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Towards an improved seismic risk scenario for Bishkek, Kyrgyz Republic

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Abstract

A risk scenario for Bishkek, capital of the Kyrgyz Republic, is evaluated by considering a magnitude 7.5 earthquake occurring over the Issyk-Ata fault.The intensity values predicted through the application of an attenuation relationship and a recently compiled vulnerability composition model are used as inputs for seismic risk assessment, carried out using the CREST (Cedim Risk Estimation Tool) code. Although the results of this study show a reduction by as much as a factor of two with respect to the results of earlier studies, the risk scenario evaluated in this paper confirms the large number of expected injuries and fatalities in Bishkek, as well as the severe level of building damage.

Furthermore, the intensity map has also been evaluated by performing stochastic simulations. The spectral levels of the ground shaking are converted into intensity values by applying a previously derived conversion technique. The local site effects are empirically estimated considering the spectral ratios between the earthquakes recorded by a temporary network deployed in Bishkek and the recordings at two reference sites. Although the intensities computed via stochastic simulations are lower than those estimated with the attenuation relationship, the simulations showed that site effects, which can contribute to intensity increments as large as 2 units in the north part of the town, are playing an important role in altering the risk estimates for different parts of the town.

Introduction

Central Asia is a region prone to large earthquakes, as evidenced by its historical seismicity. A first update of the Soviet seismic hazard map, which was based on the maximum expected seismic intensity in MSK units, has been provided by the GSHAP project (Zhang et al., 1999). In addition to the high hazard level shown by the GSHAP map, the 1988 and 1995 earthquakes that occurred in Armenia and Shakalin, respectively, pointed out that some types of the Soviet-era buildings were highly vulnerable to earthquakes and their resistance was significantly lower than was officially stated (Geohazardard International, 1997).

A probabilistic assessment of the seismic hazard for Kyrgyzstan has recently been computed at a regional scale, by Abdrakhmatov et al. (2003) and Erdik et al. (2005) showing that the highest hazard lies along the southern border of the city, closest to the Issyk-Ata fault system which is expected to generate a M=7.5 earthquake. Resulting from a risk assessment for Bishkek, the authors who conducted the project found that the expected number of night-time casualties in Bishkek is about 34,000 and about 90,000 people are expected to need hospitalization.

In this paper, we explore the feasibility of developing a scenario-based approach to evaluate the risk for Bishkek. Since all existing seismic codes and regulation in the region are intensity-based, the seismic input is computed by means of the Ambraseys (1985) attenuation relationship while updated information about the vulnerability composition model for Bishkek are considered to develop the risk scenario. Furthermore, we perform a first attempt to include empirical estimates of local site effects in the seismic input for the risk assessment. The seismic intensities are computed by applying the method proposed by Sokolov and Chernov (1998) to the Fourier amplitude spectra generated by a stochastic simulation technique (Motazedian and Atkinson, 2005), considering a M=7.5 earthquake occurring over the Issyk-Ata fault.

Bishkek: geological settings and previous site effect studies

The town of Bishkek (Figure 1) is located in one of the largest depressions of the Northern Tien Shan, the Chu basin, which is some 50 km wide and 150 km long. This basin is bounded by the Kyrgyz Range to the south, where the Issyk-Ata fault is located, and the Chu-Lli mountains in the north (Bullen et al., 2001). . Below the urban area of Bishkek, the Paleozoic basement depth is expected to generally decrease from north (~1 km) to south (~3 km). Quaternary sediments, made up of gravel, rubble, and sandy material, with a thickness of 200 to 300 m overlie the Tertiary formations. Parolai et al., (2010) showed that the alluvial materials are quite stiff, with average S-wave velocities in the shallowest layers of ~600 m/s.

