AN ENGINEERING APPLICATION OF THE SYNTHETIC SIGNALS: CASE STUDY FOR SOFIA CITY

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Key words: seismic hazard, ground motion modelling, hybrid approach, vulnerability, damage estimations

The aim of this study is to: (1) contribute to the earthquake hazard assessment of Sofia, providing earthquake scenarios consistent with the recent geological outline and the regional earthquake hazard at Sofia; (2) supply synthetic seismic signals computed using available source and structural model; (3) provide site response estimates at Sofia due to the chosen earthquake scenarios; (4) vulnerability assessment of structures designed according to the Eurocodes 2 and 8. The study of the site effects and the microzonation of a part of the metropolitan Sofia, based on the modeling of seismic ground motion along three cross sections are performed. Realistic synthetic strong motion waveforms are computed for a scenario earthquakes (M=7) applying a hybrid modeling method, based on the modal summation technique and finite differences scheme. The synthesized ground motion time histories are source and site specific. The site amplification is determined in terms of response spectra ratio (RSR). A suite of time histories and quantities of earthquake engineering interest are supplied. The results of this study constitute a "database" that describes the ground shaking of the urban area. A case study of experiment-based assessment of vulnerability of a cast-in-situ single storey, industrial, reinforced concrete frame, designed according to Eurocode 2 and 8 is presented. The main characteristics as spectral acceleration on the roof, damage index, and story drift are discussed for the purposes of microzonation.

Local seismicity

Strong earthquakes with magnitude M up to 7 hit Sofia in the past centuries. During the XIX century two destructive earthquakes, in 1818 ($M_s \sim 6.0$) and 1858 ($M_s \sim 6.5$) and several others with macroseismic intensity I = VI - VII (MSK - 64) have been reported. The strongest events that occurred in the region are the earthquakes of 18/30.9.1858. The hypocenters have been under the town itself and the intensity is evaluated to be IX MSK (Christoskov et al., 1989). The detailed description and summary of the local seismicity in the vicinity of Sofia can be found in Solakov et al. (2001) and Slavov et al. (2004).

Parameterization of the earthquake scenarios

When the ground motions for evaluation and design are characterized by a scenario earthquake, the primary earthquake source parameter is the magnitude or seismic moment of the scenario earthquake. In a deterministic analysis, the scenario earthquake is typically the largest earthquake that is expected to occur on the source that controls the seismic hazard around the city. Alternatively, a possible scale of scenario earthquakes is: disastrous earthquake (average return period about 500 years), very strong earthquake (average return period 200-250 years), strong earthquake (average return period 120-140 years) and frequent earthquake (average return period 50-60 years). The maximum macroseismic intensity at Sofia, I = IX (MSK), observed in 1858 (Bonchev et al., 1982), can be expected to occur with a return period of 150 years (Christoskov et al., 1989), i.e. it could correspond to the strong scenario earthquake. Recently seismic hazard maps of the Circum - Pannonian Region (Panza, Vaccari, 2000; Gorshkov et al., 2000), show that Sofia is placed in a node having potential for the occurrence of an earthquake with M> 6.5 and that it could suffer macroseismic intensity up to X. The seismicity of Sofia region is limited to the upper 20 - 30 km of the lithosphere. In the computations carried out in this study, on the basis of the earthquake history at Sofia and of the available seismic hazard assessments provided in the literature, earthquake scenarios have been considered that correspond to seismic sources, located at 10 km distance from the center of the city in the West and South directions The assumed source parameters, common to all cases, are chosen to approximate the seismic event which hit Sofia in 1858. The parameters of the source mechanism adopted are: strike angle 340°, fault dip 77° and rake (with respect to strike) 285°. This source mechanism has been used to generate seismograms along the profiles shown in Fig. 1 and named: 1A-1B "Sofia 1" (M1), 2C-2D "Sofia 2" (M2) and 3E-3F "Sofia 3" (M3). To assess influence of

the source mechanism on the so called site effects the source with strike angle 0°, fault dip 44° and rake (with respect to strike) 309° has been used, as well. With this mechanism the synthetic seismograms have been calculated only for the profile "Sofia 3A" (M3A), identified as model M3A. Both mechanisms are consistent with the available geological studies performed within the epicentral area (Christoskov, 1989; Solakov et al., 2001; Slavov, 2000; Slavov et al., 2004).

