Comprehensive Risk Assessment of Basic Services and Transport Infrastructure

101004830 - CRISIS - UCPM-2020-PP-AG

Cross-border risk assessment of basic services and transport infrastructure
Vulnerability assessment based on seismic and landslide hazard

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1. Introduction

In recent years, the improvement of disaster and emergency management through building a harmonized and efficient system for risk assessment of structures in the cross-border region has become increasingly popular. The CRISIS project specifically focuses on enhancing the cross-border cooperation and coordination in disaster risk management based on developed models and tools and raising public awareness and preparedness for disasters.

The main objective of this report is the vulnerability assessment of the representative building and bridge typologies, concerning the identified levels of seismic and landslide hazards.

2. Methodology

2.1. Earthquake hazard

Earthquakes represent the main natural hazard in the cross-border region. Seismic vulnerability is presented both regarding the critical buildings selected and the bridges along the road network of the area.

2.1.1. Seismic fragility and vulnerability of buildings

The vulnerable conditions of a building can be described using vulnerability functions or fragility functions. Vulnerability functions describe the probability of losses given a level of ground shaking, whereas fragility functions describe the probability of exceeding different limit states given a level of ground shaking. Vulnerability functions can be derived from fragility functions using consequence functions that describe the probability of loss given a level or performance (e.g., collapse).

Different methods can be used to estimate a fragility or a vulnerability function. It is possible to classify them into four generic groups: empirical, expert opinion-based, analytical and hybrid. Empirical fragility curves are constructed based on statistics of observed damage from past earthquakes, such as from data collected by post-earthquake surveys. Expert opinion-based fragility curves depend on judgment and information of experts. Analytical fragility curves are constructed starting from the statistical elaboration of damage distributions that are simulated from analyses of structural models under increasing earthquake intensity. Finally, hybrid fragility curves are based on the combination of different methods for damage prediction.

Numerous research groups around the world have addressed the problem of quantifying the vulnerability of structures and calculating the damage they suffer after seismic events in terms of fragility and vulnerability functions based on the different aforementioned methods. In the following, we focus on fragility models developed for common classes of European building stock that may be appropriate for the selected hospitals and school buildings at the cross-border region of Greece, North Macedonia and Albania.

Kappos et al. [30] proposed a hybrid approach for the vulnerability assessment of reinforced concrete (RC) and unreinforced masonry (URM) residential structures in Greece. It combines statistical data from earthquake-damaged Greek buildings with appropriately processed results from non-linear either dynamic or static analyses.

Donà et al [23] presented a mechanics-based seismic fragility model for Italian residential masonry buildings. This model was based on the classification of the building stock in macro-typologies, defined by age of construction and number of storeys, allowing the simulation of damage scenarios and the assessment of risk analyses on a territorial scale. The model was based on the fragility of over 500 buildings, sampled according to Italian representativeness criteria. The calculated fragility functions were extended to obtain a fragility model defined based on the five European Macroseismic Scale (EMS98) damage states.

Lagomarsino et al. [31] presented a macroseismic vulnerability model for unreinforced masonry existing buildings that built upon the original proposal of Lagomarsino and Giovinazzi [32] and further developed in recent years. The method was classified as heuristic, in the sense that it was based on the expertise that is implicit in the EMS98, with fuzzy assumptions on the binomial damage distribution; and it was calibrated on the observed damage in Italy. The model has been applied in the context of ReLUIS project, funded by the DPC to support the development of Italian Risk Maps. To this aim, the vulnerability model has been applied for deriving fragility curves using an appropriate correlation law between the Macroseismic Intensity and the Peak Ground Acceleration.

Zuccaro et al. [52] provided an empirical vulnerability model, in terms of PGA, for masonry structures in Italy, starting from damage probability matrices (DPMs). To this purpose, the PLINIVS database, containing data on major Italian seismic events, has been used and supported by “critical” assumption on missing data. Two vulnerability models, considering or not the hypothesis on the missing data, have been estimated and used to calculate the seismic scenario of the L’Aquila 2009 earthquake.

Rosti et al. [44] developed an empirical fragility model for residential URM buildings, calibrated on Italian post-earthquake damage data and compatible with the key features of the Italian national seismic risk platform. Seismic vulnerability was described by fragility functions for three vulnerability classes, then refined based on the building height. To this aim, a clustering strategy is implemented to merge predefined building typologies into vulnerability classes, based on the similarity of the observed seismic fragility. On the other side, a specific procedure was built up to determine the vulnerability composition of the exposed URM building stock, starting from Italian census data.

Moreover, in Rosti et al. [43], empirical fragility curves for reinforced concrete buildings have been derived, based on post-earthquake damage data collected in the aftermath of earthquakes occurred in Italy in the period 1976–2012. PGA and a metric based on six damage levels according to EMS-98 are used for fragility analysis. The damage levels are obtained from observed damage collected during post-earthquake inspections through existing conversion rules, considering damage to vertical structures and infills/partitions. The maximum damage level observed on vertical structures and infills/partitions was then associated to the whole building. Fragility curves for two vulnerability classes, C2 and D, further subdivided into three classes of building height, were obtained from those derived for specific structural typologies (identified based on building height and type of design), using their frequency of occurrence at national level as weights.

Borzi et al [7] developed an analytical fragility model for frame RC buildings, based on the following derivation phases and hypotheses: i) Definition of the sample of buildings through a Monte Carlo generation, starting from a representative building prototype for each building typology and varying predefined structural parameters according to a-priori probabilistic distributions. ii) Application of the SP-BELA methodology [8] to develop the vulnerability model, based on: simulated design of the buildings, according to the code in place at the time of construction, non-linear static analysis to define the associated equivalent single-degree-offreedom (SDOF) systems, evaluation of the exceedance probabilities of two DSs (severe damage and collapse), for various PGA values, comparing the displacement capacity and demand of the SDOF systems. iii) Extensions of the fragility curves to all DSs of the EMS98 through calibrations based on comparisons between simulated and observed damage scenarios.

Martin and Silva [34] developed new fragility functions covering the most common building classes at the global scale. This fragility model has been used for the assessment of economic losses due to earthquakes as part of the global seismic risk model supported by the Global Earthquake Model (GEM) Foundation. The building classes considered buildings divided according to (i) the construction material, (ii) the lateral load resisting system, (iii) ductility level and (iv) height. Fragility curves were generated for different damage states (as in the present study ranging from slight (LS1) to complete damage (LS4)) considering different intensity measures (PGA, SA(0.3 s), SA(0.6 s) and SA(1.0 s)).

Recently, Crowley et al. [15] presented the recently released input models and open-source software to assess the vulnerability of the European building stock within the 2020 European Seismic Risk Model (ESRM20). The classification of the vulnerability of European buildings is performed according to their (i) material, (ii) lateral load resisting system, (iii) code level or ductility, (iv) height and (v) lateral force coefficient (applied to reinforced concrete moment and infilled frames only). Similarly to the fragility curves by Martins and Silva [34], the fragility curves provided by Crowley et al. [15] have been derived for four different damage states ranging from slight (LS1) to complete damage (LS4)) considering different intensity measures (PGA, SA(0.3 s), SA(0.6 s) and SA(1.0 s)).

2.1.2. Seismic fragility and vulnerability of bridges

Bridges are key components of the road network, especially those located in road axes with high traffic loads, or which are characterized as of strategic importance. Earthquake damage observed worldwide on road bridges has consequent impact on the wider economic and social activities of the affected areas, while bridges are the most sensitive component of the road network in terms of seismic vulnerability. In the recent years, methods have been developed internationally to assess the seismic risk of networks, aiming at making the seismic risk assessment as realistic as possible, describing the potential damage for a given seismic scenario.

In particular, bridges are the most vulnerable structures of the road network, as in the past significant damage was recorded in individual parts (e.g. supports, foundations), while in some cases they were completely damaged. In addition, the time needed to repair the damage to these structures is usually longer than for other road infrastructure. In any case, the total cost is high and includes, in addition to the restoration of the damage, the cost of indirect losses due to downtime.

As a general rule, to describe the vulnerability of the different bridge typologies in the context of this project, the taxonomy developed in the INFRA-NAT [29] project is adopted, especially for the Italian and N. Macedonian bridges that best fit the purpose of this project. This taxonomy is explained in Figure 1 and presented, for the specific cases examined in INFRA-NAT, in Table 1.

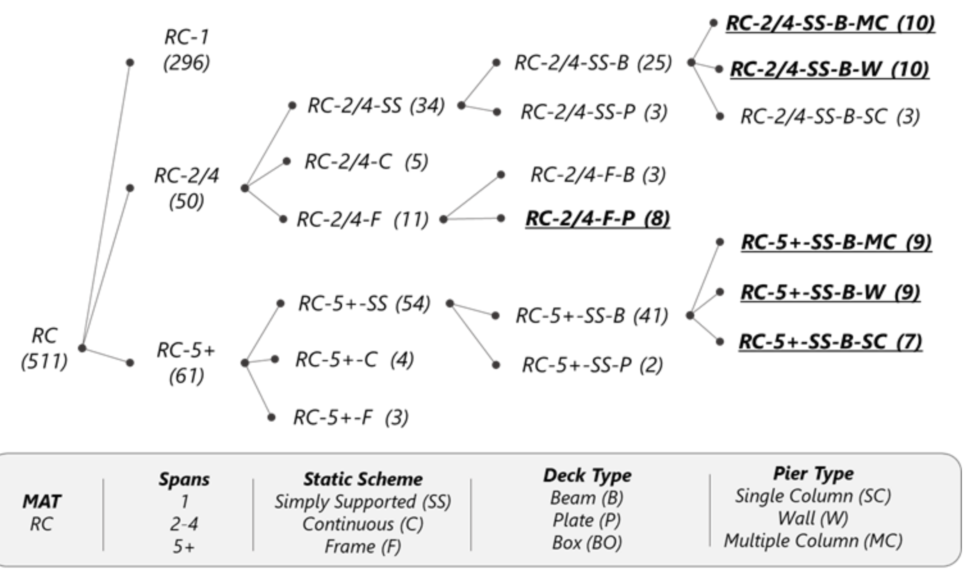


Figure 1 Breakdown and identification of representative taxonomy branches; adopted from INFRANAT.

Table 1. Representative taxonomies; adopted from INFRANAT.

