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Seismic assessment of consequences in the building stock in Bulgaria based on statistical calibration of public data

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Abstract: A generally accepted step to reduce the consequences of strong earthquakes and be prepared to face them, is to assess the possible damages and undertake countermeasures proactively. The aassessments are made based on analyses of seismic hazard and vulnerability of building structures. To collect the data about the buildings requires a lot of financial resources and time especially for a large-scale study. In this paper an assessment of the possible consequences in the building stock of a town in Bulgaria is performed by using public data. Some problems arising in the use of the available public data for the building stock in Bulgaria collected by the National Statistical Institute are discussed. A statistical approach is applied to calibrate this data for the buildings to classify them according the building typology and period of construction, which are main factors that determine their vulnerability. The consequences to the building stock has been evaluated with public data for several large cities in Bulgaria. Different approaches for the relation between the earthquake intensity and the level of damage are applied. Comparison of the calculated damages in the building stock of the town of Pernik and the observed damages during the 22 May 2012 earthquake is made. The results are discussed in view of applying public data for the building stock to estimate possible consequences from a strong earthquake in large urban areas.

1. Introduction

For successful protection and prevention of disasters, the municipalities in the country prepare plans in which the possible disasters and their consequences have to be assessed. These assessments envisage the relevant preventive actions, assess the ability of municipalities to deal with the consequences (their readiness), organization and management in case of disaster. Risk assessment based on detailed data with important engineering parameters for each building in the municipality is difficult and in most cases impossible. Collecting data is a long and expensive process. This is even more true for risk assessment for large cities across the country. For a quick and rough assessment of the consequences of the earthquake in the building stock, it is necessary to use the available public summary data, which are collected by the NSI (National Statistical Institute) during the census of the population and the building stock. These data impose significant limitations and can lead to misleading estimates. In the article the consequences for the city of Pernik are assessed using public data, EMS98 [1] methodology and mean fragility curves defined in the Syner-G European project [2] for masonry buildings and in RISK-UE WP13 [3]. The results are discussed regarding the observed effects of the earthquake in 2012, May 22, near Pernik.

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2. Available public data, constrains and missing data in view of assessment of structural performance during earthquakes

In Bulgaria data about the building stock is collected in the National Statistical Institute (NSI). The NSI Census 2011 data is organized on territorial units, 28 administrative districts in Bulgaria. The data on the buildings is characterized by three factors: type of building (inhabited, non-inhabited, with common house hold.), type of structural system, which includes 4 categories (large-panel buildings, RC buildings, the so called "massive" buildings and others), and the period of construction in decades starting from a period "built till the end of 1949). This public data has several shortcomings in view of the seismic risk assessment.

1. Only residential buildings are included in the NSI data. The non-residential buildings with different functionality may comprise a great deal of the building stock. For example, according the Census2011 data [5] in 2001 there are 2334 residential buildings in one of the capital municipality, "Triaditza". The total number of buildings in "Triaditza" in 2001 is 3677 (data from the cadastre, RISK-UE project [3]), or the ratio of non-residential buildings to the total number of buildings is 0,36. In the present paper only the residential buildings are considered in the estimates due to the constraints in the available data.

2. The building typologies for the districts included in the Census 2011 are four, less than the typologies in Census2001. These are: Large-panel buildings, RC buildings, „Massive", and "other buildings". The RC buildings are described in the methodological notes [6] as „buildings which bearing system and the floor constructions are built of reinforced-concrete and the walls are made of panels, brick masonry or other materials". Here both frame and wall systems are in one group. The so called „Massive" buildings are the masonry ones "with bearing walls of brick and stone masonry and the belts, the beams and the floor construction are made of RC but have no reinforced concrete columns". In the Census survey list the masonry buildings are described by two types: with RC floors and with wood/steel beams floors. In the public data masonry buildings are one group only.

In the group of "other buildings" are included the structures that are built of stones, sun-dried brick, wood and other materials.

3. Data for the year of construction is considered in decades that do not coincide with the changes of design codes for constructions in seismic areas. Construction period "till the end of 1949" is the first one in 2011 census.

