Earthquake Risk in Multifamily Residential Buildings

Europe and Central Asia Region

WORLD BANK GROUP

GFDRR
Global Facility for Disaster Reduction and Recovery

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The report was edited by Anne Himmelfarb and designed by Zahraa Saiyed (Scyma Consulting).

Cover photos: (Top) “Boy in the Window.” A young boy outside a damaged home near Spitak, Armenia. © Razmik Zackaryan
(Center) Nine-story precast-frame building collapse in Gyumri after the 1988 Spitak earthquake, Armenia. *Credit*: Wyllie, L. A., and J. R. Filson, 1989. ©Earthquake Spectra, EERI. Reprinted with permission.
(Bottom) “Terremoto Albania [2019]” by Dipartimento Protezione Civile, licensed under CC BY 2.0 / Added color transparency.
Back cover photo: “Relief.” The Bulvar district of Gyumri [Armenia] was built for earthquake victims. © Lilit Galstyan.
Bottom-right photo: Image from above of buildings collapsed following the [2019 Albania] earthquake. “Terremoto Albania” by Dipartimento Protezione Civile, licensed under CC BY 2.0 / Added color transparency.

CONTENTS

ABBREVIATIONS

AAL	average annual loss
AAL%	average annual loss ratio
BLK	block
DFW	dual frame-wall
ECA	Europe and Central Asia
GDP	gross domestic product
GEM	Global Earthquake Model
GNI	gross national income
GNIPC	gross national income per capita
LPB	large panel building
M	magnitude
RCF	reinforced concrete frame
RCW	reinforced concrete wall
SCS	slab-column system
URM	unreinforced masonry

EXECUTIVE SUMMARY

INTRODUCTION

Multifamily residential buildings in earthquake-prone cities across Central Europe, Balkans, and Central Asia have proved to be vulnerable and have revealed several structural deficiencies during previous earthquake events. Earthquakes in these regions have damaged certain types of multifamily buildings beyond repair or have caused complete collapse, resulting in extensive homelessness and many fatalities.

The vulnerability of some of these buildings can be attributed to the mass-produced nature of multifamily residential buildings as well as lack of maintenance, oversight, and disinvestment over many decades. **This study investigates earthquake risk of multifamily buildings constructed before 2000 across 27 cities in 20 countries within Europe and Central Asia (ECA) to better understand their behavior and potential losses when subjected to earthquakes, and to inform recommendations for mitigation.** The table on the right shows the cities and countries considered within this study. The intended audience for this report includes government officials, policy and decision makers, engineers, researchers and analysts, among other stakeholders and beneficiaries. Two supplementary technical documents provide additional insight into the inputs, methods, and results, and can be found in the *Works Cited* section (Mott MacDonald 2020a, 2020b).

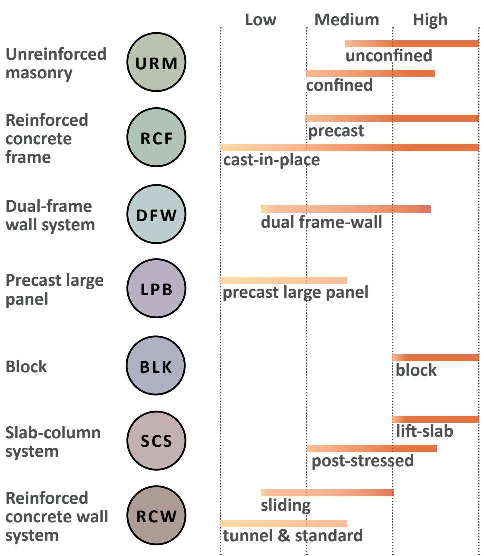
TYPES OF MULTIFAMILY BUILDINGS IN ECA

The study evaluated seven broad classes of multifamily buildings found in the cities and countries under consideration. The buildings are categorized into classes based on their behavior when subjected to earthquake shaking, and according to the data available across the different cities. Building classes are characterized by specific features that affect their earthquake performance: horizontal and vertical structural elements and the material type, connections, building height, construction quality, potential deterioration, and period of construction. The diagram on the right shows the seven building types and the acronyms used in this study, as well as the relative vulnerability of major subtypes indicated as low, medium, and high. For example, the unreinforced masonry building type has two considered subtypes: unconfined and confined masonry.

CITIES INVESTIGATED IN STUDY

Country	City
Albania	Tirana, Durrës
Bosnia & Herzegovina	Mostar
Bulgaria	Sofia, Plovdiv
Croatia	Zagreb, Rijeka
Hungary	Budapest
Moldova	Chișinău
Montenegro	Podgorica
North Macedonia	Skopje
Romania	Bucharest, Iași
Serbia	Belgrade
Slovakia	Bratislava
Slovenia	Ljubljana
Kazakhstan	Almaty, Shymkent
Kyrgyz Republic	Bishkek, Osh
Tajikistan	Dushanbe
Turkmenistan	Ashgabat
Uzbekistan	Tashkent
Armenia	Yerevan, Gyumri
Azerbaijan	Baku
Georgia	Tbilisi

MULTIFAMILY BUILDING TYPES IN STUDY AND RELATIVE EARTHQUAKE VULNERABILITY



METHODOLOGY

A probabilistic seismic risk analysis of multifamily buildings was conducted in order to predict damage and losses due to earthquakes in the 27 cities. The risk analysis used a combination of hazard, exposure, and vulnerability models, and was performed using an open source software called OpenQuake, developed by the Global Earthquake Model (GEM).

Earthquake Hazard Model: The overall earthquake hazard model is comprised of three existing regional models (ESHM13, EMME14, EMCA15) and modifications that are based on two local seismic hazard models (BIGSEES15, BUL18). The regional models are obtained from the Global Earthquake Model GEM2018 global mosaic.

Exposure Model: The building exposure model was developed by analyzing country-specific, cross-country, and structural typology-specific information sources. For each building type, many data sets were evaluated to understand the number of buildings, number of dwellings, and number of occupants, as well as the associated construction costs. The sources used include census data (mainly 2011 and 2014 data), national energy efficiency programs, building inventory reports, past projects on risk assessment, international building databases, post-earthquake reports, technical publications, and satellite images. It should be noted that the reliability of exposure data varies from city to city, based on the information that was available. The relative reliability of the exposure data is shown in the exposure reliability matrix (Table 2) in the *Methodology* section.

Vulnerability Model: The vulnerability models used in the risk analysis are based on existing damage and loss models from various sources. Over 400 damage and loss models were reviewed and the most appropriate ones for each city and building type were selected. The models were used to quantify several earthquake consequences, including: direct financial losses from building damage, permanent relocation of occupants based on building repair time, and fatalities due to building damage. Similar to the exposure data, vulnerability data varies by city. The relative reliability of vulnerability models is shown in the vulnerability reliability matrix (Table 3) in the *Methodology* section.

RESULTS SUMMARY

Results for each of the 27 cities are presented in the *City Earthquake Risk Profiles* section, which include an earthquake history background, predicted estimated losses per building type and impact on occupants, and city-specific reliability and exposure information. The following are key findings from the risk analysis results of the 27 cities.

Overall population exposure: This study finds that on average, approximately half of the population of the cities investigated reside in multifamily residential buildings constructed before 2000.

High population exposure: Bucharest has the most inhabitants living in pre-2000 multifamily housing, with nearly 90% of the total city population residing in these multifamily buildings. This is followed by Tashkent and Belgrade.

Population in high-risk buildings: High-risk building types are considered to be the top two building types within each city that have the highest average annual loss ratios* due to building damage. By this definition, Bucharest has the largest portion of its population residing in high-risk reinforced concrete frame and unreinforced masonry buildings. The next two cities with a large segment of its population residing in its respective high-risk building types are Belgrade and Tashkent.

Absolute building damage loss: Bucharest is expected to have the highest total losses from future earthquakes, with almost €200 million in average annual losses. This is followed by Yerevan and Tbilisi, which are expected to have average annual losses of nearly €73 million and €60 million, respectively.

Vulnerable building typologies: It is found that unreinforced masonry buildings (URM) are expected to experience the most damage out of all seven building classes in the considered cities. URMs contribute to a significant portion of the direct financial losses, number of fatalities, and number of people who will be permanently displaced after an earthquake, even in regions with lower seismicity. Reinforced concrete frame buildings (RCF) are also large contributors to annual losses in many of the cities studied. RCF vulnerability is attested to by the immense damage and collapse of many precast reinforced concrete frame buildings witnessed in the 1988 Spitak earthquake in Armenia.

RECOMMENDATIONS AND POTENTIAL APPLICATIONS

Given the assumptions and limitations of this study (see the *Methodology* section for more details), the following recommendations and applications are proposed for seismic risk reduction of multifamily buildings in the Europe and Central Asia region.

• Prepare databases with building information relevant to the earthquake risk assessment on a large scale.

• Collect data on buildings' current condition and level of maintenance to understand their vulnerability.

• Develop an appropriate earthquake risk reduction strategy and prioritization plan for investment in pre-disaster risk reduction measures.

• Integrate earthquake risk reduction measures into ongoing investment programs.

• Update current codes and legislation related to safety assessment and retrofit of existing buildings.

• Increase public awareness about earthquake risk.

• Design and promote the adoption of risk financing and risk transfer strategies by owners and residents.

See the *Recommendations* section for further detail.

Results of this study offer government officials, decision makers, engineers, researchers, and stakeholders, among other users, a high-level understanding of earthquake risk to multifamily residential buildings and are intended to be a starting point for addressing seismic risk and prioritizing interventions. The scoping, procedural documentation, methodology, and results of this investigation offer an opportunity for further, more detailed studies and continued work towards earthquake risk reduction. •

*High risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The replacement value includes only the multifamily buildings assessed in this study. See Box 1 for more information.

Image Credit: Precast large panel buildings in Bulgaria, by Maryia Markhvida.

INTRODUCTION

Much of the Europe and Central Asia (ECA) region is exposed to earthquake hazard: from historical earthquakes to today's events, earthquakes have created dramatic consequences for ECA countries and their populations. Many catastrophic earthquakes have occurred within the ECA region, with lasting impacts including deaths, displacement of people, destruction of assets, impediments to business and economic growth, and overall stunting of affected countries' development for years and even decades. At least 20 countries across the region have a 10–20 percent chance of experiencing a major earthquake in the next 50 years (Mathema and Simpson 2018). Past regional earthquake events have also shown that a significant portion of the damaged buildings are residential.

The sociopolitical and economic transition of countries in Central Europe, the Balkans, Central Asia, and the Caucasus since the 1990s has revealed the challenges of ensuring safe housing in regions exposed to earthquake perils. Many buildings in these regions exhibit inherent structural vulnerabilities due to their mass-produced nature across both seismic and non-seismic regions and the limited knowledge of building earthquake behavior. Buildings have also been weakened by post-construction modifications, or have outlived their design life span. Over the past several decades, mass-produced housing has suffered from lack of maintenance and oversight as well as disinvestment, and as a result certain types of multifamily buildings have become some of the most vulnerable in the region. Moreover, these buildings represent a significant portion of the building stock and house a large segment of the population. Earthquake events in the past (see Figure 1) have demonstrated the fragility of multifamily residential buildings: many have been damaged beyond repair or completely collapsed, causing extensive homelessness and many deaths.

This report investigates earthquake risk to multifamily buildings across 27 cities within Europe and Central Asia (Table 1). The 27 *City Earthquake Risk Profiles* are based on a probabilistic seismic risk analysis that quantifies the extent of the risks associated with multifamily residential buildings. The buildings considered in this study include those designed and constructed before 2000; this focus captures the typical pre-2000 construction practices within the 20 countries described herein. This high-level assessment seeks to provide meaningful information to governments and stakeholders on the underlying earthquake risks to multifamily housing and supports prioritization of risk reduction efforts and further studies for resilient cities and communities. •

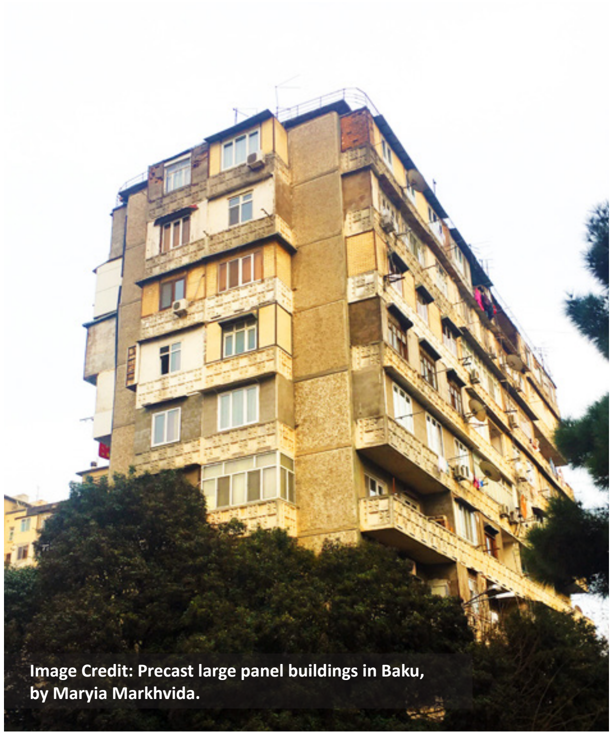
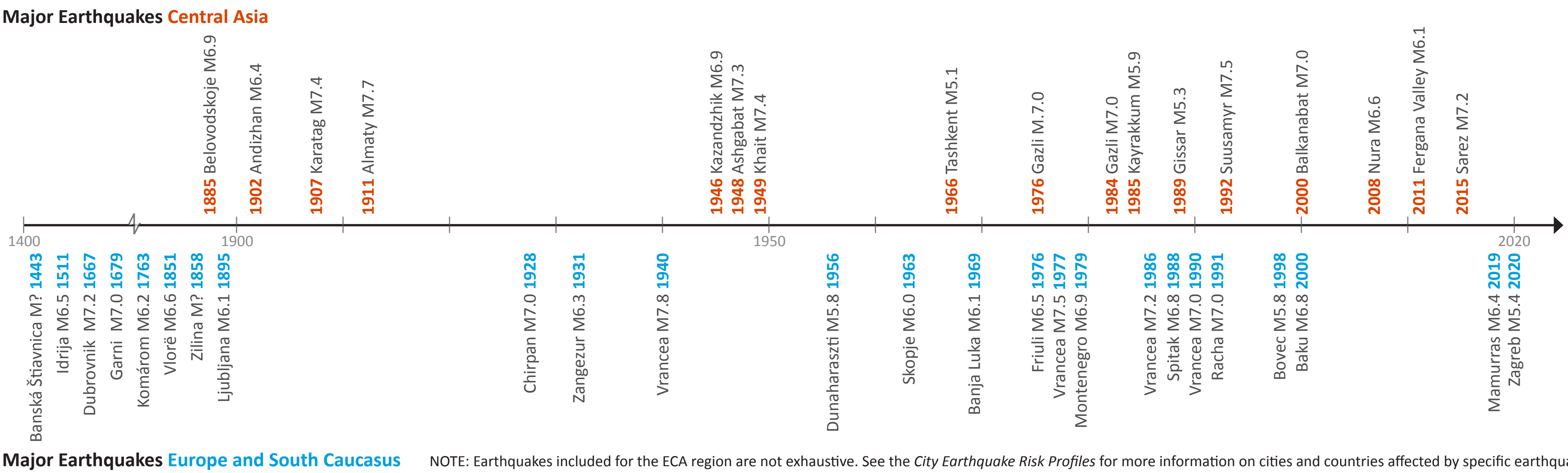


Image Credit: Precast large panel buildings in Baku, by Maryia Markhvida.

FIGURE 1. SELECTED HISTORIC EARTHQUAKES IN ECA REGION



NOTE: Earthquakes included for the ECA region are not exhaustive. See the *City Earthquake Risk Profiles* for more information on cities and countries affected by specific earthquakes.

MOTIVATION OF THIS STUDY

EARTHQUAKE RISK IN MULTIFAMILY BUILDINGS

Multifamily buildings comprise 40–70 percent of the existing ECA housing stock (Mathema and Simpson 2018) and house a large portion of the population in many cities within the region. From the 1950s to the 1990s, shortages of housing in Central Europe and Central Asia were eased by mass construction of buildings, through processes that followed standardized designs and employed prefabrication of building components for economic efficiency.

The multifamily housing built during this period was often designed and constructed with low quality control, an omission that increased buildings' vulnerability. Many of the buildings have also been inadequately maintained, have suffered deterioration, or have been subject to post-construction modifications, putting their structural safety in question. This study finds that on average, half of the population of all the cities investigated live in multifamily buildings designed and constructed before 2000.

Past disasters like the 1988 Spitak earthquake in Armenia demonstrate the tragic consequences of poor-quality design and construction. The earthquake killed over 25,000 people, injured 130,000, and left over 500,000 people homeless (World Bank Group 2017). Many of the fatalities were due to vulnerable multifamily buildings that were severely damaged or suffered complete collapse. The town of Spitak was wholly destroyed, and cities like Gyumri are still recovering decades later.

Nine-story precast-frame building collapse in Gyumri after the 1988 Spitak earthquake, Armenia. *Credit*: Wyllie, L. A., and J. R. Filson, 1989. ©Earthquake Spectra, EERI. Reprinted with permission.

Partial collapse of masonry building after 1988 Spitak earthquake, Armenia. *Credit*: WHE, n.d. (Report 202). © World Housing Encyclopedia, EERI, and IAEE.

> ***Multifamily buildings comprise 40 to 70 % of the existing Europe and Central Asia region housing stock.***
>
> *(Mathema and Simpson 2018)*

> ***Many of the buildings have been inadequately maintained, have suffered deterioration, or have been subject to post-construction modifications, putting their structural safety in question.***

TABLE 1. CITIES INVESTIGATED IN STUDY

Country	City	% city population in multifamily buildings
Albania	Tirana	34%
	Durrës	27%
Bosnia & Herzegovina	Mostar	40%
Bulgaria	Sofia	71%
	Plovdiv	69%
Croatia	Zagreb	52%
	Rijeka	54%
Hungary	Budapest	68%
Moldova	Chișinău	81%
Montenegro	Podgorica	33%
North Macedonia	Skopje	29%
Romania	Bucharest	89%
	Iași	71%
Serbia	Belgrade	74%
Slovakia	Bratislava	64%
Slovenia	Ljubljana	67%
Kazakhstan	Almaty	36%
	Shymkent	26%
Kyrgyz Republic	Bishkek	38%
	Osh	44%
Tajikistan	Dushanbe	54%
Turkmenistan	Ashgabat	39%
Uzbekistan	Tashkent	62%
Armenia	Yerevan	71%
	Gyumri	39%
Azerbaijan	Baku	48%
Georgia	Tbilisi	82%

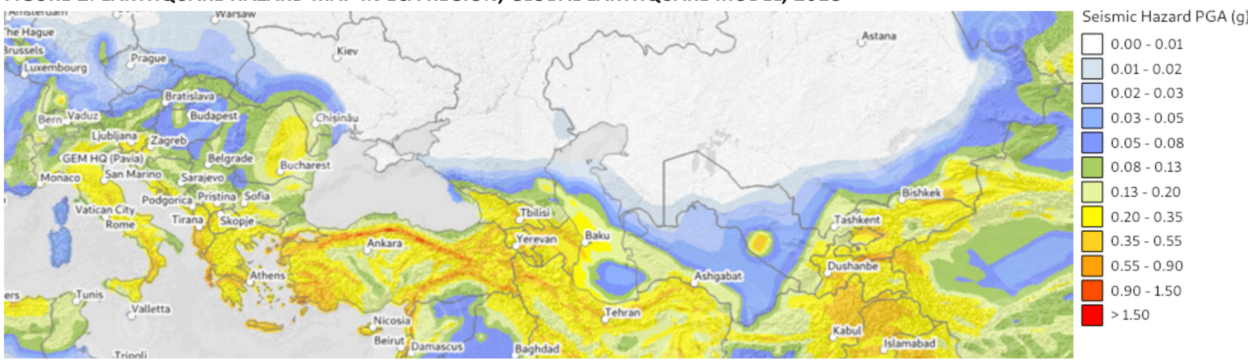
CITIES INCLUDED IN RISK ANALYSIS

In response to the general seismicity of the region (Figure 2) and the known consequences of past earthquakes, this study carried out quantitative earthquake risk analysis for 27 of the largest and most risk-prone cities in 20 countries across Europe and Central Asia that include mass constructed multifamily buildings. These 27 cities were chosen by ranking a combination of the earthquake hazard and city size,[1] then selecting for each country one or two cities that are most susceptible to earthquake shaking and to building and population impacts (cities are shown in Figure 3). It should be noted that the cities selected through this ranking process do not represent an exhaustive list; many other risk-prone cities and areas exist in the region.

OUTPUT OF EARTHQUAKE RISK ANALYSIS

The probabilistic seismic risk analysis of regional multifamily residential housing stock evaluates buildings' structural characteristics, quantifies the population living within these buildings, and investigates the performance of the buildings when subjected to regional earthquake hazard. The results of the assessment provide information on the distribution of losses (in euros) arising from earthquake-induced building damage, loss of life, and displacement of population. Information on results is in the *Overall Findings* section. •

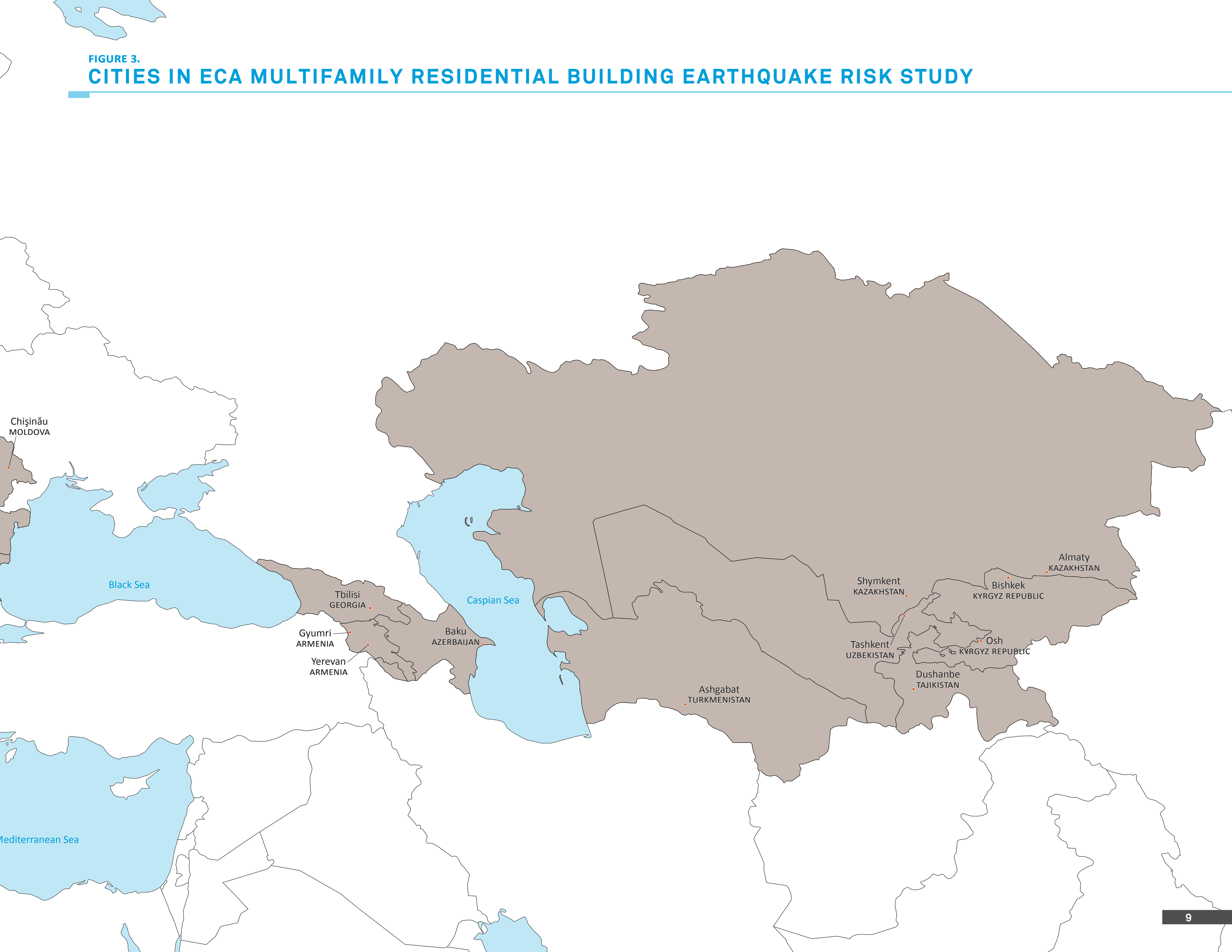
FIGURE 2. EARTHQUAKE HAZARD MAP IN ECA REGION, GLOBAL EARTHQUAKE MODEL, 2018



Source: Pagani et al. 2018. © 2020 GEM Foundation and Partners. Licensed under CC BY-NC-SA 4.0 (CC BY-NC-SA 4.0). Note: PGA = peak ground acceleration.

[1] The seismic hazard used in the risk index for the ranking process included peak ground acceleration for a 475-year return period. The size of city was based on the number of exposed buildings and the size of the affected population. See Technical Report 1 by Mott MacDonald (2020a) for more information.

FIGURE 3.
CITIES IN ECA MULTIFAMILY RESIDENTIAL BUILDING EARTHQUAKE RISK STUDY



TYPES OF MULTIFAMILY BUILDINGS IN ECA

The scope of this study is limited to evaluation of the earthquake risk associated with multifamily residential buildings constructed before 2000; single-family homes and nonresidential buildings are not included in the investigation. After 2000, privatized development created varying building typologies with differing performance during earthquakes. Because the data on these are limited and the building types cannot be compared for performance among the countries and cities of interest, post-2000 multifamily buildings are not included in this study.

In neighborhoods across the studied cities, rapid urbanization and attempts to reduce housing shortages led to the construction of many buildings using standard designs. In large urban centers such as the ones considered in this study, more than half of the population lives in apartments within such standardized multifamily buildings. These buildings range in height from 3 to 20 stories and contain 3 to more than 100 apartment units, and they represent a high concentration of risk due to the large percentage of the population they house. The risk is exacerbated due to shared ownership by residents and lack of consensus in decision making around capital investment, as well as by poor maintenance and inability of some lower-income households to contribute to building upgrades. Moreover, apartments in these buildings often did not match the needs of their owners and therefore post-construction modifications are very common, including removal of internal walls, addition of balconies and extension of rooms creating a cantilever outside of the building.

The following classification was developed specifically for typologies of multifamily housing in the considered countries. Buildings are subdivided into seven classes according to their behavior when subjected to earthquake shaking, and according to the data available across different cities. Buildings are first classified at the regional level, and then further categorized according to specific features that affect earthquake performance in each country. These features include horizontal and vertical structural elements, connections, building height, construction quality, potential deterioration, and period of construction. It is important to note that the classification is not exhaustive but is generally compatible with other existing building taxonomies. The seven building descriptions in this section indicate the approximate construction period of the building type within the 20 countries and 27 cities studied, along with significant earthquakes in which the building class faced varying degrees of damage, including total collapse.[2] It can be assumed that multifamily buildings built between 1950 and 2000 were designed and constructed to meet low to mid code levels.[3]

The *City Earthquake Risk Profiles* include information on the distribution of the building types within the 27 studied cities as well as the specific information related to the loss incurred by each type.

[2] The technical reports accompanying this document use a slightly different nomenclature for the seven building classes. See Mott MacDonald (2020a, 2020b).

[3] Low to mid code refers to the level of earthquake-resistant design concepts prescribed in the building code and can vary by construction period, country, and (at times) city.

Image Credit: "Damaged Building Ilicia [Zagreb, 2020]" by Franjo Tahy, licensed under CC0 1.0.


TOSCA BLU
TOSCA BLU
GALILEO

URM

UNREINFORCED MASONRY (URM) BUILDINGS

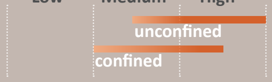
Unreinforced masonry buildings have walls composed of brick, stone, or cement blocks that lack steel reinforcement bars embedded within the masonry. URM buildings in this study are further classified as **"confined"** or **"unconfined."** Confined masonry buildings have masonry walls that are confined by reinforced concrete tie beams and tie columns around the wall. Unconfined masonry buildings have walls that do not include such reinforced concrete elements around the wall. They perform much worse than confined masonry buildings in earthquakes. Confined masonry buildings are constructed by installing the masonry walls first and subsequently installing concrete beam (horizontal) and column (vertical) elements. In this configuration, the masonry wall is better able to resist earthquake loading. It should be noted that this study did not include reinforced masonry buildings—those that include steel bars inside the masonry wall—as a subcategory, since such buildings are rarely found in the ECA region.

URM buildings are among the building types that are most vulnerable in an earthquake. The wall and facade elements of URMs can fall away from the building and are especially dangerous to people outside of the building. Because of their poor performance in earthquakes around the world, unconfined URM multifamily buildings are no longer built in medium- to high-seismic-risk regions in ECA. This typology also allows for relatively easy structural modifications, such as ad hoc removal of walls on the ground floor, which can greatly increase its vulnerability in the face of an earthquake.

Past earthquakes in the investigated region in which unreinforced masonry buildings faced damage, partial collapse, or total collapse include the following: the 1988 Spitak earthquake (Armenia), 1985 Kayrakkum earthquake (Tajikistan), 1992 Suusamyr earthquake (Kyrgyz Republic), 1976 Fruili earthquake and 1998 Bovec earthquake (Slovenia), and 1940, 1977, 1986, and 1990 Vrancea earthquakes (Romania, Bulgaria, Moldova).

Construction period of URM in countries studied: 1920-present

Relative Vulnerability



Undamaged unreinforced masonry building, Armenia.
Credit: JICA 2012.

Damage to unreinforced masonry buildings after the 1988 Spitak earthquake, Armenia.
Credit: WHE, n.d. (Report 202). © World Housing Encyclopedia, EERI, and IAEE.

RCF

REINFORCED CONCRETE FRAME (RCF) BUILDINGS

Reinforced concrete frame buildings are those in which more than half of the earthquake resistance is provided by reinforced concrete beams and columns connected as frames. This category is further classified into **precast concrete frames** and **cast-in-place concrete frames**. Precast frames consist of prefabricated reinforced concrete elements joined together on the construction site by welding, or welding and grouting. Cast-in-place frames have elements that are constructed at the building site. As observed in the 1988 Spitak earthquake, precast RCF buildings' weak connections led to building collapse and other grave consequences. Precast RCF buildings pose some of the greatest risks and are much more vulnerable than cast-in-place concrete frame buildings.

The main structural design deficiencies of RCF buildings are weak or low-quality beam-column and frame-floor connections, which make the frame structures especially vulnerable to earthquakes. In addition, insufficient reinforcement and poor concrete confinement increase the vulnerability of these buildings. In precast frame buildings, those with grouted on-site connections are often less vulnerable than those with welded on-site connections because the welded connections are prone to rusting and are often placed in critical stress zones of the beam-column interface. For the cast-in-place subclass, the vulnerability is greatly influenced by the year of construction, as lessons learned over time from major earthquakes have led to implementation of increasingly rigorous seismic design concepts. Following the 1970s, enhanced engineering principles began to be applied universally and improved the performance of cast-in-place RCF buildings. Past earthquake damage shows that precast RCF buildings and the low-to-mid-code cast-in-place RCF buildings are very vulnerable to earthquake shaking damage and collapse.

Past earthquakes in the investigated region in which RCF buildings faced damage, partial collapse, or total collapse include the following: the 1988 Spitak earthquake (Armenia), in which nearly 70 percent of the precast RCF buildings collapsed and the remaining were demolished; and the 1940, 1977, 1986, and 1990 Vrancea earthquakes (Romania, Bulgaria, Moldova).

Construction period of RCF in countries studied: 1945-present

Relative Vulnerability

Existing cast-in-place reinforced concrete frame buildings, Romania.
Credit: WHE 2003.

Total collapse of prefabricated reinforced concrete frame buildings in foreground and minor damage to large panel buildings in background, Gyumri, Armenia.
Credit: Peter Yanev. © EQE Engineering. Reprinted with permission.

DFW

DUAL FRAME-WALL (DFW) SYSTEM BUILDINGS

Dual frame-wall systems have reinforced concrete frame and wall elements that work together to resist earthquake forces. Like other reinforced concrete structures, they can be **precast** or **cast-in-place**; in some cases precast frames are seen in combination with cast-in-place walls. As is the case for RCF buildings, precast concrete frame and wall elements are often more vulnerable to earthquake damage than are cast-in-place frame and wall elements.

The main seismic design deficiencies in this building category arise from weak connections and from inadequate distribution of the frames and walls in the two main perpendicular directions of the building. Frames and walls must be positioned carefully in two perpendicular directions to appropriately resist the seismic forces. If not carefully engineered and constructed, DFW buildings could suffer severe damage in earthquakes.

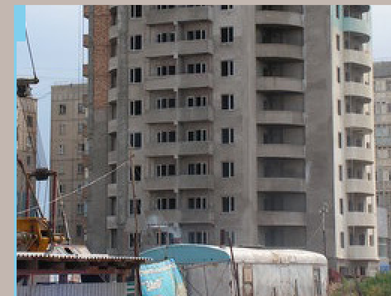
Past earthquakes in the investigated region in which DFW system buildings experienced a range of damage levels, from no damage to total collapse, include the following: the 1977 Vrancea earthquake (Romania, Bulgaria, Moldova), in which many buildings were damaged and one collapsed completely; and the 1986 and 1990 Vrancea earthquakes, in which no damage to this building class was observed.

Construction period of DFW in countries studied: 1945-present

Relative Vulnerability

Low Medium High

dual frame-wall



Dual frame-wall system, Kyrgyz Republic.
Credit: U. Begaliev, A. Duishev, and R. Musakov, in OpenQuake, "Glossary for GEM Taxonomy," https://taxonomy.openquake.org/terms/dual-frame-wall-system-ldual licensed under CC BY 3.0.

Damage to cast-in-place frame building with reinforced concrete shear walls following the 1977 Vrancea earthquake, Bucharest, Romania.
Credit: Georgescu and Pomonis 2012.

LPB

PRECAST LARGE PANEL BUILDINGS (LPB)

Large panel buildings are found in all of the investigated cities. Precast LPBs are built with precast reinforced concrete panels that are assembled on the construction site by steel welded connections, or grouted dowel and welded connections. LPBs generally have floor-to-ceiling-height facade panels with additional steel reinforcement around window openings. Included in the LPB category is the uncommon typology of "precast boxes"—buildings built of prefabricated 3D components assembled on the construction site with welded or grouted connections. Compared to other buildings in this study, LPBs have faced much less damage from past earthquakes.

The main structural design deficiencies in large panel buildings arise from the connections of the precast panels. Post-earthquake building surveys have shown that some grouted connections did not have appropriate quality control when being constructed; as a result, the ability of the system to resist earthquake shaking was reduced and buildings were damaged. In addition, the arrangement of interior walls in two perpendicular directions changes the behavior of LPBs when subjected to earthquakes: LPBs with one long interior load-bearing wall are more vulnerable to earthquakes than those with two or more load-bearing walls. As in URM buildings, facade elements that are large panels may be especially dangerous to individuals outside the building during an earthquake: if the panel connections are weak, the entire concrete panel could fall off the building due to earthquake shaking.

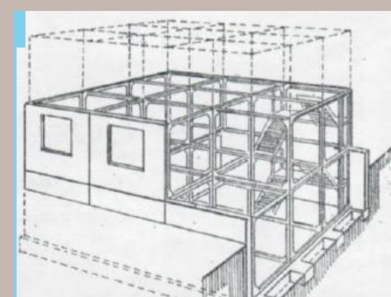
Past earthquakes in the investigated region in which LPBs faced slight damage include the following: the 1966 Tashkent earthquake (Uzbekistan), 1988 Spitak earthquake (Armenia), 1985 Kayrakkum earthquake (Tajikistan), 1977 Vrancea earthquake (Romania, Bulgaria, Moldova), and 1984 Gazli earthquake (Uzbekistan).

Construction period of LPB in countries studied: 1950-1995

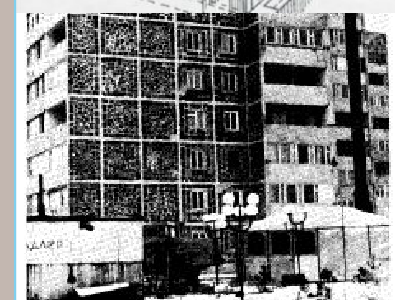
Relative Vulnerability

Low Medium High

precast large panel



Large panel building construction technique typical of Bratislava, Slovakia.
Credit: Stoychev 1976.



Large panel building that sustained minor cracking, Gyumri, Armenia.
Credit: Wyllie, L. A., and J. R. Filson, 1989. ©Earthquake Spectra, EERI. Reprinted with permission.

BLOCK (BLK) BUILDINGS

Block buildings ("крупноблочный" in Russian), or precast plane element structures, consist of reinforced concrete precast elements assembled on the construction site by welding or grouting connections. They are similar to LPBs except that their prefabricated elements are smaller; instead of one large floor-to-ceiling precast facade panel, block buildings have four elements surrounding the window opening. Observation of building damage following past earthquakes indicates that this building typology is one of the most vulnerable among the types considered in this study.

The main structural design deficiencies in BLK buildings arise from the inadequate connections between the precast concrete elements. For these buildings (as for LPBs), earthquake shaking may affect weak or deteriorated facade element connections and cause portions of the building to fall on people outside the building.

Past earthquakes in the investigated region in which block buildings faced damage include the following: the 1971 Kamchatka earthquake (Russian Federation); and the 1995 Neftegorsk earthquake (Russia), in which most of the BLK buildings completely collapsed.

Construction period of BLK in countries studied: 1960-mid 1990s

Relative Vulnerability

Block building in Baku, Azerbaijan, 2019.
Credit: Maryia Markhvida, World Bank.

Damage to block building, Russia.
Credit: WHE 2002a.

SLAB-COLUMN SYSTEM (SCS) BUILDINGS

This group of buildings includes structural types in which the steel reinforced concrete floors are directly connected to the columns. This typology is further classified as follows: some buildings have floors that are cast-in-place at the ground level and then lifted one by one to each floor level (**lift slabs**), and some buildings have steel reinforcement that is pulled in tension following the casting of the concrete on the construction site (**post-stressed**) to reduce cracking of the concrete slab. Observations from past earthquakes and expected behavior of this typology suggest that the lift slab subclass may be more vulnerable than the post-stressing subclass.

The main structural design deficiencies are in the connections between the concrete slabs and the columns, often with poorly executed construction joints. It has been found that the connections to the columns are often inadequately reinforced with steel, further weakening the joints at this location.

A past earthquake in the investigated region in which SCS buildings experienced damage was the 1988 Spitak earthquake (Armenia); in this event, lift slab SCS buildings suffered severe damage to complete collapse.

Construction period of SCS in countries studied: 1957-1996

Relative Vulnerability

Slab-column building under construction, Kyrgyz Republic.
Credit: WHE, n.d. (Report 39).