Country	**Spans**	**Static Scheme**	**Deck Type**	**Pier Type**	**Taxonomy Code**
Italy	2 to 4	Simply Supported	Beam	Multiple Column	RC-2/4-SS-B-MC
				Wall	RC-2/4-SS-B-W
		Frame	Plate	Any	RC-2/4-F-P
	Above 5	Simply Supported	Beam	Multiple Column	RC-5+-SS-B-MC
				Wall	RC-5+-SS-B-W
				Single Column	RC-5+-SS-B-SC
North Macedonia	2	Simply Supported	Beam	Wall	RC-2-SS-B-W
	3				RC-3-SS-B-W
	4				RC-4-SS-B-W
	3	Frame	Plate	Wall	RC-3-F-P-W

To derive the corresponding fragility curves, nonlinear bridge models were defined, each of which was evaluated using a NLTHA set of 30 bi-directional records. The fragility curves adopted are presented in Figure 2 to Figure 10.

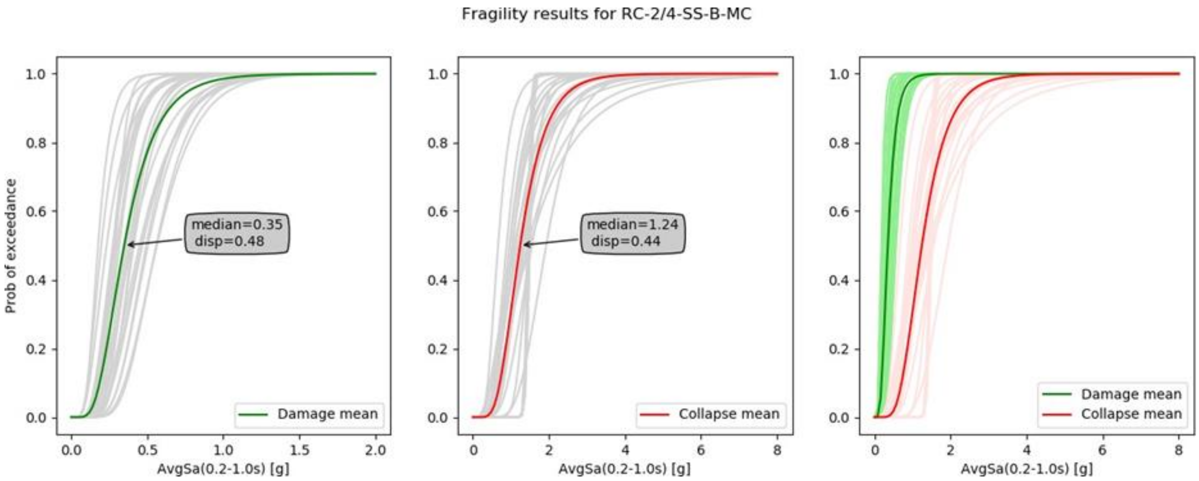


Figure 2 Fragility functions for the RC-2/4-SS-B-MC taxonomy of the Italian case study: a) Damage limit state, b) Collapse limit state, c) Summary

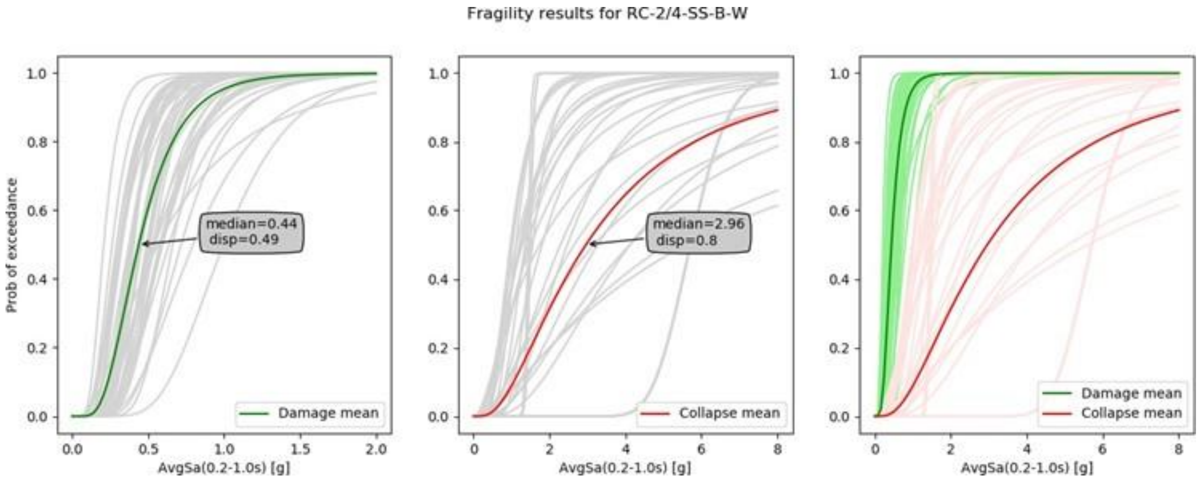


Figure 3 Fragility functions for the RC-2/4-SS-B-W taxonomy of the Italian case study: a) Damage limit state, b) Collapse limit state, c) Summary

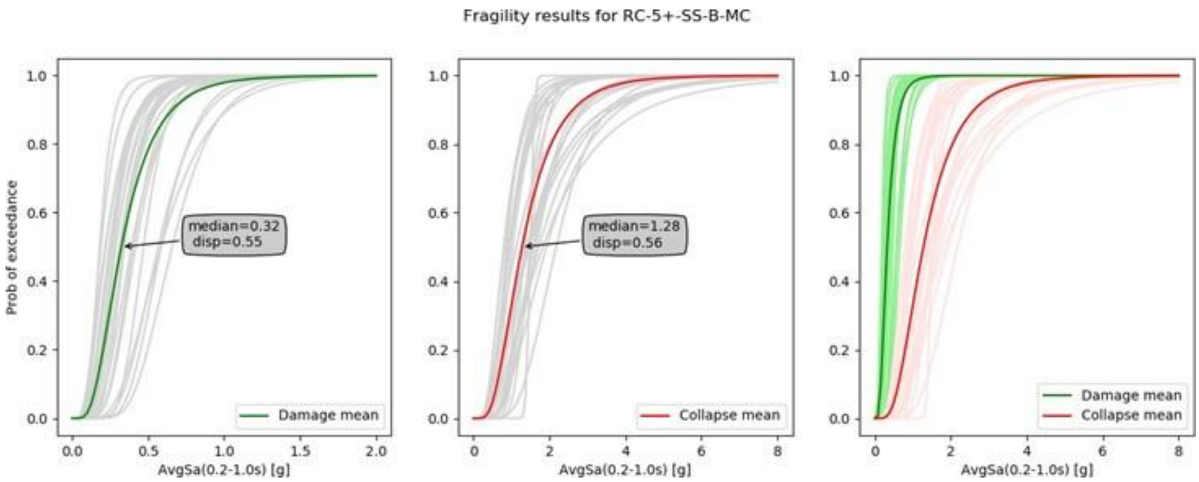


Figure 4 Fragility functions for the RC-5+-SS-B-MC taxonomy of the Italian case study: a) Damage limit state, b) Collapse limit state, c) Summary

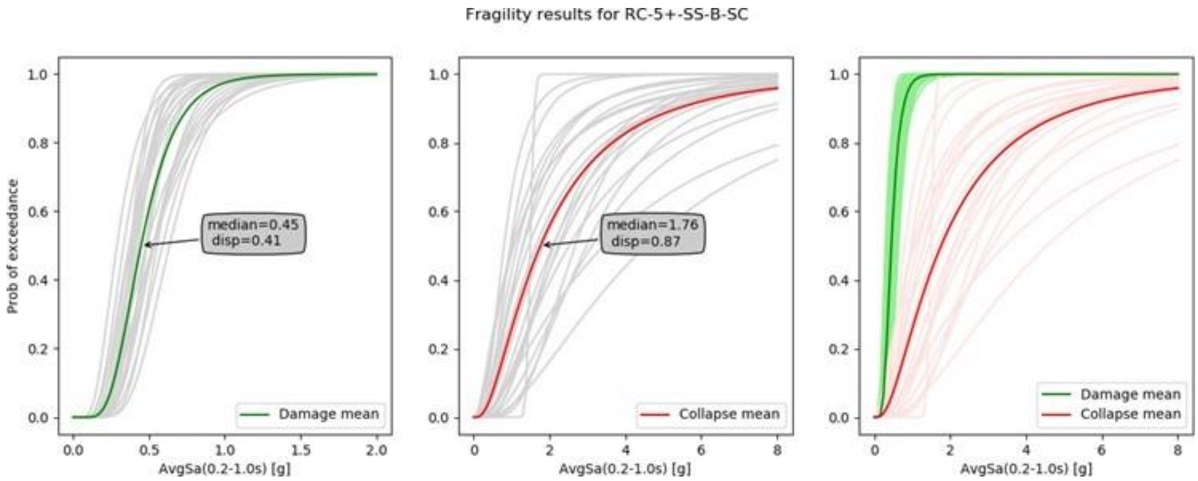


Figure 5 Fragility functions for the RC-5+-SS-B-SC taxonomy of the Italian case study: a) Damage limit state, b) Collapse limit state, c) Summary

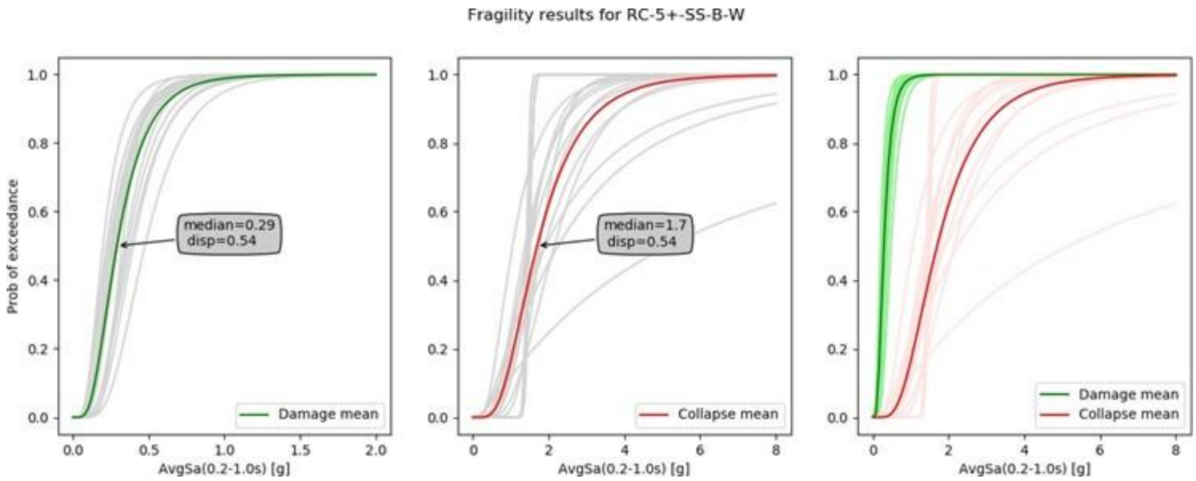


Figure 6 Fragility functions for the RC-5+-SS-B-W taxonomy of the Italian case study: a) Damage limit state, b) Collapse limit state, c) Summary