FIGURE 1

In 2008, within the CASCADE (Cross-Border Natural Disaster Prevention in Central Asia) project, a temporary network of 19 seismic stations was installed in Bishkek with the aim of quantifying the local site amplification effects and their spatial variability. Parolai et al. (2010) showed that both the layering of Quaternary material and the impedance contrast within the Tertiary layers play a major role in amplifying the ground motion over a broad frequency range. The site effects were estimated by applying the Standard Spectral Ratio technique (Borcherdt, 1970), considering two different reference stations: BI04, installed on rock in the Kyrgyz Range, and BI06, installed in the southern part of the basin over the outcropping of the Chu formation. The spectral ratios calculated for the two different reference stations are shown in Figure 1.

Risk assessment

Seismic risk assessment is carried out using the CREST (Cedim Risk Estimation Tool) code developed by CEDIM (Center for Disaster Management and Risk Reduction Technology), which combines exposure, vulnerability, and hazard to evaluate potential damage and losses due to ground shaking (Tyagunov et al., 2006). The code uses an intensity-based methodology, as defined by the European Macroseismic Scale 1998, EMS-98, (Grünthal, 1998) for seismic risk and loss assessment. Macroseismic intensity is considered, along with vulnerability and exposed assets, as the ground-motion parameters which all damage and loss computations are based upon.

EMS-98 building taxonomies are used to group buildings with similar damage/loss characteristics into six vulnerability classifications, denoted A through F. The vulnerability classifications are based, in the first line, on the building material and structural type, and can be modified based on date of construction, number of floors, and other available information about the buildings. Damage and risk are computed based on the percentage of total number of buildings in each EMS-98 vulnerability class, within a geographical unit.

The vulnerability composition is used to compute the damage to buildings, distributed between six damage grades that range from no damage (grade 0) to complete destruction (grade 5) as defined by EMS-98 (Grünthal, 1998). Each damage grade represents a combination of structural and non-structural damage.

A damage probability matrix is created in the code, based on damage state and intensity, for each vulnerability class. Therefore, each matrix describes the probable distribution of damage to buildings of equal vulnerability at a certain level of seismic intensity. (Tyagunov et al., 2006). The damage probability matrices are then used to compute the percent of buildings in each damage grade, within a geographical unit. The mean damage ratio (MDR), defined as total cost of repair divided by total cost of reconstruction (Tyagunov et al,. 2006), is calculated for each geographical unit from the computed distribution of damage grades.

CREST employs empirical functions, which use weighted averages of damage grade distribution, to consider losses (Tyagunov et al,. 2006). All components of damage and loss calculations are at the same resolution, which is based on the resolution of the inventory.

Results output by CREST include percent of buildings in each of the six damage grades, mean damage ratio, direct structural losses (number of buildings damaged and number of buildings collapsed) due to damage, and direct social losses (number of people injured and number of people killed) due to damage. The output is not disaggregated for an individual building or building type; rather, they are reported as single values that are evenly distributed within a geographical unit. The values for all geographical units can be summed to obtain the total losses for the entire affected region.

A more detailed description of the adopted risk assessment method (e.g. derivation of the damage probability matrices, causality model used) is provided by Tyagunov et al. (2006) and Colombi et al. (2010).

Seismic input calculation

In this work, the seismic risk for Bishkek is assessed by assuming a scenario earthquake. In particular, the intensities are computed based on the attenuation relationship of Ambraseys (1985), derived for Europe. The radial distances are computed from a hypothetical epicenter located on the Issyk-Ata fault, with a hypocentral depth of 20 km, which is consistent with the depth of earthquakes occurring in this area. Considering the minimum horizontal distance from the fault, the intensity values computed for different sites spread over the urban extension of Bishkek are fairly homogeneous, ranging from 8.7 to 9.4. Therefore, the risk scenario for Bishkek is computed by considering intensity IX for the entire town. Also, since the vulnerability composition model is known for the entire town, the risk assessment is performed without introducing a parameterization of the town in different cells.

In addition, a first attempt is made to estimate the seismic input by performing a numerical simulation in order to account for local site effects. The intensity map is constructed starting from the Fourier spectra and applying the approach of Sokolov and Chernov (1998). Following this method, the intensity can be determined by comparing the observed spectrum with those determined empirically through regression analysis (Sokolov, 2002). The empirical relationship between Fourier amplitude spectra and macroseismic intensity was derived by assuming that the MMI and MSK scales provide essentially the same intensity values (Sokolov and Chernov, 1998) and neglecting the difference between MSK and EMS.