Damage to slab-column due to twisting at the top floors from the 1988 Spitak earthquake, Gyumri, Armenia.
Credit: Wyllie, L. A., and J. R. Filson, 1989. ©Earthquake Spectra, EERI. Reprinted with permission.

RCW

REINFORCED CONCRETE WALL (RCW) SYSTEM

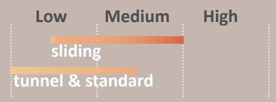
This group includes buildings that have cast-in-place concrete walls to provide earthquake resistance. RCW buildings are further categorized by the kind of formwork used in construction—that is, the type of temporary molds into which concrete is poured to construct the walls. Subtypes include buildings with **standard, sliding**, or **tunnel formwork**. Standard formwork is usually used in RCW buildings that have varying geometries and architectural plan layouts. Tunnel or sliding formwork is used in buildings with established and repetitive designs, most typically in buildings constructed between the mid-1960s and late 1990s. Observations of damage from past earthquakes show that this building typology has performed better than others in this study.

The main structural design deficiencies of the cast-in-place RCW system buildings are limited steel reinforcement in the concrete walls and poorly executed construction joints. In addition, the very slender walls in these buildings are susceptible to damage and failure during earthquake shaking. RCW buildings that use sliding formwork are more vulnerable to earthquakes than those that use standard or tunnel formwork because buildings employing sliding formwork typically have less steel reinforcement. These deficiencies are most commonly noted in RCW buildings constructed before the 1990s.

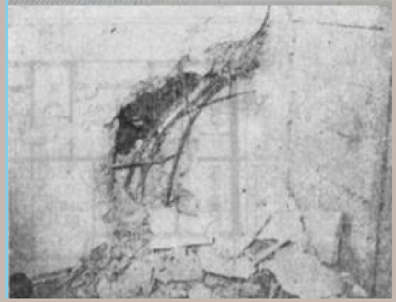
A past earthquake in the investigated region in which cast-in-place RCW system buildings faced damage was the 1977 Vrancea earthquake (Romania, Bulgaria, Moldova). This event caused superficial damage on the walls and cracks along the wall connections, and in more severe cases concrete crushing in the shear walls.

Construction period of RCW in countries studied: 1960-present

Relative Vulnerability



Reinforced concrete wall system building under construction, Kyrgyz Republic.
Credit: Kanat Kanbolotov, in OpenQuake, "Glossary for GEM Taxonomy," https://taxonomy.openquake.org/terms/wall-lwal licensed under CC BY 3.0.



Damage to reinforced concrete wall system building after 1977 Vrancea earthquake, Romania.
Credit: WHE 2002b.

SUMMARY OF MULTIFAMILY BUILDING TYPES

Of the seven building types described, those with the highest relative risk from earthquake shaking include unreinforced masonry buildings (URM), precast frame (RCF) buildings, block buildings (BLK), and slab-column system buildings with lift slab construction (SCS). Overall, building vulnerabilities arise from low construction quality associated with construction period, weak historical design codes and standards, or a combination of both. See *Overall Findings* for more details. •

FIGURE 4. BUILDING CONSTRUCTION PERIOD OF MULTIFAMILY BUILDING TYPES IN STUDY

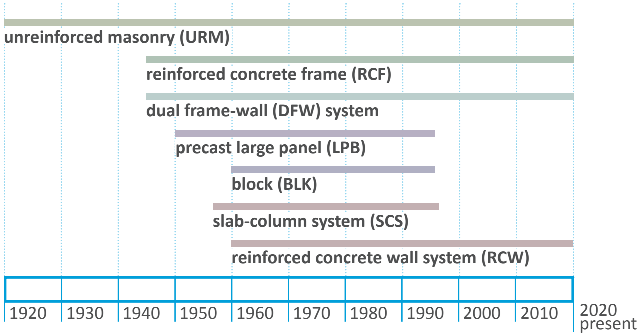
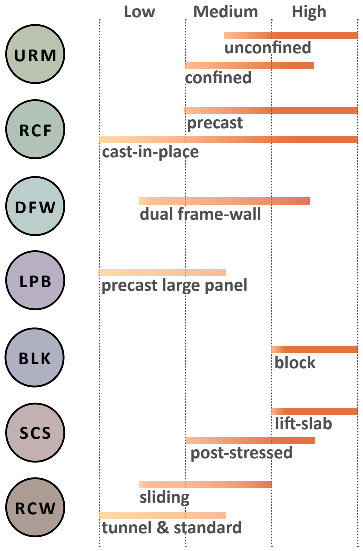


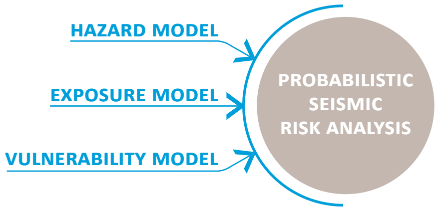
FIGURE 5. RELATIVE VULNERABILITY OF MULTIFAMILY BUILDING TYPES IN STUDY



Of the building types studied, unreinforced masonry (URM) buildings, precast concrete frame (RCF) buildings, block (BLK) buildings, and slab-column system (SCS) buildings with lift slab construction have the highest relative risk.

The probabilistic seismic risk analysis of multifamily buildings in the 27 cities required development of hazard, exposure, and vulnerability models (see Figure 6; key definitions are in Box 1). The following describes the process of addressing each of these components to output quantifiable information on the building and human impacts from earthquakes in the ECA region.

FIGURE 6. MODELS USED IN PROBABILISTIC SEISMIC RISK ANALYSIS



SEISMIC HAZARD MODEL

The earthquake model consists of three regional models and modifications based on two local seismic hazard models for the seismic hazard computations in this study. The regional models are obtained from the Global Earthquake Model GEM2018 global mosaic of seismic hazard models. They include the Euro-Mediterranean Seismic Hazard Model 2013 (ESHM13) developed within the SHARE Project (Woessner et al. 2015), the Earthquake Model Middle East 2014 (EMME14), and the Earthquake Model Central Asia 2015 (EMCA15). Two local seismic hazard models used in the hazard component are the BIGSEES15 model, which includes the latest Romanian national seismic hazard model (Pavel et al. 2016) and the BUL18 model for Bulgarian cities (Mott MacDonald 2020a).

The assumptions and considerations for the hazard component are as follows:

• Only strong ground motion is considered. Estimates of secondary seismic hazards—such as liquefaction, landslides, subsidence, or slope instability—are not provided.

• National seismic hazard models are used only where regional models are inconsistent with detailed national hazard models. Seismic hazard was calculated only at several locations (sometimes one location) throughout the city.

• The development of the hazard model is intended only to provide risk results at the regional scale and not at a single-building level.

EXPOSURE MODEL

The building exposure model was developed through reviewing and collecting country-specific, cross-country, and structural typology–specific information sources. For each building typology, many data sets were evaluated to understand the number of buildings, number of dwellings, and number of occupants, as well as the associated construction cost (exposure value). The sources used include censuses and national statistical institutions, national energy efficiency programs, building inventory reports, past projects on risk and exposure, international building databases, post-earthquake reports, technical publications, and satellite images. In most cases, the number of buildings was deduced or projected from combined information on the number of dwellings in multifamily buildings, number of dwellings according to the year of construction, buildings according to number of stories, damage to buildings after earthquakes, buildings renovated as part of ongoing energy efficiency programs, statistics on the tallest buildings in the cities, and examples of past building inventories (Mott MacDonald 2020a).

Key assumptions and considerations for the exposure component are as follows:

• Exposure data and its reliability vary across cities. Where required, deduction and expert judgment were used to complete the exposure information (see Table 2).

• Exposure data was aggregated at a single point in a city, or in some cases, across several points within a city.

• Asset values of the buildings under consideration are the replacement value, or construction cost, of each building typology within each city. The replacement value does not include removal of debris, design, quality assurance, project approval costs, or price increase surge due to high reconstruction demand following an earthquake.

• Multifamily buildings are defined as residential buildings with more than two dwellings and three or more floors. It is assumed that the population within these buildings is proportional to the number of dwellings.

• The exposure data are based on the latest census statistics available for the countries and cities. In most cases, the census data used are from 2011 and 2014.

• Where construction costs for a city are unavailable, data from nearby cities are used.

The reliability of exposure data varies across building types and city to city, based on the available information; see the exposure data reliability matrix (Table 2) and *City Profile Sources*. It should be noted that the exposure reliability index is relevant for high-level regional risk analysis, whereas even the most highly reliable data are not sufficient or appropriate for building-specific analysis.

VULNERABILITY MODEL

The vulnerability models used in the risk analysis were obtained by combining different loss models from various sources, since models for specific building types within each city or country were not readily available. The types of consequences that were quantified in this study are direct financial losses from building damage, permanent relocation of occupants, and fatalities due to building damage. Over 400 models using both empirical and analytical methods were reviewed for direct financial losses from building damage, and expert judgment was used to develop damage and loss models for the various building typologies under consideration. For each building type, the vulnerability model considers the earthquake load resisting system, and is further classified by vulnerabilities of connections, infills, facade elements, and cladding. The reliability of vulnerability data varies across building types and city to city, based on the available information; see the vulnerability data reliability matrix (Table 3). Vulnerability models produced from this approach also provide the basis for the relocation period, depending on the time needed to repair or replace the building. The HAZUS methodology developed in the USA was used for repair time and fatality modeling (DHS, FEMA n.d.).

For many of the buildings, the structural elements and their connections will likely have different levels of strength degradation throughout their lifetime. In addition, some of the buildings may have undergone structural modifications—by extending and closing balconies, cutting openings, or even removing walls to modify the interior or to add entrances at the ground floor. Although statistical data on such post-construction structural changes are not available, these considerations are indirectly included in the uncertainties within the vulnerability models (Mott MacDonald 2020a).

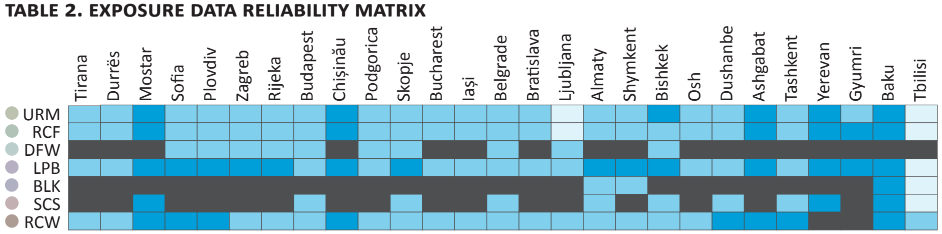
The assumptions and considerations for the vulnerability model are as follows:

- The model for casualties is specific to indoor fatalities and does not include outdoor fatalities caused by falling building elements.
- The fatalities are assessed at nighttime (2:00 a.m.) on a weekend. It is assumed that 100 percent of the occupants are inside their homes, which is considered a worst-case scenario in the vulnerability models.

PROBABILISTIC SEISMIC RISK ANALYSIS

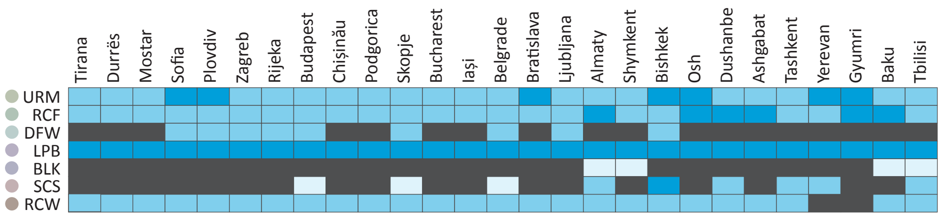
The risk analysis combining the hazard, exposure, and vulnerability component was performed with open source software OpenQuake,[4] and the results are presented in terms of damage and losses per building type and impacts on occupants. •

TABLE 2. EXPOSURE DATA RELIABILITY MATRIX



- High-reliability data are found in publications, based on manual counting, or otherwise precisely derived.
- Low-reliability data reflect the number of buildings projected with other assumptions.
- Medium-reliability data reflect the number of buildings projected from the national census data through optimization processes.
- Dark-colored cells indicate building types that were not present in the city under investigation.

TABLE 3. VULNERABILITY DATA RELIABILITY MATRIX



- High-reliability data have good correspondence with respect to the building type and the country.
- Low-reliability data indicate data that are not found for the specific building type or country; in this case, models are developed based on expected vulnerability and employ expert engineering judgment.
- Medium-reliability data have good correspondence with respect to the building type, but not with respect to the country; in this case, models developed for different countries are combined and applied.
- Dark-colored cells indicate building types that were not present in the city under investigation.

[4] OpenQuake was developed by the Global Earthquake Model (GEM); see the OpenQuake web page at https://www.globalquakemodel.org/openquake.

BOX 1. TERMINOLOGY

Hazard: Hazard refers to the physical forces produced by a peril, such as ground shaking induced by an earthquake. In this study, the hazard is strictly that of earthquake shaking and does not include soil liquefaction, subsidence, or slope instability.

Exposure: Exposure refers to the location, characteristics, and value of assets such as people, buildings, critical facilities, and transport networks located in an area that may be subject to a hazard event. In this study, only multifamily residential buildings are considered and the value of the building is determined through the present day construction cost considering similar buildings today (i.e., building replacement value).

Vulnerability: Vulnerability is the susceptibility of people and assets to the forces of a hazard event. For example, a building's earthquake vulnerability depends on a variety of factors, including material and structural system, quality and year of construction, and height. Human earthquake vulnerability depends on whether it is a weekend or weekday when an earthquake occurs, and whether people are more or less likely to be home at different times in the day. For example, a nighttime earthquake has a high likelihood of all residents being inside of their homes, whereas an afternoon earthquake may have fewer residents at home.

Risk: Disaster risk is a function of hazard, exposure, and vulnerability. Several risk metrics are calculated in this study: average annual loss (AAL) and average annual loss ratio (AAL%), as well as financial loss and number of lives lost at a specified return period. The city risk profiles provide annualized loss values to compare between cities and regions, as well as risk information for earthquake impacts with a 100-year return period (i.e., this impact or greater impact occurs on average once in 100 years) and a 475-year return period.

Average annual loss: AAL is the total loss when averaged over a very large number of years. In this study, the AAL is provided in absolute monetary terms (euros) and is strictly expected loss as a result of multifamily building damage from earthquake ground shaking.

Average annual loss ratio: AAL% is the ratio of expected average annual loss to buildings' replacement value. The building replacement value is the cost of constructing a new building in a given building typology. When the loss is normalized over the replacement cost, it provides a useful loss-to-value metric on the relative risk across cities and regions. Note that a higher AAL% indicates a more risk-prone portfolio of buildings.

$$\text{Average Annual Loss Ratio (AAL\%)} = \frac{\text{Average Annual Loss (AAL,€)}}{\text{Building Replacement Value (€)}}$$

Return period: The return period of an earthquake impact metric (e.g., loss) indicates that on average that metric is exceeded once during that period. For example, a 100-year loss indicates a loss that on average is exceeded once in 100 years. It is very important to understand that a loss with a return period of 100 years could occur in any given year, irrespective of when that impact last occurred. The greater the return period, the more intense and less frequent the event's occurrence. This study presents both 100-year return period losses and 475-year return period losses.

Probabilistic Seismic Risk Analysis: A probabilistic analysis considers the consequences of all possible damaging earthquakes affecting the region, considering their probability of occurrence.

OVERALL FINDINGS

Although many uncertainties are associated with the earthquake risk analysis conducted in this study (including uncertainty in the composition of the building stock), the most obvious trend is the influence of the level of seismicity in the investigated regions in combination with the vulnerabilities of the buildings studied. This section provides results and trends based on earthquake losses and commentary on pre-2000 multifamily buildings in the 27 cities studied.

Table 4 presents findings that include city-specific population data of pre-2000 multifamily housing, as well as absolute and relative losses from the probabilistic seismic risk analysis. The highlighted cells indicate the highest three values (cities) for the result metric, where the dark-colored cell is the largest value and the light-colored cell is the lowest.

For the 27 cities in this study:

- Total population in pre-2000 multifamily housing is approximately **13.9 million**.
- On average, **half of the population** lives in pre-2000 multifamily housing.
- Total multifamily building exposure value is nearly **€238 billion**.
- Total average annual loss** from earthquakes is nearly **€680 million**.
- Top two building types contributing to total average annual loss are **unreinforced masonry (URM)** and **precast large panel (LPB)**.
- Top two high-risk* building types are **unreinforced masonry (URM)** and **reinforced concrete frame (RCF)**.

TABLE 4. SUMMARY OF EARTHQUAKE RISK ASSESSMENT RESULTS

City, Country	Total population in pre-2000 multifamily housing	Percent of city population in pre-2000 multifamily housing	Top 2 high-risk building types*	Total population in top 2 high-risk building types*	Percent of city population in top 2 high-risk building types*	Average annual loss total (million euros)**	Average annual loss ratio (AAL%)*
Tirana, Albania	164,900	34%	RCF, URM	47,000	10%	€ 5.25	0.39%
Durrës, Albania	30,510	27%	RCF, URM	7,000	6%	€ 1.28	0.37%
Mostar, Bosnia & Herzegovina	44,070	39%	URM, SCS	20,000	18%	€ 5.27	0.61%
Sofia, Bulgaria	881,820	71%	RCF, URM	260,000	21%	€ 41.10	0.26%
Plovdiv, Bulgaria	239,430	69%	RCF, URM	65,000	20%	€ 6.55	0.21%
Zagreb, Croatia	418,080	52%	URM, RCF	280,000	35%	€ 48.80	0.44%
Rijeka, Croatia	64,260	54%	URM, RCF	38,000	32%	€ 4.75	0.40%
Budapest, Hungary	1,191,360	68%	URM, RCF	440,000	25%	€ 48.80	0.13%
Chişinău, Moldova	555,660	81%	URM, LPB	324,000	47%	€ 6.26	0.08%
Podgorica, Montenegro	49,830	33%	RCF, URM	14,000	9%	€ 2.90	0.26%
Skopje, North Macedonia	158,340	29%	SCS, RCF	38,000	7%	€ 5.78	0.29%
Bucharest, Romania	1,626,920	89%	RCF, URM	1,100,000	61%	€ 192.00	0.42%
Iaşi, Romania	205,900	71%	URM, RCF	154,000	53%	€ 5.41	0.31%
Belgrade, Serbia	1,248,380	74%	RCF, URM	550,000	33%	€ 33.60	0.10%
Bratislava, Slovakia	271,360	64%	RCF, URM	30,000	7%	€ 8.48	0.06%
Ljubljana, Slovenia	187,600	67%	RCF, URM	78,000	28%	€ 17.90	0.32%
Almaty, Kazakhstan	670,680	36%	BLK, SCS	13,000	1%	€ 31.50	0.38%
Shymkent, Kazakhstan	242,320	26%	BLK, URM	100,000	11%	€ 3.04	0.19%
Bishkek, Kyrgyz Republic	384,940	38%	URM, RCF	143,000	14%	€ 4.28	0.20%
Osh, Kyrgyz Republic	113,080	44%	URM, RCF	105,000	41%	€ 1.27	0.47%
Dushanbe, Tajikistan	456,840	54%	SCS, URM	67,000	8%	€ 3.21	0.39%
Ashgabat, Turkmenistan	322,920	39%	URM, RCF	115,000	14%	€ 5.45	0.20%
Tashkent, Uzbekistan	1,543,800	62%	SCS, URM	550,000	22%	€ 13.00	0.15%
Yerevan, Armenia	776,030	71%	URM, SCS	250,000	23%	€ 72.50	0.67%
Gyumri, Armenia	45,630	39%	URM, RCF	43,000	37%	€ 8.17	0.70%
Baku, Azerbaijan	1,110,240	48%	BLK, URM	125,000	5%	€ 42.40	0.41%
Tbilisi, Georgia	883,140	82%	BLK, SCS	300,000	28%	€ 59.50	0.89%

*High risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The replacement value includes only the multifamily buildings assessed in this study. See Box 1 for more information.
**Average annual loss (AAL) is the total loss when averaged over a very large number of years, considering current building stock. In this study, the AAL is provided in absolute monetary terms (euros) and is strictly expected loss as a result of multifamily building damage from earthquake ground shaking.

RESULTS SNAPSHOT

Population in pre-2000 multifamily buildings

BUCHAREST

has the most inhabitants living in pre-2000 multifamily housing, followed by Tashkent and Belgrade. Nearly 90% of the total city population in Bucharest lives in these multifamily buildings.

Population in high-risk multifamily buildings

BUCHAREST

has the greatest number of its residents in its high-risk reinforced concrete frame and unreinforced masonry buildings. High-risk building typologies are considered the top two building types in each city with the highest average annual loss ratios* from building damage. Similar to the previous findings, Belgrade and Tashkent follow Bucharest with the most number of residents housed within their high-risk building types.

Absolute and relative loss

BUCHAREST

is also expected to have the highest total losses from future earthquakes, with almost €200 million in average annual losses. This is followed by Yerevan and Tbilisi, which are expected to have average annual losses of nearly €73 million and €60 million, respectively.**

TBILISI

is the city with the highest loss-to-value ratio when comparing the ratio of total euro loss (average annual loss) to the replacement value of all buildings within a city.* This is followed by Gyumri and Yerevan. While Bucharest has the highest total euro loss value, it has less than half of the relative losses (average annual loss ratio) as Tbilisi, indicating that Bucharest has a larger replacement value of multifamily buildings than does Tbilisi.

MULTIFAMILY BUILDING VULNERABILITIES

The study is able to quantify the relative vulnerability of the seven typologies under consideration. The most vulnerable typology is unreinforced masonry buildings (URM), especially the unconfined masonry structures. During and after an earthquake, bricks can fall out of such buildings, leading to irreparable damage and even total collapse. In addition, and as verified by the 1988 Spitak earthquake in Armenia and other countries, reinforced concrete frame buildings (RCF) contribute to much of annual loss in absolute terms, and in relative terms as a share of building value. Slab-column system buildings (SCS)—especially those in the lift-slab subcategory, which increase in vulnerability with earthquake intensity—can experience total collapse. Large panel buildings (LPB) are expected to be less likely to collapse than other types of buildings designed and constructed before 2000. However, the final losses and the investment needed to repair LPBs after an earthquake may be considerable. Similarly, the anticipated damage to reinforced concrete wall system buildings (RCW) will occur in localized areas of the structural system, and these buildings are not expected to collapse completely. For SCS buildings, the financial ramifications of repair may be substantial, just as they are for LPBs.

Overall, unreinforced masonry buildings (URM) are expected to experience the most damage, contributing to a significant portion of the direct financial losses, number of fatalities, and number of people who will be permanently displaced after an earthquake. This remains true even in regions with lower seismicity; where other building types are expected to experience light to moderate damage, the most severely damaged and collapsed buildings are of the masonry type. •

Overall, unreinforced masonry buildings (URM) are expected to experience the most damage, contributing to a significant portion of the direct financial losses, number of fatalities, and number of people who will be permanently displaced after an earthquake.

RECOMMENDATIONS

Considering all assumptions and limitations of this study (see *Methodology*), the following recommendations are proposed for consideration by governments, authorities, policy and decision makers, engineers, researchers, and analysts, among other possible stakeholders and beneficiaries of this study to further earthquake risk evaluation and reduction.

Prepare databases with information relevant (but not restricted) to earthquake risk assessment on a large scale. While socioeconomic parameters are often well addressed by country-based censuses, adequate information about the buildings—their structures, structural deficiencies, and current conditions—is sparse and should be collected. It may be possible to collect building data in parallel to acquiring census statistics, with the goal of synchronous sharing of institutional resources and capacity. The proposed database should be updated periodically to provide information to facilitate any mitigation, response, or recovery efforts.

Collect data on buildings' current condition and level of maintenance for earthquake retrofit. Such data are generally unavailable in all cities studied. In some countries, rapid visual assessment of residential buildings has been initiated by programs related to living conditions and not necessarily to address the seismic vulnerability of the structures. An understanding of the amount of structural change and building degradation could greatly increase understanding of building typologies' overall vulnerability. The collection of such data would require the preparation of nationally approved guidelines and templates for on-site assessment and consistent application. The following is a generalized four-step process for collecting data and systematically addressing earthquake risk reduction of multifamily structures:

1. Building upon the risk analysis in this study, conduct a more detailed risk assessment of multifamily building types across a country.
2. Initiate a rapid visual assessment program to identify critical structural design deficiencies in key building types, starting with the most vulnerable buildings found under step 1.
3. Prioritize and develop earthquake risk reduction intervention plans and develop design guidelines for standardized retrofit solutions.
4. Undertake detailed asset-level engineering evaluations to refine the understanding of structural design deficiencies to design building-specific retrofits.

Develop an appropriate earthquake risk reduction strategy and prioritization plan for investment in pre-disaster risk reduction measures. This is a vital step for the safety of residents of multifamily buildings and communities. Such strategies must include stakeholder engagement and suitable government policies and procedures with regulatory measures. In addition, this step should address investments, incentives, and contingencies; community awareness and engagement; and the creation of preparedness, response, and recovery plans and business operation plans. It is critical to recognize the most vulnerable members of society when developing seismic risk reduction plans and strategies, as these groups are often disproportionately affected by disasters and recover last, if at all.

Integrate earthquake risk reduction measures into ongoing investment programs. In many of the studied countries, energy efficiency programs and other funding programs for improvement of living conditions are currently under way. Such programs could be extended to include seismic risk reduction measures and to provide a range of possible retrofit solutions to owners and public oversight agencies. Since such programs often focus on multifamily residential buildings, they offer a fitting opportunity to bridge energy efficiency with structural safety, given proper planning and foresight.

Update current assessment codes and legislation for existing buildings. It is likely that seismic building codes for existing structures as well as legislation will need to be updated to better address issues related to the seismic evaluation and retrofit of multifamily buildings. In addition, the capacity of building departments should be increased to provide improved oversight to existing buildings when they are assessed, renovated, or retrofit.

Increase public awareness about earthquake risk. The risk awareness and engagement component should not be ignored—it is one of the most important aspects to consider in order to create a resilient society. To facilitate government policies and commitment to seismic safety in countries and communities, it is imperative to continually educate the public about their earthquake risk and vulnerability. Proper modes of risk communication should be initiated, and resources for earthquake preparedness should be provided at the very minimum.

Design and promote adoption of risk financing and risk transfer strategies by owners and residents. Awareness of and opportunities for risk financing and transfer mechanisms should be made available to residents, homeowners, and public agencies. Earthquake insurance, financial incentives through premium subsidies and tax breaks, as well as funding to retrofit unsafe building types are some examples of financial instruments to reduce the risk that inhabitants and owners of multifamily housing face. These mechanisms can provide compensation for property damage and indirect losses from damage, distribute the risk and burden of recovery between public and private sectors, and encourage investment in earthquake risk reduction. •

Image Credit: "Nalband Village." Children make their way home from school, in the epicenter of the 1988 earthquake [Spitak, Armenia]. © Monica Hovhannesyan.

IMPACT OF THIS STUDY

The strength of this study is the comprehensive approach through which data were collected, analyzed, and verified in order to conduct the earthquake risk assessment. A thorough research and review process was undertaken to characterize the multifamily residential building stock. This included investigating buildings' structural deficiencies, identifying specific features of the urban territories, and determining how the building stock has been transformed through the years. For each of the studied cities, the process has led to a valuable database that can be utilized in future projects—from additional high-level studies to detailed seismic risk analyses for a single building type. In addition, data uncertainties and limitations are well documented and may inform future research to bolster any subsequent seismic risk assessments.

Detailed information on the engineering methodology and earthquake risk results of multifamily housing in the ECA can be found in the technical engineering reports listed in the *Works Cited* section (Mott MacDonald 2020a, 2020b).

The strength of this study is the comprehensive approach through which data were collected, analyzed, and verified in order to conduct the earthquake risk assessment.

Image Credit: "The Catholic Hospital in Plovdiv [Bulgaria, 1928], affected by the Chirpan earthquake" by unknown author.

CITY EARTHQUAKE RISK PROFILES

UNDERSTANDING THE CITY EARTHQUAKE RISK PROFILES

The earthquake risk profiles for the ECA countries presented here indicate the damage and loss values on a per-city basis. Profiles are organized by region then by country and city. Note that some countries have only one city that has been studied. The elements included in the profile are explained below.

City and country profiles: The profile includes a *Country Snapshot* with the 2018 gross domestic product (GDP) and the most current information on the country's population count.[5] In addition to relevant earthquake history of the city in the *Summary* section, the *Earthquake Impacts Snapshot* provides the expected average annual loss and annual affected GDP from future earthquakes. The annual affected GDP is the percentage of the average loss over the country's current GDP, averaged over many years. Furthermore, information is provided on the number of people living within the city's multifamily residential building stock. As a comparative metric for all regions in this study, the expected average annual loss ratio (AAL%) is included, with averages for all cities shown as horizontal bars, and regional averages indicated by vertical lines to understand the relative risk of the multifamily building portfolio. This is a metric for comparing loss-to-value ratios, which can provide information for prioritizing seismic strengthening interventions. It is important to understand that the expected average annual loss does not represent the impact of a single event, but an average of all possible earthquake events. Thus, much larger impacts could occur in the event of a rarer and more intense earthquake. See Box 1 for more information on the terminology used in the profiles.

Reliability and exposure: Every city profile contains a *Data Reliability and Building Exposure* diagram to visually communicate the overall confidence level for city- and building-specific exposure and vulnerability data. The diagram also shows the share of each building category as a percentage of total pre-2000 buildings in the city. Note that not all building types are found in every city, and the diagram reflects this with a null value. Highlighted in the *Data Reliability and Building Exposure* diagram are the city's two highest-risk building types.

Detailed losses: The *Building Damage Losses* section on the second page of each profile begins with a short description of the building types and specifies their relative vulnerability under *Building Classification and Vulnerability Range*. All vulnerability information presented is approximate and depends on post-construction modifications, degradation, construction quality, and year of construction. See *Types of Multifamily Buildings in ECA* for additional information. The *Absolute and Relative Loss* graph disaggregates expected average annual losses per building type in the city. The graph compares the absolute average annual loss in 2019 euros for each building type. This metric considers both the vulnerability of the building type and how widespread that type is. The graph also provides the average annual loss ratio, which is the ratio of the average annual loss to the exposure value (i.e., the replacement value) of that particular building type. This metric offers a relative risk comparison for all vulnerable buildings in the city, where the higher ratios indicate building typologies considered higher risk-to-value for the city. The two highest-risk building types that are found in the city and the associated consequences are listed below the graph.

The *Earthquake Event–Based Losses* section summarizes the losses expected from an event with a 100-year return period and an event with a 475-year return period. Note that other more hazardous earthquake events—with the potential to far exceed the losses for the 475-year return period—could take place within the city. The loss information includes damage from the event (in euros), the ratio of loss to total building value in the city, and the number of fatalities expected from an event occurring at 2:00 a.m. on a weekend. Also presented is the percentage of the damage cost per capita (considering residents of these buildings) as a percentage of the country's gross national income per capita (GNIPC) value.[6] The gross national income measures annual income per number of people within the country and is a comparable measurement of income across countries of different population sizes and living standards. If all costs of damage, and consequently repair, are borne by multifamily residential building inhabitants, the ratio of expected loss to annual income serves to explain the degree of loss per resident.[7] A high loss-to-income ratio can create challenges to recovery if mitigation and strengthening measures are not planned for and implemented.

All expected annual and event-based loss values are subject to limitation by the reliability of the input data on hazard, exposure, and vulnerability. See the *Methodology* section for more information.

FIGURE 7. USING THE CITY PROFILES: QUICK FACTS

- All loss values are in present-day values (2019 €).
- Historic earthquake loss values are in 2019 €.*
- The most current census data are listed.

* Zagreb loss values in 2020 € for March 2020 Zagreb earthquake.

The expected average annual loss does not represent the impact of a single event, but an average of all possible earthquake events. Thus, much larger impacts could occur in the event of a rarer and more intense earthquake.

[5] GDP data are from the World Bank Indicators Database, https://data.worldbank.org/indicator.

[6] Data are for 2018 and are from the World Bank Indicators Database, https://data.worldbank.org/indicator.

[7] The ratio explains how costs borne for repair after an earthquake can impact annual savings for a resident.

$$\frac{\dfrac{\text{Damage (€)}}{\text{\# of Multifamily Building Residents}}}{\text{Gross National Income per Capita}}$$

Image Credit (left): Image from above of buildings collapsed following the [2019 Albania] earthquake. "Terremoto Albania" by Dipartimento Protezione Civile, licensed under CC BY 2.0 / Added color transparency.

Tirana | ALBANIA

Summary

Tirana is the capital and largest city in Albania, home to approximately 17 percent of the total population. Albania has experienced many earthquakes of varying severity in the past. The most deadly was a series of earthquakes in 1851 (highest magnitude 6.6) near the towns of Vlorë and Berat, causing the loss of 600 lives. Another large event was the 1967 magnitude 6.5 earthquake that led to over 500 collapsed homes, 170 injuries, and nearly 20 fatalities. More recently, in 2019, Albania was struck by a series of damaging earthquakes, the strongest and most deadly of which was a 6.4 magnitude event near the town of Mamurras in November of that year. This event caused over 50 deaths, injured 2,000 people, and resulted in €1 billion (2019 €) in damage. Approximately 1,500 buildings were damaged in the capital city.

Based on the analysis, nearly one in every three people of Tirana resides in pre-2000 multifamily residential buildings. The two building types that are the most at risk* are reinforced concrete frame (RCF) buildings and unreinforced masonry (URM) buildings. Along with reinforced concrete wall (RCW) buildings, these building types are also expected to cause the most fatalities. Nearly 50,000 people, or about 10 percent of the city's population, reside in high-risk building types.

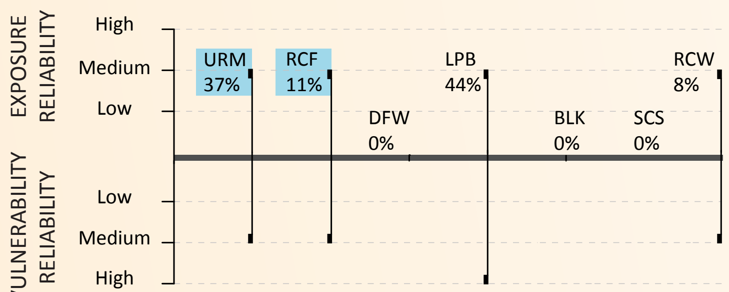
Compared to the data for all the buildings in this study, the data used to conduct the risk analysis for buildings in Tirana average a **low** reliability; this rating is a function of the assumptions, uncertainties, and data available for the city (see *Methodology*). The diagram below indicates the reliability and confidence related to building stock data (i.e., exposure data) as well as data on building vulnerability. These confidence and reliability levels should be considered when interpreting and applying the risk metrics presented in the city profile.

*At risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The expected loss results are predicted from models of future events subject to variable data availability and modeling assumptions. The replacement value is the construction cost of all multifamily buildings in the city.

TIRANA FACTS

Capital City | Population: 485,000 (2019) | GNI/capita: ~€4,000

Data Reliability and Building Exposure



Building exposure data is for pre-2000 multifamily buildings.

▷ Data on building stock and population (exposure) and their susceptibility to earthquake losses (vulnerability) for the city is conveyed with vertical bars labeled by the building typology acronym.
▷ The diagram also indicates the percentage of total building stock that a typology comprises in the city denoted as a percentage below the building typology acronym. Highlighted building types are those that are considered highest risk in the city.

Earthquake Event-Based Losses

	€ Total building damage	% Building damage, % of total value	Number of fatalities
100-year Return Period	€ 146 M 22% GNIPC	11%	360 people
475-year Return Period	€ 508 M 75% GNIPC	37%	2,400 people

▷ A 100-year return period event is one where the damage and loss have approximately a 40% probability of being exceeded in 50 years; it is considered a more frequent event. A 475-year return period event is one where the damage and loss have approximately a 10% probability of being exceeded in 50 years; it is considered a less frequent event, more damaging event.
▷ GNIPC is gross national income per capita. Percentage of GNIPC is the losses from damage per resident as a percentage of GNIPC.
▷ The fatalities presented are those that are expected to occur at nighttime (2:00 a.m.) on a weekend.
▷ *Note: Event-based losses are subject to limitation by the reliability of the input data. The chosen return periods do not suggest that more hazardous and infrequent earthquake events are not probable in this city, as higher return period events may occur at any point.*

Country Snapshot

GDP
12.8 Billion Euros*

POPULATION
2.87 Million People*

SIGNIFICANT EARTHQUAKES
1851 Vlorë / Berat M6.6
1967 Dibër M6.5
2019 Mamurras M6.4

* 2018 estimate

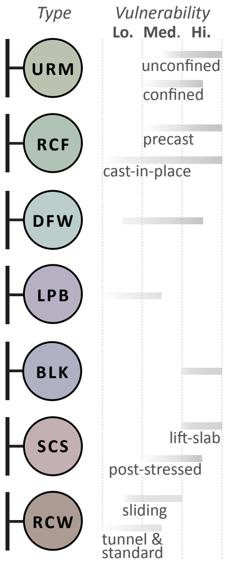
WORLD BANK GROUP   GFDRR

Earthquake Risk Profile

Building Damage Losses

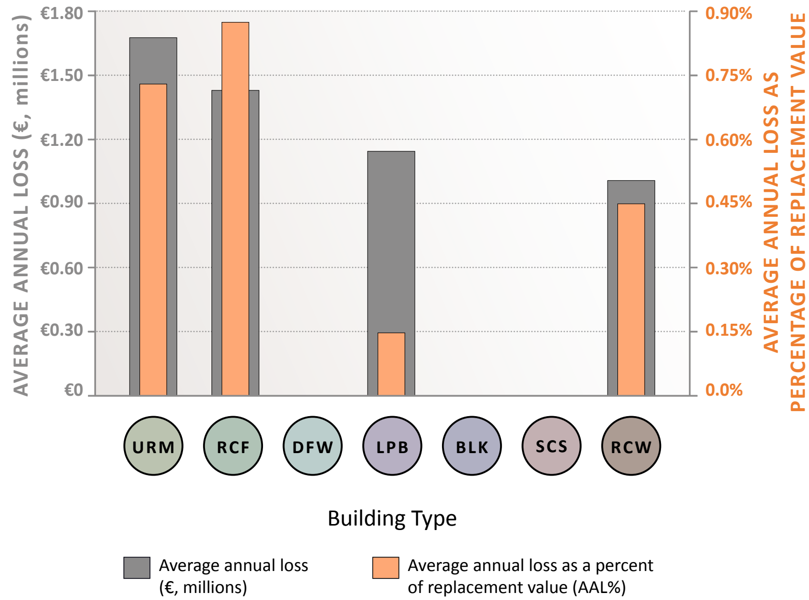
BUILDING CLASSIFICATION & VULNERABILITY RANGE

Description	Type
Unreinforced Masonry: built with masonry walls that lack steel reinforcement; includes confined and unconfined walls.	URM
Reinforced Concrete Frame: reinforced concrete frames that provide earthquake resistance; includes precast and cast-in-place frames.	RCF
Dual Frame-wall: reinforced concrete frame and wall elements work together to resist earthquake forces.	DFW
Precast Large Panel: built with precast reinforced concrete panels with floor-to-ceiling height facade panels.	LPB
Block: built with precast concrete elements assembled on site; similar to LPB with smaller facade elements.	BLK
Slab-column System: reinforced concrete floor slabs directly connected to concrete columns; includes lift slabs and post-stressed slabs.	SCS
Reinforced Concrete Wall: cast-in-place walls that provide earthquake resistance; includes standard, sliding, and tunnel formwork.	RCW



Note that the relative vulnerabilities are approximate and depend on post-construction modifications, degradation, construction quality, and year of construction. See Types of Multifamily Buildings in ECA for more information.