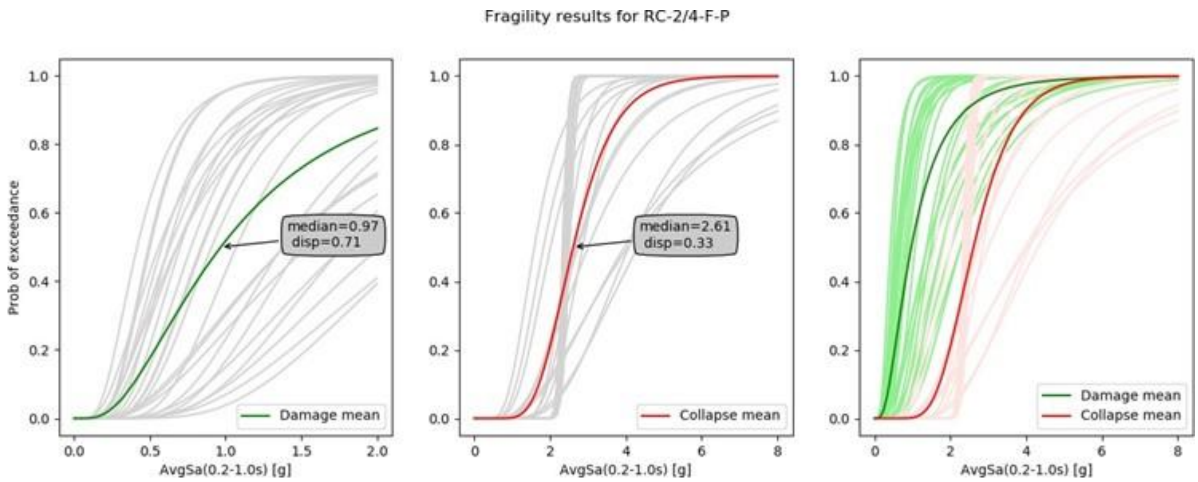


Figure 7 Fragility functions for the RC-2/4-F-P taxonomy of the Italian case study: a) Damage limit state, b) Collapse limit state, c) Summary

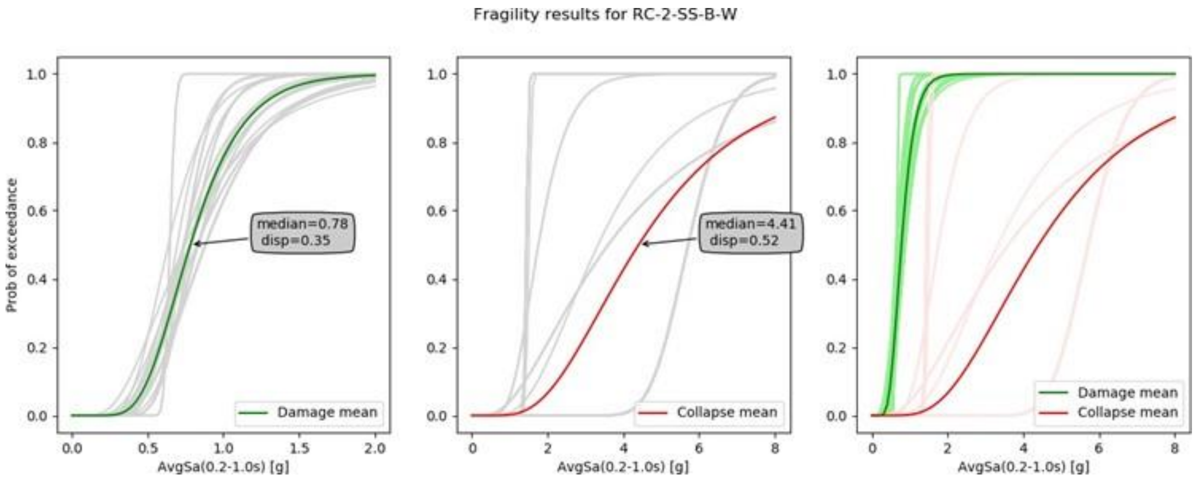


Figure 8 Fragility functions for the RC-2-SS-B-W taxonomy of the North Macedonia case study: a) Damage limit state, b) Collapse limit state, c) Summary

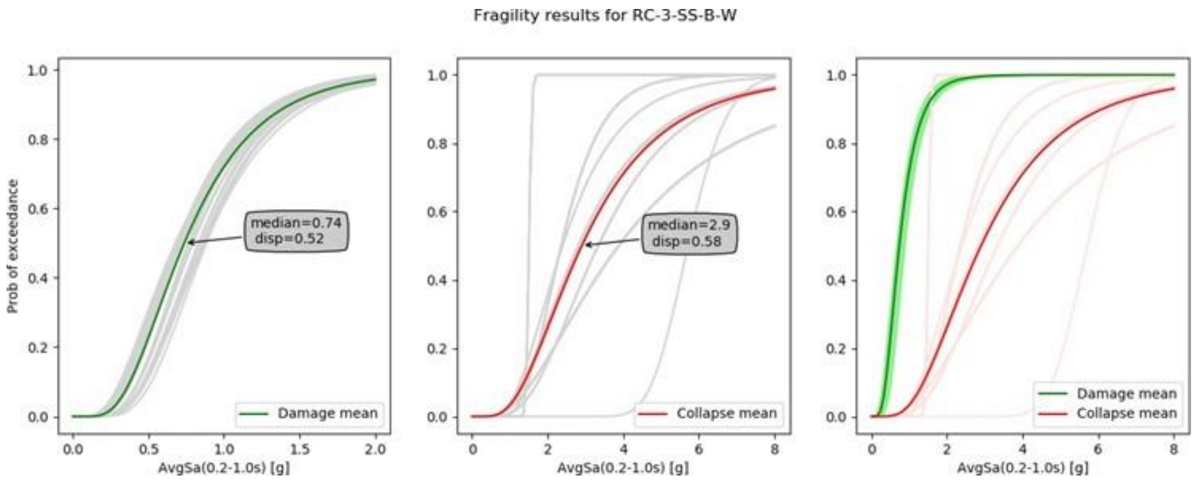


Figure 9 Fragility functions for the RC-3-SS-B-W taxonomy of the North Macedonia case study: a) Damage limit state, b) Collapse limit state, c) Summary

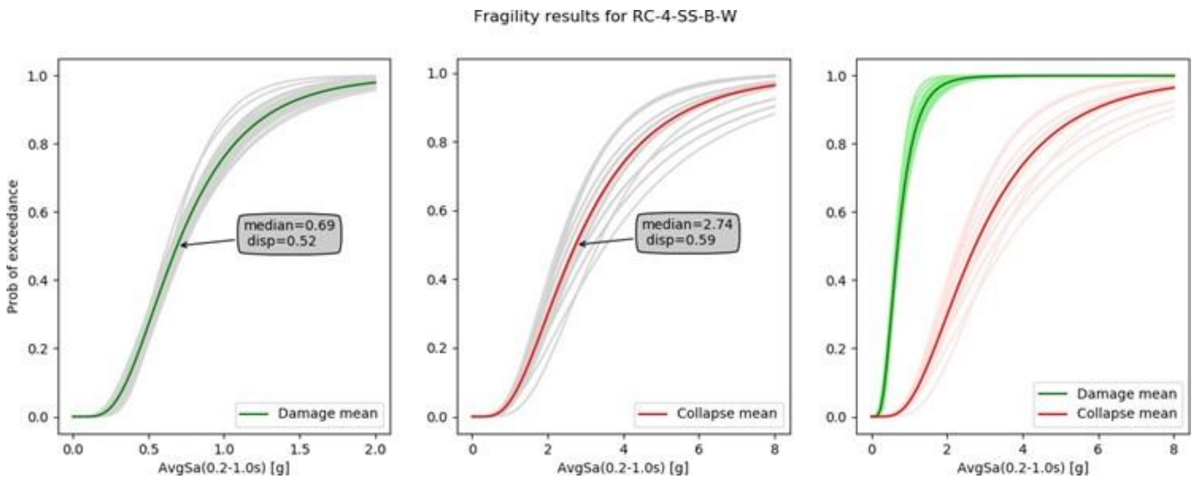


Figure 10 Fragility functions for the RC-4-SS-B-W taxonomy of the North Macedonia case study: a) Damage limit state, b) Collapse limit state, c) Summary

2.2 Landslide hazard

While substantial research has been carried out in the field of landslide hazard and risk assessment [20], [11], [25], [13], research into consequence analysis and vulnerability assessment has been limited [28]. Within the content of a landslide risk assessment framework, vulnerability is possibly the most difficult term to represent quantitatively, since it depends on many factors such as the analysis scale, the landslide type and size, the triggering mechanism, the typology of the exposed elements as well as the relative location of the element with respect to the landslide zone [27]. Vulnerability in quantitative terms may be defined using either vulnerability indices or fragility curves [13]. The vulnerability index expresses the degree of damage on a relative scale from 0 (no damage) to 1 (total damage). Fragility curves express the conditional probability of reaching or exceeding a certain damage state (e.g., slight, moderate, extensive, complete) due to a landslide event of a given type and intensity, allowing for the quantification of various sources of uncertainty [26], [27]. Recommended methods for landslide vulnerability assessment were summarized by Corominas et al. [13], classified according to the type and quality of input data and the evaluation of the response parameters as judgemental/heuristic, data-driven and analytical/physical model-based methods.