We computed synthetic spectra by applying a stochastic simulation technique (Motazedian and Atkinson, 2005 and the references therein), which allows the finite dimension of the fault to be accounted for. In particular, we considered a M=7.5 earthquake occurring on the Issyk-Ata fault with a stress drop of 100 bar (Abdrakhmatov et al., 2003). The strike is oriented in the east-west direction and the fault is immerging toward the north with a dip of 50 degrees. The spectra computed for 20 different hypocentral locations, randomly selected over the fault where the slip is assumed to be uniform, were averaged to obtain the final spectra. The extension of the fault (76 x 26 km, panel a of Figure 2) has been determined in agreement with the Wells and Coppersmith (1994) relationships. The spectra were computed at 18 locations, where the site effects were previously empirically determined. This allowed us to compute the intensity map for both rock condition and with site-specific corrections. Since station BI04 shows amplification at high frequency (Parolai et al 2010), we consider herein, for each site in Bishkek, the maximum of the two intensity values obtained considering the spectral ratios with respect to stations BI04 and BI06.

FIGURE 2

The resulting intensity maps are shown in Figure 2. The majority of the intensities for rock (panel b) are between 6.5 and 7.5. The distribution of the values reflects the distance of the sites from the fault, decreasing when moving toward the north. The introduction of site amplification factors (panel c) causes an increase in intensity at several sites (panel d). Since strong motion recordings in Bishkek (and in Kyrgyzstan, in general) are not available, the ground motion amplitude of the simulation for rock condition cannot be tuned. With respect to the intensity values obtained with the attenuation relationship, the simulated values are smaller, but the introduction of site effects produces a more variable seismic input for the risk assessment, with a maximum increment of 2 intensity units in the northern part of the town.

Vulnerability Classification Scheme

In accordance with the requirements of CREST, the vulnerability composition of Bishkek is described in terms of six vulnerability classes, denoted A through F, as defined by the European Macroseismic Scale, EMS-98 (Grünthal, 1998). The vulnerability class designation describes the ability of a building to perform seismically, where class A signifies a building that is most susceptible to damage and class F signifies a building that is least susceptible.

The present-day composition of the residential building stock of Bishkek is rather heterogeneous. Mostly, it is presented by reinforced concrete buildings and masonry buildings in the public sector and by masonry buildings and adobe buildings in the private sector. There are many factors contributing to the seismic vulnerability of the buildings, in particular, among the typical deficiencies there are quality of materials and workmanship and irregularities both in plan and elevation. Based on the most recent available information regarding typology and construction of existing buildings throughout the city of Bishkek, the vulnerability composition [12%, 33%, 16%, 27%, 11%, 1%] was obtained for classes A through F, respectively. The percentages of buildings in each vulnerability class are, in a first approximation, considered to be applicable to the city as a whole, on average. Individualized vulnerability distributions for particular sections of the city are not available at this time.

As recently as 2005, there were reportedly 77,150 buildings in Bishkek (Erdik et al., 2005). The current population count for Bishkek is 849,200 people (Office for the Coordination of Humanitarian Affairs, http://ochaonline.un.org/).

In order to compare results of the current seismic risk analysis with those reported in previous results, it is necessary to consider that they were based on old building stock information obtained considering different towns in Central Asia. While this vulnerability composition may be outdated, it is provided here for comparison purposes. Based on the distribution of structural types in all five capital cities of Central Asia, as reported by GeoHazards International (1997), the vulnerability composition [15%, 25%, 25%, 35%, 0%, 0%] was obtained for classes A through F, respectively.

The main difference between the two vulnerability composition models involves the percentage of buildings in classes E and F. In the old classification scheme, no buildings were classified as E or F, while the total percentage of buildings belonging to classes A, B, and C is almost the same for the new and old classification schemes (i.e., 61% and 65%, respectively).

Results and conclusions

The vulnerability composition model previously described is used to compute the risk scenario through application of the CEDIM code, considering a uniform input equal to intensity IX estimated with Ambraseys (1985).