Numerical experiments and discussion of the results

Realistic synthetic seismic signals have been generated for all sites of interest along the profiles shown in Fig.1 (~ 100 sites per profile), adopting the parameters: M=7, hypocentral depth 10km, epicentral distance from the beginning of each profile 10 km (Paskaleva, 2002). Two groups of experiments have been performed: (A) ground motion modelling in 1D layered anelastic media, applying an algorithm based on the modal summation method (Panza, 1985; Panza, Suhadolc, 1987), and (B) modelling in laterally heterogeneous media, making use of the hybrid technique 2D layered media (Fäh et al., 1993). The chosen frequency range (up to 5 Hz) comprehends the free period of oscillation of the built environment elements present in Sofia. Along the profiles (Fig.1) time histories for acceleration, velocity and displacement are computed for all ground motion components: transverse (TRA), radial (RAD) and vertical (VERT). Different quantities of earthquake engineering interest, like peak ground accelerations (PGA), peak ground velocities (PGV) and response spectra amplitudes (SA) are derived from the computed seismic signals. The peak amplifications of the RSR increase by more than a factor of two along the profile Sofia 3 from

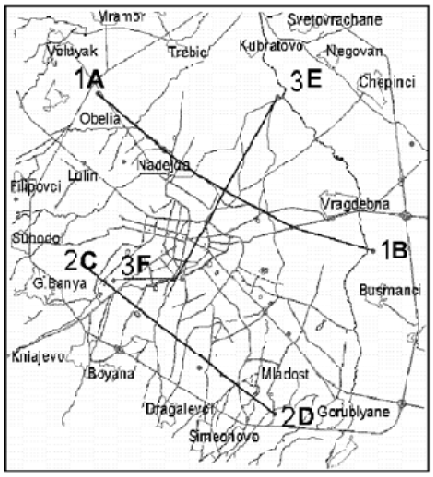

Fig. 1. Generalised tectonic scheme of Sofia region and investigated profiles.

South to North, following the deepening of the sedimentary basin. There are sites, at epicentral distances between 12 km and 17 km, where the amplification is relevant in both horizontal components RAD and TRA. The maximum amplifications are found in "Sofia 1" for the vertical component (VERT) (RSR~1.6) and for the horizontal components TRA (RSR~ 5.6), while in Sofia 2 RSR~2.7 is the maximum valued. The max. mean RSR_{mean}= 1.7 is obtained for Sofia 3 for all components along the profile. The smallest standard deviation sigma=0.25 is found for TRA component in Sofia 1.The site amplification estimated in terms of the distribution of RSR versus frequency along the profile Sofia 1 shows that the RAD amplification reaches 2.5 (1.0 - 2.75 Hz), TRA component is amplified up to 3.3 (1.5 - 2.5 Hz), and the VERT RSR goes up to 4 within the frequency interval 0.5 - 4.0 Hz. If the scenario earthquake strikes the profile Sofia 1 then the ground motion at the site for VERT can be amplified up to more than 16 times within the frequency interval 1.25 - 2 Hz.

Seismic response of one story frame

Following the results we calculate the seismic response of cast-in-situ one storey reinforced concrete (RC) frame, designed (Eurocode 2 & 8) and tested in the European Laboratory for Structural Assessment (ELSA) of the Joint Research Centre (JRC) of the European Commission at ISPRA, Italy in the framework of the research project "Seismic behavior of reinforced concrete industrial buildings" (Dimova, Negro, 2005). As input we use scaled components of the accelerogram synthesized in Sofia. The analysis objective, using IDARC 2D program, is to provide expected response as damage index, story drift, shear and SA (spectral peak acceleration) (Table 1).