2.2.1. Landslide fragility and vulnerability of buildings

Within the framework of this study, a semi-quantitative procedure fully implemented in a GIS environment is suggested based on Arnaouti et al. [3] to assess landslide vulnerability and risk of buildings in the cross-border region of Greece, North Macedonia and Albania.
The proposed framework includes four main steps that are shortly outlined below:
i) the collection of the susceptibility and hazard information based on the characteristics of the landslide inventory; ii) The identification of the buildings at risk and of the main factors influencing their vulnerability (e.g., construction material, number of floors, state of maintenance etc.). The value of the exposed buildings that is associated to their function and thus to their importance to the local community should also be specified; iii) The vulnerability assessment of the buildings by weighting the different contributing factors using engineering judgment based on the framework proposed by Papathoma et al. [39]. A different score is assigned to each category of the given factors and the total vulnerability value is calculated for each building by means of a Weighted Linear Combination Method (e.g., [39], [36]); iv) The risk estimation integrates information on the hazard, the vulnerability and the value of the element. Both hazard and vulnerability values are given in standardized terms. Landslide risk can be finally assessed either qualitatively or semi-quantitatively expressed on a scale from 0 to 1.0.
The proposed procedure, although it involves some degree of subjectivity, is generally compatible with the availability and quality of data taking also into account the scale of the analysis and the availability of input data. In addition, this index-based semi-quantitative approach allows treating on a hierarchical basis the level of risk supporting, in this way, effective risk management and decision-making processes.
The proposed framework for assessing landslide risk is implemented to strategic buildings (schools and hospitals) of the cross-border region of Greece, North Macedonia and Albania that have been repeatedly affected by different landslide hazards. The landslide susceptibility map of the cross-border region of Greece, North Macedonia and Albania is presented based on the Pan-European Landslide Susceptibility Map version 2 (ELSUS v2, [48]). It should be noted that information on the magnitude-frequency relationships of the potentially damaging landslides of different types was not made available in a homogeneous way and thus, only a preliminary hazard analysis based on its spatial component (i.e., susceptibility) was possible. In addition, a database of the exposed buildings in the Greece cross-border region including their structural characteristics and their urban function has been constructed in GIS format for the purpose of this study. Table 2 presents the description of the various factors considered

for the vulnerability assessment of buildings in the cross-border region as well as their relevant scores defined by expert knowledge and judgment. Different weightings are assigned to each of the factors on the basis of their relative importance in the vulnerability assessment. Table 3 presents the various functions of the exposed buildings and the corresponding values assigned for each function.

Table 2. Factors contributing to building vulnerability to landslides, the score of each category and their relevant weightings

Factor	Categories	Score	Weighting
Construction material	masonry	0.6	4
	RC	0.3	
	steel	0.3	
	wood	0.8	
	mixed	0.7	
Number of floors	1	0.5	1
	2-3	0.3	
	≥4	0.1	
Outdatedness	good	0.1	4
	average	0.3	
	bad	0.6	
	destroyed	0.9	
Age	before 1900	0.9	3
	1900-1950	0.7	
	1950-1970	0.5	
	1970-1990	0.3	
	1990-2000	0.1	
	after 2000	0	

Table 3. Function and the corresponding value of the building

Function	Value of the building (E)
residential	1
commercial	1.1
industrial and craft	1
agricultural	1
leisure and sportive	1.1
hotel	1.1
place of religious worship	1.2
private service	1.2
public service	1.3
education	1.3
civil service	1.3
urgency service	1.3

2.2.2. Landslide fragility and vulnerability of bridges

To assess the landslide vulnerability of bridges within the framework of CRISIS, HAZUS [37] empirical fragility curves due to ground failure may be utilized. According to HAZUS, bridges are classified based on the following structural characteristics:

- Seismic Design
- Number of spans: single vs. multiple span bridges
- Structure type: concrete, steel, others
- Pier type: multiple column bents, single column bents and pier walls
- Abutment type and bearing type: monolithic vs. non-monolithic; high rocker bearings,

low steel bearings and neoprene rubber bearings

- Span continuity: continuous, discontinuous (in-span hinges), and simply supported.

The classification followed is presented in Table 4:

Table 4. HAZUS classification of bridges.

CLASS	NBI Class	State	Year Built	# Spans	Length of Max. Span (meter)	Length less than 20 m	K_{3D} (See note below)	I_{shape} (See note below)	Design	Description
HWB1	All	Non-CA	< 1990		> 150	N/A	EQ1	0	Conventional	Major Bridge - Length > 150m
HWB1	All	CA	< 1975		> 150	N/A	EQ1	0	Conventional	Major Bridge - Length > 150m
HWB2	All	Non-CA	>= 1990		> 150	N/A	EQ1	0	Seismic	Major Bridge - Length > 150m
HWB2	All	CA	>= 1975		> 150	N/A	EQ1	0	Seismic	Major Bridge - Length > 150m
HWB3	All	Non-CA	< 1990	1		N/A	EQ1	1	Conventional	Single Span
HWB3	All	CA	< 1975	1		N/A	EQ1	1	Conventional	Single Span
HWB4	All	Non-CA	>= 1990	1		N/A	EQ1	1	Seismic	Single Span
HWB4	All	CA	>= 1975	1		N/A	EQ1	1	Seismic	Single Span
HWB5	101-106	Non-CA	< 1990			N/A	EQ1	0	Conventional	Multi-Col. Bent, Simple Support - Concrete
HWB6	101-106	CA	< 1975			N/A	EQ1	0	Conventional	Multi-Col. Bent, Simple Support - Concrete
HWB7	101-106	Non-CA	>= 1990			N/A	EQ1	0	Seismic	Multi-Col. Bent, Simple Support - Concrete
HWB7	101-106	CA	>= 1975			N/A	EQ1	0	Seismic	Multi-Col. Bent, Simple Support - Concrete
HWB8	205-206	CA	< 1975			N/A	EQ2	0	Conventional	Single Col., Box Girder - Continuous Concrete
HWB9	205-206	CA	>= 1975			N/A	EQ3	0	Seismic	Single Col., Box Girder - Continuous

										Concrete
HWB10	201-206	Non-CA	< 1990			N/A	EQ2	1	Conventional	Continuous Concrete
HWB10	201-206	CA	< 1975			N/A	EQ2	1	Conventional	Continuous Concrete
HWB11	201-206	Non-CA	>= 1990			N/A	EQ3	1	Seismic	Continuous Concrete
HWB11	201-206	CA	>= 1975			N/A	EQ3	1	Seismic	Continuous Concrete
HWB12	301-306	Non-CA	< 1990			No	EQ4	0	Conventional	Multi-Col. Bent, Simple Support - Steel
HWB13	301-306	CA	< 1975			No	EQ4	0	Conventional	Multi-Col. Bent, Simple Support - Steel
HWB14	301-306	Non-CA	>= 1990			N/A	EQ1	0	Seismic	Multi-Col. Bent, Simple Support - Steel
HWB14	301-306	CA	>= 1975			N/A	EQ1	0	Seismic	Multi-Col. Bent, Simple Support - Steel
HWB15	402-410	Non-CA	< 1990			No	EQ5	1	Conventional	Continuous Steel
HWB15	402-410	CA	< 1975			No	EQ5	1	Conventional	Continuous Steel
HWB16	402-410	Non-CA	>= 1990			N/A	EQ3	1	Seismic	Continuous Steel
HWB16	402-410	CA	>= 1975			N/A	EQ3	1	Seismic	Continuous Steel

CLASS	NBI Class	State	Year Built	# Spans	Length of Max. Span (meter)	Length less than 20 m	K_{3D} (notes below)	I_{shape} (notes below)	Design	Description
HWB17	501-506	Non-CA	< 1990			N/A	EQ1	0	Conventional	Multi-Col. Bent, SimpleSupport - Prestressed Concrete
HWB18	501-506	CA	< 1975			N/A	EQ1	0	Conventional	Multi-Col. Bent, SimpleSupport - Prestressed Concrete
HWB19	501-506	Non-CA	>= 1990			N/A	EQ1	0	Seismic	Multi-Col. Bent, SimpleSupport - Prestressed Concrete
HWB19	501-506	CA	>= 1975			N/A	EQ1	0	Seismic	Multi-Col. Bent, SimpleSupport - Prestressed Concrete
HWB20	605-606	CA	< 1975			N/A	EQ2	0	Conventional	Single Col., Box Girder -Prestressed ContinuousConcrete
HWB21	605-606	CA	>= 1975			N/A	EQ3	0	Seismic	Single Col., Box Girder -Prestressed ContinuousConcrete
HWB22	601-607	Non-CA	< 1990			N/A	EQ2	1	Conventional	Continuous Concrete
HWB22	601-607	CA	< 1975			N/A	EQ2	1	Conventional	Continuous Concrete
HWB23	601-607	Non-CA	>= 1990			N/A	EQ3	1	Seismic	Continuous Concrete
HWB23	601-607	CA	>= 1975			N/A	EQ3	1	Seismic	Continuous Concrete
HWB24	301-306	Non-CA	< 1990			Yes	EQ6	0	Conventional	Multi-Col. Bent, SimpleSupport - Steel

HWB25	301-306	CA	< 1975			Yes	EQ6	0	Conventional	Multi-Col. Bent, SimpleSupport - Steel
HWB26	402-410	Non-CA	< 1990			Yes	EQ7	1	Conventional	Continuous Steel
HWB27	402-410	CA	< 1975			Yes	EQ7	1	Conventional	Continuous Steel
HWB28										All other bridges that are not classified

Also, HAZUS defines damage to bridges as:

Slight/Minor Damage is defined by minor cracking and spalling to the abutment, cracks in shear keys at abutments, minor spalling and cracks at hinges, minor spalling at the column (damage requires no more than cosmetic repair) or minor cracking to the deck

Moderate Damage is defined by any column experiencing moderate (shear cracks) cracking and spalling (column structurally still sound), moderate movement of the abutment (<2"), extensive cracking and spalling of shear keys, any connection having cracked shear keys or bent bolts, keeper bar failure without unseating, rocker bearing failure or moderate settlement of the approach.

Extensive Damage is defined by any column degrading without collapse – shear failure - (column structurally unsafe), significant residual movement at connections, or major settlement approach, vertical offset of the abutment, differential settlement at connections, shear key failure at abutments.

Complete Damage is defined by any column collapsing and connection losing all bearing support, which may lead to imminent deck collapse, tilting of substructure due to foundation failure.

There are 28 primary bridge types for which all four damage states are identified and described. For other bridges, fragility curves of the 28 primary bridge types are adjusted to reflect the expected performance of a specific bridge which may be better or worse than the corresponding primary bridge type.