ABSOLUTE AND RELATIVE LOSS



Tirana

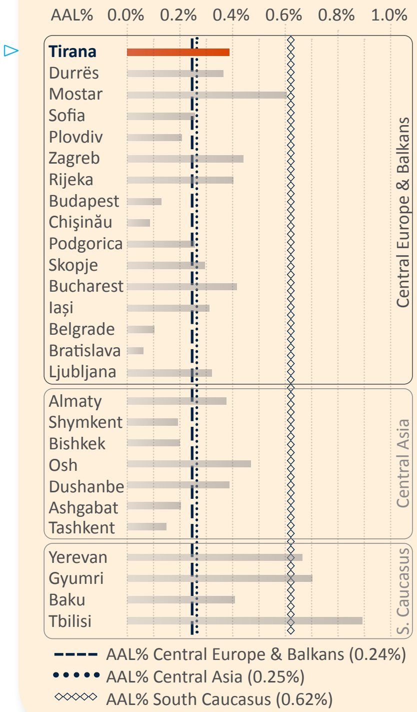
EARTHQUAKE IMPACTS SNAPSHOT

▷ Average annual loss from earthquake damage to multifamily residences is **€5.25 million**.

▷ This amounts to **0.04%** of the country's GDP.

▷ Nearly **34%** of the city's population lives in multifamily residential buildings.

LOSS COMPARISON TO REGION



High-Risk Buildings in Tirana

Reinforced concrete frame and masonry are the two highest-risk building types used for pre-2000 multifamily housing in Tirana.

~47,000 people live in these buildings, or **10%** of the total population of Tirana

RCF
URM

Reinforced Concrete Frame (RCF) and Unreinforced Masonry (URM) buildings contribute to:

60% of total **loss** from building damage

70% of all **permanent residential displacement** in the next 50 years from building damage due to earthquakes

71% of **fatalities** in multifamily buildings*

*This is an average number of fatalities when assessed over many years.

References: See *City Profile Sources* for information on building types, classification, and exposure data sources.

Durrës | ALBANIA

Summary

Durrës is a major port city and is the second largest city in Albania, home to approximately 4 percent of the total population. Albania has experienced many earthquakes of varying severity in the past. The most deadly was a series of earthquakes in 1851 (highest magnitude 6.6) near the towns of Vlorë and Berat, causing the loss of 600 lives. Another large event was the 1967 magnitude 6.5 earthquake that led to over 500 collapsed homes, 170 injuries, and nearly 20 fatalities. More recently, in 2019, Albania was struck by a series of damaging earthquakes, the strongest and most deadly of which was a 6.4 magnitude event near the town of Mamurras in November of that year. This event caused over 50 deaths, injured 2,000 people, and resulted in €1 billion (2019 €) in damage. In Durrës, at least three hotels, a residential villa, and an apartment building collapsed.

Based on the analysis, about 27 percent of the population of Durrës resides in pre-2000 multifamily residential buildings. The buildings that are the most at risk* are reinforced concrete frame (RCF) buildings and unreinforced masonry (URM) buildings. Along with reinforced concrete wall (RCW) buildings, these building types are also expected to cause the most fatalities. Approximately 7,000 people, or about 6 percent of the city's population, reside in high-risk building types.

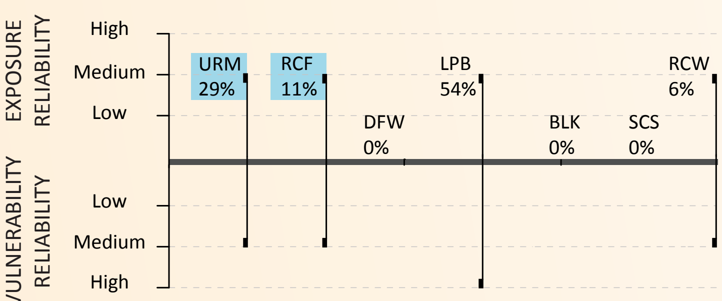
Compared to the data for all the buildings in this study, the data used to conduct the risk analysis for buildings in Durrës average a **low** reliability; this rating is a function of the assumptions, uncertainties, and data available for the city (see *Methodology*). The diagram below indicates the reliability and confidence related to building stock data (i.e., exposure data) as well as data on building vulnerability. These confidence and reliability levels should be considered when interpreting and applying the risk metrics presented in the city profile.

*At risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The expected loss results are predicted from models of future events subject to variable data availability and modeling assumptions. The replacement value is the construction cost of all multifamily buildings in the city.

DURRËS FACTS

Second Largest City | Population: 113,000 (2011) | GNI/capita: ~€4,000

Data Reliability and Building Exposure



Building exposure data is for pre-2000 multifamily buildings.

▷ Data on building stock and population (exposure) and their susceptibility to earthquake losses (vulnerability) for the city is conveyed with vertical bars labeled by the building typology acronym.
▷ The diagram also indicates the percentage of total building stock that a typology comprises in the city denoted as a percentage below the building typology acronym. Highlighted building types are those that are considered highest risk in the city.

Earthquake Event-Based Losses

	€ Total building damage	% Building damage, % of total value	Number of fatalities
100-year Return Period	€ 35 M 28% GNIPC	10%	70 people
475-year Return Period	€ 125 M 99% GNIPC	36%	400 people

▷ A 100-year return period event is one where the damage and loss have approximately a 40% probability of being exceeded in 50 years; it is considered a more frequent event. A 475-year return period event is one where the damage and loss have approximately a 10% probability of being exceeded in 50 years; it is considered a less frequent event, more damaging event.
▷ GNIPC is gross national income per capita. Percentage of GNIPC is the losses from damage per resident as a percentage of GNIPC.
▷ The fatalities presented are those that are expected to occur at nighttime (2:00 a.m.) on a weekend.
▷ *Note: Event-based losses are subject to limitation by the reliability of the input data. The chosen return periods do not suggest that more hazardous and infrequent earthquake events are not probable in this city, as higher return period events may occur at any point.*

Country Snapshot

GDP
12.8 Billion Euros*

POPULATION
2.87 Million People*

SIGNIFICANT EARTHQUAKES
1851 Vlorë / Berat M6.6
1967 Dibër M6.5
2019 Mamurras M6.4

* 2018 estimate

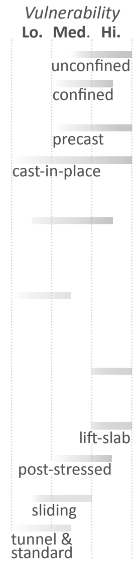
WORLD BANK GROUP | GFDRR Global Facility for Disaster Reduction and Recovery

Earthquake Risk Profile

Building Damage Losses

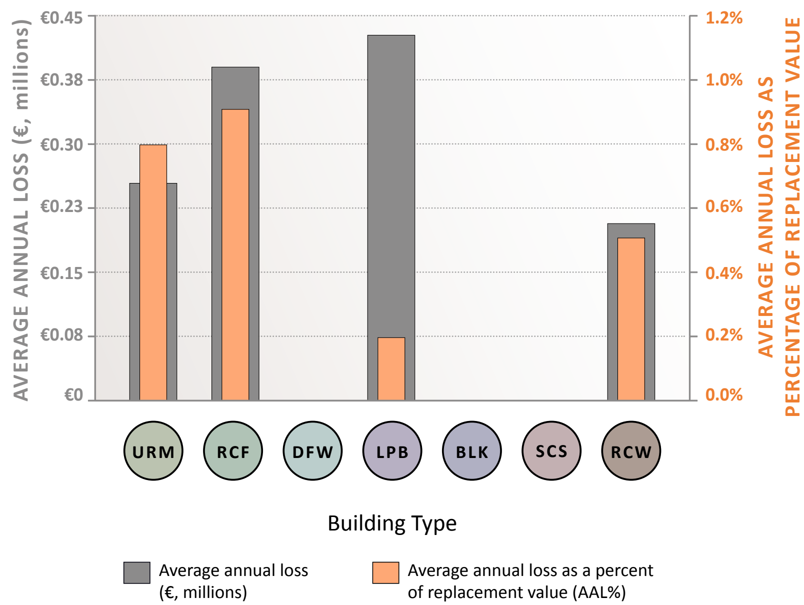
BUILDING CLASSIFICATION & VULNERABILITY RANGE

Description	Type
Unreinforced Masonry: built with masonry walls that lack steel reinforcement; includes confined and unconfined walls.	URM
Reinforced Concrete Frame: reinforced concrete frames that provide earthquake resistance; includes precast and cast-in-place frames.	RCF
Dual Frame-wall: reinforced concrete frame and wall elements work together to resist earthquake forces.	DFW
Precast Large Panel: built with precast reinforced concrete panels with floor-to-ceiling height facade panels.	LPB
Block: built with precast concrete elements assembled on site; similar to LPB with smaller facade elements.	BLK
Slab-column System: reinforced concrete floor slabs directly connected to concrete columns; includes lift slabs and post-stressed slabs.	SCS
Reinforced Concrete Wall: cast-in-place walls that provide earthquake resistance; includes standard, sliding, and tunnel formwork.	RCW



Note that the relative vulnerabilities are approximate and depend on post-construction modifications, degradation, construction quality, and year of construction. See Types of Multifamily Buildings in ECA for more information.

ABSOLUTE AND RELATIVE LOSS

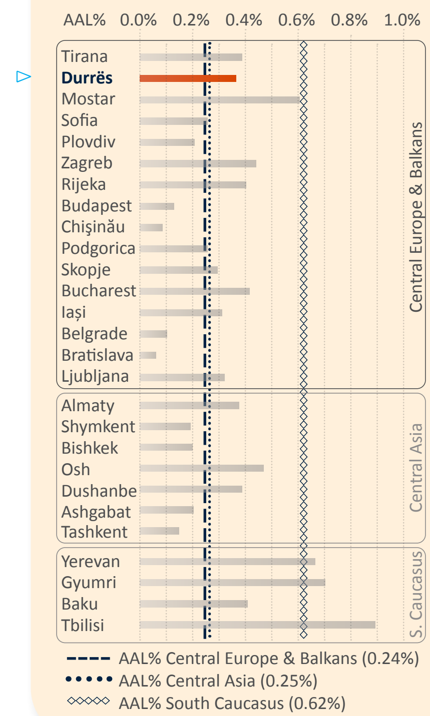


Durrës

EARTHQUAKE IMPACTS SNAPSHOT

- Average annual loss from earthquake damage to multifamily residences is **€1.28 million**.
- This amounts to **0.01%** of the country's GDP.
- Nearly **27%** of the city's population lives in multifamily residential buildings.

LOSS COMPARISON TO REGION



High-Risk Buildings in Durrës

Reinforced concrete frame and masonry are the two highest-risk building types used for pre-2000 multifamily housing in Durrës.

~7,000 people live in these buildings, or **6%** of the total population of Durrës

RCF
URM

Reinforced Concrete Frame (RCF) and Unreinforced Masonry (URM) buildings contribute to:

50% of total **loss** from building damage

70% of all **permanent residential displacement** in the next 50 years from building damage due to earthquakes

58% of **fatalities** in multifamily buildings*

*This is an average number of fatalities when assessed over many years.

References: See *City Profile Sources* for information on building types, classification, and exposure data sources.

Mostar | BOSNIA & HERZEGOVINA

Summary

Mostar is the fifth largest city in Bosnia and Herzegovina and home to about 3 percent of the country's population. It is notable as the location of one of the country's most visited landmarks—the Stari Most, or "Old Bridge," built in the 16th century. Bosnia and Herzegovina has been impacted by earthquakes in the past, such as the 1943 event that led to 19 fatalities. The Banja Luka earthquake of 1969 was a strong magnitude 6.1 event that killed 15 people, left over 1,000 people injured, severely damaged or completely destroyed 86,000 apartments, and resulted in more than €50 million (2019 €) in damage.

Based on the analysis, nearly 40 percent of the population of Mostar resides in pre-2000 multifamily residential buildings. The buildings that are the most at risk* are unreinforced masonry (URM) and slab-column system (SCS) buildings. Along with reinforced concrete frame (RCF) buildings, these building types are also expected to cause the most fatalities. Approximately 20,000 inhabitants, or about one in every five people in Mostar, reside in high-risk building types.

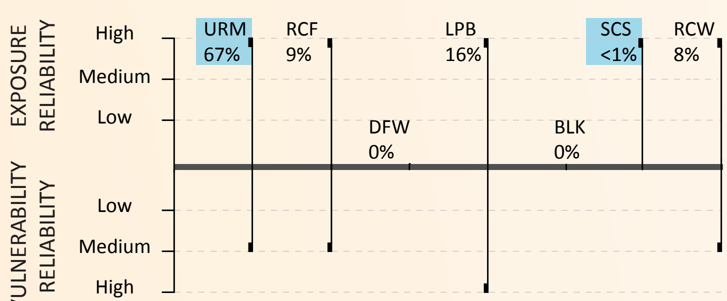
Compared to the data for all the buildings in this study, the data used to conduct the risk analysis for buildings in Mostar average a **high** reliability; this rating is a function of the assumptions, uncertainties, and data available for the city (see *Methodology*). The diagram below indicates the reliability and confidence related to building stock data (i.e., exposure data) as well as data on building vulnerability. These confidence and reliability levels should be considered when interpreting and applying the risk metrics presented in the city profile.

*At risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The expected loss results are predicted from models of future events subject to variable data availability and modeling assumptions. The replacement value is the construction cost of all multifamily buildings in the city.

MOSTAR FACTS

Fifth Largest City | Population: 113,000 (2013) | GNI/capita: ~€5,000

Data Reliability and Building Exposure



Building exposure data is for pre-2000 multifamily buildings.

▷ Data on building stock and population (exposure) and their susceptibility to earthquake losses (vulnerability) for the city is conveyed with vertical bars labeled by the building typology acronym.
▷ The diagram also indicates the percentage of total building stock that a typology comprises in the city denoted as a percentage below the building typology acronym. Highlighted building types are those that are considered highest risk in the city.

Earthquake Event-Based Losses

	€ Total building damage	% Building damage, % of total value	Number of fatalities
100-year Return Period	€ 120 M 55% GNIPC	14%	200 people
475-year Return Period	€ 380 M 175% GNIPC	44%	880 people

▷ A 100-year return period event is one where the damage and loss have approximately a 40% probability of being exceeded in 50 years; it is considered a more frequent event. A 475-year return period event is one where the damage and loss have approximately a 10% probability of being exceeded in 50 years; it is considered a less frequent event, more damaging event.
▷ GNIPC is gross national income per capita. Percentage of GNIPC is the losses from damage per resident as a percentage of GNIPC.
▷ The fatalities presented are those that are expected to occur at nighttime (2:00 a.m.) on a weekend.
▷ *Note: Event-based losses are subject to limitation by the reliability of the input data. The chosen return periods do not suggest that more hazardous and infrequent earthquake events are not probable in this city, as higher return period events may occur at any point.*

Country Snapshot

GDP
17.0 Billion Euros*

POPULATION
3.32 Million People*

SIGNIFICANT EARTHQUAKES
1962 Sarajevo M6.3
1969 Banja Luka M6.1
2015 Tuzla M3.6

* 2018 estimate

WORLD BANK GROUP GFDRR

Earthquake Risk Profile

Mostar

Building Damage Losses

BUILDING CLASSIFICATION & VULNERABILITY RANGE

Description — *Type* — *Vulnerability* (Lo. Med. Hi.)

Unreinforced Masonry: built with masonry walls that lack steel reinforcement; includes confined and unconfined walls. — URM

Reinforced Concrete Frame: reinforced concrete frames that provide earthquake resistance; includes precast and cast-in-place frames. — RCF

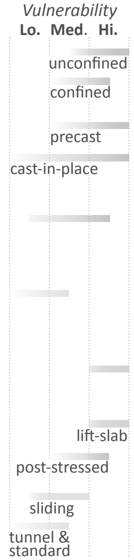
Dual Frame-wall: reinforced concrete frame and wall elements work together to resist earthquake forces. — DFW

Precast Large Panel: built with precast reinforced concrete panels with floor-to-ceiling height facade panels. — LPB

Block: built with precast concrete elements assembled on site; similar to LPB with smaller facade elements. — BLK

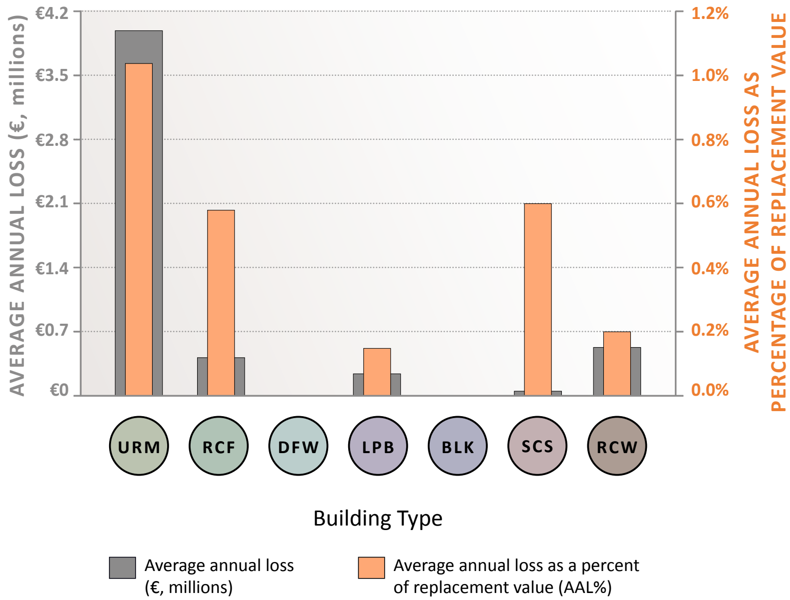
Slab-column System: reinforced concrete floor slabs directly connected to concrete columns; includes lift slabs and post-stressed slabs. — SCS

Reinforced Concrete Wall: cast-in-place walls that provide earthquake resistance; includes standard, sliding, and tunnel formwork. — RCW



Note that the relative vulnerabilities are approximate and depend on post-construction modifications, degradation, construction quality, and year of construction. See Types of Multifamily Buildings in ECA for more information.

ABSOLUTE AND RELATIVE LOSS



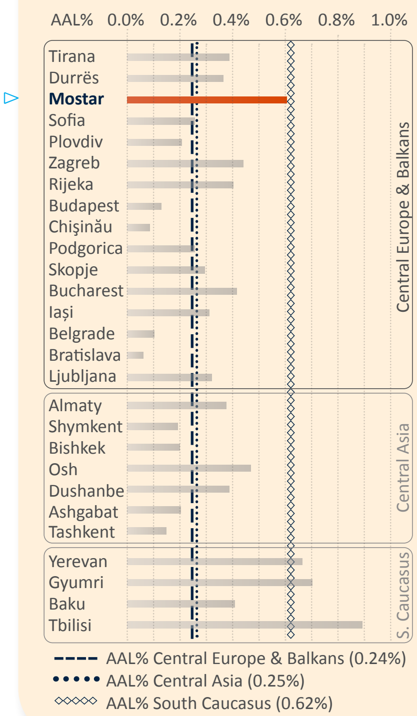
EARTHQUAKE IMPACTS SNAPSHOT

▷ Average annual loss from earthquake damage to multifamily residences is **€5.27 million**.

▷ This amounts to **0.03%** of the country's GDP.

▷ Nearly **40%** of the city's population lives in multifamily residential buildings.

LOSS COMPARISON TO REGION



High-Risk Buildings in Mostar

Masonry and slab-column system are the two highest-risk building types used for pre-2000 multifamily housing in Mostar.

~20,000 people live in these buildings, or **18%** of the total population of Mostar

URM

SCS

Unreinforced Masonry (URM) and Slab-column System (SCS) buildings contribute to:

77% of total **loss** from building damage

63% of all **permanent residential displacement** in the next 50 years from building damage due to earthquakes

61% of **fatalities** in multifamily buildings*

*This is an average number of fatalities when assessed over many years.

References: See *City Profile Sources* for information on building types, classification, and exposure data sources.

Sofia | BULGARIA

Summary

Sofia is Bulgaria's capital and largest city, home to nearly 20 percent of the country's total population. Bulgaria has faced several large earthquakes in the past, the most damaging and deadly of which occurred in 1928 near Plovdiv. This magnitude 7.0 earthquake caused over 1,700 injuries and 120 deaths. In 1986, Bulgaria experienced a magnitude 5.7 earthquake in the Veliko Turnovo-Turgovishte region that caused nearly €11 million (2019 €) in damage; over 150 homes were destroyed and approximately 7,000 suffered damage, leaving 80 percent of homes uninhabitable. The earthquake also injured 60 people and killed three. Over a century earlier, in 1858, Sofia faced a magnitude 6.2 earthquake that damaged nearly 80 percent of the city's building stock and left many residents homeless.

Based on the analysis, over 70 percent of the population of Sofia resides in pre-2000 multifamily residential buildings. The buildings that are the most at risk* are reinforced concrete frame (RCF) buildings and unreinforced masonry (URM) buildings. Along with large panel buildings (LPBs), these building types are also expected to cause the most fatalities. Approximately 260,000 people, or 20 percent of the city's population, reside in high-risk building types.

Compared to the data for all the buildings in this study, the data used to conduct the risk analysis for buildings in Sofia averages a **medium** reliability; this rating is a function of the assumptions, uncertainties, and data available for the city (see *Methodology*). The diagram below indicates the reliability and confidence related to building stock data (i.e., exposure data) as well as data on building vulnerability. These confidence and reliability levels should be considered when interpreting and applying the risk metrics presented in the city profile.

*At risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The expected loss results are predicted from models of future events subject to variable data availability and modeling assumptions. The replacement value is the construction cost of all multifamily buildings in the city.

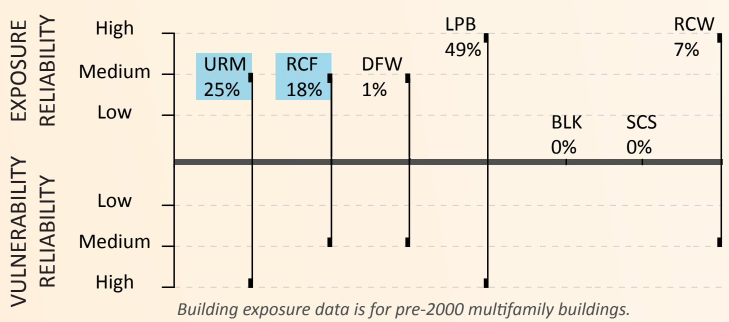
SOFIA FACTS

Capital City

Population: 1,242,000 (2017)

GNI/capita: ~€7,500

Data Reliability and Building Exposure



Building exposure data is for pre-2000 multifamily buildings.

▷ Data on building stock and population (exposure) and their susceptibility to earthquake losses (vulnerability) for the city is conveyed with vertical bars labeled by the building typology acronym.
▷ The diagram also indicates the percentage of total building stock that a typology comprises in the city denoted as a percentage below the building typology acronym. Highlighted building types are those that are considered highest risk in the city.

Earthquake Event-Based Losses

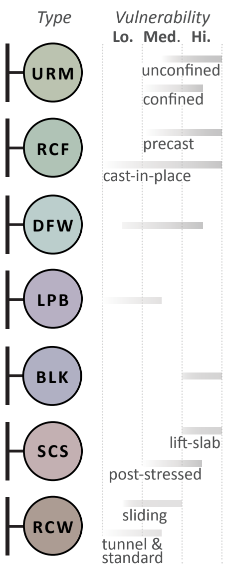
	€ Total building damage	% Building damage, % of total value	Number of fatalities
100-year Return Period	€ 900 M 14% GNIPC	6%	650 people
475-year Return Period	€ 4.4 B 66% GNIPC	27%	5,600 people

▷ A 100-year return period event is one where the damage and loss have approximately a 40% probability of being exceeded in 50 years; it is considered a more frequent event. A 475-year return period event is one where the damage and loss have approximately a 10% probability of being exceeded in 50 years; it is considered a less frequent event, more damaging event.
▷ GNIPC is gross national income per capita. Percentage of GNIPC is the losses from damage per resident as a percentage of GNIPC.
▷ The fatalities presented are those that are expected to occur at nighttime (2:00 a.m.) on a weekend.
▷ *Note: Event-based losses are subject to limitation by the reliability of the input data. The chosen return periods do not suggest that more hazardous and infrequent earthquake events are not probable in this city, as higher return period events may occur at any point.*

Building Damage Losses

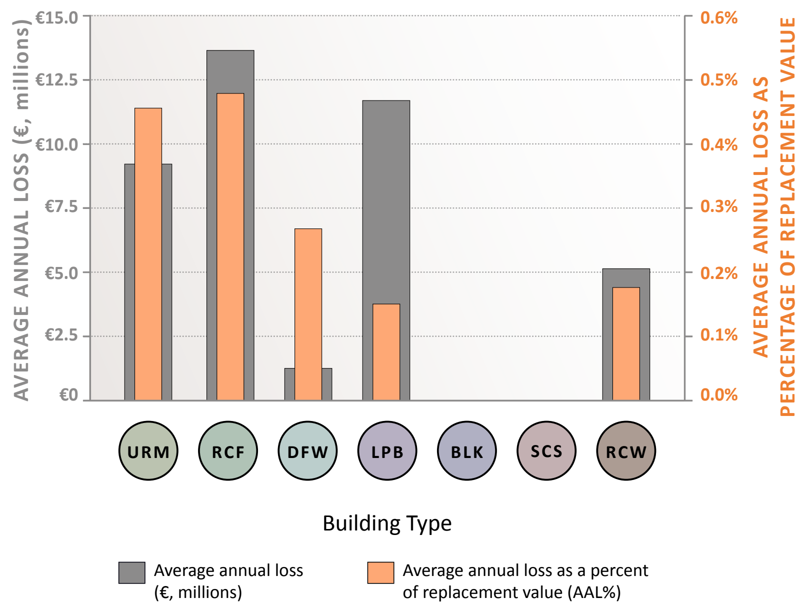
BUILDING CLASSIFICATION & VULNERABILITY RANGE

Description	Type
Unreinforced Masonry: built with masonry walls that lack steel reinforcement; includes confined and unconfined walls.	URM
Reinforced Concrete Frame: reinforced concrete frames that provide earthquake resistance; includes precast and cast-in-place frames.	RCF
Dual Frame-wall: reinforced concrete frame and wall elements work together to resist earthquake forces.	DFW
Precast Large Panel: built with precast reinforced concrete panels with floor-to-ceiling height facade panels.	LPB
Block: built with precast concrete elements assembled on site; similar to LPB with smaller facade elements.	BLK
Slab-column System: reinforced concrete floor slabs directly connected to concrete columns; includes lift slabs and post-stressed slabs.	SCS
Reinforced Concrete Wall: cast-in-place walls that provide earthquake resistance; includes standard, sliding, and tunnel formwork.	RCW



Note that the relative vulnerabilities are approximate and depend on post-construction modifications, degradation, construction quality, and year of construction. See Types of Multifamily Buildings in ECA for more information.

ABSOLUTE AND RELATIVE LOSS

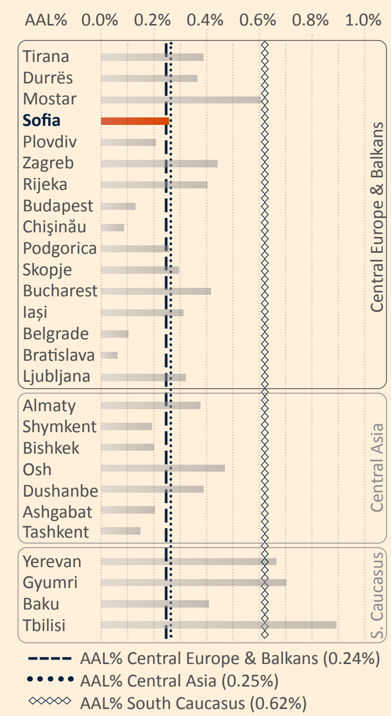


Sofia

EARTHQUAKE IMPACTS SNAPSHOT

- Average annual loss from earthquake damage to multifamily residences is **€41.1 million**.
- This amounts to **0.07%** of the country's GDP.
- Nearly **71%** of the city's population lives in multifamily residential buildings.

LOSS COMPARISON TO REGION



High-Risk Buildings in Sofia

Reinforced concrete frame and masonry are the two highest-risk building types used for pre-2000 multifamily housing in Sofia.

~260,000 people live in these buildings, or **21%** of the total population of Sofia

RCF URM

Reinforced Concrete Frame (RCF) and Unreinforced Masonry (URM) buildings contribute to:

56% of total **loss** from building damage

76% of all **permanent residential displacement** in the next 50 years from building damage due to earthquakes

55% of **fatalities** in multifamily buildings*

*This is an average number of fatalities when assessed over many years.

References: See *City Profile Sources* for information on building types, classification, and exposure data sources.

Plovdiv | BULGARIA

Summary

Plovdiv—once known as Philippoupole—is Bulgaria's third largest city and home to nearly 5 percent of the country's total population. Bulgaria has faced several large earthquakes in the past, the most damaging and deadly of which occurred in 1928 near Plovdiv. This magnitude 7.0 earthquake caused over 1,700 injuries and 120 deaths. In 1986, Bulgaria experienced a magnitude 5.7 earthquake in the Veliko Turnovo-Turgovishte region that caused €11 million (2019 €) in damage; over 150 homes were destroyed and approximately 7,000 suffered damage, leaving 80 percent of homes uninhabitable. This earthquake also left 60 people injured and killed three.

Based on the analysis, over two-thirds of the population of Plovdiv resides in pre-2000 multifamily residential buildings. The buildings that are the most at risk* are reinforced concrete frame (RCF) buildings and unreinforced masonry (URM) buildings. These two building types are also expected to cause the most fatalities. Approximately 65,000 people, or 20 percent of the city's population, reside in high-risk building types.

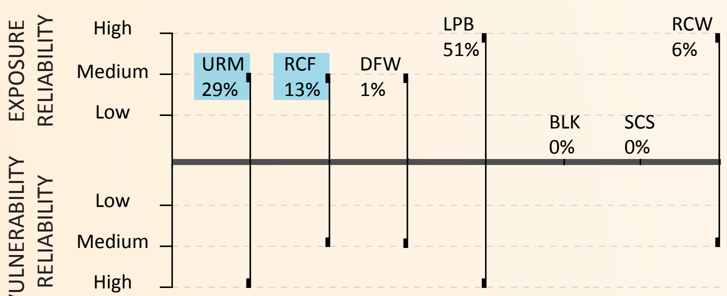
Compared to the data for all the buildings in this study, the data used to conduct the risk analysis for buildings in Plovdiv average a **medium** reliability; this rating is a function of the assumptions, uncertainties, and data available for the city (see *Methodology*). The diagram below indicates the reliability and confidence related to building stock data (i.e., exposure data) as well as data on building vulnerability. These confidence and reliability levels should be considered when interpreting and applying the risk metrics presented in the city profile.

*At risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The expected loss results are predicted from models of future events subject to variable data availability and modeling assumptions. The replacement value is the construction cost of all multifamily buildings in the city.

PLOVDIV FACTS

Third Largest City | Population: 347,000 (2018) | GNI/capita: ~€7,500

Data Reliability and Building Exposure



Building exposure data is for pre-2000 multifamily buildings.

▷ Data on building stock and population (exposure) and their susceptibility to earthquake losses (vulnerability) for the city is conveyed with vertical bars labeled by the building typology acronym.
▷ The diagram also indicates the percentage of total building stock that a typology comprises in the city denoted as a percentage below the building typology acronym. Highlighted building types are those that are considered highest risk in the city.

Earthquake Event-Based Losses

	€ Total building damage	% Building damage, % of total value	Number of fatalities
100-year Return Period	€ 140 M 8% GNIPC	4%	150 people
475-year Return Period	€ 660 M 37% GNIPC	21%	1,100 people

▷ A 100-year return period event is one where the damage and loss have approximately a 40% probability of being exceeded in 50 years; it is considered a more frequent event. A 475-year return period event is one where the damage and loss have approximately a 10% probability of being exceeded in 50 years; it is considered a less frequent event, more damaging event.
▷ GNIPC is gross national income per capita. Percentage of GNIPC is the losses from damage per resident as a percentage of GNIPC.
▷ The fatalities presented are those that are expected to occur at nighttime (2:00 a.m.) on a weekend.
▷ *Note: Event-based losses are subject to limitation by the reliability of the input data. The chosen return periods do not suggest that more hazardous and infrequent earthquake events are not probable in this city, as higher return period events may occur at any point.*

Country Snapshot

GDP
55.2 Billion Euros*

POPULATION
7.03 Million People*

SIGNIFICANT EARTHQUAKES
1928 Chripan M7.0
1986 Strazhitsa M5.7
2012 Pernik M5.6

* 2018 estimate

WORLD BANK GROUP | GFDRR

Earthquake Risk Profile

Building Damage Losses

BUILDING CLASSIFICATION & VULNERABILITY RANGE

Description

Unreinforced Masonry: built with masonry walls that lack steel reinforcement; includes confined and unconfined walls.

Reinforced Concrete Frame: reinforced concrete frames that provide earthquake resistance; includes precast and cast-in-place frames.

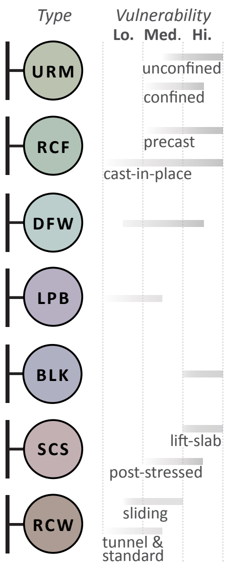
Dual Frame-wall: reinforced concrete frame and wall elements work together to resist earthquake forces.

Precast Large Panel: built with precast reinforced concrete panels with floor-to-ceiling height facade panels.

Block: built with precast concrete elements assembled on site; similar to LPB with smaller facade elements.

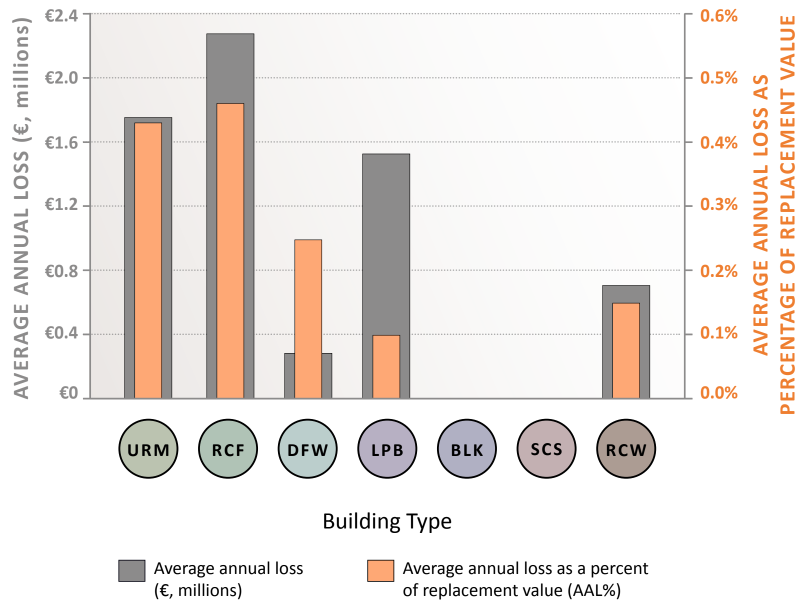
Slab-column System: reinforced concrete floor slabs directly connected to concrete columns; includes lift slabs and post-stressed slabs.

Reinforced Concrete Wall: cast-in-place walls that provide earthquake resistance; includes standard, sliding, and tunnel formwork.



Note that the relative vulnerabilities are approximate and depend on post-construction modifications, degradation, construction quality, and year of construction. See Types of Multifamily Buildings in ECA for more information.

ABSOLUTE AND RELATIVE LOSS

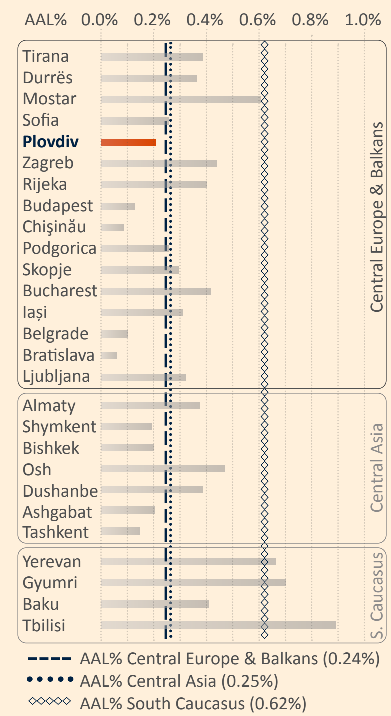


Plovdiv

EARTHQUAKE IMPACTS SNAPSHOT

- Average annual loss from earthquake damage to multifamily residences is **€6.55 million**.
- This amounts to **0.01%** of the country's GDP.
- Nearly **69%** of the city's population lives in multifamily residential buildings.

LOSS COMPARISON TO REGION



High-Risk Buildings in Plovdiv

Reinforced concrete frame and masonry are the two highest-risk building types used for pre-2000 multifamily housing in Plovdiv.

~65,000 people live in these buildings, or **20%** of the total population of Plovdiv

RCF
URM

Reinforced Concrete Frame (RCF) and Unreinforced Masonry (URM) buildings contribute to:

61% of total **loss** from building damage

80% of all **permanent residential displacement** in the next 50 years from building damage due to earthquakes

67% of **fatalities** in multifamily buildings*

*This is an average number of fatalities when assessed over many years.

References: See *City Profile Sources* for information on building types, classification, and exposure data sources.

Zagreb | CROATIA

Summary

Croatia's capital and largest city, Zagreb is home to nearly 20 percent of the country's total population. Croatia has faced several large earthquakes in the past, the most damaging of which occurred in Dubrovnik in 1667. This catastrophic magnitude 7.2 earthquake and tsunami killed 5,000 people, nearly one-third of the city's population. More recently, in March 2020, Zagreb experienced a magnitude 5.4 earthquake that resulted in €6.9 billion (2020 €) in damage to the housing sector, with approximately 24,000 residential buildings affected, 29 people injured, and one person killed.

Based on the analysis, over half of the population of Zagreb resides in pre-2000 multifamily residential buildings. The buildings that are the most at risk* are unreinforced masonry (URM) buildings and reinforced concrete frame (RCF) buildings. These two building types are also expected to cause the most fatalities. Approximately 280,000 people, over two-thirds of the city's population, reside in high-risk building types.