The influence of the geological conditions (Models M1, M2 and M3), on the damage index the scaling factor of the seismic action in %g (32%, 64%, 80%), and the epicentral distance (11km, 16km-center of the city, 22km) is shown in Fig. 2.A-C. The spatial distribution of the damage index is shown in Fig. 2A, C and B. In Fig. 2A for the synthetic accelerograms scaled with a peak value of 0.8g, the damage index distribution on the territory covered by the profiles shows that for the first mechanism we can expect: 67% of the region to be affected by moderate damage, 23% by extensive damage, and 11% by partial collapse. For the accelerograms scaled with a peak of 0.64g (Fig. 2.B) the damage index distribution shows that light damages covered 44% and moderate 56% of the territory covered by the profiles. The ad-

Table 1. Some amplitude responses from IDARC 2D dynamic analysis

	Model "Sofia 1"				Model "Sofia 2"				Model "Sofia 3"				Model "Sofia 3A"			
scale	**5%**	**32%**	**64%**	**80%**	**5%**	**32%**	**64%**	**80%**	**5%**	**32%**	**64%**	**80%**	**5%**	**32%**	**64%**	**80%**
Epicentral distance 11km																
Index	0	0.177	0.165	0.272	0.021	0.184	0.254	0.406	0.02	0.194	0.304	0.503	0.029	0.328	0.423	0.583
Drift [mm]	8	140	130	199	11	148	202	311	10	155	242	387	16	280	339	445
Sear [kN]	40	191	223	224	48	205	228	229	45	213	232	235	63	235	243	236
SA [cm/s^2]	534	2517	2929	2894	650	2755	2958	2900	607	2780	2970	2898	854	2973	3032	2888
Epicentral distance 16km																
Index	0	0.09	0.248	0.416	0	0.136	0.225	0.345	0	0.115	0.232	0.347	0.022	0.194	0.22	0.281
Drift	7	62	198	321	8	111	180	268	8	86	186	267	11	150	175	260
Shear	36	173	225	228	38	187	220	219	39	180	218	217	47	207	228	224
SA	479	2315	2904	2853	517	2463	2899	2769	532	2405	2862	2801	662	2719	2966	2899
Epicentral distance 25km																
Index	0	0.227	0.32	0.457	0.029	0.223	0.452	0.759	0.022	0.174	0.344	1.029	0.039	0.33	0.983	1.017
Drift	9	198	276	327	15	193	372	*	11	141	294	267	23	281	*	*
Shear	43	216	237	233	63	218	248	*	50	202	240	246	84	221	*	*
SA	577	2818	3008	2912	846	2839	3079	2909	679	2655	3036	2916	1120	2856	3230	2917

*Note: * - partial collapse, i.e. storey drift larger than 491 mm, base shear lower than 207 kN*

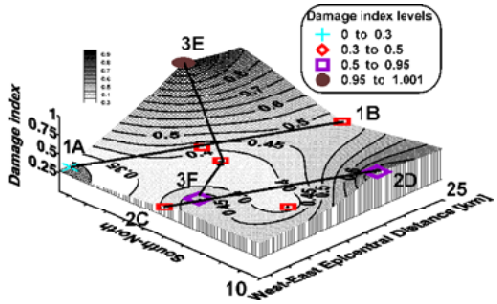

Fig. 2A. Damage index distribution on the territory covered by the superimposed profiles with levels of damage: 0.25-0.50 moderate cover 67%; 0.5-0.95 extensive cover 23%; 0.95-1.0 partial collapse cover 11%. The synthetic accelerograms are scaled to a peak value of 0.8 g.