The damage is evaluated in terms of percent of buildings in each damage grade, from which the mean damage ratio (column MDR) is evaluated..

For the new vulnerability composition model, the MDR is equal to 36.5. Considering the total number of buildings (77,148) and population (849,204), the estimated number of damaged and collapsed buildings is 48,410 and 22,219, respectively, with 93,447 injuries and 16,624 fatalities. For the old vulnerability composition model, only slight differences from the results of the new model are observed. Since the two vulnerability models differ in the percentage of buildings in classes D, E, and F, but the sum of percentages in classes A, B, and C is almost the same, the estimated risk values are very similar. In particular, the MDR value is 37.3. The estimated total number of collapsed buildings is 21,794 and the number of estimated fatalities is 18,056.

Although the intensities estimated through the stochastic simulations for rock condition cannot be calibrated with recordings, the variability observed for soil conditions can be used to investigate the role played by site effects in determining the risk scenario. For example, considering the intensities simulated at sites where the site effects are evaluated (Figure 2), three different MDR values are obtained, as listed in Table 1. MDR is equal to 5.9 for intensities between 6.8 and 7.5 (corresponding to intensity VII as input for CEDIM code), and then increases to 17.6 for intensities between 7.8 and 8.5 (VIII), and increases again to 36.5 when intensity is equal to 8.8 (IX). Since the intensities estimated with the stochastic simulations are generally smaller that IX, the estimated risk parameters are also smaller than the values obtained considering the Ambraseys (1985) relationship but, introducing the local site effects, a variability as large as a factor 6 is obtained for MDR.

Finally, by comparing the scenario estimated in this work, for the new vulnerability composition model considering intensity IX as seismic input, with the results obtained by Erdik et al. (2005) under exposure to earthquakes with a 2% probability of exceedance in 50 years, we obtained very similar values for expected injuries and values smaller by a factor of nearly 2 for expected fatalities.

Although a direct comparison between the results provided by a probabilistic approach with those coming from a deterministic one is not straightforward, the discrepancy between the losses estimated by different studies and methods confirms the importance of refining the calculation of the seismic risk for Bishkek as soon as more detailed information is available.

Future activities will be devoted to improvement of the inputs for the risk evaluation. In particular, on the engineering side, vulnerability composition models over a district scale will be defined to increase the spatial resolution of the estimated risk parameters. On the seismological side, new seismic hazard maps for the area will be computed in terms of intensity values.