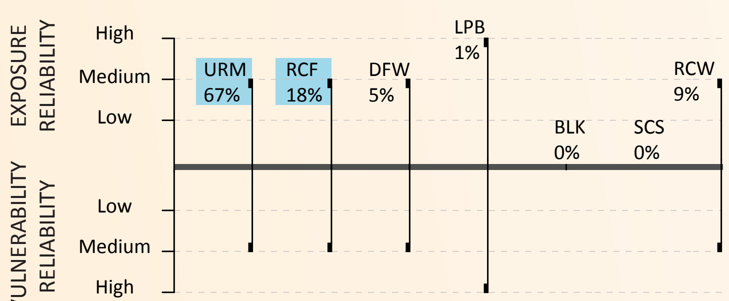
Compared to the data for all the buildings in this study, the data used to conduct the risk analysis for buildings in Zagreb average a **medium** reliability; this rating is a function of the assumptions, uncertainties, and data available for the city (see *Methodology*). The diagram below indicates the reliability and confidence related to building stock data (i.e., exposure data) as well as data and models on building vulnerability. These confidence and reliability levels should be considered when interpreting and applying the risk metrics presented in the city profile.

*At risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The expected loss results are predicted from models of future events subject to variable data availability and modeling assumptions. The replacement value is the construction cost of all multifamily buildings in the city.

ZAGREB FACTS

Capital City | Population: 804,000 (2017) | GNI/capita: ~€12,000

Data Reliability and Building Exposure



Building exposure data is for pre-2000 multifamily buildings.

▷ Data on building stock and population (exposure) and their susceptibility to earthquake losses (vulnerability) for the city is conveyed with vertical bars labeled by the building typology acronym.
▷ The diagram also indicates the percentage of total building stock that a typology comprises in the city denoted as a percentage below the building typology acronym. Highlighted building types are those that are considered highest risk in the city.

Earthquake Event-Based Losses

	€ Total building damage	% Building damage, % of total value	Number of fatalities
100-year Return Period	€ 1.3 B 26% GNIPC	12%	1,900 people
475-year Return Period	€ 5.2 M 104% GNIPC	47%	9,500 people

▷ A 100-year return period event is one where the damage and loss have approximately a 40% probability of being exceeded in 50 years; it is considered a more frequent event. A 475-year return period event is one where the damage and loss have approximately a 10% probability of being exceeded in 50 years; it is considered a less frequent event, more damaging event.
▷ GNIPC is gross national income per capita. Percentage of GNIPC is the losses from damage per resident as a percentage of GNIPC.
▷ The fatalities presented are those that are expected to occur at nighttime (2:00 a.m.) on a weekend.
▷ *Note: Event-based losses are subject to limitation by the reliability of the input data. The chosen return periods do not suggest that more hazardous and infrequent earthquake events are not probable in this city, as higher return period events may occur at any point.*

Country Snapshot

GDP
51.6 Billion Euros*

POPULATION
4.09 Million People*

SIGNIFICANT EARTHQUAKES
1667 Dubrovnik M7.2
1962 Makarska M6.1
2020 Zagreb M5.4

* 2018 estimate

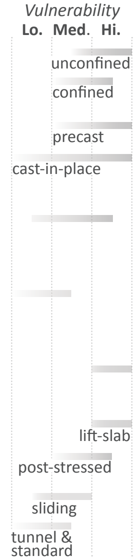
WORLD BANK GROUP | GFDRR

Earthquake Risk Profile

Building Damage Losses

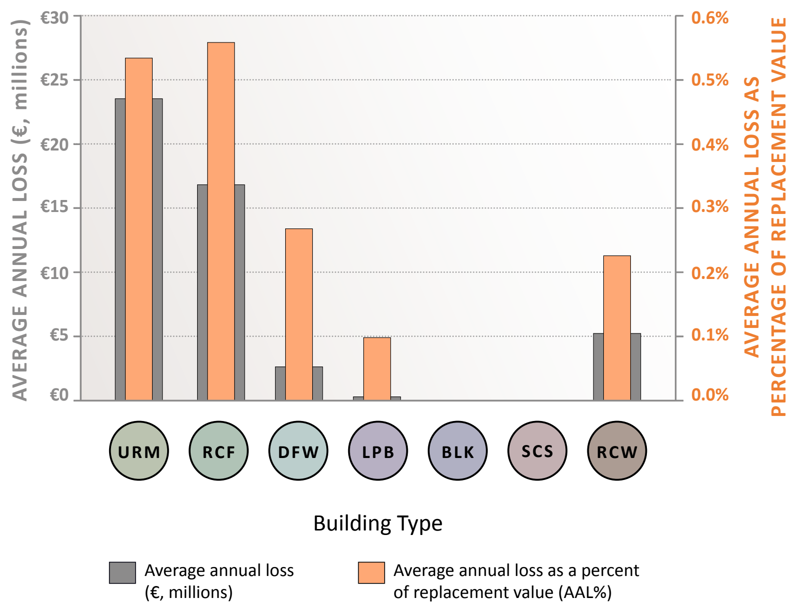
BUILDING CLASSIFICATION & VULNERABILITY RANGE

Description	Type
Unreinforced Masonry: built with masonry walls that lack steel reinforcement; includes confined and unconfined walls.	URM
Reinforced Concrete Frame: reinforced concrete frames that provide earthquake resistance; includes precast and cast-in-place frames.	RCF
Dual Frame-wall: reinforced concrete frame and wall elements work together to resist earthquake forces.	DFW
Precast Large Panel: built with precast reinforced concrete panels with floor-to-ceiling height facade panels.	LPB
Block: built with precast concrete elements assembled on site; similar to LPB with smaller facade elements.	BLK
Slab-column System: reinforced concrete floor slabs directly connected to concrete columns; includes lift slabs and post-stressed slabs.	SCS
Reinforced Concrete Wall: cast-in-place walls that provide earthquake resistance; includes standard, sliding, and tunnel formwork.	RCW



Note that the relative vulnerabilities are approximate and depend on post-construction modifications, degradation, construction quality, and year of construction. See Types of Multifamily Buildings in ECA for more information.

ABSOLUTE AND RELATIVE LOSS



Zagreb

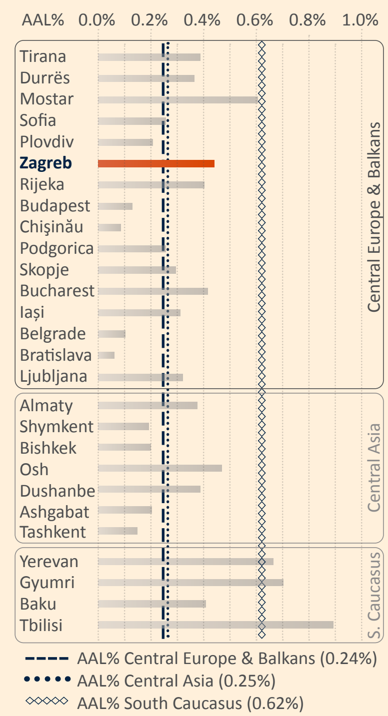
EARTHQUAKE IMPACTS SNAPSHOT

▷ Average annual loss from earthquake damage to multifamily residences is **€48.8 million**.

▷ This amounts to **0.09%** of the country's GDP.

▷ Nearly **52%** of the city's population lives in multifamily residential buildings.

LOSS COMPARISON TO REGION



High-Risk Buildings in Zagreb

Masonry and reinforced concrete frame are the two highest-risk building types used for pre-2000 multifamily housing in Zagreb.

~280,000 people live in these buildings, or **35%** of the total population of Zagreb

URM
RCF

Unreinforced Masonry (URM) and Reinforced Concrete Frame (RCF) buildings contribute to:

83% of total **loss** from building damage

77% of all **permanent residential displacement** in the next 50 years from building damage due to earthquakes

87% of **fatalities** in multifamily buildings*

*This is an average number of fatalities when assessed over many years.

References: See *City Profile Sources* for information on building types, classification, and exposure data sources.

Rijeka | CROATIA

Summary

A major port city and Croatia's third largest city, Rijeka is home to nearly 3 percent of Croatia's total population. Croatia has faced several large earthquakes in the past, the most damaging of which occurred in Dubrovnik in 1667. This catastrophic magnitude 7.2 earthquake and tsunami killed 5,000 people, nearly one-third of the city's population. More recently, in March 2020, Zagreb experienced a magnitude 5.4 earthquake that resulted in €6.9 billion (2020 €) in damage to the housing sector, with approximately 24,000 residential buildings affected, 29 people injured, and one person killed.

Based on the analysis, over half of the population of Rijeka resides in pre-2000 multifamily residential buildings. The buildings that are the most at risk* are unreinforced masonry (URM) buildings and reinforced concrete frame (RCF) buildings. These two building types are also expected to cause the most fatalities. Approximately 38,000 people, or about one-third of the city's population, reside in high-risk building types.

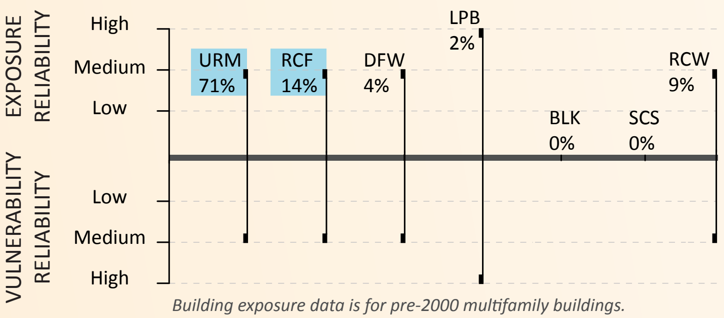
Compared to the data for all the buildings in this study, the data used to conduct the risk analysis for buildings in Rijeka average a **medium** reliability; this rating is a function of the assumptions, uncertainties, and data available for the city (see *Methodology*). The diagram below indicates the reliability and confidence related to building stock data (i.e., exposure data) as well as data on building vulnerability. These confidence and reliability levels should be considered when interpreting and applying the risk metrics presented in the city profile.

*At risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The expected loss results are predicted from models of future events subject to variable data availability and modeling assumptions. The replacement value is the construction cost of all multifamily buildings in the city.

RIJEKA FACTS

Third Largest City | Population: 119,000 (2017) | GNI/capita: ~€12,000

Data Reliability and Building Exposure



Building exposure data is for pre-2000 multifamily buildings.

▷ Data on building stock and population (exposure) and their susceptibility to earthquake losses (vulnerability) for the city is conveyed with vertical bars labeled by the building typology acronym.
▷ The diagram also indicates the percentage of total building stock that a typology comprises in the city denoted as a percentage below the building typology acronym. Highlighted building types are those that are considered highest risk in the city.

Earthquake Event-Based Losses

	€ Total building damage	% Building damage, % of total value	Number of fatalities
100-year Return Period	€ 108 M 14% GNIPC	9%	240 people
475-year Return Period	€ 450 M 60% GNIPC	40%	1,200 people

▷ A 100-year return period event is one where the damage and loss have approximately a 40% probability of being exceeded in 50 years; it is considered a more frequent event. A 475-year return period event is one where the damage and loss have approximately a 10% probability of being exceeded in 50 years; it is considered a less frequent event, more damaging event.
▷ GNIPC is gross national income per capita. Percentage of GNIPC is the losses from damage per resident as a percentage of GNIPC.
▷ The fatalities presented are those that are expected to occur at nighttime (2:00 a.m.) on a weekend.
▷ *Note: Event-based losses are subject to limitation by the reliability of the input data. The chosen return periods do not suggest that more hazardous and infrequent earthquake events are not probable in this city, as higher return period events may occur at any point.*

Country Snapshot

GDP
51.6 Billion Euros*

POPULATION
4.09 Million People*

SIGNIFICANT EARTHQUAKES
1667 Dubrovnik M7.2
1962 Makarska M6.1
2020 Zagreb M5.4

* 2018 estimate

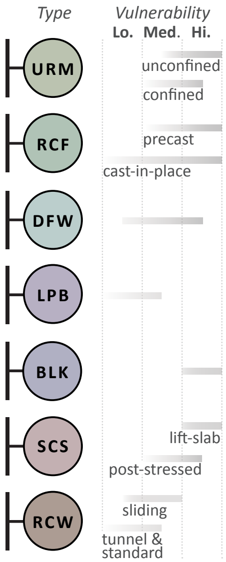
WORLD BANK GROUP GFDRR

Earthquake Risk Profile

Building Damage Losses

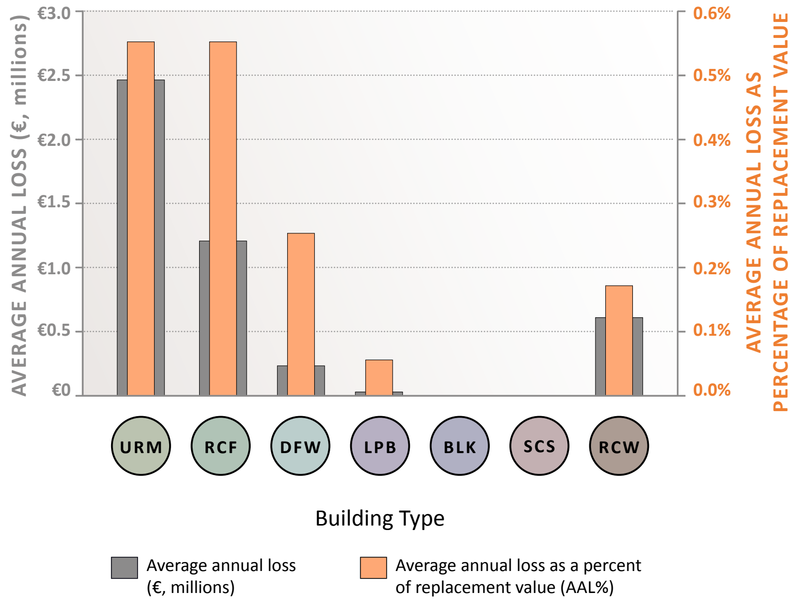
BUILDING CLASSIFICATION & VULNERABILITY RANGE

Description	Type
Unreinforced Masonry: built with masonry walls that lack steel reinforcement; includes confined and unconfined walls.	URM
Reinforced Concrete Frame: reinforced concrete frames that provide earthquake resistance; includes precast and cast-in-place frames.	RCF
Dual Frame-wall: reinforced concrete frame and wall elements work together to resist earthquake forces.	DFW
Precast Large Panel: built with precast reinforced concrete panels with floor-to-ceiling height facade panels.	LPB
Block: built with precast concrete elements assembled on site; similar to LPB with smaller facade elements.	BLK
Slab-column System: reinforced concrete floor slabs directly connected to concrete columns; includes lift slabs and post-stressed slabs.	SCS
Reinforced Concrete Wall: cast-in-place walls that provide earthquake resistance; includes standard, sliding, and tunnel formwork.	RCW



Note that the relative vulnerabilities are approximate and depend on post-construction modifications, degradation, construction quality, and year of construction. See Types of Multifamily Buildings in ECA for more information.

ABSOLUTE AND RELATIVE LOSS



Rijeka

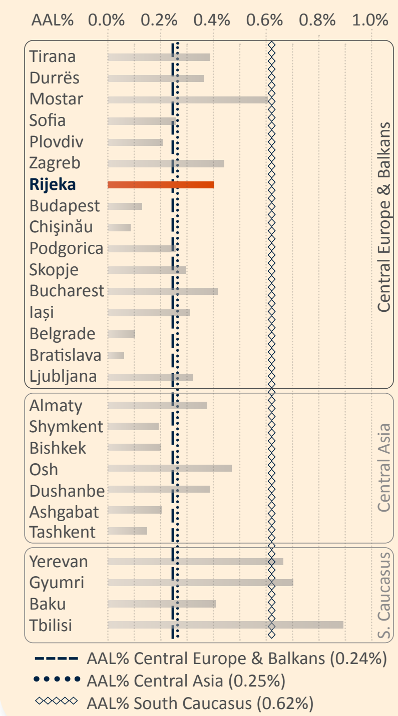
EARTHQUAKE IMPACTS SNAPSHOT

▷ Average annual loss from earthquake damage to multifamily residences is **€4.75 million**.

▷ This amounts to **0.01%** of the country's GDP.

▷ Nearly **54%** of the city's population lives in multifamily residential buildings.

LOSS COMPARISON TO REGION



High-Risk Buildings in Rijeka

Masonry and reinforced concrete frame are the two highest-risk building types used for pre-2000 multifamily housing in Rijeka.

~38,000 people live in these buildings, or **32%** of the total population of Rijeka

URM RCF

Unreinforced Masonry (URM) and Reinforced Concrete Frame (RCF) buildings contribute to:

81% of total **loss** from building damage

82% of all **permanent residential displacement** in the next 50 years from building damage due to earthquakes

80% of **fatalities** in multifamily buildings*

*This is an average number of fatalities when assessed over many years.

References: See *City Profile Sources* for information on building types, classification, and exposure data sources.

Budapest | HUNGARY

Summary

Budapest is the capital and largest city in Hungary, home to nearly 20 percent of the total population. Hungary has experienced several earthquakes in the past, including a historic magnitude 6.2 event in 1763 that killed 83 people. In 1956, the magnitude 5.8 Dunaharaszti earthquake caused damage to over 3,000 buildings and led to two deaths.

Based on the analysis, about 70 percent of the population of Budapest resides in pre-2000 multifamily residential buildings. The buildings that are the most at risk* are unreinforced masonry (URM) buildings and reinforced concrete frame (RCF) buildings. These two building types are also expected to cause the most fatalities. Nearly 440,000 people, or about one in every four inhabitants, reside in high-risk building types.

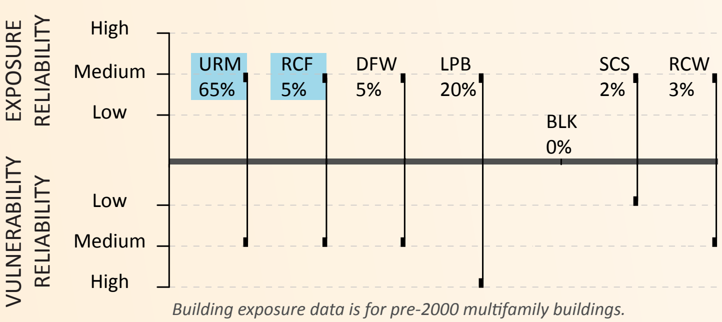
Compared to the data for all the buildings in this study, the data used to conduct the risk analysis for buildings in Budapest average a **low** reliability; this rating is a function of the assumptions, uncertainties, and data available for the city (see *Methodology*). The diagram below indicates the reliability and confidence related to building stock data (i.e., exposure data) as well as data on building vulnerability. These confidence and reliability levels should be considered when interpreting and applying the risk metrics presented in the city profile.

*At risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The expected loss results are predicted from models of future events subject to variable data availability and modeling assumptions. The replacement value is the construction cost of all multifamily buildings in the city.

BUDAPEST FACTS

Capital City | Population: 1,752,000 (2017) | GNI/capita: ~€12,500

Data Reliability and Building Exposure



Building exposure data is for pre-2000 multifamily buildings.

▷ Data on building stock and population (exposure) and their susceptibility to earthquake losses (vulnerability) for the city is conveyed with vertical bars labeled by the building typology acronym.
▷ The diagram also indicates the percentage of total building stock that a typology comprises in the city denoted as a percentage below the building typology acronym. Highlighted building types are those that are considered highest risk in the city.

Earthquake Event-Based Losses

	€ Total building damage	% Building damage, % of total value	Number of fatalities
100-year Return Period	€ 1.1 B 7% GNIPC	3%	280 people
475-year Return Period	€ 5.0 B 34% GNIPC	13%	4,000 people

▷ A 100-year return period event is one where the damage and loss have approximately a 40% probability of being exceeded in 50 years; it is considered a more frequent event. A 475-year return period event is one where the damage and loss have approximately a 10% probability of being exceeded in 50 years; it is considered a less frequent event, more damaging event.
▷ GNIPC is gross national income per capita. Percentage of GNIPC is the losses from damage per resident as a percentage of GNIPC.
▷ The fatalities presented are those that are expected to occur at nighttime (2:00 a.m.) on a weekend.
▷ *Note: Event-based losses are subject to limitation by the reliability of the input data. The chosen return periods do not suggest that more hazardous and infrequent earthquake events are not probable in this city, as higher return period events may occur at any point.*

Earthquake Risk Profile

Country Snapshot

GDP
133.7 Billion Euros*

POPULATION
9.78 Million People*

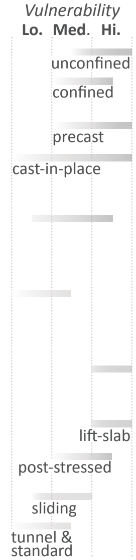
SIGNIFICANT EARTHQUAKES
1763 Komárom M6.2
1956 Dunaharaszti M5.8
2006 Beregdaróc M4.8

* 2018 estimate

Building Damage Losses

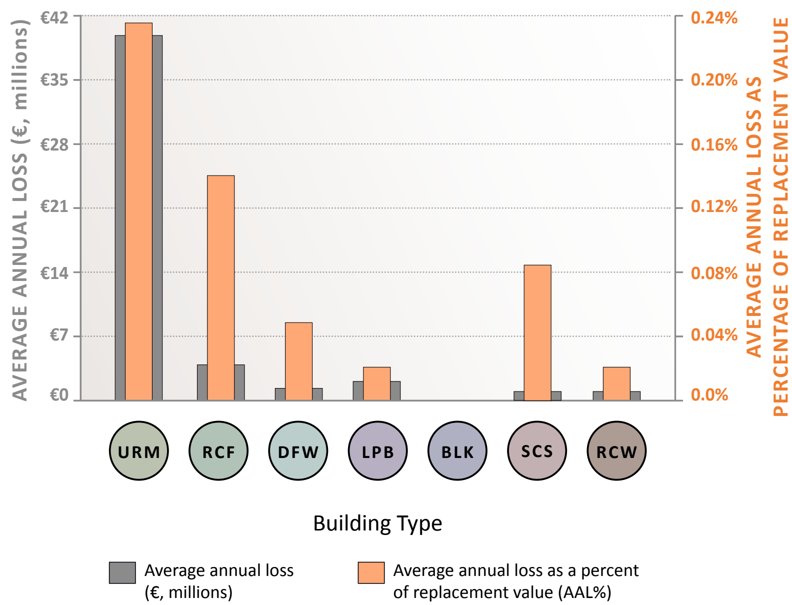
BUILDING CLASSIFICATION & VULNERABILITY RANGE

Description	Type
Unreinforced Masonry: built with masonry walls that lack steel reinforcement; includes confined and unconfined walls.	URM
Reinforced Concrete Frame: reinforced concrete frames that provide earthquake resistance; includes precast and cast-in-place frames.	RCF
Dual Frame-wall: reinforced concrete frame and wall elements work together to resist earthquake forces.	DFW
Precast Large Panel: built with precast reinforced concrete panels with floor-to-ceiling height facade panels.	LPB
Block: built with precast concrete elements assembled on site; similar to LPB with smaller facade elements.	BLK
Slab-column System: reinforced concrete floor slabs directly connected to concrete columns; includes lift slabs and post-stressed slabs.	SCS
Reinforced Concrete Wall: cast-in-place walls that provide earthquake resistance; includes standard, sliding, and tunnel formwork.	RCW



Note that the relative vulnerabilities are approximate and depend on post-construction modifications, degradation, construction quality, and year of construction. See Types of Multifamily Buildings in ECA for more information.

ABSOLUTE AND RELATIVE LOSS

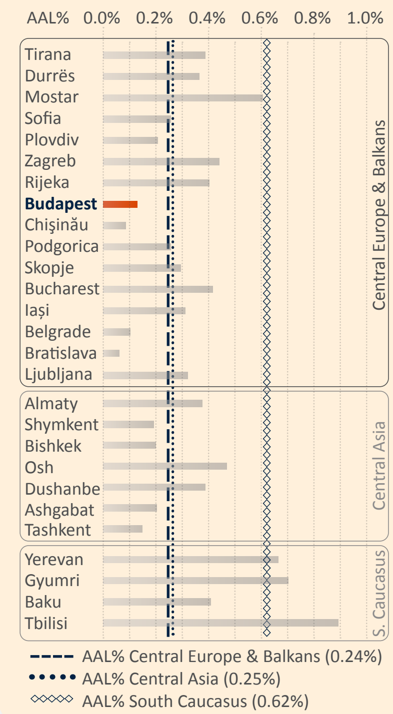


Budapest

EARTHQUAKE IMPACTS SNAPSHOT

- Average annual loss from earthquake damage to multifamily residences is **€48.8 million**.
- This amounts to **0.04%** of the country's GDP.
- Nearly **68%** of the city's population lives in multifamily residential buildings.

LOSS COMPARISON TO REGION



High-Risk Buildings in Budapest

Masonry and reinforced concrete frame are the two highest-risk building types used for pre-2000 multifamily housing in Budapest.

~440,000 people live in these buildings, or **25%** of the total population of Budapest

URM
RCF

Unreinforced Masonry (URM) and Reinforced Concrete Frame (RCF) buildings contribute to:

90% of total **loss** from building damage

80% of all **permanent residential displacement** in the next 50 years from building damage due to earthquakes

79% of **fatalities** in multifamily buildings*

*This is an average number of fatalities when assessed over many years.

References: See *City Profile Sources* for information on building types, classification, and exposure data sources.

Chişinău | MOLDOVA

Summary

Chişinău is Moldova's capital and largest city, home to nearly a quarter of the country's total population. Moldova has been affected by devastating earthquakes in the past, the most deadly of which was the 1940 magnitude 7.8 Vrancea earthquake that killed 78 people. In 1986, another earthquake centered in Vrancea of magnitude 7.2 caused over 550 injuries and two deaths, damaged 55,000 homes, and left 12,500 people homeless.

Based on the analysis, over 80 percent of the population of Chişinău resides in pre-2000 multifamily residential buildings. The buildings that are the most at risk* are unreinforced masonry (URM) buildings and precast large panel buildings (LPBs). Including reinforced concrete wall (RCW), these building types are also expected to cause the most fatalities. Over 324,000 people, or about one in every two inhabitants, reside in high-risk building types.

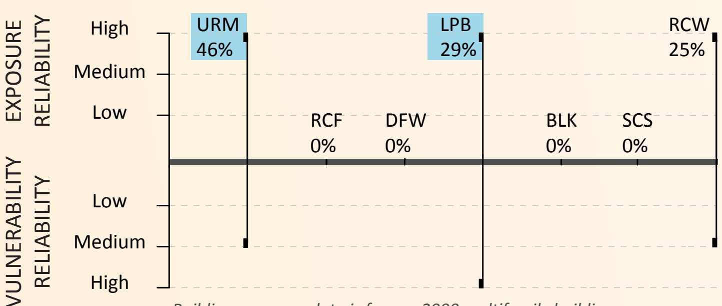
Compared to the data for all the buildings in this study, the data used to conduct the risk analysis for buildings in Chişinău average a **high** reliability; this rating is a function of the assumptions, uncertainties, and data available for the city (see *Methodology*). The diagram below indicates the reliability and confidence related to building stock data (i.e., exposure data) as well as data on building vulnerability. These confidence and reliability levels should be considered when interpreting and applying the risk metrics presented in the city profile.

*At risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The expected loss results are predicted from models of future events subject to variable data availability and modeling assumptions. The replacement value is the construction cost of all multifamily buildings in the city.

CHIŞINĂU FACTS

Capital City | Population: 686,000 (2017) | GNI/capita: ~€2,500

Data Reliability and Building Exposure



Building exposure data is for pre-2000 multifamily buildings.

▷ Data on building stock and population (exposure) and their susceptibility to earthquake losses (vulnerability) for the city is conveyed with vertical bars labeled by the building typology acronym.
▷ The diagram also indicates the percentage of total building stock that a typology comprises in the city denoted as a percentage below the building typology acronym. Highlighted building types are those that are considered highest risk in the city.

Earthquake Event-Based Losses

	€ Total building damage	% Building damage, % of total value	Number of fatalities
100-year Return Period	€ 76 M 5% GNIPC	1%	100 people
475-year Return Period	€ 700 M 50% GNIPC	9%	940 people

▷ A 100-year return period event is one where the damage and loss have approximately a 40% probability of being exceeded in 50 years; it is considered a more frequent event. A 475-year return period event is one where the damage and loss have approximately a 10% probability of being exceeded in 50 years; it is considered a less frequent event, more damaging event.
▷ GNIPC is gross national income per capita. Percentage of GNIPC is the losses from damage per resident as a percentage of GNIPC.
▷ The fatalities presented are those that are expected to occur at nighttime (2:00 a.m.) on a weekend.
▷ *Note: Event-based losses are subject to limitation by the reliability of the input data. The chosen return periods do not suggest that more hazardous and infrequent earthquake events are not probable in this city, as higher return period events may occur at any point.*

Country Snapshot

GDP
9.70 Billion Euros*

POPULATION
2.71 Million People*

SIGNIFICANT EARTHQUAKES
1940 Vrancea M7.8
1986 Vrancea M7.2
1990 Vrancea M7.0

* 2018 estimate

WORLD BANK GROUP GFDRR

Earthquake Risk Profile

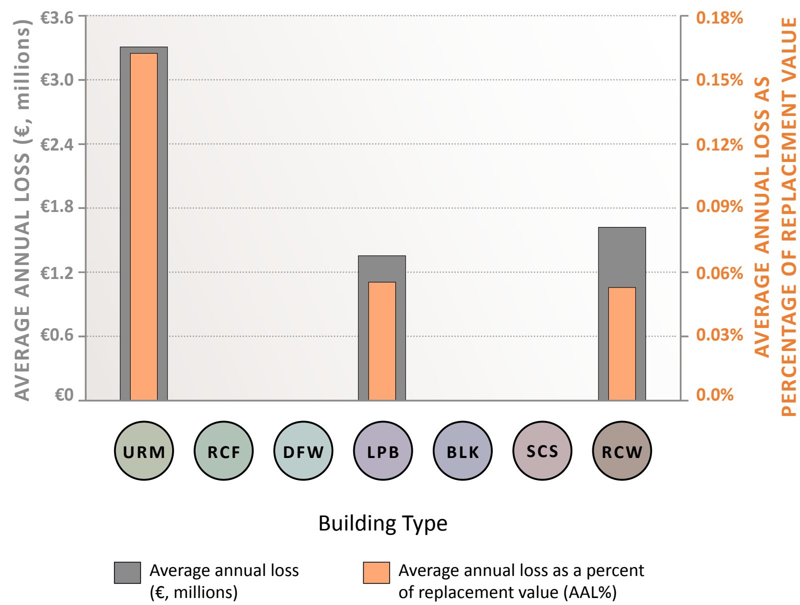
Building Damage Losses

BUILDING CLASSIFICATION & VULNERABILITY RANGE

Description	Type	Vulnerability (Lo. Med. Hi.)
Unreinforced Masonry: built with masonry walls that lack steel reinforcement; includes confined and unconfined walls.	URM	unconfined; confined
Reinforced Concrete Frame: reinforced concrete frames that provide earthquake resistance; includes precast and cast-in-place frames.	RCF	precast; cast-in-place
Dual Frame-wall: reinforced concrete frame and wall elements work together to resist earthquake forces.	DFW	
Precast Large Panel: built with precast reinforced concrete panels with floor-to-ceiling height facade panels.	LPB	
Block: built with precast concrete elements assembled on site; similar to LPB with smaller facade elements.	BLK	
Slab-column System: reinforced concrete floor slabs directly connected to concrete columns; includes lift slabs and post-stressed slabs.	SCS	lift-slab; post-stressed
Reinforced Concrete Wall: cast-in-place walls that provide earthquake resistance; includes standard, sliding, and tunnel formwork.	RCW	sliding; tunnel & standard

Note that the relative vulnerabilities are approximate and depend on post-construction modifications, degradation, construction quality, and year of construction. See Types of Multifamily Buildings in ECA for more information.

ABSOLUTE AND RELATIVE LOSS



Chişinău

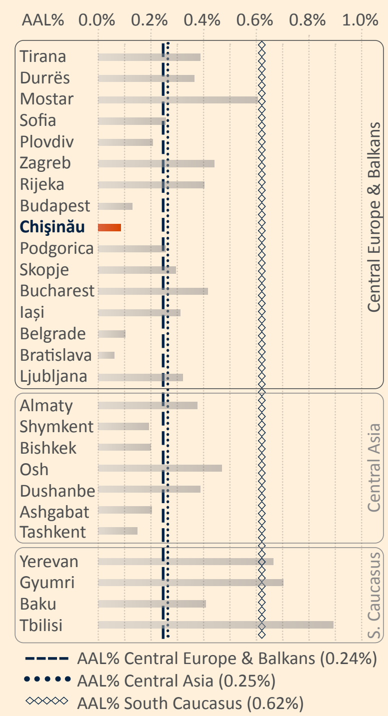
EARTHQUAKE IMPACTS SNAPSHOT

▷ Average annual loss from earthquake damage to multifamily residences is **€6.26 million**.

▷ This amounts to **0.06%** of the country's GDP.

▷ Nearly **81%** of the city's population lives in multifamily residential buildings.

LOSS COMPARISON TO REGION



High-Risk Buildings in Chişinău

Masonry and precast large panel are the two highest-risk building types used for pre-2000 multifamily housing in Chişinău.

~324,000 people live in these buildings, or **47%** of the total population of Chişinău

URM LPB

Unreinforced Masonry (URM) and Precast Large Panel (LPB) buildings contribute to:

74% of total **loss** from building damage

87% of all **permanent residential displacement** in the next 50 years from building damage due to earthquakes

74% of **fatalities** in multifamily buildings*

*This is an average number of fatalities when assessed over many years.

References: See *City Profile Sources* for information on building types, classification, and exposure data sources.

Podgorica | MONTENEGRO

Summary

Podgorica is Montenegro's capital and largest city, home to nearly a quarter of the country's total population. Montenegro has faced several large earthquakes in the past, the most damaging and deadly of which occurred in 1979 near the Montenegrin coastline. The magnitude 6.9 earthquake and tsunami caused nearly €9 billion (2019 €) in damage, injured 1,000 individuals, and killed 121.

Based on the analysis, one-third of the population of Podgorica resides in pre-2000 multifamily residential buildings. The buildings that are the most at risk* are reinforced concrete frame (RCF) buildings and unreinforced masonry (URM) buildings. These two building types are also expected to cause the most fatalities. Approximately 14,000 people, or 9 percent of the city's population, reside in high-risk building types.

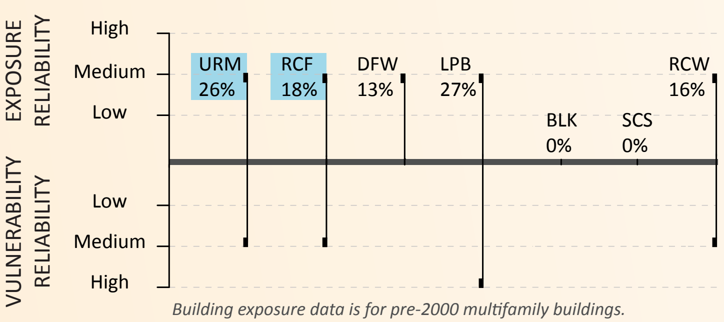
Compared to the data for all the buildings in this study, the data used to conduct the risk analysis for buildings in Podgorica average a **low** reliability; this rating is a function of the assumptions, uncertainties, and data available for the city (see *Methodology*). The diagram below indicates the reliability and confidence related to building stock data (i.e., exposure data) as well as data on building vulnerability. These confidence and reliability levels should be considered when interpreting and applying the risk metrics presented in the city profile.

*At risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The expected loss results are predicted from models of future events subject to variable data availability and modeling assumptions. The replacement value is the construction cost of all multifamily buildings in the city.

PODGORICA FACTS

Capital City | Population: 151,000 (2011) | GNI/capita: ~€7,000

Data Reliability and Building Exposure



Building exposure data is for pre-2000 multifamily buildings.

▷ Data on building stock and population (exposure) and their susceptibility to earthquake losses (vulnerability) for the city is conveyed with vertical bars labeled by the building typology acronym.
▷ The diagram also indicates the percentage of total building stock that a typology comprises in the city denoted as a percentage below the building typology acronym. Highlighted building types are those that are considered highest risk in the city.

Earthquake Event-Based Losses

	€ Total building damage	% Building damage, % of total value	Number of fatalities
100-year Return Period	€ 61 M 17% GNIPC	6%	40 people
475-year Return Period	€ 276 M 78% GNIPC	25%	260 people

▷ A 100-year return period event is one where the damage and loss have approximately a 40% probability of being exceeded in 50 years; it is considered a more frequent event. A 475-year return period event is one where the damage and loss have approximately a 10% probability of being exceeded in 50 years; it is considered a less frequent event, more damaging event.
▷ GNIPC is gross national income per capita. Percentage of GNIPC is the losses from damage per resident as a percentage of GNIPC.
▷ The fatalities presented are those that are expected to occur at nighttime (2:00 a.m.) on a weekend.
▷ *Note: Event-based losses are subject to limitation by the reliability of the input data. The chosen return periods do not suggest that more hazardous and infrequent earthquake events are not probable in this city, as higher return period events may occur at any point.*

Country Snapshot

GDP
4.66 Billion Euros*

POPULATION
0.622 Million People*

SIGNIFICANT EARTHQUAKES
1968 Montenegro M5.3
1979 Montenegro M6.9
2018 Plav M4.9

* 2018 estimate

WORLD BANK GROUP | GFDRR

Earthquake Risk Profile

Building Damage Losses

BUILDING CLASSIFICATION & VULNERABILITY RANGE

Description | *Type* | *Vulnerability* Lo. Med. Hi.

Unreinforced Masonry: built with masonry walls that lack steel reinforcement; includes confined and unconfined walls.

Reinforced Concrete Frame: reinforced concrete frames that provide earthquake resistance; includes precast and cast-in-place frames.

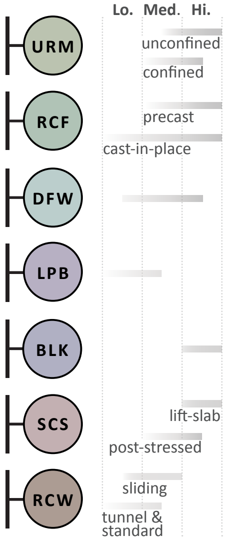
Dual Frame-wall: reinforced concrete frame and wall elements work together to resist earthquake forces.

Precast Large Panel: built with precast reinforced concrete panels with floor-to-ceiling height facade panels.

Block: built with precast concrete elements assembled on site; similar to LPB with smaller facade elements.