4. The data in Census 2011 for the structure type is not correlated to the period of construction. The only such correlated data is available in the Census 2001 and it is generalized for the buildings in the whole country. Two more tables of such data are presented for the buildings in the towns/cities and the buildings in the villages.

5. Data for the buildings concerns the administrative units, districts (total 28 in the country) and municipalities (total 265 in Bulgaria). For the towns, only total number of buildings is available.

All these constraints and missing data are factors that can lead to great uncertainties in the estimates.

3. Assumptions to calibrate the data for the buildings to overcome missing data

One of the most applied methodology to assess the possible damages in the building stock is the EMS98 [1], and it is used in this study too. The limitations in the public data are also a factor to apply this approach. The building characteristics that are considered in a quick but rough estimate are the structure type and period of construction in accordance to the level of the earthquake resistance design code. The relation between the structure type and period of construction in EMS-98 defines the vulnerability class (from A to F). This implies the data for the type of structure to be related to the period of construction (level of seismic code) of the buildings. Such data is missing in the last census. As already mentioned this data is related only in the Census 2001 (figure 1) where the type of structure is correlated to the period of construction in generalized form for the whole country (for cities and for villages). The data in figure 1 is for all residential buildings in the country. In figure 2 is presented the distribution of buildings by type and period of construction for the cities.

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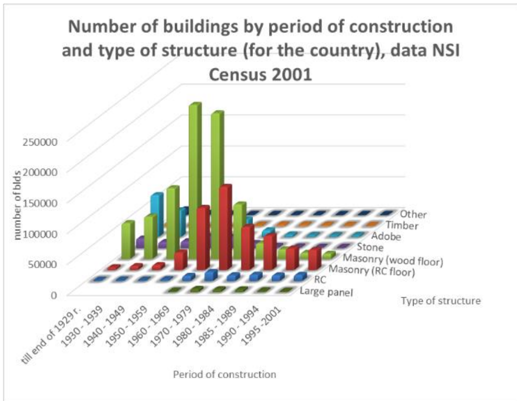

Figure 1 Buildings by period of construction and type in Bulgaria

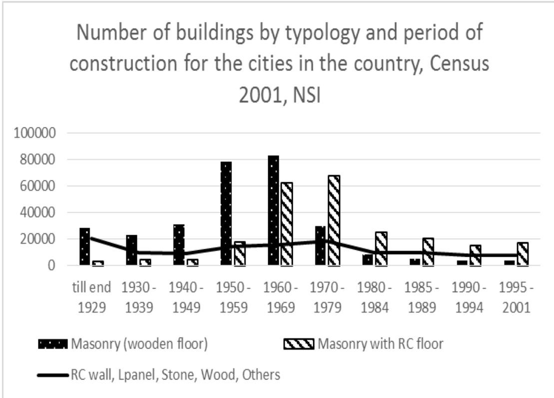

Figure 2 Buildings by period of construction and type in Bulgaria

To illustrate the available public data for the Municipality of Pernik [4], the data for 2011 is presented in Table 1 and 2.

Table 1. Number of buildings by construction period in Municipality of Pernik data [4]

Construction period	Number buildings
till end of 1949	2250
1950 - 1959	4377
….	
2000-2011	1212

Table 2. Number of buildings by building type in the Municipality of Pernik, data [4][5]

Building structure type	Number of buildings
RC-Large panels	409
RC- skeleton	1271
Massive - Masonry	22775
Others	701

For each municipality the total number of buildings is available, grouped in the 4 typologies (Table 2). The typology identification is the main factor that determines the building vulnerability. The missing data is the number of buildings in each construction period of the same typology. In this study it is assumed to calibrate the data based on the statistical distribution from the 2001 Census separately for the towns and for the villages (by proportional distribution respective to the data from Census 2001).