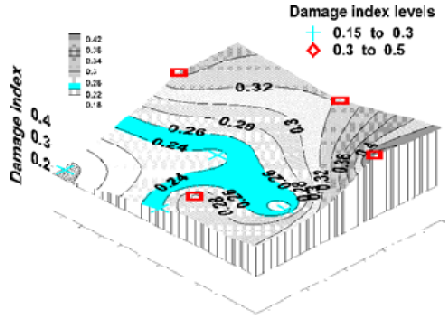

Fig.2B. Damage index distribution on the territory covered by the superimposed profiles with levels 0-0.25 light cover 44%; 0.25-0.50 moderate cover 56%. The synthetic accelerograms are scaled to a peak value of 0.64g.

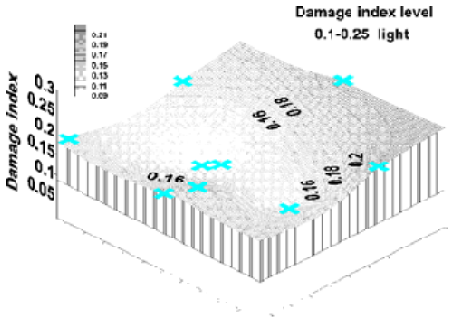

Fig. 2C. Damage index distribution on the territory covered by the superimposed profiles with levels 0-0.25 light cover 100%. The synthetic accelerograms are scaled to a peak value of 0.32g.

hock national seismic code is prescribing design peak ground acceleration (DPGA) of 0.27g. So we have to expect light damages (Fig. 2.C) if the same value of the DPGA will be accepted in the National Standards implementing Eurocodes. The damage index distribution along the superimposed profiles for synthesized accelerograms scaled to 32%g is shown in Fig.2C. The DI distribution by the level light damages e.g. DI= 0-0.3 cover 100% of the territory.

Conclusions

This is the first detailed study for the maximum possible scenario done for Sofia City, based on ground motion modeling, in terms of both the peak ground acceleration and the spectral amplification estimated along three profiles. By taking into account parametric studies, regarding the focal mechanism of the source and the velocity model, it is shown that the hybrid method is a powerful approach that may be considered fundamental when adding information to the multidisciplinary "database" that must be defined for microzonation purposes. Given a certain earthquake scenario, and an appropriate structural model, based on detailed geological, geophysical and geotechnical data, it is possible realistically to evaluate the local amplification in the frequency range of interest for civil engineering, and to obtain valuable parameters for the realistic microzonation. The most important result concerns the site response behavior. The obtained records are used for engineering purpose to assess the distribution of the damage index which is useful for urban planning, retrofitting of the built environment, insurance industry, earthquake preparedness, earthquake risk reduction and earthquake risk management. The results of this study can readily be applied to site-specific design spectra based on average or maximum amplification. Such

results should be accounted for in site-specific design procedures, especially for long structures and underground lifeline systems more sensitive to near surface strains than to maximum peak ground acceleration. This is a good starting point for the microzonation of Sofia. Many more cross-sections will be required to cover the whole city, in view of a better understanding and estimation of the maximum expected risk.

Acknoweledgement: These investigations are carried out with financial support of the Bulgarian Science Fund, project NZ 12-14-I/02 and NATO SfP project N980468.

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ИНЖЕНЕРНО ПРИЛОЖЕНИЕ НА ГЕНЕРИРАНИ АКСЕЛЕРОГРАМИ НА ПРИМЕРА НА ГР. СОФИЯ

Иванка Паскалева

Анализирано е очакваното сеизмично въздействие по три инженерногеоложки профила, минаващи през централната част на гр. София. Синтезирани са акселерограми за сценарии на събитие с M=7. Използуван е хибриден метод, основан на модално сумиране и схема на крайни разлики. Усилването заради локалната геология в синтезираните акселерограми е определено с отношението спектрите за 2D към 1D модели. Резултатът от това изследване са генерирани акселерограми през 100 m по продължението на трите профила. Акселерограмите са използувани за изчисление на едноетажна сграда, проектирана по Еврокод 2 и 8. Изчислени са основни характеристики като индекс на разрушение, преместване, спектрално ускорение и др. (табл. 1). Показано е разпределение на индекса на разрушенията за площа, обхванатa от трите профила за избрания сценарий.