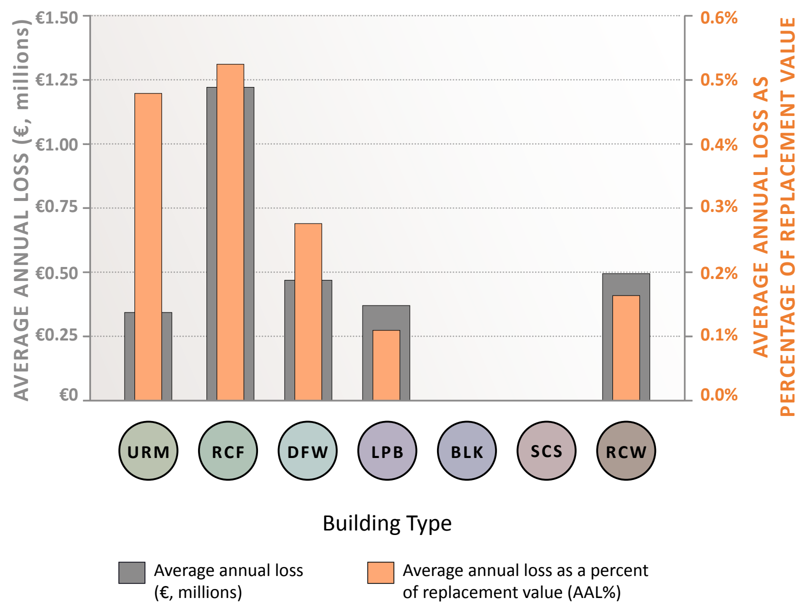
Slab-column System: reinforced concrete floor slabs directly connected to concrete columns; includes lift slabs and post-stressed slabs.

Reinforced Concrete Wall: cast-in-place walls that provide earthquake resistance; includes standard, sliding, and tunnel formwork.



Note that the relative vulnerabilities are approximate and depend on post-construction modifications, degradation, construction quality, and year of construction. See Types of Multifamily Buildings in ECA for more information.

ABSOLUTE AND RELATIVE LOSS



Podgorica

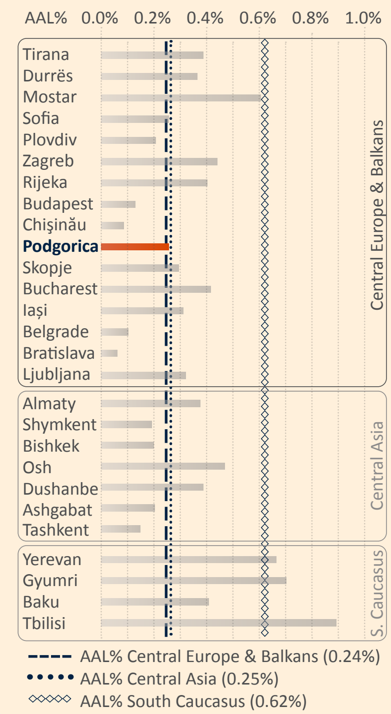
EARTHQUAKE IMPACTS SNAPSHOT

▷ Average annual loss from earthquake damage to multifamily residences is **€2.90 million**.

▷ This amounts to **0.06%** of the country's GDP.

▷ Nearly **33%** of the city's population lives in multifamily residential buildings.

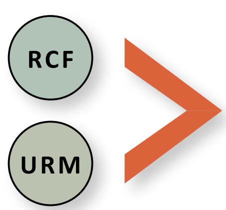
LOSS COMPARISON TO REGION



High-Risk Buildings in Podgorica

Reinforced concrete frame and masonry are the two highest-risk building types used for pre-2000 multifamily housing in Podgorica.

~14,000 people live in these buildings, or **9%** of the total population of Podgorica



Reinforced Concrete Frame (RCF) and Unreinforced Masonry (URM) buildings contribute to:

54% of total **loss** from building damage

79% of all **permanent residential displacement** in the next 50 years from building damage due to earthquakes

76% of **fatalities** in multifamily buildings*

*This is an average number of fatalities when assessed over many years.

References: See *City Profile Sources* for information on building types, classification, and exposure data sources.

Skopje | NORTH MACEDONIA

Summary

Skopje is North Macedonia's capital and largest city, home to more than a quarter of the country's total population. North Macedonia has faced several large earthquakes in the past, the most damaging and deadly of which was in 1963 in Skopje. The magnitude 6.0 Skopje earthquake caused €7.7 billion (2019 €) in damage, injured 3,300 individuals, and killed over 1,000. The earthquake damaged 80 percent of Skopje's building stock, including historic monuments, and left three of every four residents homeless. The extensive damage can be attributed to the prevalence of non-engineered multistory brick buildings, many of which collapsed. Following this destructive earthquake, unconfined masonry buildings were no longer constructed in the country, and redevelopment of Skopje limited the density of inhabitants in central areas to reduce the population's vulnerability to future earthquakes. Historic earthquakes that destroyed the city of Skopje occurred in 518 and 1555; other damaging and fatal earthquakes occurred more recently in 1982 and 1983.

Based on the analysis, about 30 percent of the population of Skopje resides in pre-2000 multifamily residential buildings. The buildings that are the most at risk* are slab-column system (SCS) buildings and reinforced concrete frame (RCF) buildings. These two building types are also expected to cause the most fatalities. Approximately 38,000 people, or 7 percent of the city's population, reside in high-risk building types.

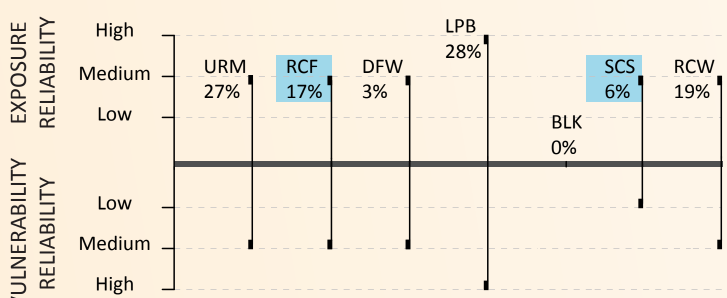
Compared to the data for all the buildings in this study, the data used to conduct the risk analysis for buildings in Skopje average a **medium** reliability; this rating is a function of the assumptions, uncertainties, and data available for the city (see *Methodology*). The diagram below indicates the reliability and confidence related to building stock data (i.e., exposure data) as well as data on building vulnerability. These confidence and reliability levels should be considered when interpreting and applying the risk metrics presented in the city profile.

*At risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The expected loss results are predicted from models of future events subject to variable data availability and modeling assumptions. The replacement value is the construction cost of all multifamily buildings in the city.

SKOPJE FACTS

Capital City | Population: 546,000 (2018) | GNI/capita: ~€4,600

Data Reliability and Building Exposure



Building exposure data is for pre-2000 multifamily buildings.

▷ Data on building stock and population (exposure) and their susceptibility to earthquake losses (vulnerability) for the city is conveyed with vertical bars labeled by the building typology acronym.

▷ The diagram also indicates the percentage of total building stock that a typology comprises in the city denoted as a percentage below the building typology acronym. Highlighted building types are those that are considered highest risk in the city.

Earthquake Event-Based Losses

	€ Total building damage	% Building damage, % of total value	Number of fatalities
100-year Return Period	€ 130 M 18% GNIPC	7%	110 people
475-year Return Period	€ 630 M 86% GNIPC	32%	1,100 people

▷ A 100-year return period event is one where the damage and loss have approximately a 40% probability of being exceeded in 50 years; it is considered a more frequent event. A 475-year return period event is one where the damage and loss have approximately a 10% probability of being exceeded in 50 years; it is considered a less frequent event, more damaging event.

▷ GNIPC is gross national income per capita. Percentage of GNIPC is the losses from damage per resident as a percentage of GNIPC.

▷ The fatalities presented are those that are expected to occur at nighttime (2:00 a.m.) on a weekend.

▷ *Note: Event-based losses are subject to limitation by the reliability of the input data. The chosen return periods do not suggest that more hazardous and infrequent earthquake events are not probable in this city, as higher return period events may occur at any point.*

Country Snapshot

GDP
10.7 Billion Euros*

POPULATION
2.08 Million People*

SIGNIFICANT EARTHQUAKES
1963 Skopje M6.0
1983 Skopje M4.7
2016 Skopje M5.1

* 2018 estimate

WORLD BANK GROUP | GFDRR

Earthquake Risk Profile

Building Damage Losses

BUILDING CLASSIFICATION & VULNERABILITY RANGE

Description | Type | *Vulnerability* Lo. Med. Hi.

Unreinforced Masonry: built with masonry walls that lack steel reinforcement; includes confined and unconfined walls. (URM)

Reinforced Concrete Frame: reinforced concrete frames that provide earthquake resistance; includes precast and cast-in-place frames. (RCF)

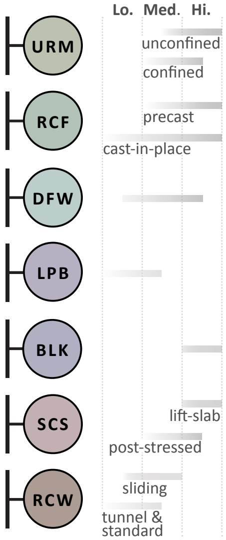
Dual Frame-wall: reinforced concrete frame and wall elements work together to resist earthquake forces. (DFW)

Precast Large Panel: built with precast reinforced concrete panels with floor-to-ceiling height facade panels. (LPB)

Block: built with precast concrete elements assembled on site; similar to LPB with smaller facade elements. (BLK)

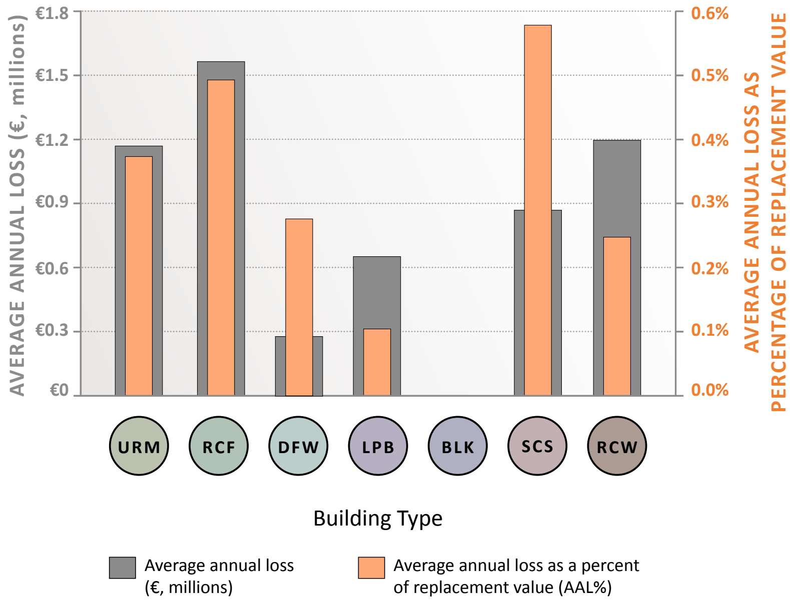
Slab-column System: reinforced concrete floor slabs directly connected to concrete columns; includes lift slabs and post-stressed slabs. (SCS)

Reinforced Concrete Wall: cast-in-place walls that provide earthquake resistance; includes standard, sliding, and tunnel formwork. (RCW)



Note that the relative vulnerabilities are approximate and depend on post-construction modifications, degradation, construction quality, and year of construction. See Types of Multifamily Buildings in ECA for more information.

ABSOLUTE AND RELATIVE LOSS



High-Risk Buildings in Skopje

Slab-column system and reinforced concrete frame are the two highest-risk building types used for pre-2000 multifamily housing in Skopje.

~38,000 people live in these buildings, or **7%** of the total population of Skopje

SCS
RCF

Slab-column System (SCS) and Reinforced Concrete Frame (RCF) buildings contribute to:

42% of total **loss** from building damage

51% of all **permanent residential displacement** in the next 50 years from building damage due to earthquakes

60% of **fatalities** in multifamily buildings*

*This is an average number of fatalities when assessed over many years.

Skopje

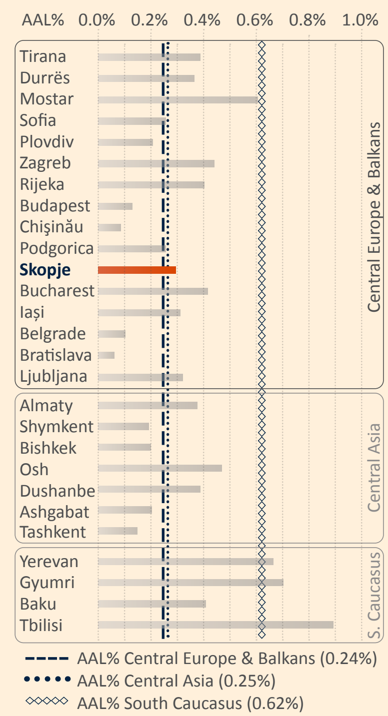
EARTHQUAKE IMPACTS SNAPSHOT

▷ Average annual loss from earthquake damage to multifamily residences is **€5.78 million**.

▷ This amounts to **0.05%** of the country's GDP.

▷ Nearly **29%** of the city's population lives in multifamily residential buildings.

LOSS COMPARISON TO REGION



References: See *City Profile Sources* for information on building types, classification, and exposure data sources.

Bucharest | ROMANIA

Summary

Bucharest is Romania's capital and largest city, home to nearly 10 percent of the country's total population. Romania has experienced many severe earthquakes in the past, the most damaging and deadly of which was the 1977 Vrancea earthquake. This magnitude 7.5 earthquake resulted in over 11,000 injuries, more than 1,500 fatalities (90 percent of them in Bucharest), and €5.5 billion (2019 €) in damage to the capital city. Romania experienced a magnitude 7.8 earthquake in 1940, also centered in Vrancea, which resulted in approximately 600 deaths and 1,200 injuries in the country. In Bucharest, the 14-story Carlton Block residential building completely collapsed, killing 140 residents and injuring nearly 90 people. Following the 1977 Vrancea earthquake, Romania updated the building design code to improve seismic requirements for reinforced concrete structures.

Based on the analysis, about 90 percent of the population of Bucharest resides in pre-2000 multifamily residential buildings. The buildings that are the most at risk* are reinforced concrete frame (RCF) and unreinforced masonry (URM) buildings. These two building types are also expected to cause the most fatalities. Approximately 1.1 million people, or about 60 percent of the city's population, reside in high-risk building types.

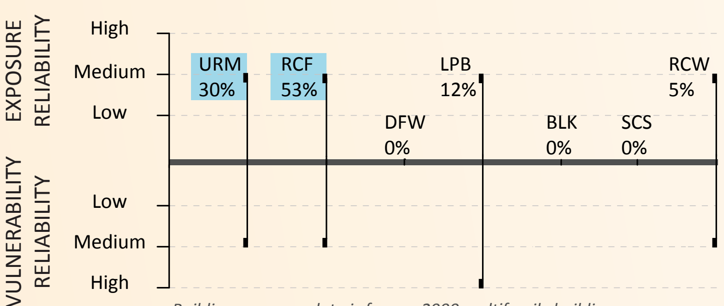
Compared to the data for all the buildings in this study, the data used to conduct the risk analysis for buildings in Bucharest average a **low** reliability; this rating is a function of the assumptions, uncertainties, and data available for the city (see *Methodology*). The diagram below indicates the reliability and confidence related to building stock data (i.e., exposure data) as well as data for building vulnerability. These confidence and reliability levels should be considered when interpreting and applying the risk metrics presented in the city profile.

*At risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The expected loss results are predicted from models of future events subject to variable data availability and modeling assumptions. The replacement value is the construction cost of all multifamily buildings in the city.

BUCHAREST FACTS

Capital City | Population: 1,828,000 (2018) | GNI/capita: ~€10,000

Data Reliability and Building Exposure



Building exposure data is for pre-2000 multifamily buildings.

- ▷ Data on building stock and population (exposure) and their susceptibility to earthquake losses (vulnerability) for the city is conveyed with vertical bars labeled by the building typology acronym.
- ▷ The diagram also indicates the percentage of total building stock that a typology comprises in the city denoted as a percentage below the building typology acronym. Highlighted building types are those that are considered highest risk in the city.

Earthquake Event-Based Losses

	€ Total building damage	% Building damage, % of total value	Number of fatalities
100-year Return Period	€ 5.3 B 34% GNIPC	11%	3,000 people
475-year Return Period	€ 18.9 B 121% GNIPC	41%	19,300 people

- ▷ A 100-year return period event is one where the damage and loss have approximately a 40% probability of being exceeded in 50 years; it is considered a more frequent event. A 475-year return period event is one where the damage and loss have approximately a 10% probability of being exceeded in 50 years; it is considered a less frequent event, more damaging event.
- ▷ GNIPC is gross national income per capita. Percentage of GNIPC is the losses from damage per resident as a percentage of GNIPC.
- ▷ The fatalities presented are those that are expected to occur at nighttime (2:00 a.m.) on a weekend.
- ▷ *Note: Event-based losses are subject to limitation by the reliability of the input data. The chosen return periods do not suggest that more hazardous and infrequent earthquake events are not probable in this city, as higher return period events may occur at any point.*

Country Snapshot

GDP
203.0 Billion Euros*

POPULATION
19.5 Million People*

SIGNIFICANT EARTHQUAKES
1940 Vrancea M7.8
1977 Vrancea M7.5
1986 Vrancea M7.2

* 2018 estimate

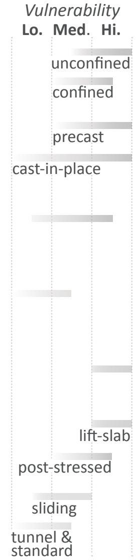
WORLD BANK GROUP GFDRR

Earthquake Risk Profile

Building Damage Losses

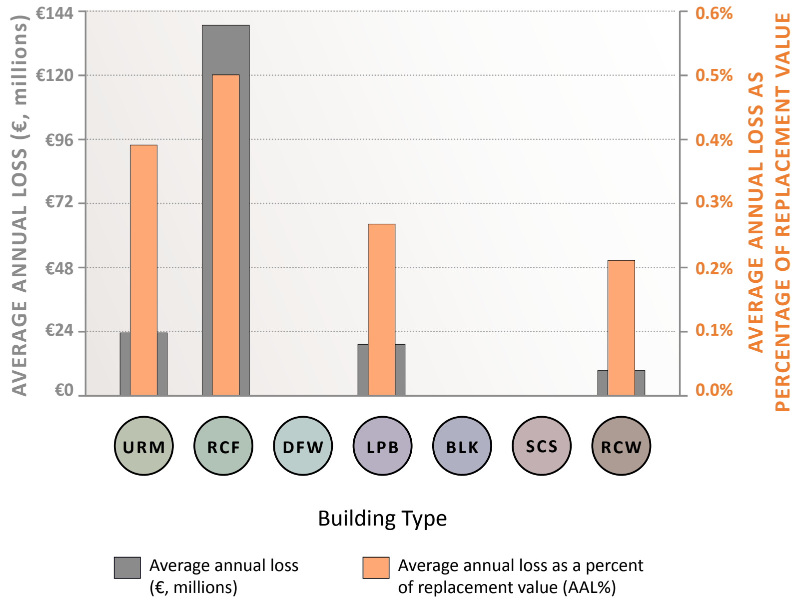
BUILDING CLASSIFICATION & VULNERABILITY RANGE

Description	Type
Unreinforced Masonry: built with masonry walls that lack steel reinforcement; includes confined and unconfined walls.	URM
Reinforced Concrete Frame: reinforced concrete frames that provide earthquake resistance; includes precast and cast-in-place frames.	RCF
Dual Frame-wall: reinforced concrete frame and wall elements work together to resist earthquake forces.	DFW
Precast Large Panel: built with precast reinforced concrete panels with floor-to-ceiling height facade panels.	LPB
Block: built with precast concrete elements assembled on site; similar to LPB with smaller facade elements.	BLK
Slab-column System: reinforced concrete floor slabs directly connected to concrete columns; includes lift slabs and post-stressed slabs.	SCS
Reinforced Concrete Wall: cast-in-place walls that provide earthquake resistance; includes standard, sliding, and tunnel formwork.	RCW



Note that the relative vulnerabilities are approximate and depend on post-construction modifications, degradation, construction quality, and year of construction. See Types of Multifamily Buildings in ECA for more information.

ABSOLUTE AND RELATIVE LOSS



Bucharest

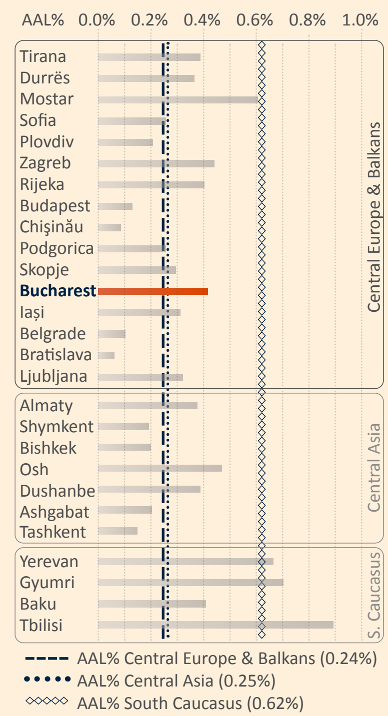
EARTHQUAKE IMPACTS SNAPSHOT

▷ Average annual loss from earthquake damage to multifamily residences is **€192 million**.

▷ This amounts to **0.10%** of the country's GDP.

▷ Nearly **89%** of the city's population lives in multifamily residential buildings.

LOSS COMPARISON TO REGION



High-Risk Buildings in Bucharest

Reinforced concrete frame and masonry are the two highest-risk building types used for pre-2000 multifamily housing in Bucharest.

~1,100,000 people live in these buildings,

or **61%** of the total population of Bucharest

RCF

URM

Reinforced Concrete Frame (RCF) and Unreinforced Masonry (URM) buildings contribute to:

84% of total **loss** from building damage

82% of all **permanent residential displacement** in the next 50 years from building damage due to earthquakes

89% of **fatalities** in multifamily buildings*

*This is an average number of fatalities when assessed over many years.

References: See *City Profile Sources* for information on building types, classification, and exposure data sources.

Iași | ROMANIA

Summary

Iași is Romania's second largest city and is home to about 1 percent of the country's total population. Romania has experienced many severe earthquakes in the past, the most damaging and deadly of which was the 1977 Vrancea earthquake. This magnitude 7.5 earthquake resulted in over 11,000 injuries and more than 1,500 fatalities, destroyed more than 10 percent of the dwellings in Iași, and resulted in €7.8 billion in damage. Romania experienced a magnitude 7.8 earthquake in 1940, also centered in Vrancea, which resulted in approximately 600 deaths and 1,200 injuries in the country. Iași had many more injuries than fatalities from both events, mainly from damage to mid-rise masonry buildings. Following the 1977 Vrancea earthquake, Romania updated the building design code to improve seismic requirements for reinforced concrete structures.

Based on the analysis, over 70 percent of the population of Iași resides in pre-2000 multifamily residential buildings. The buildings that are the most at risk* are unreinforced masonry (URM) and reinforced concrete frame (RCF) buildings. These two building types are also expected to cause the most fatalities. Approximately 154,000 people, or over half of the city's population, reside in high-risk building types.

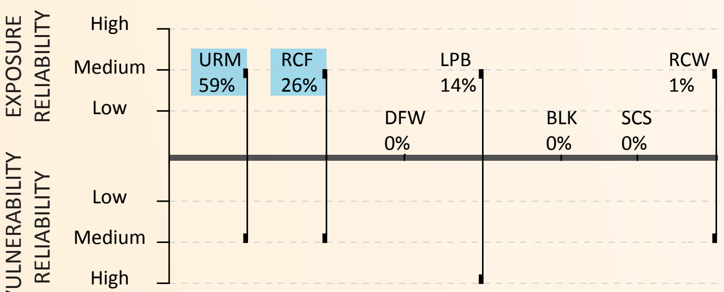
Compared to the data for all the buildings in this study, the data used to conduct the risk analysis for buildings in Iași average a **low** reliability; this rating is a function of the assumptions, uncertainties, and data available for the city (see *Methodology*). The diagram below indicates the reliability and confidence related to building stock data (i.e., exposure data) as well as data on building vulnerability. These confidence and reliability levels should be considered when interpreting and applying the risk metrics presented in the city profile.

*At risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The expected loss results are predicted from models of future events subject to variable data availability and modeling assumptions. The replacement value is the construction cost of all multifamily buildings in the city.

IAȘI FACTS

Second Largest City | Population: 290,000 (2011) | GNI/capita: ~€10,000

Data Reliability and Building Exposure



Building exposure data is for pre-2000 multifamily buildings.

▷ Data on building stock and population (exposure) and their susceptibility to earthquake losses (vulnerability) for the city is conveyed with vertical bars labeled by the building typology acronym.
▷ The diagram also indicates the percentage of total building stock that a typology comprises in the city denoted as a percentage below the building typology acronym. Highlighted building types are those that are considered highest risk in the city.

Earthquake Event-Based Losses

	€ Total building damage	% Building damage, % of total value	Number of fatalities
100-year Return Period	€ 140 M 7% GNIPC	8%	400 people
475-year Return Period	€ 570 M 29% GNIPC	32%	2,200 people

▷ A 100-year return period event is one where the damage and loss have approximately a 40% probability of being exceeded in 50 years; it is considered a more frequent event. A 475-year return period event is one where the damage and loss have approximately a 10% probability of being exceeded in 50 years; it is considered a less frequent event, more damaging event.
▷ GNIPC is gross national income per capita. Percentage of GNIPC is the losses from damage per resident as a percentage of GNIPC.
▷ The fatalities presented are those that are expected to occur at nighttime (2:00 a.m.) on a weekend.
▷ *Note: Event-based losses are subject to limitation by the reliability of the input data. The chosen return periods do not suggest that more hazardous and infrequent earthquake events are not probable in this city, as higher return period events may occur at any point.*

Country Snapshot

GDP
203.0 Billion Euros*

POPULATION
19.5 Million People*

SIGNIFICANT EARTHQUAKES
1940 Vrancea M7.8
1977 Vrancea M7.5
1986 Vrancea M7.2

* 2018 estimate

WORLD BANK GROUP GFDRR

Earthquake Risk Profile

Building Damage Losses

BUILDING CLASSIFICATION & VULNERABILITY RANGE

Description

Unreinforced Masonry: built with masonry walls that lack steel reinforcement; includes confined and unconfined walls.

Reinforced Concrete Frame: reinforced concrete frames that provide earthquake resistance; includes precast and cast-in-place frames.

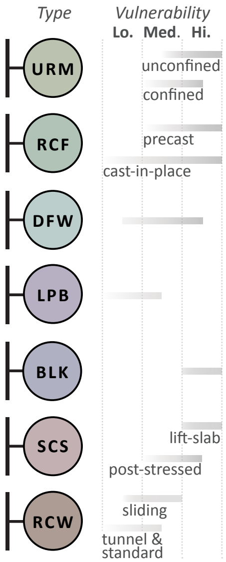
Dual Frame-wall: reinforced concrete frame and wall elements work together to resist earthquake forces.

Precast Large Panel: built with precast reinforced concrete panels with floor-to-ceiling height facade panels.

Block: built with precast concrete elements assembled on site; similar to LPB with smaller facade elements.

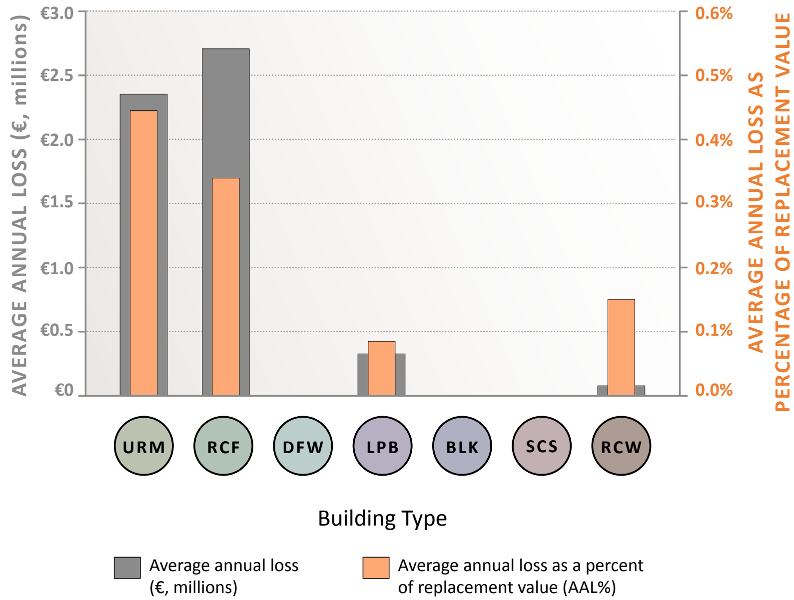
Slab-column System: reinforced concrete floor slabs directly connected to concrete columns; includes lift slabs and post-stressed slabs.

Reinforced Concrete Wall: cast-in-place walls that provide earthquake resistance; includes standard, sliding, and tunnel formwork.



Note that the relative vulnerabilities are approximate and depend on post-construction modifications, degradation, construction quality, and year of construction. See Types of Multifamily Buildings in ECA for more information.

ABSOLUTE AND RELATIVE LOSS



Iași

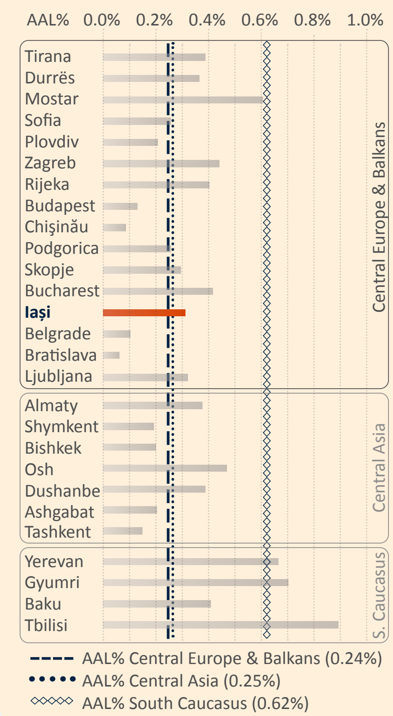
EARTHQUAKE IMPACTS SNAPSHOT

▷ Average annual loss from earthquake damage to multifamily residences is **€5.41 million**.

▷ This amounts to less than **0.01%** of the country's GDP.

▷ Nearly **71%** of the city's population lives in multifamily residential buildings.

LOSS COMPARISON TO REGION



High-Risk Buildings in Iași

Masonry and reinforced concrete frame are the two highest-risk building types used for pre-2000 multifamily housing in Iași.

~154,000 people live in these buildings, or **53%** of the total population of Iași

URM

RCF

Unreinforced Masonry (URM) and Reinforced Concrete Frame (RCF) buildings contribute to:

93% of total **loss** from building damage

83% of all **permanent residential displacement** in the next 50 years from building damage due to earthquakes

94% of **fatalities** in multifamily buildings*

*This is an average number of fatalities when assessed over many years.

References: See *City Profile Sources* for information on building types, classification, and exposure data sources.

Belgrade | SERBIA

Summary

Belgrade is Serbia's capital and largest city, home to nearly a quarter of the country's total population. Serbia has experienced several earthquakes of varying severity in the past, the most recent of which occurred in 2010 in Kraljevo. This magnitude 5.5 earthquake injured over 100, killed two, destroyed 1,000 homes, and damaged a further 5,000.

Based on the analysis, nearly three-quarters of the population of Belgrade resides in pre-2000 multifamily residential buildings. The buildings that are the most at risk* are reinforced concrete frame (RCF) and unreinforced masonry (URM) buildings. These two building types are also expected to cause the most fatalities. Nearly 550,000 inhabitants, or one in every three people, reside in high-risk building types.

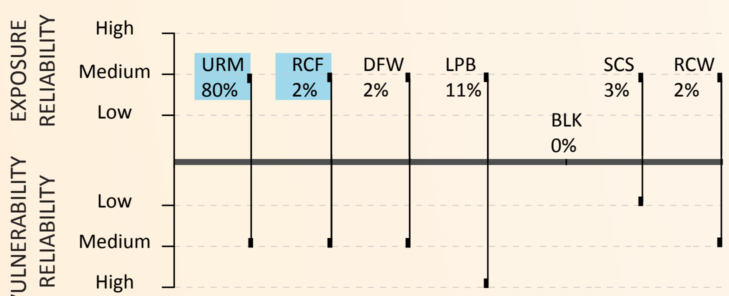
Compared to the data for all the buildings in this study, the data used to conduct the risk analysis for buildings in Belgrade average a **low** reliability; this rating is a function of the assumptions, uncertainties, and data available for the city (see *Methodology*). The diagram below indicates the reliability and confidence related to building stock data (i.e., exposure data) as well as data for building vulnerability. These confidence and reliability levels should be considered when interpreting and applying the risk metrics presented in the city profile.

*At risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The expected loss results are predicted from models of future events subject to variable data availability and modeling assumptions. The replacement value is the construction cost of all multifamily buildings in the city.

BELGRADE FACTS

Capital City | Population: 1,687,000 (2011) | GNI/capita: ~€5,400

Data Reliability and Building Exposure



Building exposure data is for pre-2000 multifamily buildings.

▷ Data on building stock and population (exposure) and their susceptibility to earthquake losses (vulnerability) for the city is conveyed with vertical bars labeled by the building typology acronym.
▷ The diagram also indicates the percentage of total building stock that a typology comprises in the city denoted as a percentage below the building typology acronym. Highlighted building types are those that are considered highest risk in the city.

Earthquake Event-Based Losses

	€ Total building damage	% Building damage, % of total value	Number of fatalities
100-year Return Period	€ 434 M 6% GNIPC	1%	240 people
475-year Return Period	€ 3.4 B 50% GNIPC	10%	2,000 people

▷ A 100-year return period event is one where the damage and loss have approximately a 40% probability of being exceeded in 50 years; it is considered a more frequent event. A 475-year return period event is one where the damage and loss have approximately a 10% probability of being exceeded in 50 years; it is considered a less frequent event, more damaging event.
▷ GNIPC is gross national income per capita. Percentage of GNIPC is the losses from damage per resident as a percentage of GNIPC.
▷ The fatalities presented are those that are expected to occur at nighttime (2:00 a.m.) on a weekend.
▷ *Note: Event-based losses are subject to limitation by the reliability of the input data. The chosen return periods do not suggest that more hazardous and infrequent earthquake events are not probable in this city, as higher return period events may occur at any point.*

GDP
42.9 Billion Euros*

POPULATION
6.93 Million People*

SIGNIFICANT EARTHQUAKES
1980 Kopaonik M5.8
1998 Mionica M5.5
2010 Kraljevo M5.5

* 2018 estimate

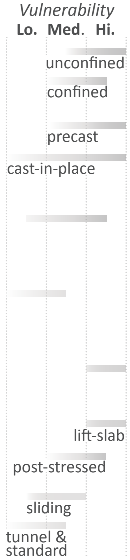
WORLD BANK GROUP GFDRR

Earthquake Risk Profile

Building Damage Losses

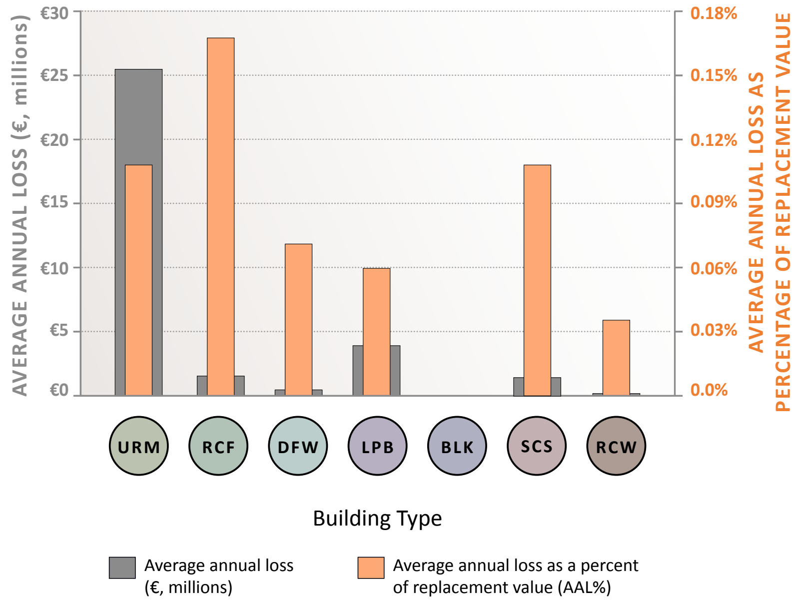
BUILDING CLASSIFICATION & VULNERABILITY RANGE

Description	Type
Unreinforced Masonry: built with masonry walls that lack steel reinforcement; includes confined and unconfined walls.	URM
Reinforced Concrete Frame: reinforced concrete frames that provide earthquake resistance; includes precast and cast-in-place frames.	RCF
Dual Frame-wall: reinforced concrete frame and wall elements work together to resist earthquake forces.	DFW
Precast Large Panel: built with precast reinforced concrete panels with floor-to-ceiling height facade panels.	LPB
Block: built with precast concrete elements assembled on site; similar to LPB with smaller facade elements.	BLK
Slab-column System: reinforced concrete floor slabs directly connected to concrete columns; includes lift slabs and post-stressed slabs.	SCS
Reinforced Concrete Wall: cast-in-place walls that provide earthquake resistance; includes standard, sliding, and tunnel formwork.	RCW



Note that the relative vulnerabilities are approximate and depend on post-construction modifications, degradation, construction quality, and year of construction. See Types of Multifamily Buildings in ECA for more information.

ABSOLUTE AND RELATIVE LOSS

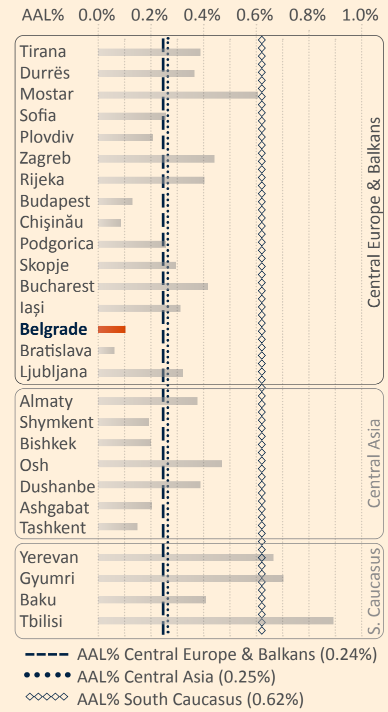


Belgrade

EARTHQUAKE IMPACTS SNAPSHOT

- Average annual loss from earthquake damage to multifamily residences is **€33.6 million**.
- This amounts to **0.08%** of the country's GDP.
- Nearly **74%** of the city's population lives in multifamily residential buildings.

LOSS COMPARISON TO REGION



High-Risk Buildings in Belgrade

Reinforced concrete frame and masonry are the two highest-risk building types used for pre-2000 multifamily housing in Belgrade.

~550,000 people live in these buildings, or **33%** of the total population of Belgrade

RCF URM

Reinforced Concrete Frame (RCF) and Unreinforced Masonry (URM) buildings contribute to:

- **81%** of total **loss** from building damage
- **59%** of all **permanent residential displacement** in the next 50 years from building damage due to earthquakes
- **77%** of **fatalities** in multifamily buildings*

*This is an average number of fatalities when assessed over many years.