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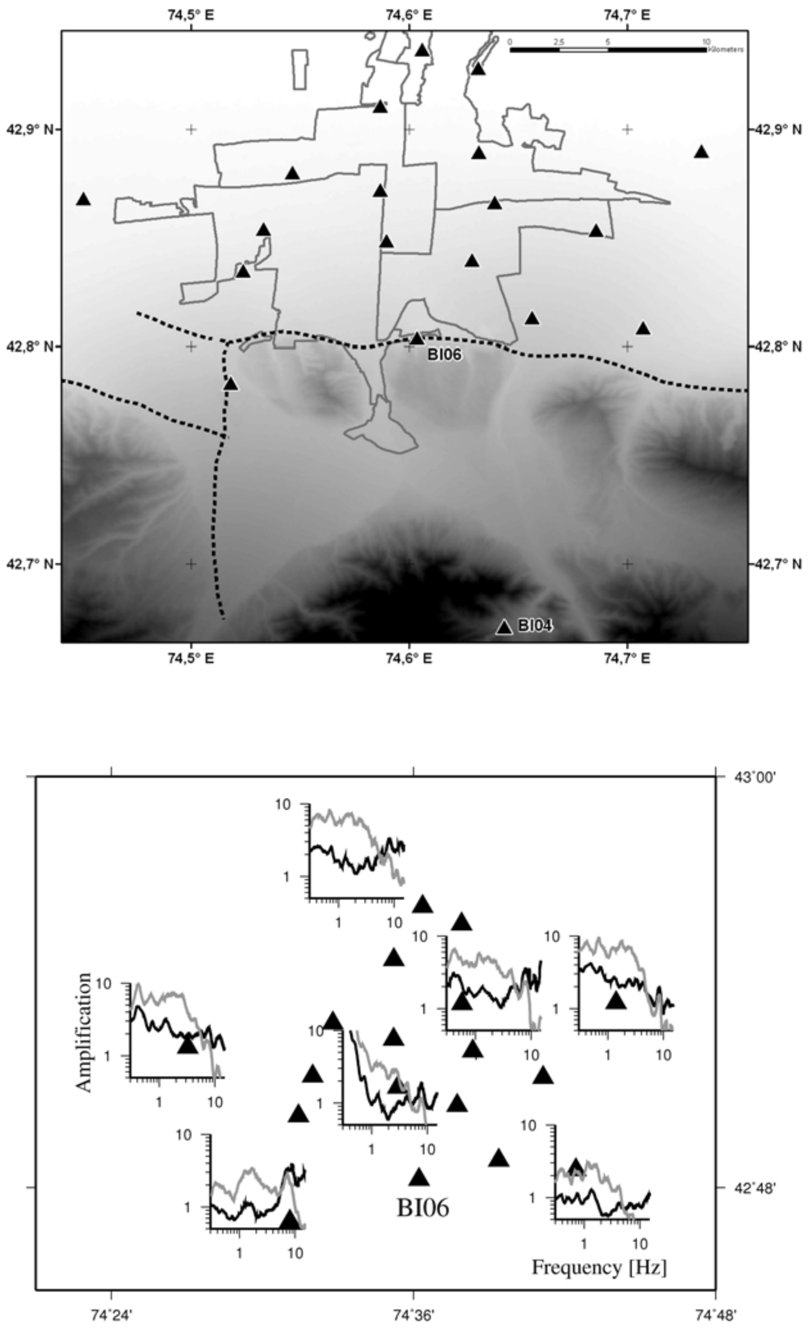

Figure 1. Top: temporary network of 19 seismic stations (triangles) installed in Bishkek to evaluate local site effects (Parolai et al., 2010). The limit of the town (gray line) and a sketch of the Issyk-Ata fault-system front (dashed lines) are also shown. Bottom: local amplification effects for some sites in Bishkek empirically estimated by computing the spectral ratio with respect to two possible reference stations (BI04, gray lines; BI06, black lines). The coordinates of station BI04 (74.64E, 42.67N) are outside the drawn map.