A total of 224 bridge damage functions are obtained, 112 due to ground shaking and 112 due to ground failure. Medians of these damage functions are given in Table 5. The dispersion is set to 0.6 for the ground shaking damage algorithm and 0.2 for the ground failure damage algorithm.

Table 5. Medians of bridge damage functions

	Sa [1.0 sec in g's] for Damage Functions due to Ground Shaking				**PGD [inches] for Damage Functions due to Ground Failure**			
CLASS	**Slight**	**Moderate**	**Extensive**	**Complete**	**Slight**	**Moderate**	**Extensive**	**Complete**
HWB1	0.40	0.50	0.70	0.90	3.9	3.9	3.9	13.8
HWB2	0.60	0.90	1.10	1.70	3.9	3.9	3.9	13.8
HWB3	0.80	1.00	1.20	1.70	3.9	3.9	3.9	13.8
HWB4	0.80	1.00	1.20	1.70	3.9	3.9	3.9	13.8
HWB5	0.25	0.35	0.45	0.70	3.9	3.9	3.9	13.8
HWB6	0.30	0.50	0.60	0.90	3.9	3.9	3.9	13.8

HWB7	0.50	0.80	1.10	1.70	3.9	3.9	3.9	13.8
HWB8	0.35	0.45	0.55	0.80	3.9	3.9	3.9	13.8
HWB9	0.60	0.90	1.30	1.60	3.9	3.9	3.9	13.8
HWB10	0.60	0.90	1.10	1.50	3.9	3.9	3.9	13.8
HWB11	0.90	0.90	1.10	1.50	3.9	3.9	3.9	13.8
HWB12	0.25	0.35	0.45	0.70	3.9	3.9	3.9	13.8
HWB13	0.30	0.50	0.60	0.90	3.9	3.9	3.9	13.8
HWB14	0.50	0.80	1.10	1.70	3.9	3.9	3.9	13.8
HWB15	0.75	0.75	0.75	1.10	3.9	3.9	3.9	13.8
HWB16	0.90	0.90	1.10	1.50	3.9	3.9	3.9	13.8
HWB17	0.25	0.35	0.45	0.70	3.9	3.9	3.9	13.8
HWB18	0.30	0.50	0.60	0.90	3.9	3.9	3.9	13.8
HWB19	0.50	0.80	1.10	1.70	3.9	3.9	3.9	13.8
HWB20	0.35	0.45	0.55	0.80	3.9	3.9	3.9	13.8
HWB21	0.60	0.90	1.30	1.60	3.9	3.9	3.9	13.8
HWB22	0.60	0.90	1.10	1.50	3.9	3.9	3.9	13.8
HWB23	0.90	0.90	1.10	1.50	3.9	3.9	3.9	13.8
HWB24	0.25	0.35	0.45	0.70	3.9	3.9	3.9	13.8
HWB25	0.30	0.50	0.60	0.90	3.9	3.9	3.9	13.8
HWB26	0.75	0.75	0.75	1.10	3.9	3.9	3.9	13.8
HWB27	0.75	0.75	0.75	1.10	3.9	3.9	3.9	13.8
HWB28	0.80	1.00	1.20	1.70	3.9	3.9	3.9	13.8

3. Regional vulnerability models

3.1. N Macedonia

The exposure model of the CBR of RN Macedonia presented in D4.1 [18] consists of 73 buildings intended for basic services, among which, 57 are school buildings and 16 are health care facilities. The exposure model of the transport infrastructure comprises 165 bridges.

Classification of the building typology has been done according to the GEM methodology, [10] (Figure 1 and 2). The bridge classification has been performed according to the methodology developed during previous research in the region [10] and implemented in the INFRA NAT project [29].

3.1.1. Seismic fragility and vulnerability of buildings - Schools and hospitals

Schools: According to the classification based on material type (Figure 11), 54.3% are masonry structures (M) and 45.6% are reinforced concrete (RC) structures.

Related to the classification based on lateral load resisting system, 96% of RC structures are moment resistant frame structures (LFM) and 4% are dual frame-wall system (LDUAL).

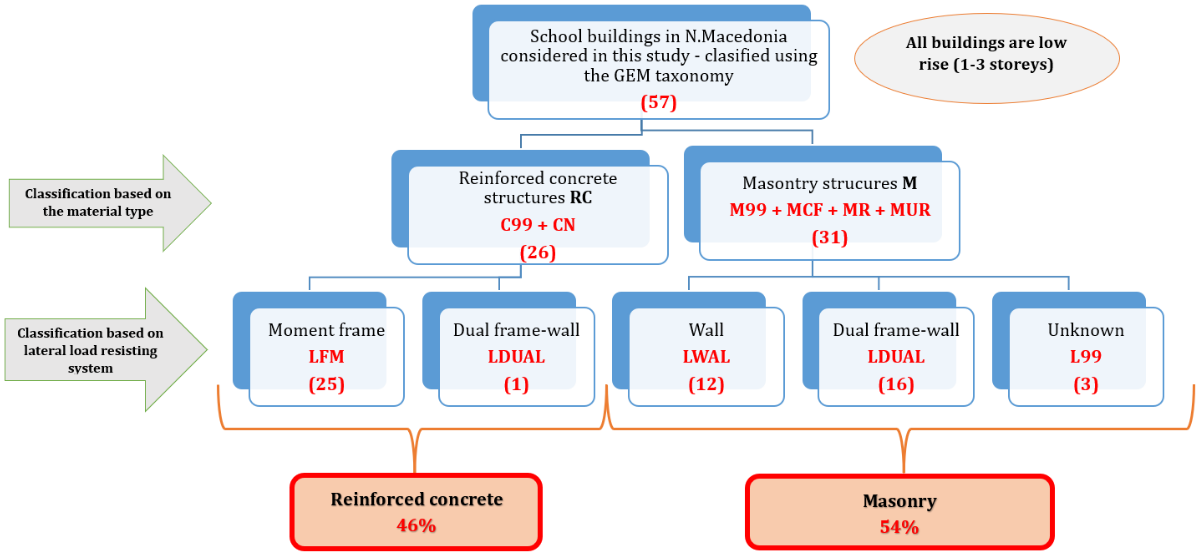


Figure 11 Exposure model of schools according to the GEM methodology (N. Macedonia)

Most of the structures constructed by use of the masonry technology represent confined masonry structures (26.3%), while the remaining ones are constructed of unreinforced masonry. According to the number of storeys of schools, most of them have two and three storeys above ground and have either one or none level below ground, meaning that all of these structures are low-rise [18].

Most of the school structures from the exposure model (70.9%) were built prior to the introduction of the currently valid national seismic regulations, namely, the Rulebook on Technical Regulations for Construction of Buildings in Seismic Regions [1]. The remaining ones (29.1%) are designed and constructed according to these codes.

Hospitals: According to the classification based on material type (Figure 12), 75% are reinforced concrete (RC) structures and 25% are masonry (M) structures.

Related to the classification based on lateral load resisting system, 83% of the RC structures are moment resistant frame structures (LFM) and 75% of masonry structures are structures with bearing walls (LWAL).

According to the number of storeys above and below ground, half of the health care structures have 2 levels above ground and 1 level below ground [18].

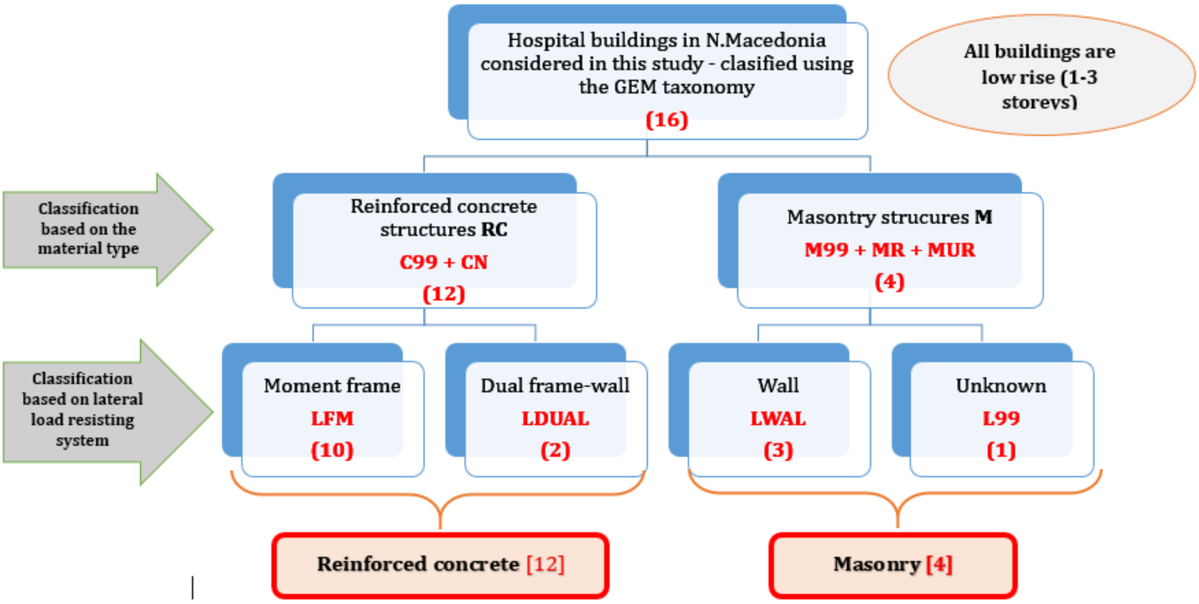


Figure 12 Exposure model of hospitals according to the GEM methodology (N. Macedonia)

More than 81% of the considered hospitals were built prior to the introduction of the national seismic regulations (1981) [17].

According to the building typology of the exposure model, the fragility curves developed for the RC and masonry structures have been selected based on recent investigations, [9], [23], [19].

The reinforced concrete structures considered in the investigation were built between 1956-2012. Most of them (52.5%) were built according to the current national seismic regulations, after 1981; 39.1% were built in the period between 1964-1981 when the first seismic codes were in use, and only 8.7% were built before 1964, when no seismic codes were used.

Regarding the number of storeys, most of the reinforced concrete structures (51.4%) are with 2 storeys, 10.8% are with 1 storey, 32.4% are with 3 storeys and the rest 5.4% are with 4 and more than 4 storeys.

For the RC building structures, fragility curves defined with the SP-BELA method for vulnerability class C2 (buildings designed according to the pre-code seismic standards) and D (buildings designed according to the seismic codes) [1] have been selected. Figure 13 shows the selected fragility curves for 2 storey RC buildings. The parameters for the fragility curves with 1, 2, 3 and 4 stories are given in Table 6.