Next assumption concerns the sub-categories of the masonry buildings which are the prevailing typology (figure 1) in the country and in the towns (figure 2). The masonry buildings considered in [3] are of two sub-categories depending on the horizontal load-bearing system: with deformable steel or wooden floors and with non-deformable reinforced concrete floors. So is the data for masonry buildings in Census 2001. In this study the number of masonry buildings in each sub-category is assumed proportional to the distribution of these sub-types of structures in the Census 2001.

To make the correspondence between the period of construction according the census decades and period of seismic code in Bulgaria, review of the code periods is taken into account. In Bulgaria the first regulations for seismic design of the buildings are from 1947 [7] (no map in the regulations attached). Before 1947 Italian regulations were accepted to be applied [8]. Next change of the regulations is in 1957 [9] when a seismostatistic map of seismic areas is included, reflecting the observed intensities of past earthquakes. In the revision in 1964 the map was re-evaluated with zones of VII, VIII and IX degree MSK. In 1977 and 1987 the changes in the code included new data and the map was re-evaluated. In 2007–2009 a new hazard map was elaborated in accordance to the requirements of EN1989. In order to take advantage of the Census 2001 interconnected data for the period of construction and the structure typology the following correspondence between the code period and Census period of construction is assumed:

Code period	Census period of construction
1. Very old - before 1929	< 1949
2. 1929-1957	1950-1959
3. 1957- 1964	1960-1969
4. 1964-1977	1970-1979
5. 1977-1987	1980- 1989
6. 1987-2009	from 1990 -
7. > 2009	

The period of construction is an important factor in the vulnerability estimate of a building as it defines the level of seismic design of the building and level of seismic loading. For example, the town of Pernik was in seismic zone VIII according the 1957 map, the static seismic force according this code is determined as 1/20 of the weight and vertical loads of the building. In the period 1964- 1987, the town of Pernik is not in seismic zone ≥VII MSK. A comparison of the seismic zones areas in Bulgaria shows that in the period 1961-1977 only 22% of the territory of Bulgaria is in zones with intensity ≥VIIMSK, in 1977 – 1987 this percentage is 40% and from 1987 it increases to 98% [10].

4. The towns selected for evaluation

Several towns are chosen for assessment, Pernik, Blagoevgrad, Plovdiv and Triaditza administrative unit of Sofia.

4.1. The town of Pernik

Pernik is a town about 20 km SW from the capital of Bulgaria, Sofia. The population of the town is 75246 inhabitants and of the Pernik municipality is 97181 inhabitants in 2011, NSI data, Census 2011. The total number of buildings in the town of Pernik is 10980 and in the municipality is 25156 [5].

The town is chosen as an earthquake of $M_s = 5.8$ ($M_w = 5.6$) hit Western Bulgaria, near Pernik on May 22, 2012. In the town of Pernik the maximum intensity was VII-VIII MSC scale [11]. The same intensity was observed in Divotino, a village in the Pernik municipality. Many damages of VII degree of MSC in other villages in the municipality were observed [11]. In [12] Intensity VIII is observed in the central part of the town of Pernik and in the village of Divotino. The number of buildings in Divotino is 1400 and in the town of Pernik, 10980.

In order to make rough estimate of expected consequences based on EMS-98 methodology, the total number of buildings for the town of Pernik is proportionally distributed among the typologies according to the data for the municipality (Table2). Then the buildings of each typology are distributed in function of the construction period based on the data of Census 2001. The results for the buildings in the town of Pernik in function of type and period of constructions after the calibration are presented in Table 3. The same procedure is applied to the data Census 2011 for Blagoevgrad, Plovdiv and Triaditza administrative unit of Sofia.