References: See *City Profile Sources* for information on building types, classification, and exposure data sources.

Bratislava | SLOVAKIA

Summary

Bratislava is Slovakia's capital and largest city, home to nearly 8 percent of the country's total population. Slovakia has faced damaging and deadly earthquakes in the past; the country's earliest recorded earthquake, in Banská Štiavnica in 1443, caused 30 deaths. In 2004, Slovakia experienced an earthquake in Slovenská Ľupca that caused minor damage in the city.

Based on the analysis, nearly two-thirds of the population of Bratislava resides in pre-2000 multifamily residential buildings. The buildings that are the most at risk* are reinforced concrete frame (RCF) buildings and unreinforced masonry (URM) buildings. These two building types are also expected to cause the most fatalities. Approximately 30,000 people, or about 7 percent of the city's population, reside in high-risk building types.

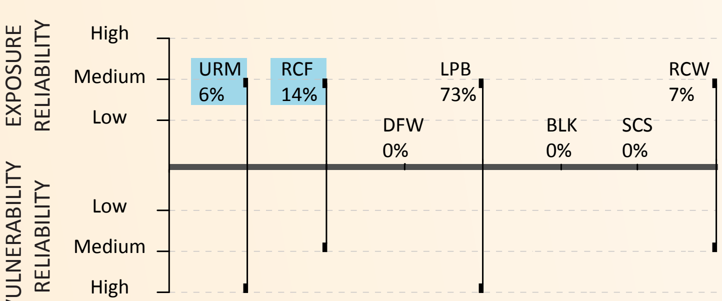
Compared to the data for all the buildings in this study, the data used to conduct the risk analysis for buildings in Bratislava average a **medium** reliability; this rating is a function of the assumptions, uncertainties, and data available for the city (see *Methodology*). The diagram below indicates the reliability and confidence related to building stock data (i.e., exposure data) as well as data for building vulnerability. These confidence and reliability levels should be considered when interpreting and applying the risk metrics presented in the city profile.

*At risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The expected loss results are predicted from models of future events subject to variable data availability and modeling assumptions. The replacement value is the construction cost of all multifamily buildings in the city.

BRATISLAVA FACTS

Capital City | Population: 424,000 (2016) | GNI/capita: ~€15,500

Data Reliability and Building Exposure



Building exposure data is for pre-2000 multifamily buildings.

▷ Data on building stock and population (exposure) and their susceptibility to earthquake losses (vulnerability) for the city is conveyed with vertical bars labeled by the building typology acronym.
▷ The diagram also indicates the percentage of total building stock that a typology comprises in the city denoted as a percentage below the building typology acronym. Highlighted building types are those that are considered highest risk in the city.

Earthquake Event-Based Losses

	€ Total building damage	% Building damage, % of total value	Number of fatalities
100-year Return Period	€ 102 M 2% GNIPC	1%	10 people
475-year Return Period	€ 830 M 20% GNIPC	6%	120 people

▷ A 100-year return period event is one where the damage and loss have approximately a 40% probability of being exceeded in 50 years; it is considered a more frequent event. A 475-year return period event is one where the damage and loss have approximately a 10% probability of being exceeded in 50 years; it is considered a less frequent event, more damaging event.
▷ GNIPC is gross national income per capita. Percentage of GNIPC is the losses from damage per resident as a percentage of GNIPC.
▷ The fatalities presented are those that are expected to occur at nighttime (2:00 a.m.) on a weekend.
▷ *Note: Event-based losses are subject to limitation by the reliability of the input data. The chosen return periods do not suggest that more hazardous and infrequent earthquake events are not probable in this city, as higher return period events may occur at any point.*

Country Snapshot

GDP
89.7 Billion Euros*

POPULATION
5.45 Million People*

SIGNIFICANT EARTHQUAKES
1443 Banská Štiavnica M-unknown
1858 Zilina M-unknown
2004 Slovenská L'upca M5.0

* 2018 estimate

WORLD BANK GROUP GFDRR

Earthquake Risk Profile

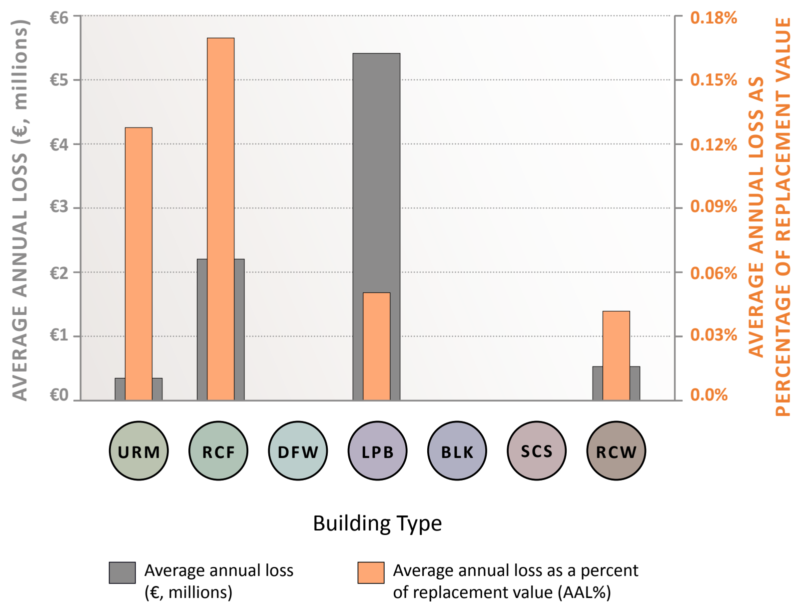
Building Damage Losses

BUILDING CLASSIFICATION & VULNERABILITY RANGE

Description	Type	Vulnerability (Lo. Med. Hi.)
Unreinforced Masonry: built with masonry walls that lack steel reinforcement; includes confined and unconfined walls.	URM	unconfined; confined
Reinforced Concrete Frame: reinforced concrete frames that provide earthquake resistance; includes precast and cast-in-place frames.	RCF	precast; cast-in-place
Dual Frame-wall: reinforced concrete frame and wall elements work together to resist earthquake forces.	DFW	
Precast Large Panel: built with precast reinforced concrete panels with floor-to-ceiling height facade panels.	LPB	
Block: built with precast concrete elements assembled on site; similar to LPB with smaller facade elements.	BLK	
Slab-column System: reinforced concrete floor slabs directly connected to concrete columns; includes lift slabs and post-stressed slabs.	SCS	lift-slab; post-stressed
Reinforced Concrete Wall: cast-in-place walls that provide earthquake resistance; includes standard, sliding, and tunnel formwork.	RCW	sliding; tunnel & standard

Note that the relative vulnerabilities are approximate and depend on post-construction modifications, degradation, construction quality, and year of construction. See Types of Multifamily Buildings in ECA for more information.

ABSOLUTE AND RELATIVE LOSS



Bratislava

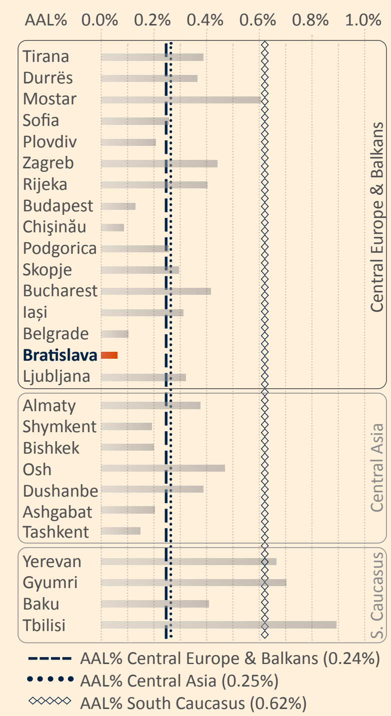
EARTHQUAKE IMPACTS SNAPSHOT

▷ Average annual loss from earthquake damage to multifamily residences is **€8.48 million**.

▷ This amounts to **0.01%** of the country's GDP.

▷ Nearly **64%** of the city's population lives in multifamily residential buildings.

LOSS COMPARISON TO REGION



High-Risk Buildings in Bratislava

Reinforced concrete frame and masonry are the two highest-risk building types used for pre-2000 multifamily housing in Bratislava.

~30,000 people live in these buildings, or **7%** of the total population of Bratislava

RCF URM

Reinforced Concrete Frame (RCF) and Unreinforced Masonry (URM) buildings contribute to:

30% of total **loss** from building damage

84% of all **permanent residential displacement** in the next 50 years from building damage due to earthquakes

76% of **fatalities** in multifamily buildings*

*This is an average number of fatalities when assessed over many years.

References: See *City Profile Sources* for information on building types, classification, and exposure data sources.

Ljubljana | SLOVENIA

Summary

Ljubljana is Slovenia's capital and largest city, home to nearly 14 percent of the country's total population. Slovenia has faced several large earthquakes in the past, the most severe of which occurred in Ljubljana in 1895. This magnitude 6.1 event, sometimes called the Easter Earthquake, killed seven people and damaged 10 percent of all homes in the city. In 2004, Slovenia experienced a magnitude 5.2 earthquake in the Bovec-Kobarid region that injured five people and killed one. This earthquake was also felt in Ljubljana, but resulted in no recorded damage or casualties.

Based on the analysis, about two-thirds of the population of Ljubljana resides in pre-2000 multifamily residential buildings. The buildings that are the most at risk* are reinforced concrete frame (RCF) and unreinforced masonry (URM) buildings. Along with reinforced concrete wall (RCW), these building types are expected to cause the most fatalities. Approximately 78,000 people, or nearly 30 percent of the city's population, reside in high-risk building types.

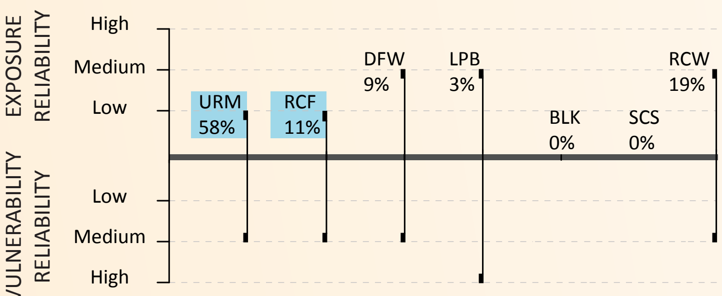
Compared to the data for all the buildings in this study, the data used to conduct the risk analysis for buildings in Ljubljana average a **low** reliability; this rating is a function of the assumptions, uncertainties, and data available for the city (see *Methodology*). The diagram below indicates the reliability and confidence related to building stock data (i.e., exposure data) as well as data for building vulnerability. These confidence and reliability levels should be considered when interpreting and applying the risk metrics presented in the city profile.

*At risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The expected loss results are predicted from models of future events subject to variable data availability and modeling assumptions. The replacement value is the construction cost of all multifamily buildings in the city.

LJUBLJANA FACTS

Capital City | Population: 280,000 (2016) | GNI/capita: ~€20,800

Data Reliability and Building Exposure



Building exposure data is for pre-2000 multifamily buildings.

- ▷ Data on building stock and population (exposure) and their susceptibility to earthquake losses (vulnerability) for the city is conveyed with vertical bars labeled by the building typology acronym.
- ▷ The diagram also indicates the percentage of total building stock that a typology comprises in the city denoted as a percentage below the building typology acronym. Highlighted building types are those that are considered highest risk in the city.

Earthquake Event-Based Losses

	€ Total building damage	% Building damage, % of total value	Number of fatalities
100-year Return Period	€ 400 M 10% GNIPC	7%	340 people
475-year Return Period	€1.9 B 47% GNIPC	34%	2,000 people

- ▷ A 100-year return period event is one where the damage and loss have approximately a 40% probability of being exceeded in 50 years; it is considered a more frequent event. A 475-year return period event is one where the damage and loss have approximately a 10% probability of being exceeded in 50 years; it is considered a less frequent event, more damaging event.
- ▷ GNIPC is gross national income per capita. Percentage of GNIPC is the losses from damage per resident as a percentage of GNIPC.
- ▷ The fatalities presented are those that are expected to occur at nighttime (2:00 a.m.) on a weekend.
- ▷ *Note: Event-based losses are subject to limitation by the reliability of the input data. The chosen return periods do not suggest that more hazardous and infrequent earthquake events are not probable in this city, as higher return period events may occur at any point.*

Country Snapshot

GDP
45.7 Billion Euros*

POPULATION
2.07 Million People*

SIGNIFICANT EARTHQUAKES
1511 Idrija M6.5
1895 Ljubljana M6.1
2004 Bovec-Kobarid M5.2

* 2018 estimate

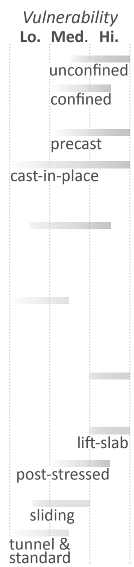
WORLD BANK GROUP | GFDRR

Earthquake Risk Profile

Building Damage Losses

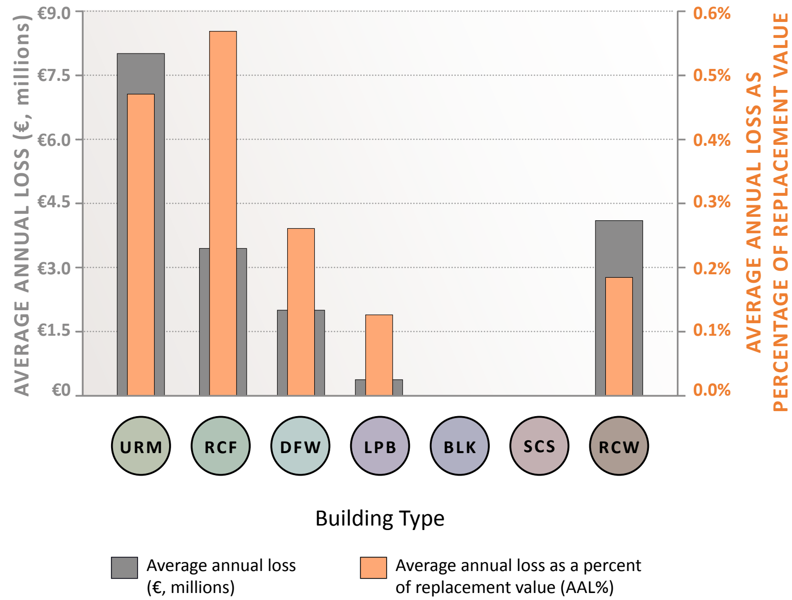
BUILDING CLASSIFICATION & VULNERABILITY RANGE

Description	Type
Unreinforced Masonry: built with masonry walls that lack steel reinforcement; includes confined and unconfined walls.	URM
Reinforced Concrete Frame: reinforced concrete frames that provide earthquake resistance; includes precast and cast-in-place frames.	RCF
Dual Frame-wall: reinforced concrete frame and wall elements work together to resist earthquake forces.	DFW
Precast Large Panel: built with precast reinforced concrete panels with floor-to-ceiling height facade panels.	LPB
Block: built with precast concrete elements assembled on site; similar to LPB with smaller facade elements.	BLK
Slab-column System: reinforced concrete floor slabs directly connected to concrete columns; includes lift slabs and post-stressed slabs.	SCS
Reinforced Concrete Wall: cast-in-place walls that provide earthquake resistance; includes standard, sliding, and tunnel formwork.	RCW



Note that the relative vulnerabilities are approximate and depend on post-construction modifications, degradation, construction quality, and year of construction. See Types of Multifamily Buildings in ECA for more information.

ABSOLUTE AND RELATIVE LOSS



Ljubljana

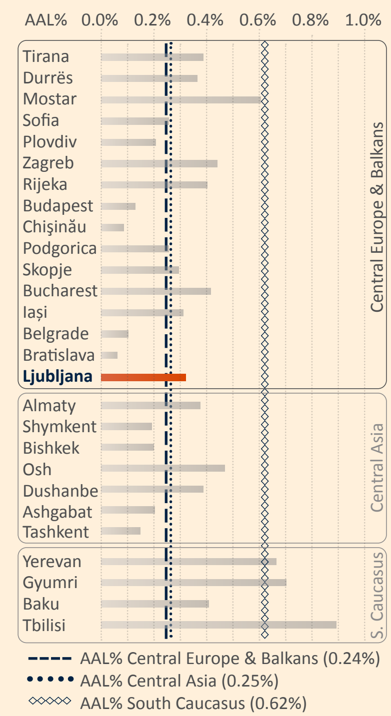
EARTHQUAKE IMPACTS SNAPSHOT

▷ Average annual loss from earthquake damage to multifamily residences is **€17.9 million**.

▷ This amounts to **0.04%** of the country's GDP.

▷ Nearly **67%** of the city's population lives in multifamily residential buildings.

LOSS COMPARISON TO REGION



High-Risk Buildings in Ljubljana

Reinforced concrete frame and masonry are the two highest-risk building types used for pre-2000 multifamily housing in Ljubljana.

~78,000 people live in these buildings, or **28%** of the total population of Ljubljana

RCF
URM

Reinforced Concrete Frame (RCF) and Unreinforced Masonry (URM) buildings contribute to:

64% of total **loss** from building damage

77% of all **permanent residential displacement** in the next 50 years from building damage due to earthquakes

75% of **fatalities** in multifamily buildings*

*This is an average number of fatalities when assessed over many years.

References: See *City Profile Sources* for information on building types, classification, and exposure data sources.

Almaty | KAZAKHSTAN

Summary

Almaty (formerly Alma-Ata) is Kazakhstan's largest city, the country's former capital, and home to 10 percent of the country's total population. Kazakhstan has faced several large earthquakes in the past, the most deadly of which was the 1911 magnitude 7.7 earthquake in Almaty that killed 450 people. Another event, the magnitude 6.8 Zaysan earthquake in 1990, killed one individual, destroyed 3,000 houses, and left 20,000 people homeless in the region.

Based on the analysis, almost 40 percent the population of Almaty resides in pre-2000 multifamily residential buildings. The buildings that are the most at risk* are block (BLK) buildings and slab-column system (SCS) buildings. Along with unreinforced masonry (URM) buildings, these building types are also expected to cause the most fatalities. Approximately 13,000 people, or less than 1 percent of the city's population, reside in high-risk building types.

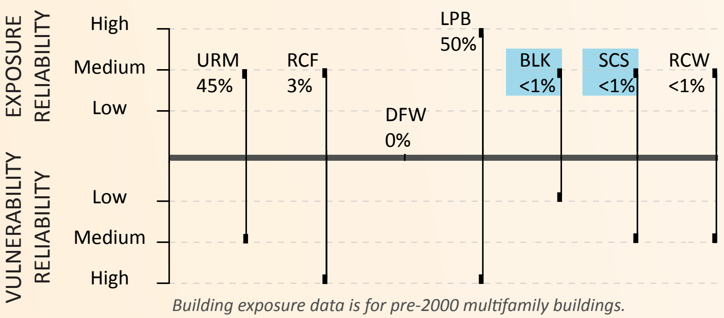
Compared to the data for all the buildings in this study, the data used to conduct the risk analysis for buildings in Almaty average a **low** reliability; this rating is a function of the assumptions, uncertainties, and data available for the city (see *Methodology*). The diagram below indicates the reliability and confidence related to building stock data (i.e., exposure data) as well as data for building vulnerability. These confidence and reliability levels should be considered when interpreting and applying the risk metrics presented in the city profile.

*At risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The expected loss results are predicted from models of future events subject to variable data availability and modeling assumptions. The replacement value is the construction cost of all multifamily buildings in the city.

ALMATY FACTS

Capital City | Population: 1,863,000 (2019) | GNI/capita: ~€6,800

Data Reliability and Building Exposure



Building exposure data is for pre-2000 multifamily buildings.

▷ Data on building stock and population (exposure) and their susceptibility to earthquake losses (vulnerability) for the city is conveyed with vertical bars labeled by the building typology acronym.
▷ The diagram also indicates the percentage of total building stock that a typology comprises in the city denoted as a percentage below the building typology acronym. Highlighted building types are those that are considered highest risk in the city.

Earthquake Event-Based Losses

	€ Total building damage	% Building damage, % of total value	Number of fatalities
100-year Return Period	€ 760 M 16% GNIPC	9%	1,600 people
475-year Return Period	€ 3.5 B 75% GNIPC	42%	15,000 people

▷ A 100-year return period event is one where the damage and loss have approximately a 40% probability of being exceeded in 50 years; it is considered a more frequent event. A 475-year return period event is one where the damage and loss have approximately a 10% probability of being exceeded in 50 years; it is considered a less frequent event, more damaging event.
▷ GNIPC is gross national income per capita. Percentage of GNIPC is the losses from damage per resident as a percentage of GNIPC.
▷ The fatalities presented are those that are expected to occur at nighttime (2:00 a.m.) on a weekend.
▷ *Note: Event-based losses are subject to limitation by the reliability of the input data. The chosen return periods do not suggest that more hazardous and infrequent earthquake events are not probable in this city, as higher return period events may occur at any point.*

Country Snapshot

GDP
152 Billion Euros*

POPULATION
18.3 Million People*

SIGNIFICANT EARTHQUAKES
1911 Almaty M7.7
1990 Zaysan M6.8
2009 Tekeli M5.4

* 2018 estimate

WORLD BANK GROUP GFDRR Global Facility for Disaster Reduction and Recovery

Earthquake Risk Profile

Building Damage Losses

BUILDING CLASSIFICATION & VULNERABILITY RANGE

Description — *Type* — *Vulnerability* (Lo. Med. Hi.)

Unreinforced Masonry: built with masonry walls that lack steel reinforcement; includes confined and unconfined walls. — URM

Reinforced Concrete Frame: reinforced concrete frames that provide earthquake resistance; includes precast and cast-in-place frames. — RCF

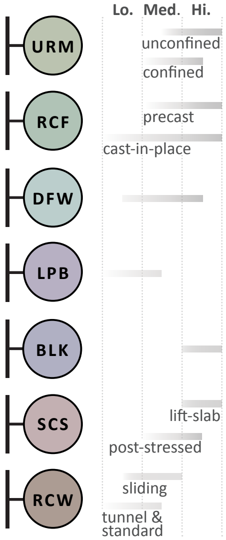
Dual Frame-wall: reinforced concrete frame and wall elements work together to resist earthquake forces. — DFW

Precast Large Panel: built with precast reinforced concrete panels with floor-to-ceiling height facade panels. — LPB

Block: built with precast concrete elements assembled on site; similar to LPB with smaller facade elements. — BLK

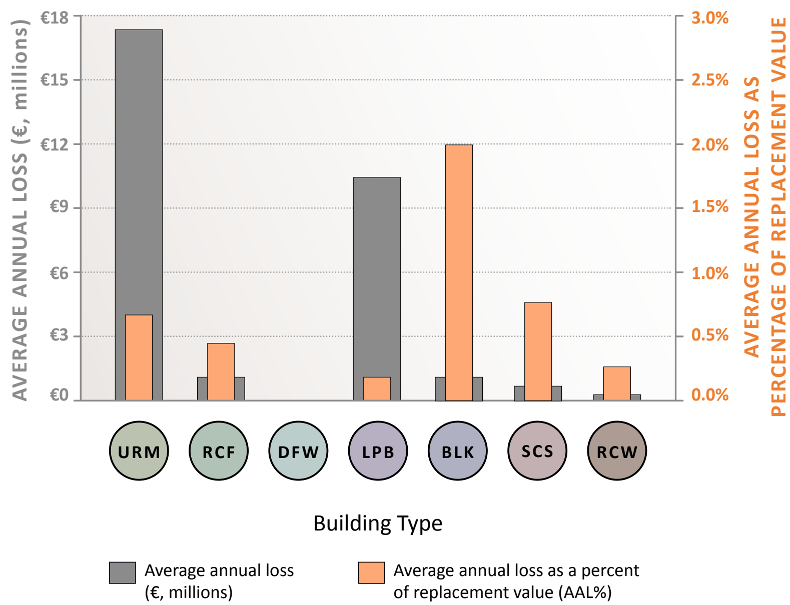
Slab-column System: reinforced concrete floor slabs directly connected to concrete columns; includes lift slabs and post-stressed slabs. — SCS

Reinforced Concrete Wall: cast-in-place walls that provide earthquake resistance; includes standard, sliding, and tunnel formwork. — RCW



Note that the relative vulnerabilities are approximate and depend on post-construction modifications, degradation, construction quality, and year of construction. See Types of Multifamily Buildings in ECA for more information.

ABSOLUTE AND RELATIVE LOSS



Almaty

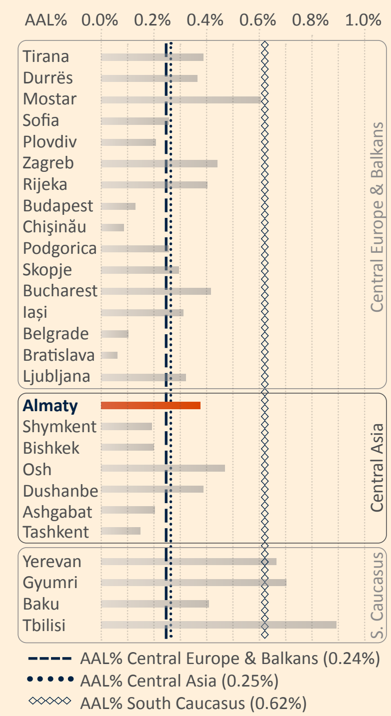
EARTHQUAKE IMPACTS SNAPSHOT

▷ Average annual loss from earthquake damage to multifamily residences is **€31.5 million**.

▷ This amounts to **0.02%** of the country's GDP.

▷ Nearly **36%** of the city's population lives in multifamily residential buildings.

LOSS COMPARISON TO REGION



High-Risk Buildings in Almaty

Block and slab-column system are the two highest-risk building types used for pre-2000 multifamily housing in Almaty.

~13,000 people live in these buildings, or less than **1%** of the total population of Almaty

BLK SCS

Block (BLK) and Slab-column System (SCS) buildings contribute to:

6% of total **loss** from building damage

60% of all **permanent residential displacement** in the next 50 years from building damage due to earthquakes

58% of **fatalities** in multifamily buildings*

*This is an average number of fatalities when assessed over many years.

References: See *City Profile Sources* for information on building types, classification, and exposure data sources.

Shymkent | KAZAKHSTAN

Summary

Shymkent is Kazakhstan's third largest city and home to 5 percent of the country's total population. Kazakhstan has faced several large earthquakes in the past, the most deadly of which was the 1911 magnitude 7.7 earthquake in Almaty (formerly Alma-Ata) that killed 450 people. Another event, the magnitude 6.8 Zaysan earthquake in 1990, killed one individual, destroyed 3,000 houses, and left 20,000 people homeless in the region.

Based on the analysis, over a quarter of the population of Shymkent resides in pre-2000 multifamily residential buildings. The buildings that are the most at risk* are block (BLK) buildings and unreinforced masonry (URM) buildings. These two building types are also expected to cause the most fatalities. Approximately 100,000 people, or about 11 percent of the city's population, reside in high-risk building types.

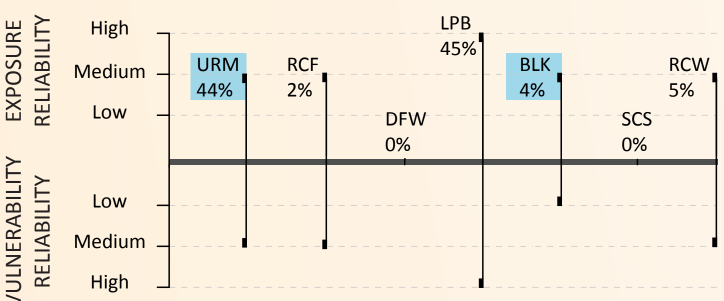
Compared to the data for all the buildings in this study, the data used to conduct the risk analysis for buildings in Shymkent average a **low** reliability; this rating is a function of the assumptions, uncertainties, and data available for the city (see *Methodology*). The diagram below indicates the reliability and confidence related to building stock data (i.e., exposure data) as well as data for building vulnerability. These confidence and reliability levels should be considered when interpreting and applying the risk metrics presented in the city profile.

*At risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The expected loss results are predicted from models of future events subject to variable data availability and modeling assumptions. The replacement value is the construction cost of all multifamily buildings in the city.

SHYMKENT FACTS

Third Largest City | Population: 932,000 (2017) | GNI/capita: ~€6,800

Data Reliability and Building Exposure



Building exposure data is for pre-2000 multifamily buildings.

▷ Data on building stock and population (exposure) and their susceptibility to earthquake losses (vulnerability) for the city is conveyed with vertical bars labeled by the building typology acronym.
▷ The diagram also indicates the percentage of total building stock that a typology comprises in the city denoted as a percentage below the building typology acronym. Highlighted building types are those that are considered highest risk in the city.

Earthquake Event-Based Losses

	€ Total building damage	% Building damage, % of total value	Number of fatalities
100-year Return Period	€ 67 M 4% GNIPC	4%	340 people
475-year Return Period	€ 290 M 18% GNIPC	18%	2,300 people

▷ A 100-year return period event is one where the damage and loss have approximately a 40% probability of being exceeded in 50 years; it is considered a more frequent event. A 475-year return period event is one where the damage and loss have approximately a 10% probability of being exceeded in 50 years; it is considered a less frequent event, more damaging event.
▷ GNIPC is gross national income per capita. Percentage of GNIPC is the losses from damage per resident as a percentage of GNIPC.
▷ The fatalities presented are those that are expected to occur at nighttime (2:00 a.m.) on a weekend.
▷ *Note: Event-based losses are subject to limitation by the reliability of the input data. The chosen return periods do not suggest that more hazardous and infrequent earthquake events are not probable in this city, as higher return period events may occur at any point.*

Country Snapshot

GDP
152 Billion Euros*

POPULATION
18.3 Million People*

SIGNIFICANT EARTHQUAKES
1911 Almaty M7.7
1990 Zaysan M6.8
2009 Tekeli M5.4

* 2018 estimate

WORLD BANK GROUP GFDRR

Earthquake Risk Profile

Building Damage Losses

BUILDING CLASSIFICATION & VULNERABILITY RANGE

Description — *Type* — *Vulnerability* (Lo. Med. Hi.)

Unreinforced Masonry: built with masonry walls that lack steel reinforcement; includes confined and unconfined walls. — URM

Reinforced Concrete Frame: reinforced concrete frames that provide earthquake resistance; includes precast and cast-in-place frames. — RCF

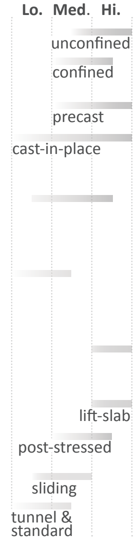
Dual Frame-wall: reinforced concrete frame and wall elements work together to resist earthquake forces. — DFW

Precast Large Panel: built with precast reinforced concrete panels with floor-to-ceiling height facade panels. — LPB

Block: built with precast concrete elements assembled on site; similar to LPB with smaller facade elements. — BLK

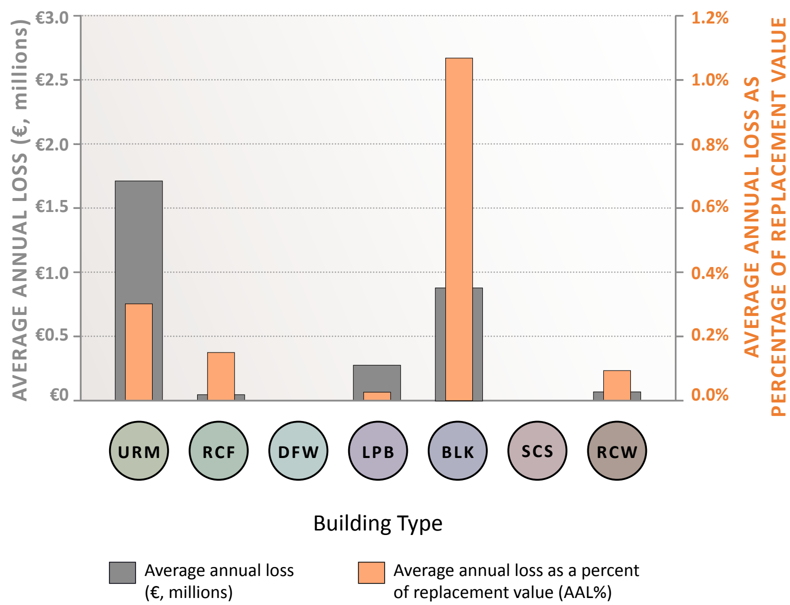
Slab-column System: reinforced concrete floor slabs directly connected to concrete columns; includes lift slabs and post-stressed slabs. — SCS

Reinforced Concrete Wall: cast-in-place walls that provide earthquake resistance; includes standard, sliding, and tunnel formwork. — RCW



Note that the relative vulnerabilities are approximate and depend on post-construction modifications, degradation, construction quality, and year of construction. See Types of Multifamily Buildings in ECA for more information.

ABSOLUTE AND RELATIVE LOSS

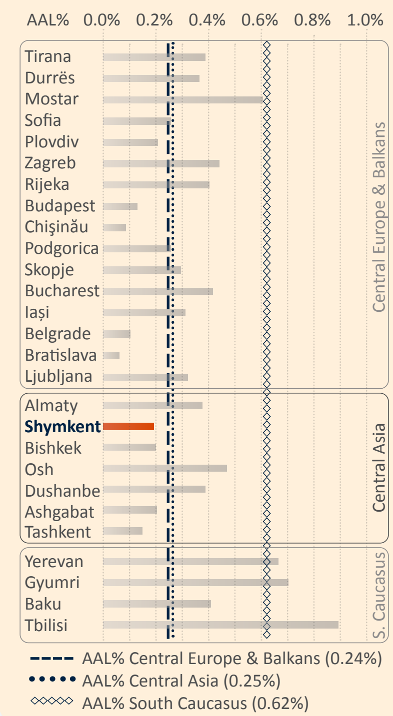


Shymkent

EARTHQUAKE IMPACTS SNAPSHOT

- Average annual loss from earthquake damage to multifamily residences is **€3.04 million**.
- This amounts to less than **0.01%** of the country's GDP.
- Nearly **26%** of the city's population lives in multifamily residential buildings.

LOSS COMPARISON TO REGION



High-Risk Buildings in Shymkent

Block and masonry are the two highest-risk building types used for pre-2000 multifamily housing in Shymkent.

~100,000 people live in these buildings, or **11%** of the total population of Shymkent

BLK URM

Block (BLK) and Unreinforced Masonry (URM) buildings contribute to:

86% of total **loss** from building damage

81% of all **permanent residential displacement** in the next 50 years from building damage due to earthquakes

86% of **fatalities** in multifamily buildings*

*This is an average number of fatalities when assessed over many years.

References: See *City Profile Sources* for information on building types, classification, and exposure data sources.

Bishkek | KYRGYZ REPUBLIC

Summary

Bishkek is the capital and largest city in the Kyrgyz Republic, home to nearly 17 percent of the total population. The Kyrgyz Republic has faced several large earthquakes in the past, the most damaging of which was the Suusamyr earthquake that occurred in Toluk in 1992. This magnitude 7.5 event killed 75 people, destroyed over 8,000 houses, and caused damage totaling €217 million (2019 €); in Bishkek, it collapsed about 95 percent of the single-story masonry homes. More recently, in 2008, the country experienced a magnitude 6.6 earthquake centered in the town of Nura. This earthquake killed 74 people and injured 140.

Based on the analysis, almost 40 percent of the population of Bishkek resides in pre-2000 multifamily residential buildings. The buildings that are the most at risk* are reinforced concrete frame (RCF) and unreinforced masonry (URM) buildings. These two building types are also expected to cause the most fatalities. Approximately 143,000 people, or about 14 percent of the population of Bishkek, reside in high-risk building types.

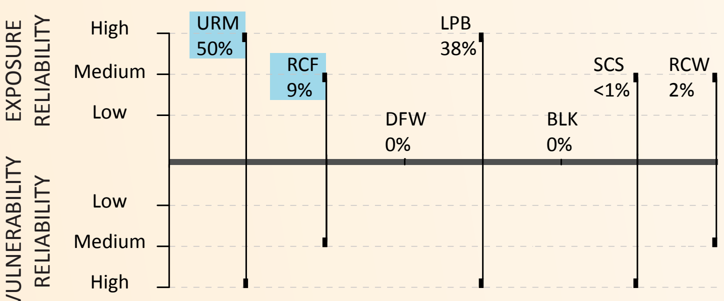
Compared to the data for all the buildings in this study, the data used to conduct the risk analysis for buildings in Bishkek average a **medium** reliability; this rating is a function of the assumptions, uncertainties, and data available for the city (see *Methodology*). The diagram below indicates the reliability and confidence related to building stock data (i.e., exposure data) as well as the data on building vulnerability. These confidence and reliability levels should be considered when interpreting and applying the risk metrics presented in the city profile.

*At risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The expected loss results are predicted from models of future events subject to variable data availability and modeling assumptions. The replacement value is the construction cost of all multifamily buildings in the city.

BISHKEK FACTS

Capital City | Population: 1,013,000 (2019) | GNI/capita: ~€1,000

Data Reliability and Building Exposure



Building exposure data is for pre-2000 multifamily buildings.

▷ Data on building stock and population (exposure) and their susceptibility to earthquake losses (vulnerability) for the city is conveyed with vertical bars labeled by the building typology acronym.
▷ The diagram also indicates the percentage of total building stock that a typology comprises in the city denoted as a percentage below the building typology acronym. Highlighted building types are those that are considered highest risk in the city.