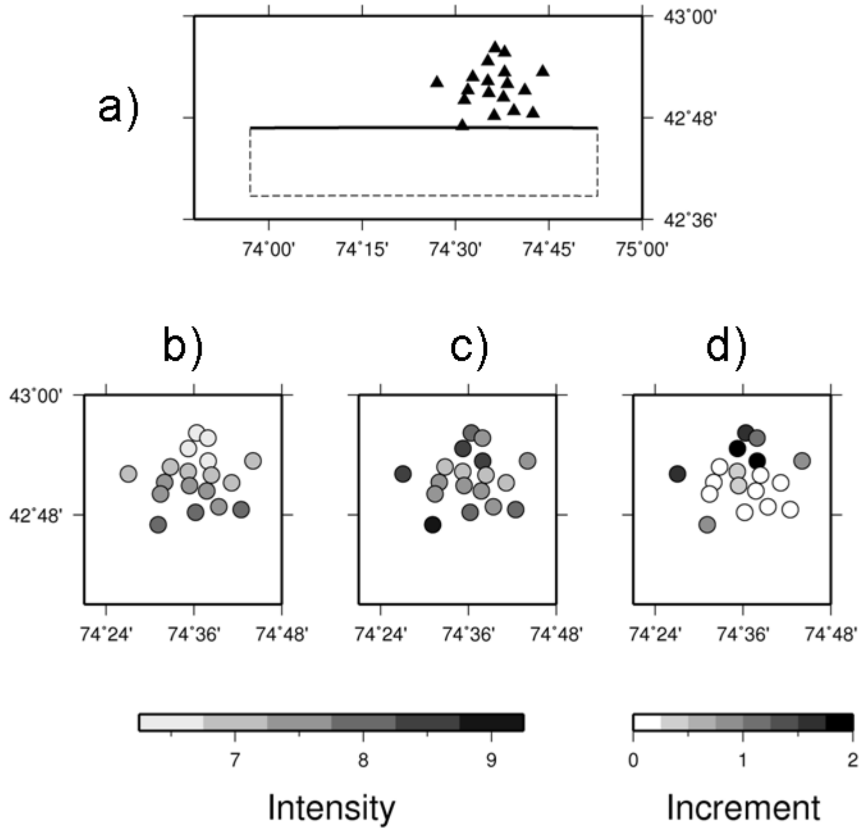

Figure 2. Panel a): surface projection of the fault considered for the stochastic simulations and stations installed in Bishkek (see Figure 1). Panel b): intensity distribution computed starting from stochastic simulations for rock sites. Panel c): the same as panel b), but considering the local site effects (for details, see Figure 1 and the text). Panel d): increment of intensity values due to local site effects.

Table 1. Results for new vulnerability composition (vulnerability scenario 1) with intensity based on stochastic simulations

X_COORD	Y_COORD	INTENSITY_NO_SITE_EFFECTS (M7.5, SD100)	INTENSITY_MAX (M7.5, SD100)	Vulnerability composition (%)						Damage Grade						MDR
				VA	VB	VC	VD	VE	VF	D0	D1	D2	D3	D4	D5	
64.845	17.158	7.5	7.5	12	33	16	27	11	1	47.5	23.8	20.3	7.6	0.9	0.0	5.9
66.331	20.029	6.8	6.8	12	33	16	27	11	1	47.5	23.8	20.3	7.6	0.9	0.0	5.9
63.802	15.011	7.5	7.5	12	33	16	27	11	1	47.5	23.8	20.3	7.6	0.9	0.0	5.9
70.804	19.149	6.8	7.0	12	33	16	27	11	1	47.5	23.8	20.3	7.6	0.9	0.0	5.9
70.818	23.453	6.5	8.3	12	33	16	27	11	1	25.9	21.6	23.8	20.3	7.6	0.9	17.6
76.639	18.516	7.0	7.0	12	33	16	27	11	1	47.5	23.8	20.3	7.6	0.9	0.0	5.9
78.552	12.602	7.5	7.5	12	33	16	27	11	1	47.5	23.8	20.3	7.6	0.9	0.0	5.9
71.113	16.551	7.3	7.5	12	33	16	27	11	1	47.5	23.8	20.3	7.6	0.9	0.0	5.9
75.487	15.569	7.3	7.3	12	33	16	27	11	1	47.5	23.8	20.3	7.6	0.9	0.0	5.9
75.837	21.081	6.5	8.3	12	33	16	27	11	1	25.9	21.6	23.8	20.3	7.6	0.9	17.6
72.949	26.327	6.5	8.0	12	33	16	27	11	1	25.9	21.6	23.8	20.3	7.6	0.9	17.6
75.803	25.378	6.3	7.3	12	33	16	27	11	1	47.5	23.8	20.3	7.6	0.9	0.0	5.9
87.186	21.136	6.8	7.5	12	33	16	27	11	1	47.5	23.8	20.3	7.6	0.9	0.0	5.9
55.653	18.718	7.0	8.5	12	33	16	27	11	1	25.9	21.6	23.8	20.3	7.6	0.9	17.6
81.812	17.090	7.0	7.0	12	33	16	27	11	1	47.5	23.8	20.3	7.6	0.9	0.0	5.9
72.681	11.564	7.8	7.8	12	33	16	27	11	1	25.9	21.6	23.8	20.3	7.6	0.9	17.6
84.224	12.083	7.8	7.8	12	33	16	27	11	1	25.9	21.6	23.8	20.3	7.6	0.9	17.6
63.180	9.300	8.0	8.8	12	33	16	27	11	1	8.5	17.4	21.6	23.8	20.3	8.5	36.5