Table 3. Distribution of buildings in function of type and period of construction in the town of Pernik, calibrated to data from Census2001

Construction period	Large panel	RC	Masonry (RC floor)	Masonry (wood floor)	Others
till end of 1949	0	23	232	1541	170
1950- 1959	0	20	327	1465	57
1960- 1969	12	85	1168	1553	37
1970- 1979	53	139	1264	557	18
1980- 1989	90	133	844	250	13
1990 -	23	155	603	138	10
total	179	555	4436	5504	306

4.2. The town of Blagoevgrad, Plovdiv and Triaditza administrative unit of Sofia
Blagoevgrad is a town in the SW part of Bulgaria with population of 68679 at the end of 2019 and the number of residential buildings 4630 in 2011 [5]. It is situated in seismic zone with one of the strongest shallow earthquake in Europe in the last two centuries occurred in the Krupnik-Kresna area on April 4, 1904. Its magnitude is estimated as 7.8 [13].
Plovdiv is the second largest town after Sofia in Bulgaria. The population of the town is 347851, the number of the residential buildings is 18828 [4], [5]. The earthquakes in 1928 in this zone were assessed as of X and XI Forel - Mercalli scale (figure 3 and 4) [14].

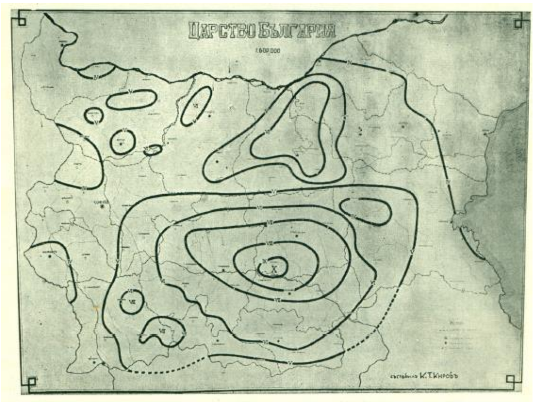

Figure 3 Isoseists of the April 14, 1928 earthquake [14]

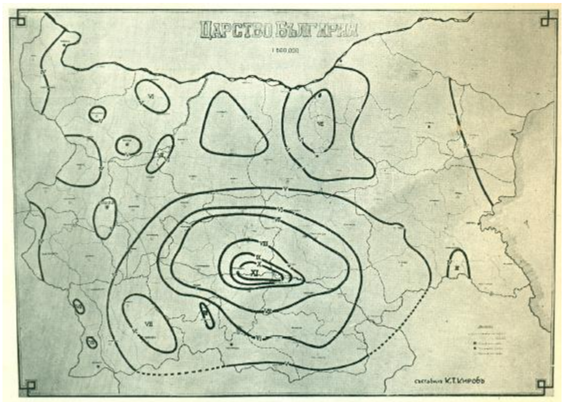

Figure 4 Isoseists of the April 18, 1928 earthquake [14]

5. Results of the assessments and analysis
All estimates are performed under the following assumptions:

Each town is considered as a point in the seismic map with equal intensity.

When assessment is performed applying EMS-98 methodology the intensity measure for each town is from the seismic zone map for 1000 years return period [15]. These are for Pernik and V. Tarnovo - VIII MSK –intensity (PGA= 0,15g); for Blagoevgrad, Plovdiv and Sofia- IX MSK –intensity (PGA=0,27g). When assessment is performed applying fragility curves with intensity measure type PGA, the values of PGA are according the hazard map 475 years return period of [16] (figure.5).

The definitions of the range of damages in EMS98 are assumed fixed as: “few” is minimum equal to 0 and maximum value is 15 %, “many” is 15 and 55% for minimum and maximum and most is from 55 to 100%. The vulnerability class based on EMS98 in function of design code period is according [19].

In this study the selected fragility curves are for the masonry buildings from the set collected in [2]. The curves are for low-rise buildings with flexible and rigid floors, typical for the conditions in Bulgaria and the type of intensity measure is PGA. The fragility curves for “masonry” buildings in [3] are applied.

5.1. Results for the town of Pernik and comparison to observed damages and other estimates

The resulting picture of the expected damages to buildings in the town of Pernik based on the EMS98 definition of VIII degree is as follows: From 0 up to 3% (295 buildings) of all the buildings in Pernik are assessed to be in grade 5 (Table 4). From 3 to 14% are in grade 4. From 4 to 22% are in grade 3 and from 6 to 25% are in grade 2. In summary from 13% to 63% (6929 buildings) of all residential buildings in Pernik are in grade 2 to 5 including.

