to bad construction or poor materials. A number of weak older buildings also collapsed.

Fig. 4.1. Properly constructed

Fig. 4.2. Cracks in the walls

Fig. 4.3. Fracture at the roof line

Fig. 4.4. Serious failure of a wall

The major inference from the analysis of damages in Pernik area is that the buildings that suffered seriously are concentrated mainly in villages. It is important to underline that some of them were build illegally, others without design documents, all of them with no provisions for aseismic design, many of them were put up with no observation of elementary construction rules (e.g. masonry without clear lining or bindings etc.), with poor quality of the building materials and with the construction process executed by unqualified personnel.

5. FINAL REMARKS

The data acquired from the SGM monitoring play a key role for consistent solution of the seismic safety problems for buildings, engineering structures and the life-line systems. The records of May 22, 2012 Pernik earthquake and the aftershocks on sites of Sofia city are of significant interest for EQ research/engineering and prevention, since they are the first ever digital records of near type EQ (with M > 5.5) to strike the buildings and sites of the city with the genuine source mechanism, travel path and local geology response included. They are and would be an indispensable tool for proper evaluation of the input forces endangering local buildings and engineering structures in case of seismic impact and present a prerequisite for adequate earthquake resistant design according Eurocode-8.

Particular attention deserves the shape of the acceleration response spectra derived from records of this earthquake in the center of the city. The response is almost one and the same for all SDF systems in a broad interval of periods – from 0.2 sec to 2.0 sec. That means that city planners, architects and structural engineers have to recognize the reality that all variety structures with natural periods within this interval would experience similar seismic forces.

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