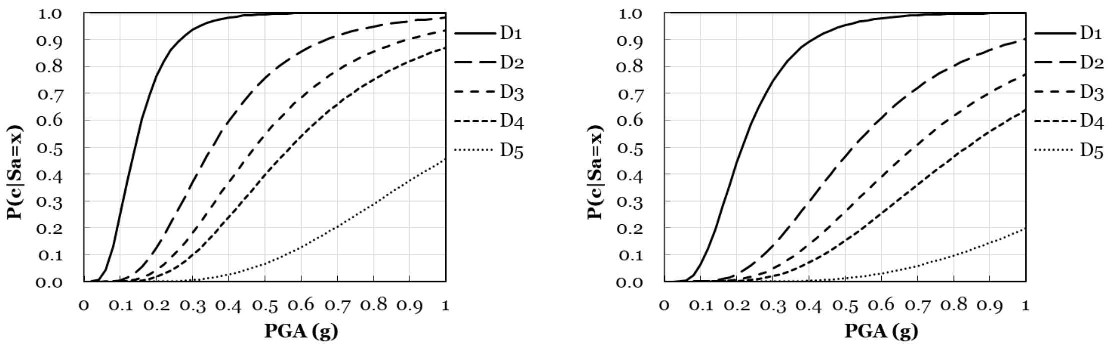


Figure 13 Fragility curves of 2-storey RC frame buildings of vulnerability class C2 (left) and D (right) [6]

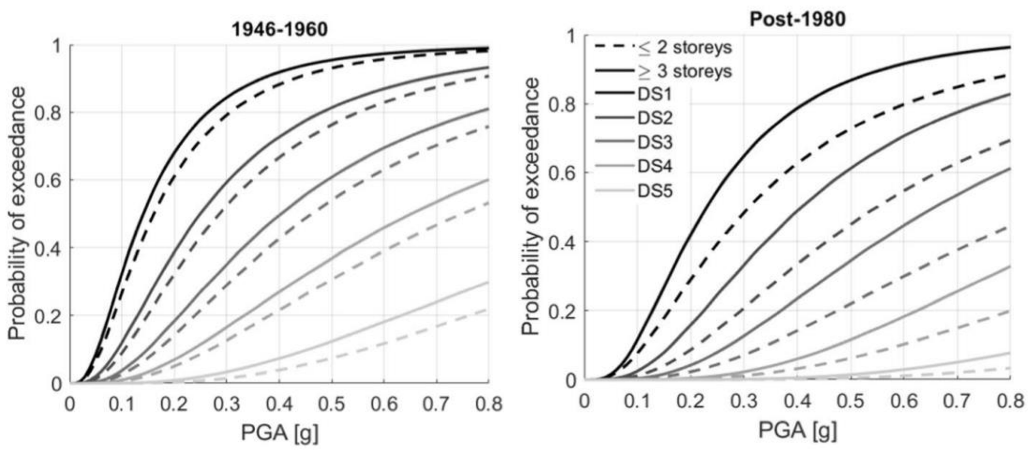
Table 6 Median and standard deviation β of the fragility curves for five damage levels [6]

Vulnerability class	DS1		DS2		DS3		DS4		DS5	
	Median	β	Median	β	Median	β	Median	β	Median	β
1 storey										
C2	0.144	0.504	0.364	0.504	0.485	0.504	0.611	0.502	1.132	0.502
D	0.269	0.483	0.655	0.483	0.865	0.483	1.066	0.494	1.952	0.494
2 storeys										
C2	0.140	0.498	0.354	0.498	0.472	0.498	0.570	0.499	1.056	0.499
D	0.215	0.501	0.522	0.501	0.690	0.501	0.837	0.501	1.532	0.501
3 storeys										
C2	0.163	0.496	0.412	0.496	0.548	0.496	0.645	0.497	1.194	0.497
D	0.220	0.496	0.535	0.496	0.706	0.496	0.832	0.497	1.525	0.497
>4 storeys										
C2	0.183	0.500	0.463	0.500	0.617	0.500	0.712	0.501	1.318	0.501
D	0.239	0.513	0.582	0.513	0.768	0.513	0.897	0.518	1.642	0.518

D1- light damage, D2-moderate damage, D3-extensive damage, D4-complete damage, and D5 collapse

The masonry structures in the exposure model were built in the period 1847-1982. 70% of the buildings were built prior to 1964, before enforcement of any seismic design codes ("no-code structures"), 26.7% were constructed between 1964-1981 following the first national seismic codes ("low/moderate" code structures) and only 3% were designed and built after actual seismic codes from 1981.

According to the quality of materials and construction as well as period of construction, for the buildings built prior to 1964, the fragility set of curves given in Figure 4a has been adopted. For the buildings constructed after the enforcement of the contemporary seismic code, the fragility set of curves presented in Figure 14 has been adopted, [7]. The parameters for the fragility curves are presented in Table 7.



a) b)

Figure 14 Fragility sets (from DS1 to DS5) of the LUW model of all building macro-typologies [7]

Table 7 μ and β values of the LUW fragility model [7]

Building macro-typologies	DS1		DS2		DS3		DS4		DS5	
	μ (g)	β (–)	μ (g)	β (–)	μ (g)	β (–)	μ (g)	β (–)	μ (g)	β (–)
1946-1960 ≤2 storeys	0.1613	0.7651	0.2862	0.7791	0.4625	0.7818	0.7496	0.8015	1.3660	0.6933
Post 1980 ≤2 storeys	0.3098	0.7918	0.5492	0.7429	0.8849	0.7393	1.4160	0.6780	2.4700	0.6132

3.1.2. Seismic fragility and vulnerability of bridges

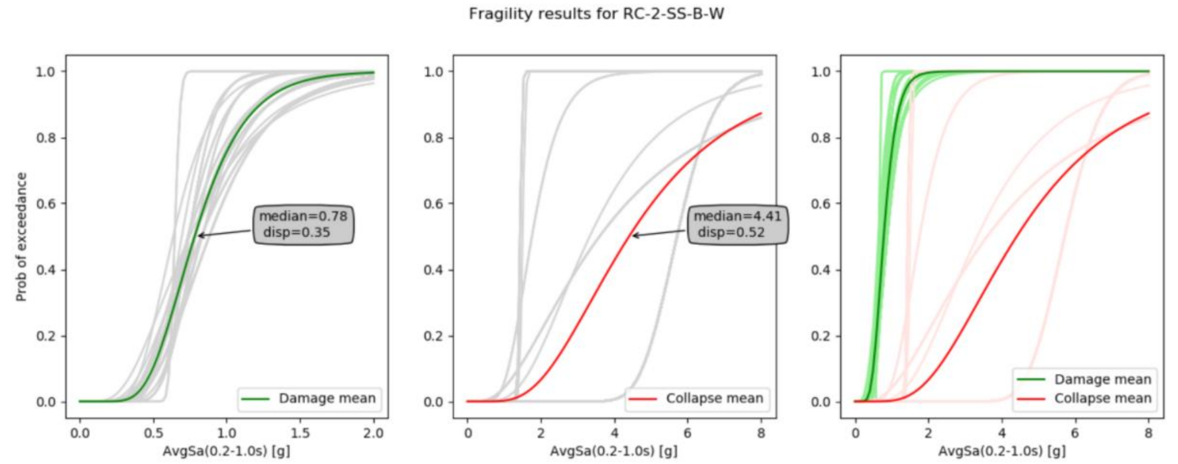
Most of the bridge structures in the considered region are constructed of reinforced concrete. According to the type of structural system, the most frequently found bridge types in this region are bridges with a frame structural system, then bridges with a girder system (with beam and slab main girders), while arch bridges account for the least number of bridges. As to the number of spans of structures for which there are data, half of them have 1 span, about 28% have 3 spans, while the greatest number of spans in this region is 6 [1].

Considering the number of spans, the static scheme, the type of superstructure and pier type of bridge structures, they can be classified into 4 groups: (Table 8):

Table 8 Classification of bridge structures

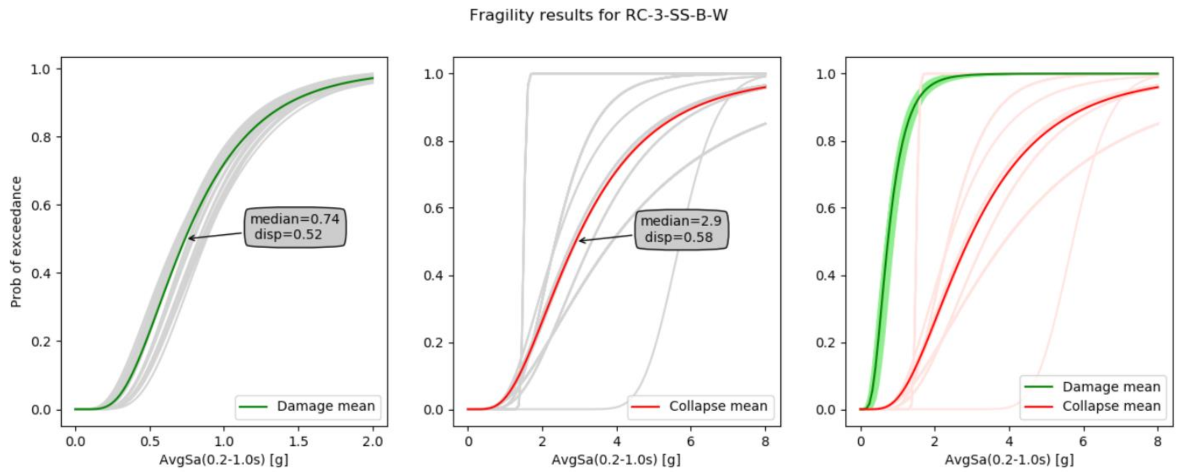
Country	Material	Static scheme	Deck type	Pier type	Spans	Taxonomy code
North Macedonia	Reinforced-concrete	Simply supported	Beam	Wall	2	RC-2-SS-B-W
					3	RC-3-SS-B-W
					4	RC-4-SS-B-W
		Frame	Plate		3	RC-3-F-P-W

For all these typologies, fragility curves have been developed in the frames of the project Increased Resilience of Critical Infrastructure under Natural and Human- induced Hazards (INFRA-NAT) (www.infra-nat.eu) [29]. The parameters for all these typologies are presented in the Table 9.