Information for the impact of this earthquake in Pernik can be find in the plan for disaster protection of the Municipality [18]: „The social effects of the earthquake were that 40-50 inhabitants were slightly injured and sought medical help; 270 families left homeless; 8203 dwellings suffered some degree of damages; 273 buildings were marked as dangerous and the mayor ordered to be fully demolished“. These demolished buildings can be interprited as buldings in damage grade 5 and 4 and fall in the lower limit of the estimate made in this study for VIII MSK intensity measure. Hadjiiski et al [12] underline that the intensity VIII MSK is observed in the central part of Pernik and the heavy damages are in the old buildings without seismic design. This fact outlines that assuming one intensity for the whole studied area is not the best practice to make estimates but gives idea of the limits of number of buildings in each expected damage grade.

The results for the damaged buildings in Pernik obtained in this study are quite rough estimate. However, the observed damages fall within the calculated range of damages calculated using public data for the buildings, calibrated in a manner to be classified according building typology and period of construction/level of seismic design.

5.2. The towns of Blagoevgrad, Plovdiv and Triaditza administrative unit of Sofia.

The procedure to assess the consequences in the residential buildings in Pernik was performed for several towns in Bulgaria. The intensity measure of the earthquake used to calculate the damages to the buildings is given in brackets after the name of the town (**Table 4**). The resulting number of buildings suffering different damage grades are listed for each town in the table.

Table 4 Number of buildings in each damage grade for several towns in Bulgaria, estimates with public data and EMS98 methodology

EMS98 damage grades	Town of Pernik (VIII MSK)	Town of Blagoevgrad (IX MSK)	Town of Plovdiv (IX MSK)	Town of Sofia-Triaditza (IX MSK)
Grade 5	0 - 295	134 - 676	500 - 2568	61 – 317
Grade 4	295 – 1544	185 - 955	736 - 3835	95 – 493
Grade 3	436 – 2380	278 -1118	1135-4616	145 –581
Grade 2	683 - 2710	97 - 357	453 - 1661	50 – 182
In damage grade 5 to 2	1441 to 6929	694 to 3106	2824 - 12680	351 - 1573

In RISK-UE project [3] the buildings in Triaditza were studied. The data was collected from the cadastre plan and it contained the following information for each building: building typology, year of construction, functional usage, number of floors, exact built area. The estimate was for 3647 buildings, residential and non-residential. In this paper the number of studied residental buildings is 2334 as in the Census data for 2001 The ratio between the residental to all the buildings in Triaditza is 0.64. The estimates of damaged buildings in Triaditza in this study are in very good agreement with the results achieved in the RISK-UE project Level 1 [3] having in mind the ratio of buildings studied (Table 5). The use of public data calibrated to fill missing information give results for Triaditza comparable to the results with detailed cadastre data for the buildings.

Table 5. Number of buildings in different damage grades Level 1 in Triaditza [3]

Damage grade	None	Slight	Moderate	Heavy	Very heavy	Destruction
Number	236	991	933	948	465	74

5.3. Assessment based on fragility curves

In the figures below (figure 5 and 6) the fragility curves for masonry buildings in [3] and mean curves in [2] for the masonry low-rise buildings are shown. In Syner-G project fragility curves from many studies have been collected and compared. The dispersion among them is in quite wide range (mean and standard deviations) for a class of buildings. From all fragility curves for low rise bearing wall masonry type, mean curves for two limit states (yielding and collapse) are defined (figure 5 and 6) in the project.