Earthquake Event-Based Losses

	€ Total building damage	% Building damage, % of total value	Number of fatalities
100-year Return Period	€ 83 M 21% GNIPC	4%	350 people
475-year Return Period	€ 400 M 101% GNIPC	19%	3,000 people

▷ A 100-year return period event is one where the damage and loss have approximately a 40% probability of being exceeded in 50 years; it is considered a more frequent event. A 475-year return period event is one where the damage and loss have approximately a 10% probability of being exceeded in 50 years; it is considered a less frequent event, more damaging event.
▷ GNIPC is gross national income per capita. Percentage of GNIPC is the losses from damage per resident as a percentage of GNIPC.
▷ The fatalities presented are those that are expected to occur at nighttime (2:00 a.m.) on a weekend.
▷ *Note: Event-based losses are subject to limitation by the reliability of the input data. The chosen return periods do not suggest that more hazardous and infrequent earthquake events are not probable in this city, as higher return period events may occur at any point.*

Country Snapshot

GDP
6.9 Billion Euros*

POPULATION
6.3 Million People*

SIGNIFICANT EARTHQUAKES
1885 Belovodskoje M6.9
1992 Suusamyr M7.5
2008 Nura M6.6

* 2018 estimate

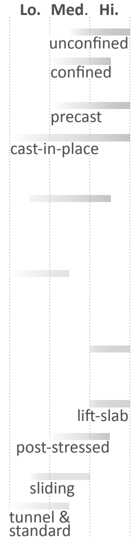
WORLD BANK GROUP GFDRR

Earthquake Risk Profile

Building Damage Losses

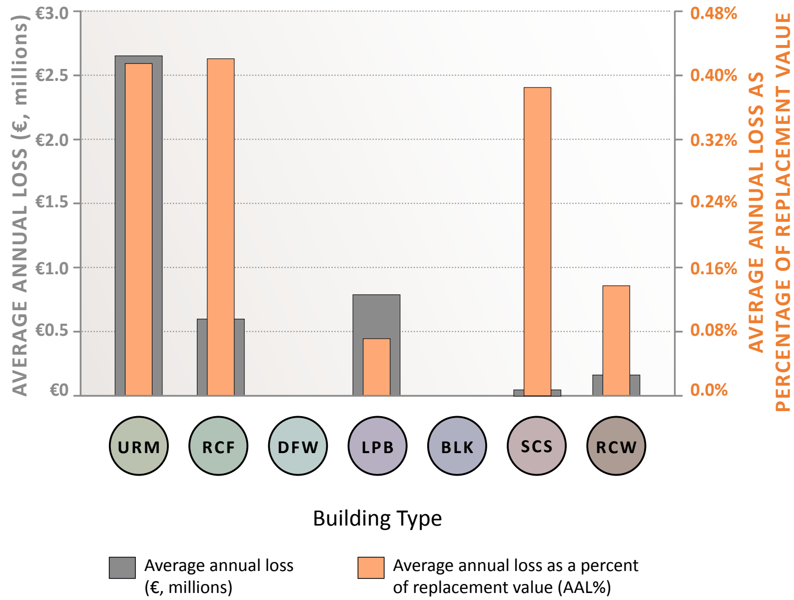
BUILDING CLASSIFICATION & VULNERABILITY RANGE

Description	Type	Vulnerability (Lo. Med. Hi.)
Unreinforced Masonry: built with masonry walls that lack steel reinforcement; includes confined and unconfined walls.	URM	unconfined; confined
Reinforced Concrete Frame: reinforced concrete frames that provide earthquake resistance; includes precast and cast-in-place frames.	RCF	precast; cast-in-place
Dual Frame-wall: reinforced concrete frame and wall elements work together to resist earthquake forces.	DFW	
Precast Large Panel: built with precast reinforced concrete panels with floor-to-ceiling height facade panels.	LPB	
Block: built with precast concrete elements assembled on site; similar to LPB with smaller facade elements.	BLK	
Slab-column System: reinforced concrete floor slabs directly connected to concrete columns; includes lift slabs and post-stressed slabs.	SCS	lift-slab; post-stressed
Reinforced Concrete Wall: cast-in-place walls that provide earthquake resistance; includes standard, sliding, and tunnel formwork.	RCW	sliding; tunnel & standard



Note that the relative vulnerabilities are approximate and depend on post-construction modifications, degradation, construction quality, and year of construction. See Types of Multifamily Buildings in ECA for more information.

ABSOLUTE AND RELATIVE LOSS



Bishkek

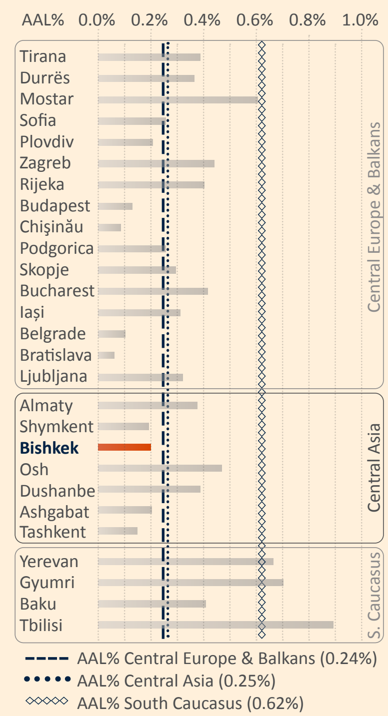
EARTHQUAKE IMPACTS SNAPSHOT

▷ Average annual loss from earthquake damage to multifamily residences is **€4.28 million**.

▷ This amounts to **0.06%** of the country's GDP.

▷ Nearly **38%** of the city's population lives in multifamily residential buildings.

LOSS COMPARISON TO REGION



High-Risk Buildings in Bishkek

Reinforced concrete frame and masonry are the two highest-risk building types used for pre-2000 multifamily housing in Bishkek.

~143,000 people live in these buildings, or **14%** of the total population of Bishkek

RCF
URM

Reinforced Concrete Frame (RCF) and Unreinforced Masonry (URM) buildings contribute to:

77% of total **loss** from building damage

61% of all **permanent residential displacement** in the next 50 years from building damage due to earthquakes

60% of **fatalities** in multifamily buildings*

*This is an average number of fatalities when assessed over many years.

References: See *City Profile Sources* for information on building types, classification, and exposure data sources. Image credit: "Bishkek, Kyrgyzstan" by Ninara, licensed under CC BY 2.0 / Lowered opacity from original.

Osh | KYRGYZ REPUBLIC

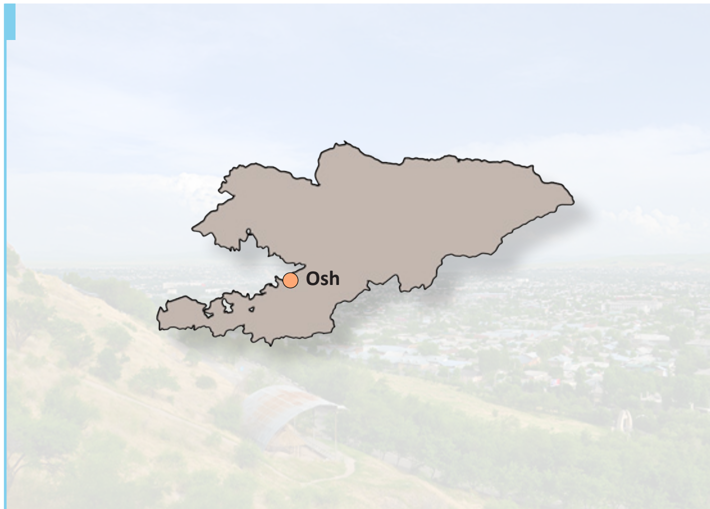
Summary

Osh, the second largest city in the Kyrgyz Republic, is considered the capital of the south and is home to over 4 percent of the total population. The Kyrgyz Republic has faced several large earthquakes in the past, the most damaging of which was the Suusamyr earthquake that occurred in Toluk in 1992. This magnitude 7.5 event killed 75 people, destroyed over 8,000 houses, and caused damage of €217 million (2019 €) . More recently, in 2008, the country experienced a magnitude 6.6 earthquake centered in the town of Nura. That earthquake killed 74 people and injured 140.

Based on the analysis, almost 45 percent of the population of Osh resides in pre-2000 multifamily residential buildings. The buildings that are the most at risk* are unreinforced masonry (URM) buildings and reinforced concrete frame (RCF) buildings. These two building types are also expected to cause the most fatalities. Approximately 105,000 people, or about two in every five inhabitants in Osh, reside in high-risk building types.

Compared to the data for all the buildings in this study, the data used to conduct the risk analysis for buildings in Osh average a **medium** reliability; this rating is a function of the assumptions, uncertainties, and data available for the city (see *Methodology*). The diagram below indicates the reliability and confidence related to building stock data (i.e., exposure data) as well as data for building vulnerability. These confidence and reliability levels should be considered when interpreting and applying the risk metrics presented in the city profile.

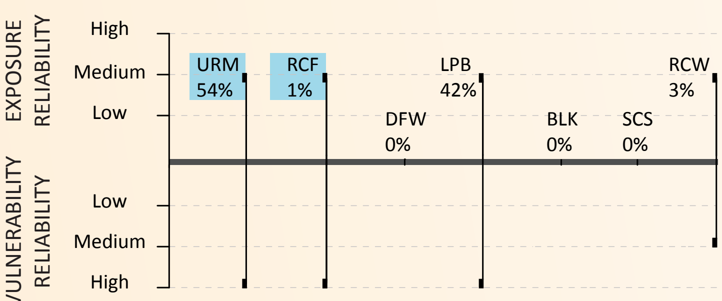
*At risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The expected loss results are predicted from models of future events subject to variable data availability and modeling assumptions. The replacement value is the construction cost of all multifamily buildings in the city.



OSH FACTS

Second Largest City | Population: 257,000 (2017) | GNI/capita: ~€1,000

Data Reliability and Building Exposure



Building exposure data is for pre-2000 multifamily buildings.

▷ Data on building stock and population (exposure) and their susceptibility to earthquake losses (vulnerability) for the city is conveyed with vertical bars labeled by the building typology acronym.
▷ The diagram also indicates the percentage of total building stock that a typology comprises in the city denoted as a percentage below the building typology acronym. Highlighted building types are those that are considered highest risk in the city.

Earthquake Event-Based Losses

	€ Total building damage	% Building damage, % of total value	Number of fatalities
100-year Return Period	€ 28 M 4% GNIPC	10%	430 people
475-year Return Period	€ 95 M 12% GNIPC	35%	2,000 people

▷ A 100-year return period event is one where the damage and loss have approximately a 40% probability of being exceeded in 50 years; it is considered a more frequent event. A 475-year return period event is one where the damage and loss have approximately a 10% probability of being exceeded in 50 years; it is considered a less frequent event, more damaging event.
▷ GNIPC is gross national income per capita. Percentage of GNIPC is the losses from damage per resident as a percentage of GNIPC.
▷ The fatalities presented are those that are expected to occur at nighttime (2:00 a.m.) on a weekend.
▷ *Note: Event-based losses are subject to limitation by the reliability of the input data. The chosen return periods do not suggest that more hazardous and infrequent earthquake events are not probable in this city, as higher return period events may occur at any point.*

Country Snapshot

GDP
6.9 Billion Euros*

POPULATION
6.3 Million People*

SIGNIFICANT EARTHQUAKES
1885 Belovodskoje M6.9
1992 Suusamyr M7.5
2008 Nura M6.6

* 2018 estimate

WORLD BANK GROUP GFDRR

Earthquake Risk Profile

Building Damage Losses

BUILDING CLASSIFICATION & VULNERABILITY RANGE

Description

Unreinforced Masonry: built with masonry walls that lack steel reinforcement; includes confined and unconfined walls.

Reinforced Concrete Frame: reinforced concrete frames that provide earthquake resistance; includes precast and cast-in-place frames.

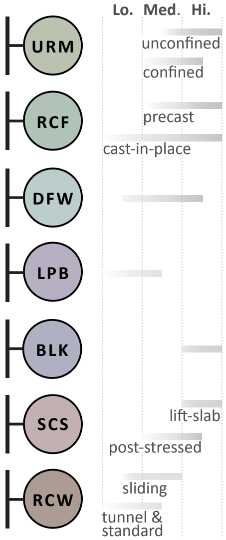
Dual Frame-wall: reinforced concrete frame and wall elements work together to resist earthquake forces.

Precast Large Panel: built with precast reinforced concrete panels with floor-to-ceiling height facade panels.

Block: built with precast concrete elements assembled on site; similar to LPB with smaller facade elements.

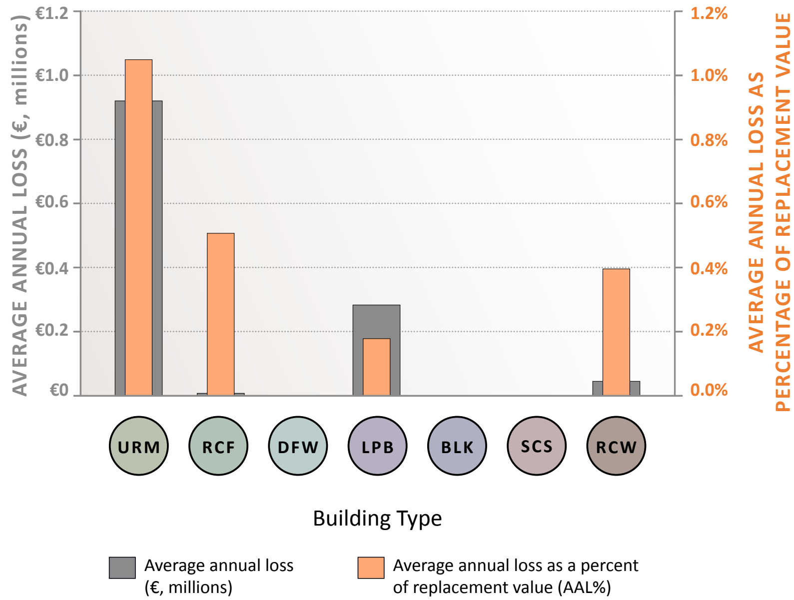
Slab-column System: reinforced concrete floor slabs directly connected to concrete columns; includes lift slabs and post-stressed slabs.

Reinforced Concrete Wall: cast-in-place walls that provide earthquake resistance; includes standard, sliding, and tunnel formwork.



Note that the relative vulnerabilities are approximate and depend on post-construction modifications, degradation, construction quality, and year of construction. See Types of Multifamily Buildings in ECA for more information.

ABSOLUTE AND RELATIVE LOSS



Osh

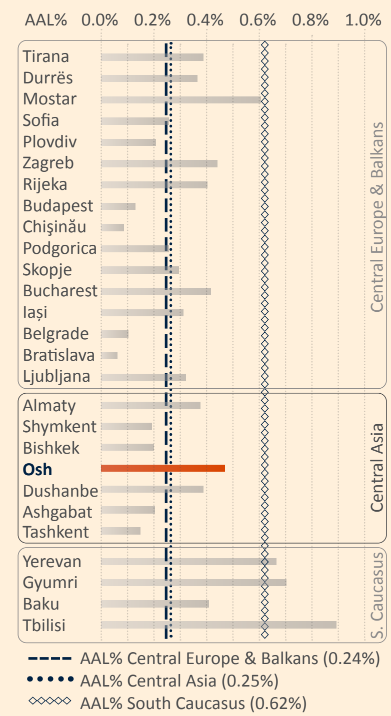
EARTHQUAKE IMPACTS SNAPSHOT

▷ Average annual loss from earthquake damage to multifamily residences is **€1.27 million**.

▷ This amounts to **0.02%** of the country's GDP.

▷ Nearly **44%** of the city's population lives in multifamily residential buildings.

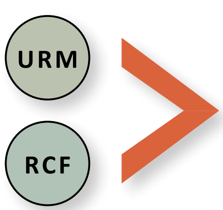
LOSS COMPARISON TO REGION



High-Risk Buildings in Osh

Masonry and reinforced concrete frame are the two highest-risk building types used for pre-2000 multifamily housing in Osh.

~105,000 people live in these buildings, or **41%** of the total population of Osh



Unreinforced Masonry (URM) and Reinforced Concrete Frame (RCF) buildings contribute to:

73% of total **loss** from building damage

78% of all **permanent residential displacement** in the next 50 years from building damage due to earthquakes

76% of **fatalities** in multifamily buildings*

*This is an average number of fatalities when assessed over many years.

References: See *City Profile Sources* for information on building types, classification, and exposure data sources.

Dushanbe | TAJIKISTAN

Summary

Dushanbe is Tajikistan's capital and largest city, home to nearly 10 percent of the country's total population. Tajikistan has been affected by many catastrophic earthquakes, the most deadly of which was the 1907 magnitude 7.4 event in Karatag that led to the loss of 12,000 lives. In 1985, a magnitude 5.9 earthquake near the Kayrakkum-Gafurov region caused 29 deaths, 80 injuries, and €428 million (2019 €) in damage. More recently, in 2015, a magnitude 7.2 earthquake located near Sarez Lake killed two, injured dozens, destroyed 500 homes, and resulted in nearly €5 million (2019 €) in damage.

Based on the analysis, more than half of the population of Dushanbe resides in pre-2000 multifamily residential buildings. The buildings that are the most at risk* are slab-column system (SCS) buildings and unreinforced masonry (URM) buildings. Along with reinforced concrete frame (RCF) buildings, these building types are also expected to cause the most fatalities. Approximately 67,000 people, or about 8 percent of the city's population, reside in high-risk building types.

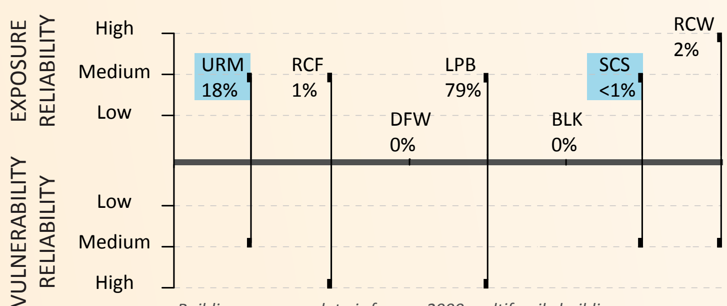
Compared to the data for all the buildings in this study, the data used to conduct the risk analysis for buildings in Dushanbe average a **medium** reliability; this rating is a function of the assumptions, uncertainties, and data available for the city (see *Methodology*). The diagram below indicates the reliability and confidence related to building stock data (i.e., exposure data) as well as data for building vulnerability. These confidence and reliability levels should be considered when interpreting and applying the risk metrics presented in the city profile.

*At risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The expected loss results are predicted from models of future events subject to variable data availability and modeling assumptions. The replacement value is the construction cost of all multifamily buildings in the city.

DUSHANBE FACTS

Capital City | Population: 846,000 (2019) | GNI/capita: ~€900

Data Reliability and Building Exposure



Building exposure data is for pre-2000 multifamily buildings.

▷ Data on building stock and population (exposure) and their susceptibility to earthquake losses (vulnerability) for the city is conveyed with vertical bars labeled by the building typology acronym.
▷ The diagram also indicates the percentage of total building stock that a typology comprises in the city denoted as a percentage below the building typology acronym. Highlighted building types are those that are considered highest risk in the city.

Earthquake Event-Based Losses

	€ Total building damage	% Building damage, % of total value	Number of fatalities
100-year Return Period	€ 81 M 21% GNIPC	10%	560 people
475-year Return Period	€ 273 M 70% GNIPC	33%	4,600 people

▷ A 100-year return period event is one where the damage and loss have approximately a 40% probability of being exceeded in 50 years; it is considered a more frequent event. A 475-year return period event is one where the damage and loss have approximately a 10% probability of being exceeded in 50 years; it is considered a less frequent event, more damaging event.
▷ GNIPC is gross national income per capita. Percentage of GNIPC is the losses from damage per resident as a percentage of GNIPC.
▷ The fatalities presented are those that are expected to occur at nighttime (2:00 a.m.) on a weekend.
▷ *Note: Event-based losses are subject to limitation by the reliability of the input data. The chosen return periods do not suggest that more hazardous and infrequent earthquake events are not probable in this city, as higher return period events may occur at any point.*

Country Snapshot

GDP
6.4 Billion Euros*

POPULATION
9.1 Million People*

SIGNIFICANT EARTHQUAKES
1907 Karatag M7.4
1985 Kayrakkum-Gafurov M5.9
2015 Sarez M7.2

* 2018 estimate

WORLD BANK GROUP GFDRR

Earthquake Risk Profile

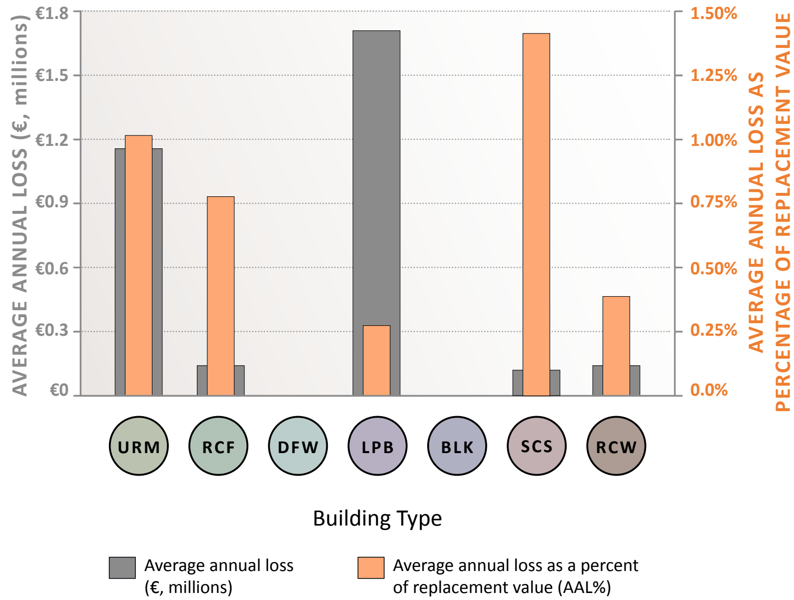
Building Damage Losses

BUILDING CLASSIFICATION & VULNERABILITY RANGE

Description	Type	Vulnerability (Lo. Med. Hi.)
Unreinforced Masonry: built with masonry walls that lack steel reinforcement; includes confined and unconfined walls.	URM	unconfined; confined
Reinforced Concrete Frame: reinforced concrete frames that provide earthquake resistance; includes precast and cast-in-place frames.	RCF	precast; cast-in-place
Dual Frame-wall: reinforced concrete frame and wall elements work together to resist earthquake forces.	DFW	
Precast Large Panel: built with precast reinforced concrete panels with floor-to-ceiling height facade panels.	LPB	
Block: built with precast concrete elements assembled on site; similar to LPB with smaller facade elements.	BLK	
Slab-column System: reinforced concrete floor slabs directly connected to concrete columns; includes lift slabs and post-stressed slabs.	SCS	lift-slab; post-stressed
Reinforced Concrete Wall: cast-in-place walls that provide earthquake resistance; includes standard, sliding, and tunnel formwork.	RCW	sliding; tunnel & standard

Note that the relative vulnerabilities are approximate and depend on post-construction modifications, degradation, construction quality, and year of construction. See Types of Multifamily Buildings in ECA for more information.

ABSOLUTE AND RELATIVE LOSS



Dushanbe

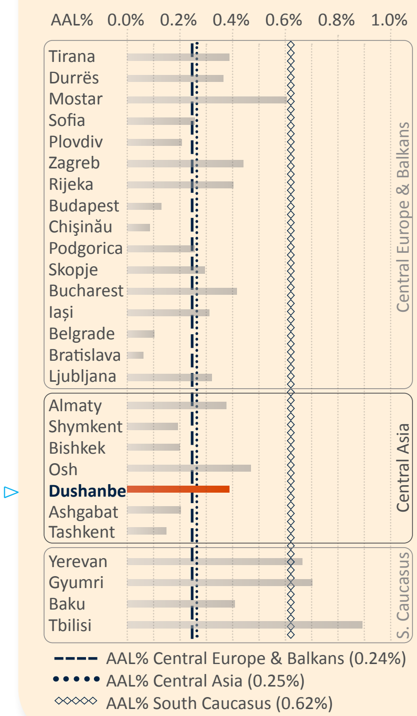
EARTHQUAKE IMPACTS SNAPSHOT

▷ Average annual loss from earthquake damage to multifamily residences is **€3.21 million**.

▷ This amounts to **0.05%** of the country's GDP.

▷ Nearly **54%** of the city's population lives in multifamily residential buildings.

LOSS COMPARISON TO REGION



High-Risk Buildings in Dushanbe

Slab-column system and masonry are the two highest-risk building types used for pre-2000 multifamily housing in Dushanbe.

~67,000 people live in these buildings, or **8%** of the total population of Dushanbe

SCS

URM

Slab-column System (SCS) and Unreinforced Masonry (URM) buildings contribute to:

40% of total **loss** from building damage

58% of all **permanent residential displacement** in the next 50 years from building damage due to earthquakes

39% of **fatalities** in multifamily buildings*

*This is an average number of fatalities when assessed over many years.

References: See *City Profile Sources* for information on building types, classification, and exposure data sources.

Ashgabat | TURKMENISTAN

Summary

Ashgabat is the capital and largest city of Turkmenistan, home to nearly 15 percent of the total population. Turkmenistan has experienced devastating earthquakes in the past, including a catastrophic 7.3 magnitude event in 1948 centered in Ashgabat. The Ashgabat earthquake killed 110,000 people, caused the collapse of many brick buildings, and resulted in over €240 million (2019 €) in damage. More recently, in 2000, a magnitude 7.0 event located near the city of Balkanabat led to the deaths of 11 individuals.

Based on the analysis, almost 40 percent of the population of Ashgabat resides in pre-2000 multifamily residential buildings. The buildings that are the most at risk* are unreinforced masonry (URM) buildings and reinforced concrete frame (RCF) buildings. These two building types are also expected to cause the most fatalities. Nearly 115,000 people, or about 14 percent of the city's inhabitants, reside in high-risk building types.

Compared to the data for all the buildings in this study, the data used to conduct the risk analysis for buildings in Ashgabat average the **highest** reliability; this rating is a function of the assumptions, uncertainties, and data available for the city (see *Methodology*). The diagram below indicates the reliability and confidence related to building stock data (i.e., exposure data) as well as the data for building vulnerability. These confidence and reliability levels should be considered when interpreting and applying the risk metrics presented in the city profile.

*At risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The expected loss results are predicted from models of future events subject to variable data availability and modeling assumptions. The replacement value is the construction cost of all multifamily buildings in the city.

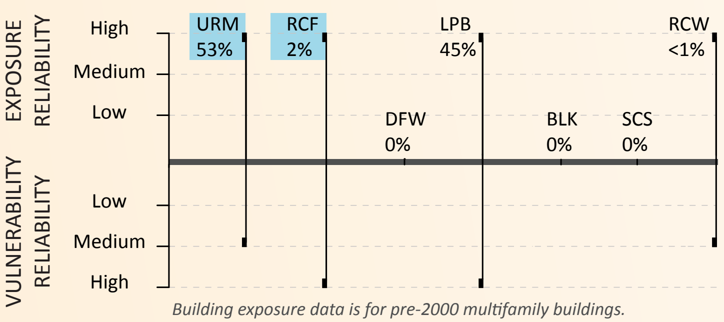
ASHGABAT FACTS

Capital City

Population: 828,000 (2019)

GNI/capita: ~€5,700

Data Reliability and Building Exposure



Building exposure data is for pre-2000 multifamily buildings.

▷ Data on building stock and population (exposure) and their susceptibility to earthquake losses (vulnerability) for the city is conveyed with vertical bars labeled by the building typology acronym.
▷ The diagram also indicates the percentage of total building stock that a typology comprises in the city denoted as a percentage below the building typology acronym. Highlighted building types are those that are considered highest risk in the city.

Earthquake Event-Based Losses

	€ Total building damage	% Building damage, % of total value	Number of fatalities
100-year Return Period	€ 100 M 6% GNIPC	10%	570 people
475-year Return Period	€ 600 M 33% GNIPC	22%	2,800 people

▷ A 100-year return period event is one where the damage and loss have approximately a 40% probability of being exceeded in 50 years; it is considered a more frequent event. A 475-year return period event is one where the damage and loss have approximately a 10% probability of being exceeded in 50 years; it is considered a less frequent event, more damaging event.
▷ GNIPC is gross national income per capita. Percentage of GNIPC is the losses from damage per resident as a percentage of GNIPC.
▷ The fatalities presented are those that are expected to occur at nighttime (2:00 a.m.) on a weekend.
▷ *Note: Event-based losses are subject to limitation by the reliability of the input data. The chosen return periods do not suggest that more hazardous and infrequent earthquake events are not probable in this city, as higher return period events may occur at any point.*

Country Snapshot

GDP
34.5 Billion Euros*

POPULATION
5.9 Million People*

SIGNIFICANT EARTHQUAKES
1946 Kazandzhik M6.9
1948 Ashgabat M7.3
2000 Balkanabat M7.0

* 2018 estimate

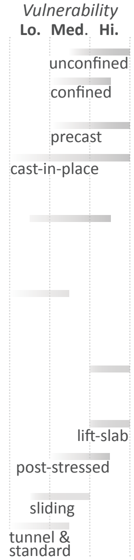
WORLD BANK GROUP GFDRR

Earthquake Risk Profile

Building Damage Losses

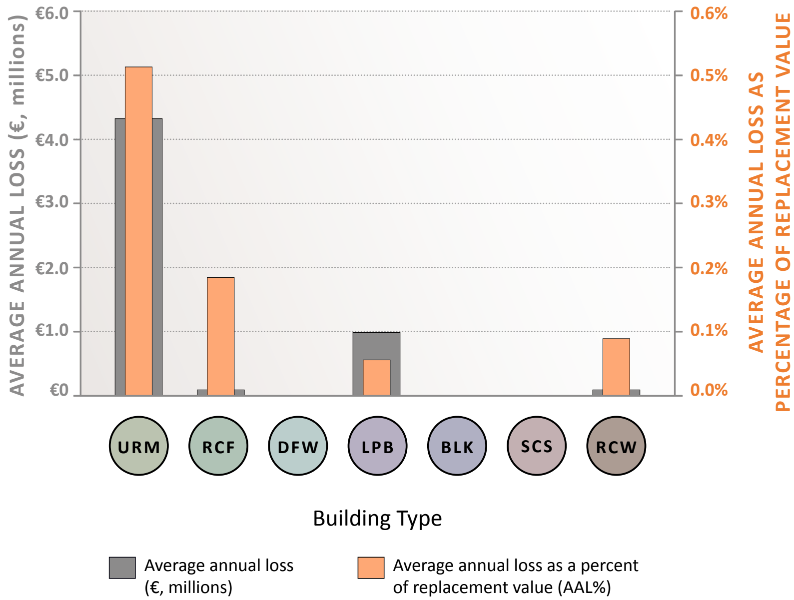
BUILDING CLASSIFICATION & VULNERABILITY RANGE

Description	Type
Unreinforced Masonry: built with masonry walls that lack steel reinforcement; includes confined and unconfined walls.	URM
Reinforced Concrete Frame: reinforced concrete frames that provide earthquake resistance; includes precast and cast-in-place frames.	RCF
Dual Frame-wall: reinforced concrete frame and wall elements work together to resist earthquake forces.	DFW
Precast Large Panel: built with precast reinforced concrete panels with floor-to-ceiling height facade panels.	LPB
Block: built with precast concrete elements assembled on site; similar to LPB with smaller facade elements.	BLK
Slab-column System: reinforced concrete floor slabs directly connected to concrete columns; includes lift slabs and post-stressed slabs.	SCS
Reinforced Concrete Wall: cast-in-place walls that provide earthquake resistance; includes standard, sliding, and tunnel formwork.	RCW



Note that the relative vulnerabilities are approximate and depend on post-construction modifications, degradation, construction quality, and year of construction. See Types of Multifamily Buildings in ECA for more information.

ABSOLUTE AND RELATIVE LOSS



Ashgabat

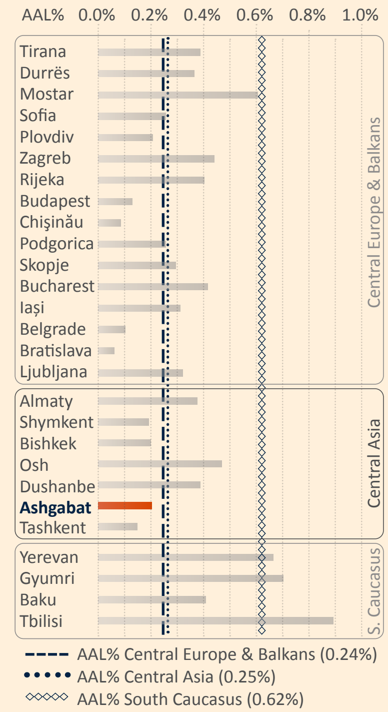
EARTHQUAKE IMPACTS SNAPSHOT

▷ Average annual loss from earthquake damage to multifamily residences is **€5.45 million**.

▷ This amounts to **0.02%** of the country's GDP.

▷ Nearly **39%** of the city's population lives in multifamily residential buildings.

LOSS COMPARISON TO REGION



High-Risk Buildings in Ashgabat

Masonry and reinforced concrete frame are the two highest-risk building types used for pre-2000 multifamily housing in Ashgabat.

~115,000 people live in these buildings, or **14%** of the total population of Ashgabat

URM
RCF

Unreinforced Masonry (URM) and Reinforced Concrete Frame (RCF) buildings contribute to:

82% of total **loss** from building damage

91% of all **permanent residential displacement** in the next 50 years from building damage due to earthquakes

83% of **fatalities** in multifamily buildings*

*This is an average number of fatalities when assessed over many years.

References: See *City Profile Sources* for information on building types, classification, and exposure data sources.

Tashkent | UZBEKISTAN

Summary

Tashkent is Uzbekistan's capital and largest city, home to about 8 percent of the country's total population. Uzbekistan has been impacted by catastrophic earthquakes in the 20th century, the most deadly of which was the magnitude 6.4 Andijan earthquake in 1902 that caused 5,000 deaths. In 1966, a magnitude 5.1 earthquake in Tashkent destroyed 80 percent of the city, with total damage estimated at over €2 billion (2019 €). Masonry buildings were hard hit—many were damaged or destroyed. More recently, in 2011, the magnitude 6.1 Fergana Valley earthquake killed 14 people and injured 86 in Uzbekistan. After the 1966 earthquake, the very vulnerable unconfined masonry building type was no longer built.

Based on the analysis, over 60 percent of the population of Tashkent resides in pre-2000 multifamily residential buildings. The buildings that are the most at risk* are slab-column system (SCS) buildings and unreinforced masonry (URM) buildings. Along with reinforced concrete frame (RCF) buildings, these building types are also expected to cause the most fatalities. Approximately 550,000 people, over one in every five people in Tashkent, reside in high-risk building types.

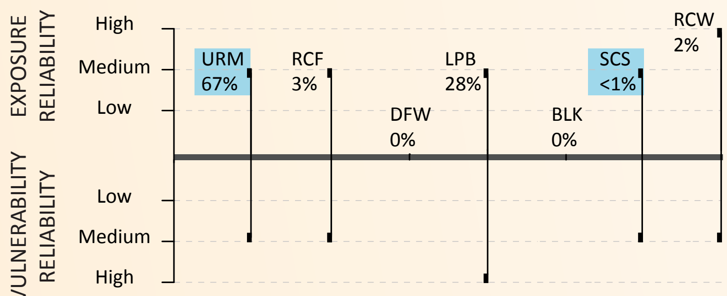
Compared to the data for all the buildings in this study, the data used to conduct the risk analysis for buildings in Tashkent average a **medium** reliability; this rating is a function of the assumptions, uncertainties, and data available for the city (see *Methodology*). The diagram below indicates the reliability and confidence related to building stock data (i.e., exposure data) as well as data for building vulnerability. These confidence and reliability levels should be considered when interpreting and applying the risk metrics presented in the city profile.

*At risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The expected loss results are predicted from models of future events subject to variable data availability and modeling assumptions. The replacement value is the construction cost of all multifamily buildings in the city.

TASHKENT FACTS

Capital City | Population: 2,490,000 (2019) | GNI/capita: ~€1,700

Data Reliability and Building Exposure



Building exposure data is for pre-2000 multifamily buildings.

▷ Data on building stock and population (exposure) and their susceptibility to earthquake losses (vulnerability) for the city is conveyed with vertical bars labeled by the building typology acronym.
▷ The diagram also indicates the percentage of total building stock that a typology comprises in the city denoted as a percentage below the building typology acronym. Highlighted building types are those that are considered highest risk in the city.

Earthquake Event-Based Losses

	€ Total building damage	% Building damage, % of total value	Number of fatalities
100-year Return Period	€ 200 M 7% GNIPC	2%	100 people
475-year Return Period	€ 1.5 B 56% GNIPC	17%	3,000 people

▷ A 100-year return period event is one where the damage and loss have approximately a 40% probability of being exceeded in 50 years; it is considered a more frequent event. A 475-year return period event is one where the damage and loss have approximately a 10% probability of being exceeded in 50 years; it is considered a less frequent event, more damaging event.
▷ GNIPC is gross national income per capita. Percentage of GNIPC is the losses from damage per resident as a percentage of GNIPC.
▷ The fatalities presented are those that are expected to occur at nighttime (2:00 a.m.) on a weekend.
▷ *Note: Event-based losses are subject to limitation by the reliability of the input data. The chosen return periods do not suggest that more hazardous and infrequent earthquake events are not probable in this city, as higher return period events may occur at any point.*

Country Snapshot

GDP
42.7 Billion Euros*

POPULATION
33.0 Million People*

SIGNIFICANT EARTHQUAKES
1902 Andizhan M6.4
1966 Tashkent M5.1
2011 Fergana Valley M6.1

* 2018 estimate

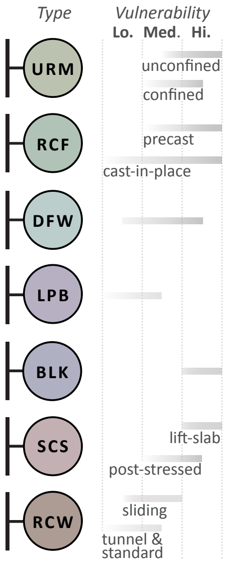
WORLD BANK GROUP GFDRR

Earthquake Risk Profile

Building Damage Losses

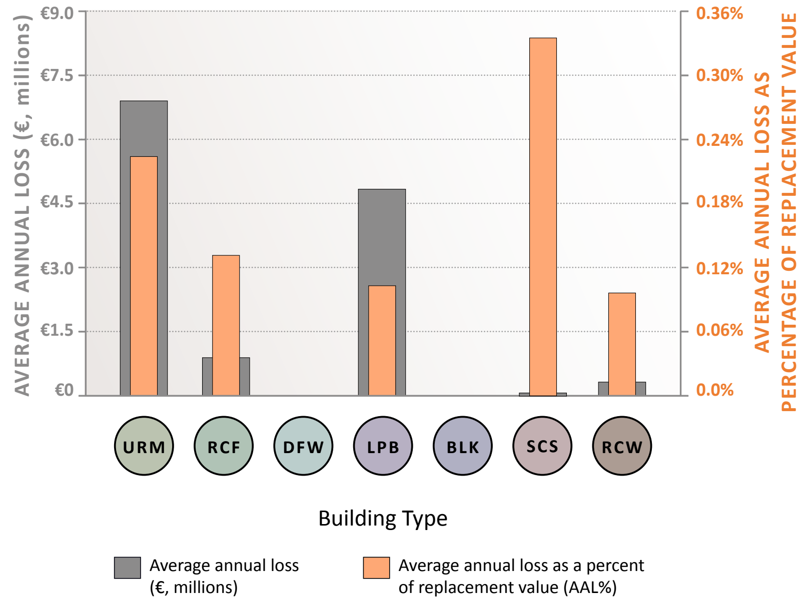
BUILDING CLASSIFICATION & VULNERABILITY RANGE

Description	Type
Unreinforced Masonry: built with masonry walls that lack steel reinforcement; includes confined and unconfined walls.	URM
Reinforced Concrete Frame: reinforced concrete frames that provide earthquake resistance; includes precast and cast-in-place frames.	RCF
Dual Frame-wall: reinforced concrete frame and wall elements work together to resist earthquake forces.	DFW
Precast Large Panel: built with precast reinforced concrete panels with floor-to-ceiling height facade panels.	LPB
Block: built with precast concrete elements assembled on site; similar to LPB with smaller facade elements.	BLK
Slab-column System: reinforced concrete floor slabs directly connected to concrete columns; includes lift slabs and post-stressed slabs.	SCS
Reinforced Concrete Wall: cast-in-place walls that provide earthquake resistance; includes standard, sliding, and tunnel formwork.	RCW



Note that the relative vulnerabilities are approximate and depend on post-construction modifications, degradation, construction quality, and year of construction. See Types of Multifamily Buildings in ECA for more information.