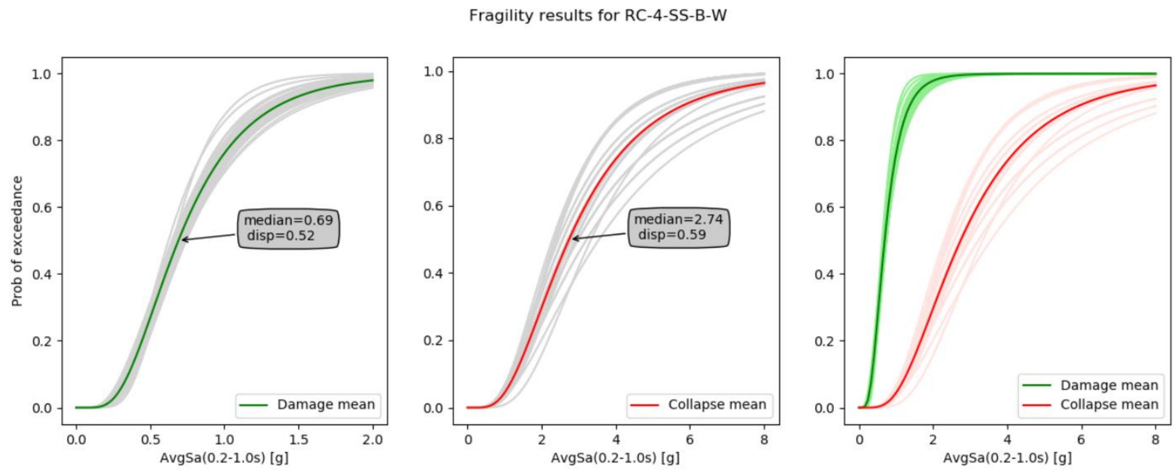
a) b) c)

Figure 15 Fragility functions for the RC-2-SS-B-W taxonomy. a) Damage limit state, b) Collapse limit state, c) Summary



a) b) c)

Figure 16 Fragility functions for the RC-3-SS-B-W taxonomy. a) Damage limit state, b) Collapse limit state, c) Summary



a) b) c)

Figure 17 Fragility functions for the RC-4-SS-B-W taxonomy. a) Damage limit state, b) Collapse limit state, c) Summary

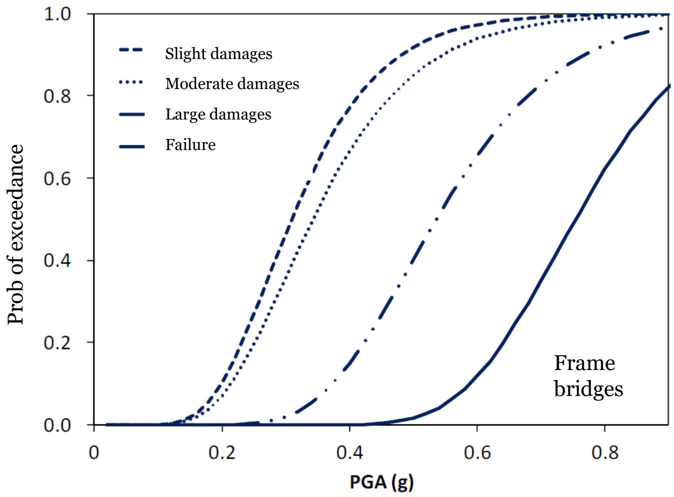


Figure 18 Fragility functions for the RC-3-F-P-W taxonomy

Table 9. Fragility curve parameters calculated for the representative taxonomies using AvgSa (0.2-1.0s) as a ground motion shaking intensity measure

Country	Taxonomy	Limit state			
		Damage		Collapse	
		Median μ_{lnY} [g]	Dispersion σ_{lnY} [g]	Median μ_{lnY} [g]	Dispersion σ_{lnY} [g]
North Macedonia	RC-2-SS-B-W	0.783	0.354	4.406	0.524
	RC-3-SS-B-W	0.738	0.520	2.900	0.581
	RC-4-SS-B-W	0.691	0.523	2.740	0.591
	RC-3-F-P-W	0.906	0.619	3.201	0.876

3.1.3. Landslide hazard

For the cross-border region in North Macedonia, the landslide-related fragility and vulnerability are estimated according to the general methodology presented in chapter 2.2 and sub chapters 2.2.1 and 2.2.2. Both sections cover landslide hazard and the corresponding fragility curves for the North Macedonian building and bridge stock may be utilized.

3.2. Greece

The exposure model of the CBR of Greece presented in D4.1 [18] consists of 26 buildings intended for basic services, among which, 19 are school buildings and 7 are health care facilities. The exposure model of the transport infrastructure comprises 16 main bridges and 9 secondary bridges.

Classification of the buildings to specific typologies has been done according to the Kappos et al. [30] taxonomy, while the bridge classification has been performed according to the methodology developed during previous research in the region and implemented in the INFRA NAT project [29].

Regarding Greece, all the bridges inside the cross-border area of interest were identified; an on-site investigation of the most critical bridges related to this project took place. While a large number of bridges exists, only a certain number spans along the main road network that connects the neighboring countries.

In general, most of the bridges are constructed as single-span, frame/slab structures, while reinforced concrete is the most used material. On the contrary, only a few multi-span or arched bridges exist. A total of 385 bridges are considered in this research project, while main (M) and secondary (S) bridges were thoroughly surveyed, on-site, in the context of CRISIS project.

In particular, sixteen main (M) bridges were reported (Table 10):

Table 10. Main bridges (M) – typology and best match with existing fragility curves

#	Total length	Height	Spans	Span length	Typology
1	15.00	8.00	1	15.00	RC-1
2	22.00	8.00	1	20.00	RC-1
3	150.00	20.00	5	30.00	RC-5+
4	210.00	5.50	6	35.00	RC-5+
5	100.00	4.50	3	33.00	RC-2/4
6	10.00	4.00	1	10.00	RC-1
7	10.00	4.00	1	10.00	RC-1
8	10.00	4.00	1	10.00	RC-1
9	12.00	4.50	1	12.00	RC-1
10	10.00	4.00	1	10.00	RC-1
11	11.00	4.50	1	11.00	RC-1
12	6.50	4.00	1	6.50	RC-1
13	10.00	4.50	1	10.00	RC-1
14	7.50	4.50	1	7.50	RC-1
15	5.00	4.00	1	5.00	RC-1
16	5.00	4.00	1	5.00	RC-1

Information about the individual typologies and fragility is provided in section 2.1.2.

3.2.1. Seismic fragility and vulnerability of buildings - Schools and hospitals

Classification of the school buildings and hospitals to specific typologies has been done according to the Kappos et al. [30] taxonomy scheme. For R/C buildings, the main attributes are the structural system, the height and the seismic design level, which is associated with the year of construction (Table 11). For masonry buildings, the only attributes are the type of masonry (stone or brick) and the number of storeys (1-2 and 3).

Table 11. Specific building types and design levels for R/C building analysis (Kappos et al., [30]).

Type	Structural system	Height (number of storeys)	Seismic design level
RC1	Concrete moment frames	(L)ow rise (1-3) (M)id rise (4-7) (H)igh-rise (8+)	(N)o/pre code (<1959) (L)ow code (1960-1984) (M)edium code
RC3 3.1 3.2	Concrete moment frames with unreinforced masonry infill walls Regularly infilled frames Irregularly infilled frames (pilotis)		

RC4	RC dual systems (RC frames and walls)		(1985-1994)
4.1	Bare frames (no infill walls)		(H)igh code
4.2	Regularly infilled dual systems		(>1995)
4.3	Irregularly infilled dual systems (pilotis)		

The classification of the school buildings and hospitals to the building typologies of Kappos et al. [30] is presented in Table 12 and Table 13 respectively. The majority of the buildings are R/C buildings with 1-3 storeys (low rise).

Table 12. Classification of considered school buildings to the building typologies of Kappos et al. [30]

#	School Name	Municipality	Material	Number of storeys	Year of construction	Typology
1	Kastoria-2nd Junior High School	Kastoria	R/C	3	1993	RC4.2LM
2	Kastoria-1st High School	Kastoria	R/C	2	1982	RC4.2LL
3	Kastoria-3rd High School	Kastoria	R/C	2	>1980	RC4.2LL
4	Kastoria-3rd Junior High School	Kastoria	Masonry	2	1920-1930	STONE 2
5	Kastoria-4th Junior High School	Kastoria	R/C	2	1996	RC4.2LH
6	Aridea- High School	Almopia	R/C	2	1990	RC3.1LM
7	Aridea-2nd Junior High School	Almopia	R/C	2	1979	RC3.1LL
8	Aridea- EPAL School	Almopia	R/C	1	1998	RC3.1LH
9	Aridea-Primary School	Almopia	R/C	2	2010	RC3.1LH
10	Kilkis 1st HighSchool	Kilkis	R/C	2	1990, 2010	RC4.2LM / RC4.2LH
11	Kilkis 1st Junior High School	Kilkis	R/C	2	<1970	RC3.1LL
12	Kilkis 2nd Junior High School	Kilkis	R/C	2	<1970	RC3.1LL
13	Kilkis 2nd EPAL	Kilkis	R/C	3	1976	RC3.1LL
14	Florina 2nd High School	Florina	R/C	3	1995	RC4.2LH
15	Florina 2nd Junior High School	Florina	R/C	3	1995	RC4.2LH
16	Florina 3rd Junior High School	Florina	R/C	3	1979	RC3.1LL
17	Konitsa EPAL	Konitsa	R/C	1-2		RC3.1LL
18	Konitsa High School	Konitsa	Masonry	2		STONE 1-2
19	Polykastro High School	Paionia	R/C	2-3	1978	RC3.1LL

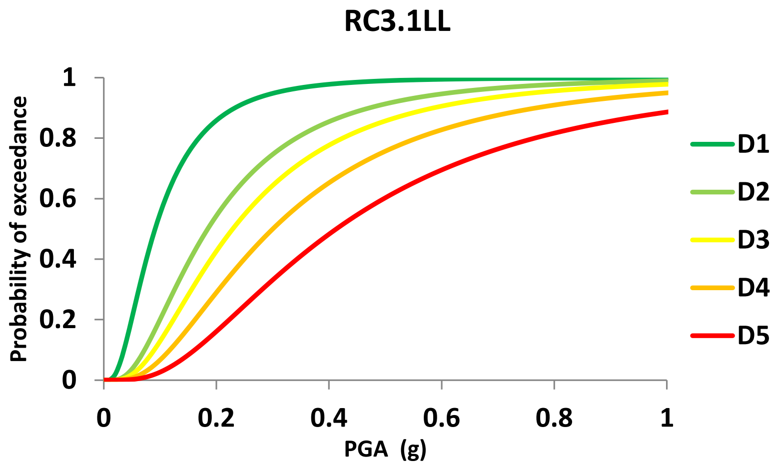
Table 13. Classification of considered healthcare facilities to the building typologies of Kappos et al. [30]