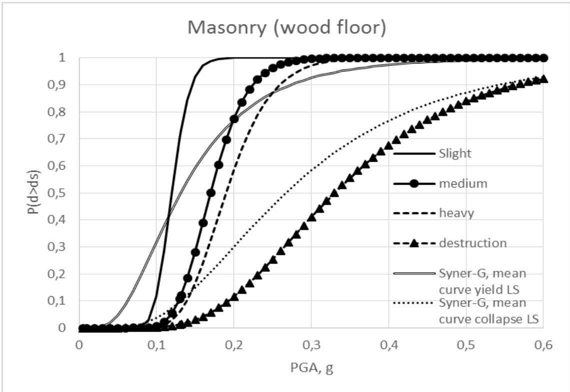

Figure 5 Fragility curves for masonry (wood floor) low-rise buildings [2][3]

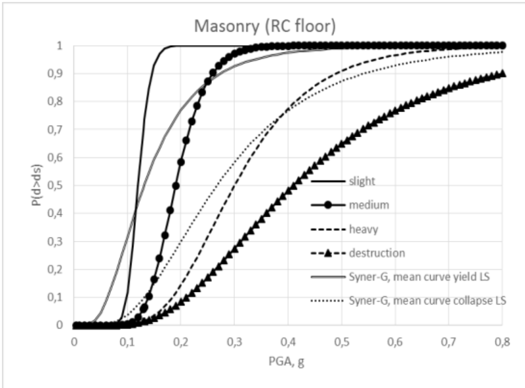

Figure 6 Fragility curves for masonry (RC floor) low-rise buildings [2][3]

These two sets of fragility curves are used to assess damages in the masonry buildings in Pernik. This type of buildings was chosen because in district Pernik 80.8% of the buildings are type masonry [4]. The reference peak ground motion for the town of Pernik is a_g =0,15g, seismic hazard map for design for 475 years return period [17]. The Syner-G project mean curve for the masonry low rise buildings defines that 15% of that type of masonry buildings would reach or be greater than limit state “collapse” for PGA =0.15 g. The RISK-UE WP13 [3] curves define about 20% masonry building with flexible floors in damage states “heavy damages and destruction” and about 3% masonry building with RC floors in damage states “heavy damages and destruction”. These assessments give results that vary from 15% to 23%. Acceleration time histories of the earthquake are recorded in several stations in Sofia with maximum acceleration with amplitude of NS component 98.55 cm/s^2 [12] but no record of the PGA in the town of Pernik is available of the 22 May 2012 earthquake to make comparison of the results.

It is worth to mention here one of the conclusions about the masonry buildings of the Syner-G project [2], i.e. that „though in Europe the number of masonry buildings is significant, the number of studies with focus on this typology are quite limited and for this reason the team of the project could identify only two main classes of the typology, low rise and mid rise“.

6. Conclusions

For quick but rough assessment of possible consequences from a strong earthquake in the residential buildings in our country public data for the building stock available from the census can be applied. In the assessment the period of construction of the buildings and the building typology should be taken into account. The leading characteristic is the typology. The period of construction can be calibrated proportional to the census 2001 data. The period of construction is the second important factor to define the vulnerability of the building. In just 60 years, the maps of seismic zones for design have undergone several changes as well as the level of seismic design. The areas of the seismic zones of different intensity have changed significantly over the years. For rough assessment, the range of expected damages from a probable earthquake can be obtained based on the EMS98 methodology.

Most of the collected fragility curves in Syner-G project are analytically obtained, some are from observed damages. These fragility curves reflect the specific characteristics of the building type in the investigated regions and should be used based on careful informed selection. When the fragility curves of a certain building type for a certain limit state/ damage grade are plotted, large dispersion of probabilities for the damages can be observed. The large dispersion for the masonry buildings estimates is due to a number of factors [20] including the level of seismic design. On the other hand the 12 degree Intensity EMS98 scale is not the measure in the hazard maps in the contemporary codes. The seismic intensity measure is PGA and that supposes increasing the number of the seismic zones. Fragility curves then would be more applicable approach for estimates of possible consequences.

Analyzes for the response of masonry buildings in seismic conditions, which reflect the specific conditions of construction practice in our country are still too limited.