ABSOLUTE AND RELATIVE LOSS

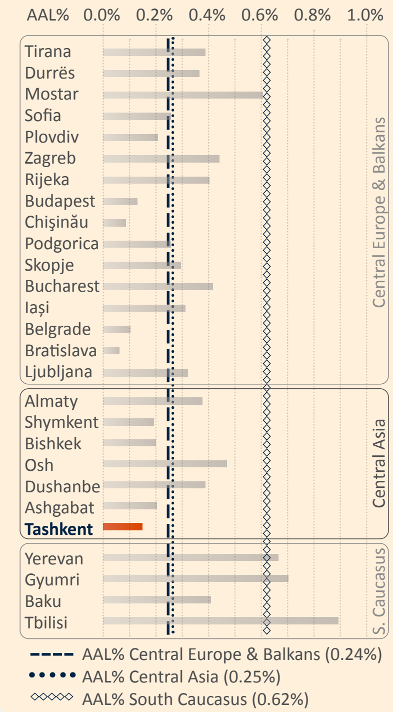


Tashkent

EARTHQUAKE IMPACTS SNAPSHOT

- Average annual loss from earthquake damage to multifamily residences is **€13.0 million**.
- This amounts to **0.03%** of the country's GDP.
- Nearly **62%** of the city's population lives in multifamily residential buildings.

LOSS COMPARISON TO REGION



High-Risk Buildings in Tashkent

Slab-column system and masonry are the two highest-risk building types used for pre-2000 multifamily housing in Tashkent.

~550,000 people live in these buildings, or **22%** of the total population of Tashkent

SCS
URM

Slab-column System (SCS) and Unreinforced Masonry (URM) buildings contribute to:

54% of total **loss** from building damage

64% of all **permanent residential displacement** in the next 50 years from building damage due to earthquakes

43% of **fatalities** in multifamily buildings*

*This is an average number of fatalities when assessed over many years.

References: See *City Profile Sources* for information on building types, classification, and exposure data sources.

Yerevan | ARMENIA

Summary

Yerevan is the capital and largest city of Armenia, home to over 35 percent of the country's total population. Armenia has faced large earthquakes in the past, the most catastrophic of which was the 1988 magnitude 6.8 earthquake in Spitak. This earthquake caused up to 25,000 deaths, injured 130,000 people, and left 500,000 people homeless, with damage totaling over €31 billion (2019 €). It affected 40 percent of the population of Armenia, with nearly 95 percent of Spitak itself completely destroyed. Precast reinforced concrete masonry buildings as well as slab-column system buildings suffered severe damage or total collapse. The event significantly affected the multifamily residential building stock and design practice, and this research found that precast reinforced concrete structures were no longer constructed in Gyumri and Yerevan after 1988.

Based on the analysis, over 70 percent of the population of Yerevan resides in pre-2000 multifamily residential buildings. The buildings that are the most at risk* are unreinforced masonry (URM) buildings and slab-column system (SCS) buildings. These two building types are also expected to cause the most fatalities. Approximately 250,000 people, or about one in every four inhabitants of Yerevan, reside in high-risk building types.

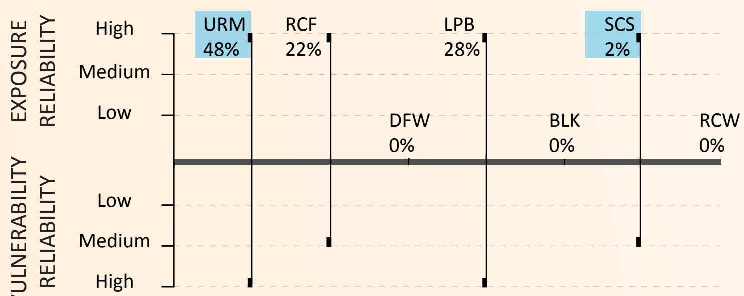
Compared to the data for all the buildings in this study, the data used to conduct the risk analysis for buildings in Yerevan average a **high** reliability; this rating is a function of the assumptions, uncertainties, and data available for the city (see *Methodology*). The diagram below indicates the reliability and confidence related to building stock data (i.e., exposure data) as well as data on building vulnerability. These confidence and reliability levels should be considered when interpreting and applying the risk metrics presented in the city profile.

*At risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The expected loss results are predicted from models of future events subject to variable data availability and modeling assumptions. The replacement value is the construction cost of all multifamily buildings in the city.

YEREVAN FACTS

Capital City | Population: 1,093,000 (2019) | GNI/capita: ~€3,600

Data Reliability and Building Exposure



Building exposure data is for pre-2000 multifamily buildings.

▷ Data on building stock and population (exposure) and their susceptibility to earthquake losses (vulnerability) for the city is conveyed with vertical bars labeled by the building typology acronym.
▷ The diagram also indicates the percentage of total building stock that a typology comprises in the city denoted as a percentage below the building typology acronym. Highlighted building types are those that are considered highest risk in the city.

Earthquake Event-Based Losses

	€ Total building damage	% Building damage, % of total value	Number of fatalities
100-year Return Period	€ 1.8 B 64% GNIPC	16%	3,000 people
475-year Return Period	€ 5.0 B 180% GNIPC	46%	10,600 people

▷ A 100-year return period event is one where the damage and loss have approximately a 40% probability of being exceeded in 50 years; it is considered a more frequent event. A 475-year return period event is one where the damage and loss have approximately a 10% probability of being exceeded in 50 years; it is considered a less frequent event, more damaging event.
▷ GNIPC is gross national income per capita. Percentage of GNIPC is the losses from damage per resident as a percentage of GNIPC.
▷ The fatalities presented are those that are expected to occur at nighttime (2:00 a.m.) on a weekend.
▷ *Note: Event-based losses are subject to limitation by the reliability of the input data. The chosen return periods do not suggest that more hazardous and infrequent earthquake events are not probable in this city, as higher return period events may occur at any point.*

Country Snapshot

GDP
10.5 Billion Euros*

POPULATION
3.0 Million People*

SIGNIFICANT EARTHQUAKES
1679 Garnì M7.0
1931 Zangezur M6.3
1988 Spitak M6.8

* 2018 estimate

WORLD BANK GROUP GFDRR

Earthquake Risk Profile

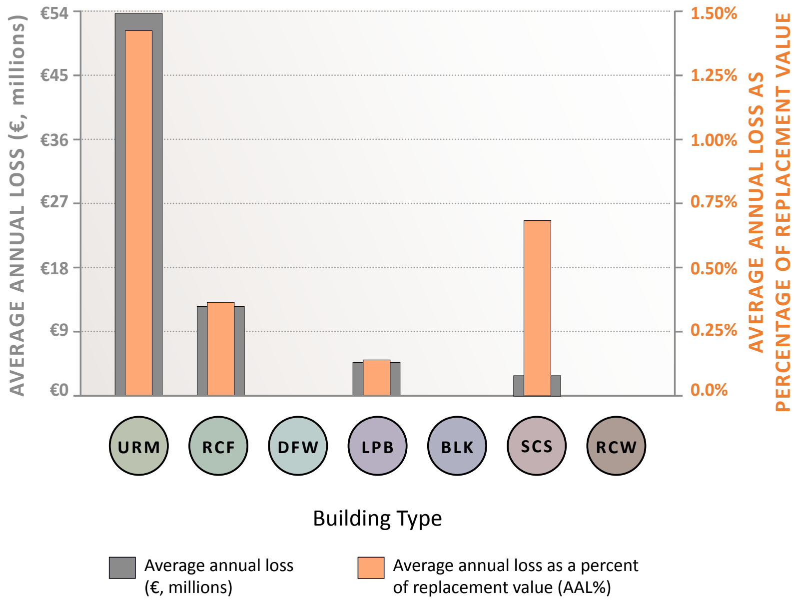
Building Damage Losses

BUILDING CLASSIFICATION & VULNERABILITY RANGE

Description	Type	Vulnerability (Lo. Med. Hi.)
Unreinforced Masonry: built with masonry walls that lack steel reinforcement; includes confined and unconfined walls.	URM	unconfined; confined
Reinforced Concrete Frame: reinforced concrete frames that provide earthquake resistance; includes precast and cast-in-place frames.	RCF	precast; cast-in-place
Dual Frame-wall: reinforced concrete frame and wall elements work together to resist earthquake forces.	DFW	
Precast Large Panel: built with precast reinforced concrete panels with floor-to-ceiling height facade panels.	LPB	
Block: built with precast concrete elements assembled on site; similar to LPB with smaller facade elements.	BLK	
Slab-column System: reinforced concrete floor slabs directly connected to concrete columns; includes lift slabs and post-stressed slabs.	SCS	lift-slab; post-stressed
Reinforced Concrete Wall: cast-in-place walls that provide earthquake resistance; includes standard, sliding, and tunnel formwork.	RCW	sliding; tunnel & standard

Note that the relative vulnerabilities are approximate and depend on post-construction modifications, degradation, construction quality, and year of construction. See Types of Multifamily Buildings in ECA for more information.

ABSOLUTE AND RELATIVE LOSS

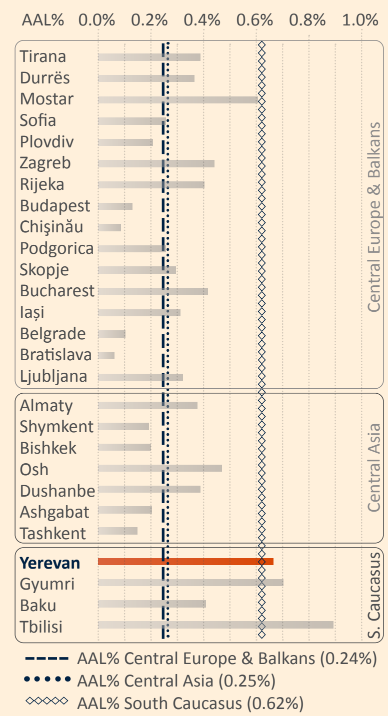


Yerevan

EARTHQUAKE IMPACTS SNAPSHOT

- Average annual loss from earthquake damage to multifamily residences is **€72.5 million**.
- This amounts to **0.69%** of the country's GDP.
- Nearly **71%** of the city's population lives in multifamily residential buildings.

LOSS COMPARISON TO REGION



High-Risk Buildings in Yerevan

Masonry and slab-column system are the two highest-risk building types used for pre-2000 multifamily housing in Yerevan.

~250,000 people live in these buildings, or **23%** of the total population of Yerevan

URM SCS

Unreinforced Masonry (URM) and Slab-column System (SCS) buildings contribute to:

77% of total **loss** from building damage

75% of all **permanent residential displacement** in the next 50 years from building damage due to earthquakes

77% of **fatalities** in multifamily buildings*

*This is an average number of fatalities when assessed over many years.

References: See *City Profile Sources* for information on building types, classification, and exposure data sources.

Gyumri | ARMENIA

Summary

Gyumri is Armenia's second largest city and home to 4 percent of the country's total population. Armenia has faced large earthquakes in the past, the most catastrophic of which was the 1988 magnitude 6.8 earthquake in Spitak. This earthquake caused up to 25,000 deaths, injured 130,000 people, and left 500,000 people homeless, with damage totaling over €31 billion (2019 €). It affected 40 percent of the population of Armenia, with nearly 95 percent of Spitak itself completely destroyed. Precast reinforced concrete masonry buildings as well as slab-column system buildings suffered severe damage or total collapse. The event significantly affected the multifamily residential building stock and design practice, and this research found that precast reinforced concrete structures were no longer constructed in Gyumri and Yerevan after 1988.

Based on the analysis, almost 40 percent of the population of Gyumri resides in pre-2000 multifamily residential buildings. The buildings that are the most at risk* are unreinforced masonry (URM) buildings and reinforced concrete frame (RCF) buildings. These two building types are also expected to cause the most fatalities. Approximately 43,000 people, or about 40 percent of the inhabitants of Gyumri, reside in high-risk building types.

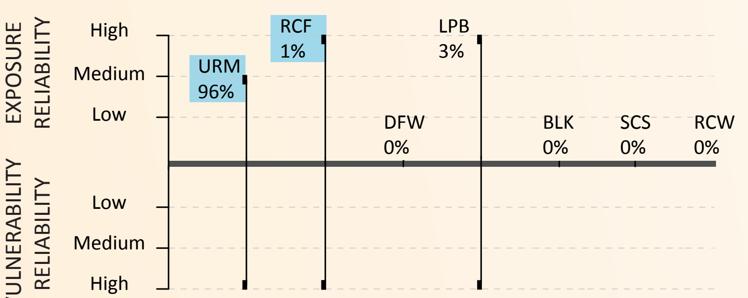
Compared to the data for all the buildings in this study, the data used to conduct the risk analysis for buildings in Gyumri average a **high** reliability; this rating is a function of the assumptions, uncertainties, and data available for the city (see *Methodology*). The diagram below indicates the reliability and confidence related to building stock data (i.e., exposure data) as well as data for building vulnerability. These confidence and reliability levels should be considered when interpreting and applying the risk metrics presented in the city profile.

*At risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The expected loss results are predicted from models of future events subject to variable data availability and modeling assumptions. The replacement value is the construction cost of all multifamily buildings in the city.

GYUMRI FACTS

Second Largest City | Population: 117,000 (2019) | GNI/capita: ~€3,600

Data Reliability and Building Exposure



Building exposure data is for pre-2000 multifamily buildings.

▷ Data on building stock and population (exposure) and their susceptibility to earthquake losses (vulnerability) for the city is conveyed with vertical bars labeled by the building typology acronym.
▷ The diagram also indicates the percentage of total building stock that a typology comprises in the city denoted as a percentage below the building typology acronym. Highlighted building types are those that are considered highest risk in the city.

Earthquake Event-Based Losses

	€ Total building damage	% Building damage, % of total value	Number of fatalities
100-year Return Period	€ 242 M 147% GNIPC	21%	320 people
475-year Return Period	€ 755 M 460% GNIPC	65%	1,300 people

▷ A 100-year return period event is one where the damage and loss have approximately a 40% probability of being exceeded in 50 years; it is considered a more frequent event. A 475-year return period event is one where the damage and loss have approximately a 10% probability of being exceeded in 50 years; it is considered a less frequent event, more damaging event.
▷ GNIPC is gross national income per capita. Percentage of GNIPC is the losses from damage per resident as a percentage of GNIPC.
▷ The fatalities presented are those that are expected to occur at nighttime (2:00 a.m.) on a weekend.
▷ *Note: Event-based losses are subject to limitation by the reliability of the input data. The chosen return periods do not suggest that more hazardous and infrequent earthquake events are not probable in this city, as higher return period events may occur at any point.*

Country Snapshot

GDP
10.5 Billion Euros*

POPULATION
3.0 Million People*

SIGNIFICANT EARTHQUAKES
1679 Garnì M7.0
1931 Zangezur M6.3
1988 Spitak M6.8

* 2018 estimate

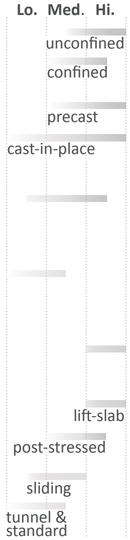
WORLD BANK GROUP | GFDRR

Earthquake Risk Profile

Building Damage Losses

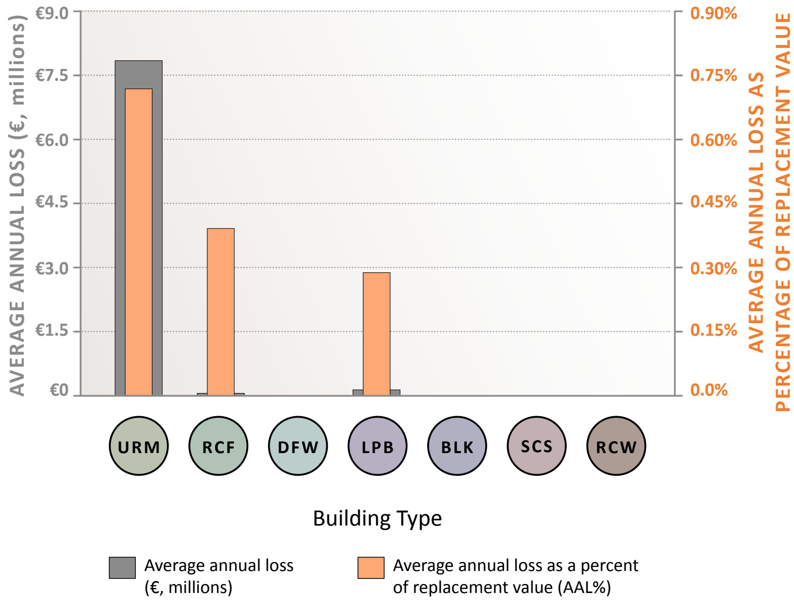
BUILDING CLASSIFICATION & VULNERABILITY RANGE

Description	Type
Unreinforced Masonry: built with masonry walls that lack steel reinforcement; includes confined and unconfined walls.	URM
Reinforced Concrete Frame: reinforced concrete frames that provide earthquake resistance; includes precast and cast-in-place frames.	RCF
Dual Frame-wall: reinforced concrete frame and wall elements work together to resist earthquake forces.	DFW
Precast Large Panel: built with precast reinforced concrete panels with floor-to-ceiling height facade panels.	LPB
Block: built with precast concrete elements assembled on site; similar to LPB with smaller facade elements.	BLK
Slab-column System: reinforced concrete floor slabs directly connected to concrete columns; includes lift slabs and post-stressed slabs.	SCS
Reinforced Concrete Wall: cast-in-place walls that provide earthquake resistance; includes standard, sliding, and tunnel formwork.	RCW



Note that the relative vulnerabilities are approximate and depend on post-construction modifications, degradation, construction quality, and year of construction. See Types of Multifamily Buildings in ECA for more information.

ABSOLUTE AND RELATIVE LOSS

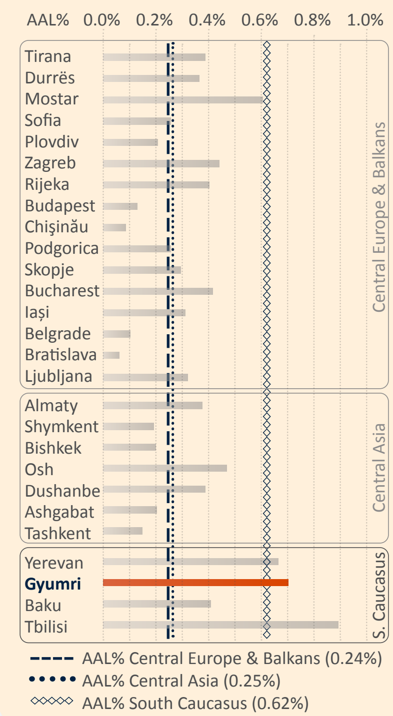


Gyumri

EARTHQUAKE IMPACTS SNAPSHOT

- Average annual loss from earthquake damage to multifamily residences is **€8.17 million**.
- This amounts to **0.08%** of the country's GDP.
- Nearly **39%** of the city's population lives in multifamily residential buildings.

LOSS COMPARISON TO REGION



High-Risk Buildings in Gyumri

Masonry and reinforced concrete frame are the two highest-risk building types used for pre-2000 multifamily housing in Gyumri.

~43,000 people live in these buildings, or **37%** of the total population of Gyumri

URM
RCF

Unreinforced Masonry (URM) and Reinforced Concrete Frame (RCF) buildings contribute to:

98% of total **loss** from building damage

92% of all **permanent residential displacement** in the next 50 years from building damage due to earthquakes

95% of **fatalities** in multifamily buildings*

*This is an average number of fatalities when assessed over many years.

References: See *City Profile Sources* for information on building types, classification, and exposure data sources. Image credit: "Holy Saviour Church Gyumri" by Armenak Margarian, licensed under CC BY 4.0 / Lowered opacity from original.

Baku | AZERBAIJAN

Summary

Baku is Azerbaijan's capital and largest city, home to nearly a quarter of the country's total population. Azerbaijan has experienced many severe earthquakes in the past, including the damaging 2000 Baku earthquake, a magnitude 6.8 event in which 31 people lost their lives and 430 were injured. In 1999, a magnitude 5.4 earthquake in the Agdas-Ucar-Ağalı area led to one death, 18 injuries, and €7 million (2019 €) in damage.

Based on the analysis, almost half of the population of Baku resides in pre-2000 multifamily residential buildings. The buildings that are the most at risk* are reinforced block (BLK) buildings and slab-column system (SCS) buildings. Along with, unreinforced masonry (URM) buildings, these building types are also expected to cause the most fatalities. Approximately 125,000 people, or about five percent of the inhabitants of Baku, reside in high-risk building types.

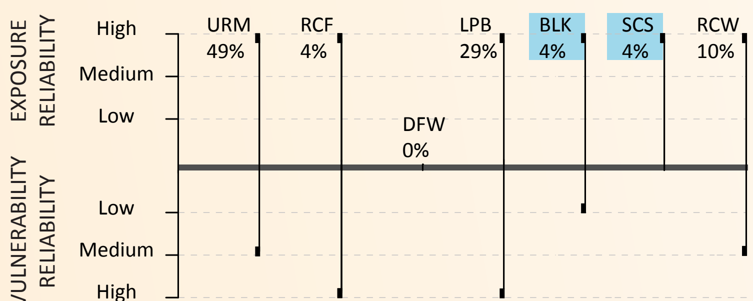
Compared to the data for all the buildings in this study, the data used to conduct the risk analysis for buildings in Baku average a **high** reliability; this rating is a function of the assumptions, uncertainties, and data available for the city (see *Methodology*). The diagram below indicates the reliability and confidence related to building stock data (i.e., exposure data) as well as data on building vulnerability. These confidence and reliability levels should be considered when interpreting and applying the risk metrics presented in the city profile.

*At risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The expected loss results are predicted from models of future events subject to variable data availability and modeling assumptions. The replacement value is the construction cost of all multifamily buildings in the city.

BAKU FACTS

Capital City | Population: 2,313,000 (2019) | GNI/capita: ~€3,400

Data Reliability and Building Exposure



Building exposure data is for pre-2000 multifamily buildings.

▷ Data on building stock and population (exposure) and their susceptibility to earthquake losses (vulnerability) for the city is conveyed with vertical bars labeled by the building typology acronym.
▷ The diagram also indicates the percentage of total building stock that a typology comprises in the city denoted as a percentage below the building typology acronym. Highlighted building types are those that are considered highest risk in the city.

Earthquake Event-Based Losses

	€ Total building damage	% Building damage, % of total value	Number of fatalities
100-year Return Period	€ 1.0 B 27% GNIPC	10%	2,800 people
475-year Return Period	€ 3.5 B 93% GNIPC	34%	11,400 people

▷ A 100-year return period event is one where the damage and loss have approximately a 40% probability of being exceeded in 50 years; it is considered a more frequent event. A 475-year return period event is one where the damage and loss have approximately a 10% probability of being exceeded in 50 years; it is considered a less frequent event, more damaging event.
▷ GNIPC is gross national income per capita. Percentage of GNIPC is the losses from damage per resident as a percentage of GNIPC.
▷ The fatalities presented are those that are expected to occur at nighttime (2:00 a.m.) on a weekend.
▷ *Note: Event-based losses are subject to limitation by the reliability of the input data. The chosen return periods do not suggest that more hazardous and infrequent earthquake events are not probable in this city, as higher return period events may occur at any point.*

Country Snapshot

GDP
40.0 Billion Euros*

POPULATION
10.0 Million People*

SIGNIFICANT EARTHQUAKES
1999 Agdas M5.4
2000 Baku M6.8
2012 Zaqatala M5.7

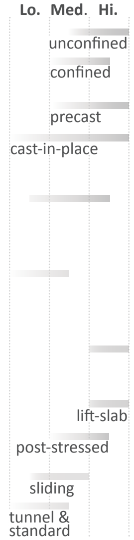
* 2018 estimate

Earthquake Risk Profile

Building Damage Losses

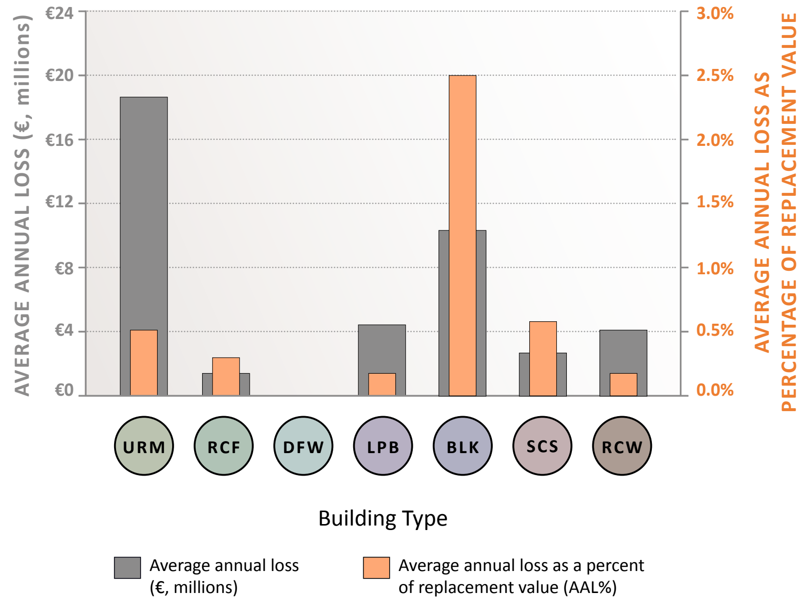
BUILDING CLASSIFICATION & VULNERABILITY RANGE

Description	Type
Unreinforced Masonry: built with masonry walls that lack steel reinforcement; includes confined and unconfined walls.	URM
Reinforced Concrete Frame: reinforced concrete frames that provide earthquake resistance; includes precast and cast-in-place frames.	RCF
Dual Frame-wall: reinforced concrete frame and wall elements work together to resist earthquake forces.	DFW
Precast Large Panel: built with precast reinforced concrete panels with floor-to-ceiling height facade panels.	LPB
Block: built with precast concrete elements assembled on site; similar to LPB with smaller facade elements.	BLK
Slab-column System: reinforced concrete floor slabs directly connected to concrete columns; includes lift slabs and post-stressed slabs.	SCS
Reinforced Concrete Wall: cast-in-place walls that provide earthquake resistance; includes standard, sliding, and tunnel formwork.	RCW



Note that the relative vulnerabilities are approximate and depend on post-construction modifications, degradation, construction quality, and year of construction. See Types of Multifamily Buildings in ECA for more information.

ABSOLUTE AND RELATIVE LOSS

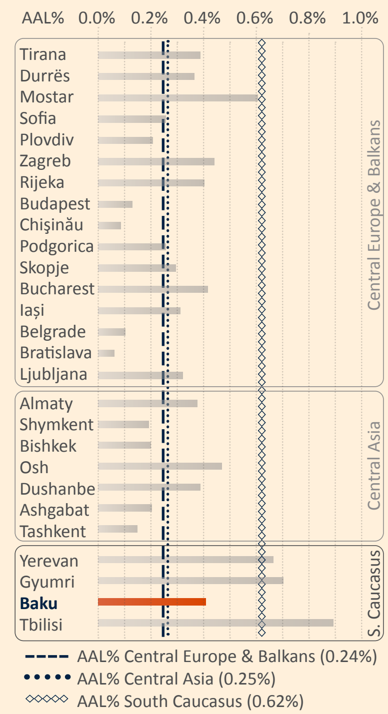


Baku

EARTHQUAKE IMPACTS SNAPSHOT

- Average annual loss from earthquake damage to multifamily residences is **€42.4 million**.
- This amounts to **0.11%** of the country's GDP.
- Nearly **48%** of the city's population lives in multifamily residential buildings.

LOSS COMPARISON TO REGION



High-Risk Buildings in Baku

Block and slab-column system are the two highest-risk building types used for pre-2000 multifamily housing in Baku.

~125,000 people live in these buildings, or **5%** of the total population of Baku

BLK
SCS

Block (BLK) and Slab-column System (SCS) buildings contribute to:

31% of total **loss** from building damage

70% of all **permanent residential displacement** in the next 50 years from building damage due to earthquakes

49% of **fatalities** in multifamily buildings*

*This is an average number of fatalities when assessed over many years.

References: See *City Profile Sources* for information on building types, classification, and exposure data sources.

Tbilisi | GEORGIA

Summary

Tbilisi is Georgia's capital and largest city, home to over a quarter of the country's total population. Georgia has been affected by many earthquakes of varying severity in the past, the most notable and damaging of which was the magnitude 7.0 Racha earthquake in 1991—the most powerful earthquake ever recorded in the Caucasus. The event caused 270 deaths, injured 1,000 people, left 67,000 people homeless, and caused nearly €3 billion (2019 €) in damage. In 2002, a magnitude 4.3 earthquake in Tbilisi killed five, injured over 50, and damaged or destroyed 2,400 buildings.

Based on the analysis, over 80 percent of the population of Tbilisi resides in pre-2000 multifamily residential buildings. The buildings that are the most at risk* are block (BLK) buildings and slab-column system (SCS) buildings. Along with unreinforced masonry (URM) buildings, these building types are also expected to cause the most fatalities. Approximately 300,000 people, or nearly 30 percent of the population of Tbilisi, reside in high-risk building types.

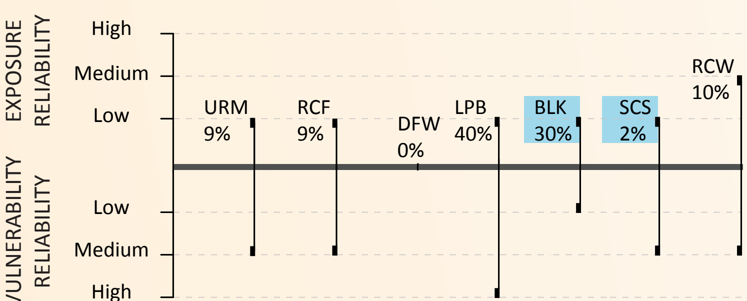
Compared to the data for all the buildings in this study, the data used to conduct the risk analysis for buildings in Tbilisi average a **low** reliability; this rating is a function of the assumptions, uncertainties, and data available for the city (see *Methodology*). The diagram below indicates the reliability and confidence related to building stock data (i.e., exposure data) as well as data on building vulnerability. These confidence and reliability levels should be considered when interpreting and applying the risk metrics presented in the city profile.

*At risk building types based on earthquake loss are determined by the expected average annual loss ratio, or average annual loss as a percentage of replacement value (AAL%). The expected loss results are predicted from models of future events subject to variable data availability and modeling assumptions. The replacement value is the construction cost of all multifamily buildings in the city.

TBILISI FACTS

Capital City | Population: 1,077,000 (2019) | GNI/capita: ~€3,800

Data Reliability and Building Exposure



Building exposure data is for pre-2000 multifamily buildings.

▷ Data on building stock and population (exposure) and their susceptibility to earthquake losses (vulnerability) for the city is conveyed with vertical bars labeled by the building typology acronym.

▷ The diagram also indicates the percentage of total building stock that a typology comprises in the city denoted as a percentage below the building typology acronym. Highlighted building types are those that are considered highest risk in the city.

Earthquake Event-Based Losses

	€ Total building damage	% Building damage, % of total value	Number of fatalities
100-year Return Period	€ 1.4 B 43% GNIPC	21%	6,600 people
475-year Return Period	€ 3.2 B 97% GNIPC	48%	19,500 people

▷ A 100-year return period event is one where the damage and loss have approximately a 40% probability of being exceeded in 50 years; it is considered a more frequent event. A 475-year return period event is one where the damage and loss have approximately a 10% probability of being exceeded in 50 years; it is considered a less frequent event, more damaging event.

▷ GNIPC is gross national income per capita. Percentage of GNIPC is the losses from damage per resident as a percentage of GNIPC.

▷ The fatalities presented are those that are expected to occur at nighttime (2:00 a.m.) on a weekend.

▷ *Note: Event-based losses are subject to limitation by the reliability of the input data. The chosen return periods do not suggest that more hazardous and infrequent earthquake events are not probable in this city, as higher return period events may occur at any point.*

Country Snapshot

GDP
15.0 Billion Euros*

POPULATION
3.7 Million People*

SIGNIFICANT EARTHQUAKES
1991 Racha M7.0
2002 Tbilisi M4.3
2009 Oni M6.0

* 2018 estimate

WORLD BANK GROUP | GFDRR

Earthquake Risk Profile

Building Damage Losses

BUILDING CLASSIFICATION & VULNERABILITY RANGE

Description

Unreinforced Masonry: built with masonry walls that lack steel reinforcement; includes confined and unconfined walls.

Reinforced Concrete Frame: reinforced concrete frames that provide earthquake resistance; includes precast and cast-in-place frames.

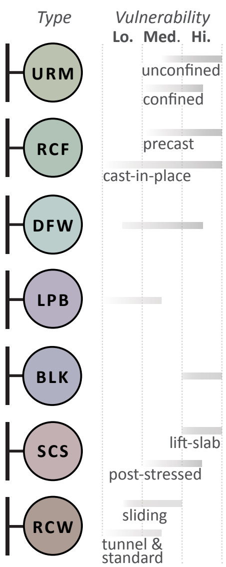
Dual Frame-wall: reinforced concrete frame and wall elements work together to resist earthquake forces.

Precast Large Panel: built with precast reinforced concrete panels with floor-to-ceiling height facade panels.

Block: built with precast concrete elements assembled on site; similar to LPB with smaller facade elements.

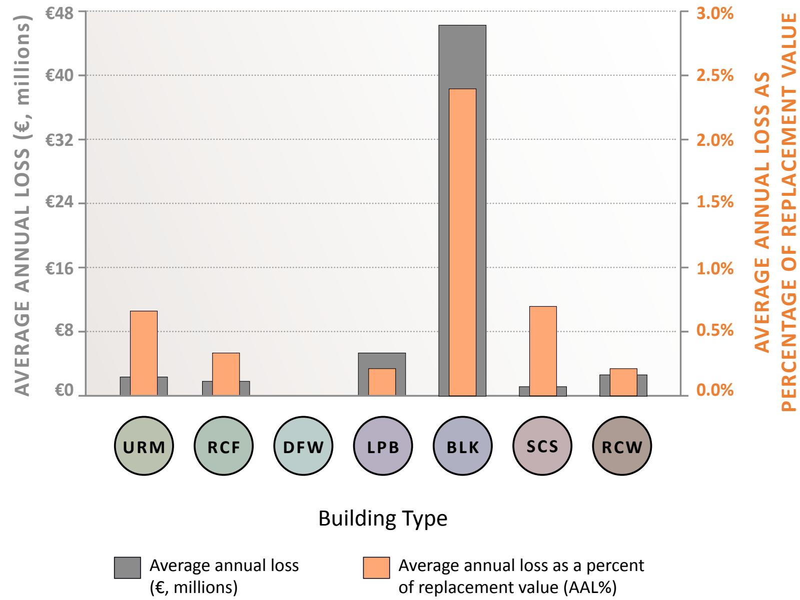
Slab-column System: reinforced concrete floor slabs directly connected to concrete columns; includes lift slabs and post-stressed slabs.

Reinforced Concrete Wall: cast-in-place walls that provide earthquake resistance; includes standard, sliding, and tunnel formwork.



Note that the relative vulnerabilities are approximate and depend on post-construction modifications, degradation, construction quality, and year of construction. See Types of Multifamily Buildings in ECA for more information.

ABSOLUTE AND RELATIVE LOSS



Tbilisi

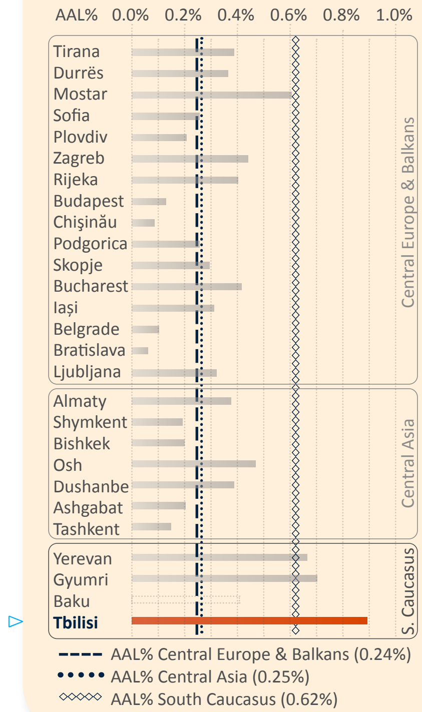
EARTHQUAKE IMPACTS SNAPSHOT

▷ Average annual loss from earthquake damage to multifamily residences is **€59.5 million**.

▷ This amounts to **0.40%** of the country's GDP.

▷ Nearly **82%** of the city's population lives in multifamily residential buildings.

LOSS COMPARISON TO REGION



High-Risk Buildings in Tbilisi

Block and slab-column system are the two highest-risk building types used for pre-2000 multifamily housing in Tbilisi.

~300,000 people live in these buildings, or **28%** of the total population of Tbilisi

BLK

SCS

Block (BLK) and Slab-column System (SCS) buildings contribute to:

80% of total **loss** from building damage

64% of all **permanent residential displacement** in the next 50 years from building damage due to earthquakes

55% of **fatalities** in multifamily buildings*

*This is an average number of fatalities when assessed over many years.

References: See *City Profile Sources* for information on building types, classification, and exposure data sources.

FUTURE WORK

The current study can be used as the basis for more detailed risk assessment of the 27 cities presented. Several areas of further research include:

• **Development and refinement of the asset data.** Researching and compiling accurate data on the number of buildings, dwellings, and occupants (exposure) per structural group, as well as information on the current condition of buildings that may influence their vulnerability, will improve the reliability of the exposure models used in this study and increase the accuracy of the assessment results.

• **Development and refinement of the damage and loss data.** Additional research on and validation of the damage and loss (vulnerability) models for the various building types could increase the accuracy of the assessment results.

• **Expansion of the study.** The sole focus of this study was pre-2000 multifamily residential buildings, as these house a large percentage of the population within all cities in the region. The study could expand to consider the entirety of the residential building stock in these cities. In addition, investigating other cities in the ECA region could provide a more holistic understanding of earthquake risk.

• **Inclusion of socioeconomic factors.** Future work should also include aspects of demographics, poverty, education, and human vulnerability to comprehensively understand the indirect losses from earthquakes. The socioeconomic layer provides an understanding of critical rehabilitation and recovery factors that are not captured by building damage consequences. •

Image Credit: "Looking out over Bishkek, Kyrgyzstan [2011]" by United Nations Development Programme in Europe and Central Asia, licensed under CC BY-NC-SA 2.0.

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