References

[1] Grünthal G 1998 European Macroseismic Scale 1998 EMS-98 (Luxembourg: Centre Européen de Geodynamique et de Séismologie)
[2] Kaynia A 2013 Guidelines for deriving seismic fragility functions of elements at risk:Buildings, lifelines, transportation networks and critical facilities, Syner-G reference report 4 (JRC scientific and policy reports, Italy)
[3] Kostov M, Vaseva E, Kaneva A, Koleva N, Varbanov G, Stefanov D, Darvarova E, Solakov D, Simeonova S and Christoskov L 2004 WP13: Application to Sofia. RISK-UE project Final report (Nice)
[4] NSI Census 2011 2012 Reference book district Pernik, https://www.nsi.bg/ (in Bulgarian)
Reference book district Blagoevgrad (in Bulgarian)
Reference book district Plovdiv (in Bulgarian)
Reference book district Sofia (NSI, Sofia) (in Bulgarian)
[5] NSI Census 2011 2012 *Districts Book **14** Pernik* Vol. **3** (NSI, Sofia)
Vol 3 *Districts Book* **1** Blagoevgrad (NSI, Sofia)
Vol 3 *Districts Book* **16** Plovdiv (NSI, Sofia) (in Bulgarian)
Vol 3 *Districts Book* **23** Sofia (NSI, Sofia) (in Bulgarian)
[6] NSI Census 2011https://www.nsi.bg/en/content/5788/housing-fund
[7] Regulations for design and construction of buildings and structures in seismic regions in Bulgaria 1947 *State newspaper* **98** (Sofia) (in Bulgarian)
[8] Ignatiev N, Sotirov P History of the Bulgarian codes for seismic design of structures and transition to the Eurocode system of analyses http://www.petkovstudio.com/documents/7.pdf (in Bulgarian)
[9] Code for design and construction of buildings and structures in seismic regions in Bulgaria 1957 *Notifications of the Presidium of the National Assembly* **65** (Sofia) (in Bulgarian)
[10] Solakov D and Simeonova S 2007 Earthquakes and seismic hazard in Bulgaria *Insurer Press newspaper* **11** (Sofia) (in Bulgarian)
[11] Botev E, Dimitrov D, Georgiev I and Protopopova V 2013 Investigations of the 22 May 2012 Earthquake in Pernik Region, Bulgaria Conf. Proc. 7th Congress of the Balkan Geophysical Society, European Association of Geoscientists & Engineers DOI: https://doi.org/10.3997/2214-4609.20131708
[12] Hadjiiski K, Simeonov S, Botev E 2012 Seismic impact of the earthquake of 05/22/2012 for Sofia, http://www.niggg.bas.bg/en/ (in Bulgarian)
[13] Georgiev I, Dimitrov D, Pashova L, Shanov S , Nikolov G and Botev E 2006 Kinematics and geodynamics of the Krupnik-Kresna seismogenic zone *J. Geodesy* **17** (Sofia: BAS) http://clg.cc.bas.bg/17thvolumeGeodesy/Georgiev6.htm
[14] Stoyanov K 1931 Report on the work done from April 25, 1928 to November 1, 1931 Directorate for assistance and reconstruction of the earthquake area of 1928 (Sofia: State printing house)
[15] Order РД-02-20-2 for design of buildings and structuresin seismic regions 2012 (Sofia MRRB)
[16] BDS EN1998-1, National annex
[17] http://gis.mrrb.government.bg/mrrgisv1/mrr_tematicmaps/geoportal/inmapnorms_local.html
[18] Plan for earthquake protection of the population Draft project Municipalityof Pernik (in Bulgarian) retrieved May 2020, official site Pernik Municipality
[19] Simeonov S, Solakov D, Georgiev I, Vatzeva R, Dimitrov D, Stefanov D, Simeonova S, Trifonova P, Vaseva E, Cherkezova E et al. 2018 Development of Method for Analysis, Assessment and Mapping of Seismic Risk in Republic of Bulgaria *Bulletine Construction and Architecture* **5** (Sofia: ITUS) (in Bulgarian)
[20] Lagomarsino S and Cattari S 2014 Fragility functions of masonry buildings Chapter 5 of *Syner-G: Typology definition and fragility functions for physical elements at seismic risk* Pitilakis K, Crowley H, Kaynia A (Springer)