#	Healthcare facility	Municipality	Material	Number of storeys	Year of construction	Typology
1	Kastoria-Hospital	Kastoria	R/C	3	1971	RC3.1LL
2	Florina-Hospital	Florina	Masonry	2	1938	STONE 1-2
3	Florina-Hospital	Florina	R/C	2-4	>1986	RC4.2LM
4	Aridea- Medical Center	Almopia	R/C	2		RC3.1LL
5	Polykastro-Medical Center	Paionia	R/C	1		RC4.2LM
6	Konitsa Medical Center	Konitsa	Masonry, R/C (extension)	2	1955, 1988 (extension)	STONE 1-2 / RC4.2LM
7	Kilkis Hospital	Kilkis	R/C	2	2011	RC4.2LH

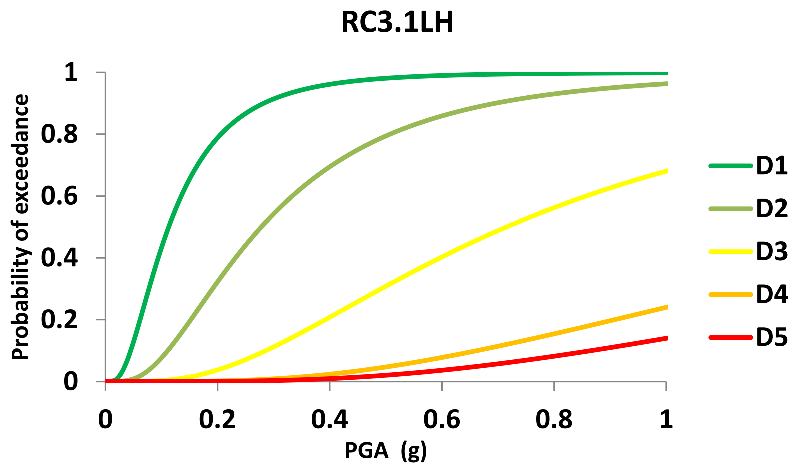
According to these building typologies, we selected appropriate fragility curves [30]. The differences between the fragility functions of Kappos et al. (2003) and Kappos et al. (2006), are attributed to slight geometric differences adopted for the studied RC building typologies as well as to the fact that the proposed curves in Kappos et al. (2003) are based solely on numerical analysis results while the ones in Kappos et al. (2006) are based on a hybrid approach, which combines statistical data from earthquake-damaged Greek buildings with appropriately processed results from non-linear either dynamic or static analyses. Both sets of fragility curves have been derived for five damage limit states corresponding to slight (D1), moderate (D2), substantial to heavy (D3), very heavy (D4) and collapse (D5) damage of the building.

A simplification has been made with respect to Kappos et al. [30] classification scheme for the selection of the appropriate fragility functions. For critical facilities with no or low seismic code provisions, we consider Kappos et al. [30] fragility curves for low code while for the ones with medium or high seismic design level we consider the corresponding fragility curves for high code.

The fragility curves for low-rise R/C buildings with regularly infilled moment frames for low code (RC3.1LL) and high code (RC3.1LH) are plotted in Figure 19, while the fragility curves for low-rise R/C dual buildings with infilled frames for low code (RC4.2LL) and high code (RC4.2LH) are plotted in Figure 20. The adopted fragility curves for the masonry buildings are plotted in Figure 21. Table 14 summarizes the lognormal fragility parameters for the selected Kappos et al. [30] structural typologies.

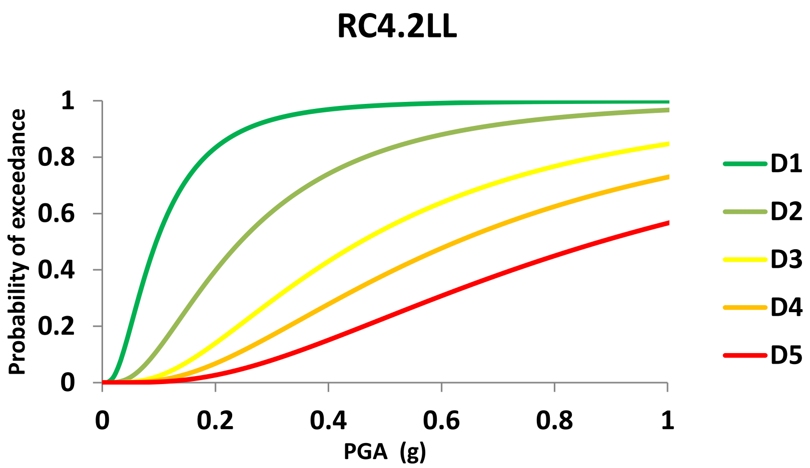


(a)

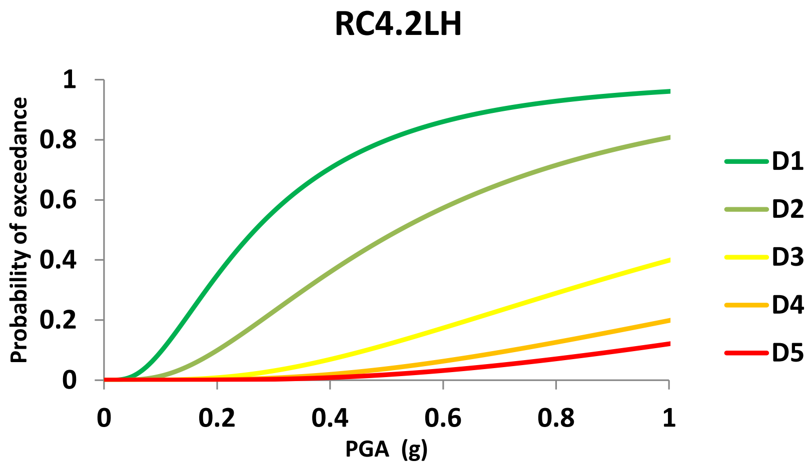


(b)

Figure 19. Fragility curves for low-rise R/C buildings with regularly infilled moment frames for (a) low code (RC3.1LL) and (b) high code (RC3.1LH) by Kappos et al. (2003)



(a)



(b)

Figure 20. Fragility curves for low-rise R/C dual buildings with infilled frames for (a) low code (RC4.2LL) and (b) high code (RC4.2LH) by Kappos et al. (2003)

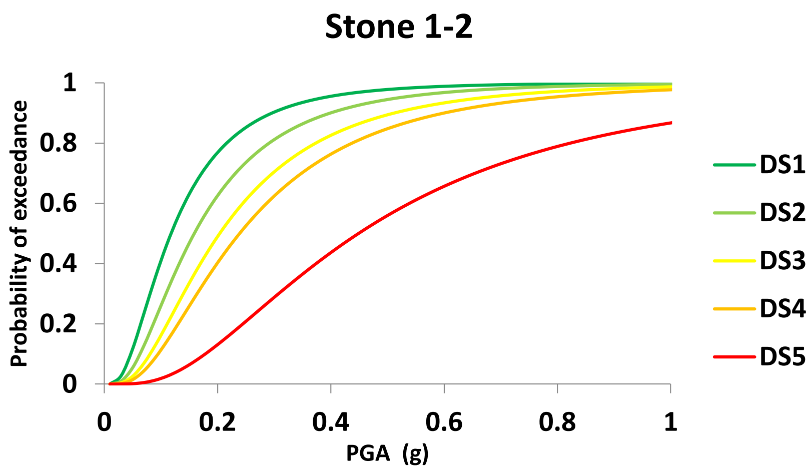


Figure 21. Fragility curves for masonry stone buildings with 1-2 storeys by Kappos et al. (2006)

Table 14 Median and standard deviation β of Kappos et al. [30] fragility curves for five damage levels

Typology	D1		D2		D3		D4		D5	
	Median	β	Median	β	Median	β	Median	β	Median	β
RC3.1LL	0.091	0.732	0.184	0.733	0.229	0.733	0.300	0.733	0.413	0.733
RC3.1LH	0.095	0.765	0.244	0.765	0.458	0.765	0.627	0.765	0.882	0.765
RC4.2LL	0.113	0.713	0.278	0.714	0.715	0.714	1.656	0.714	2.165	0.714
RC4.2LH	0.267	0.746	0.523	0.747	1.211	0.747	1.883	0.746	2.398	0.746
Stone 1-2	0.118	0.720	0.159	0.720	0.204	0.720	0.239	0.720	0.449	0.720

3.2.2. Seismic fragility and vulnerability of bridges

In Greece, earthquake damage to the road network observed is limited and related mainly to soil failures and landslides across the provincial network. The earthquakes in Kozani (1995), Lefkada (2003), NW Peloponnese (2008) and Kefallonia (2014) are examples of such damage.

On the other hand, there is no recorded significant earthquake damage to bridges in Greece. The generally satisfactory seismic behavior, the typology of the Greek bridges, as well as the nature of the earthquakes occurred (e.g. short duration) contribute to the lack of damage to date (OASP data). It is noted that in the Parnitha earthquake (1999, M_w=5.9), which is the last earthquake to hit a large urban center, no damage to bridges was reported [21], [41], despite the relatively large ground accelerations recorded.

Seismic fragility and vulnerability of bridges in Greece follows the description of 2.1.2.

3.2.3. Landslide hazard

In Greece, landslide-related fragility and vulnerability is estimated according to the general methodology presented in 2.2.1 and 2.2.2. Both sections cover landslide hazard and the corresponding fragility curves for the Greek building and bridge stock may be utilized.

3.3. Albania

The exposure model of the CBR of Albania presented in D4.1 [18] consists of 62 buildings intended for basic services, among which, 49 are school buildings and 13 are health care facilities. The exposure model of the transport infrastructure comprises 191 bridges.

Classification of the building typology has been done according to the GEM methodology, [10] (Figure 22, Figure 23). The bridge classification has been performed according to the methodology developed during previous research in the region [10] and implemented in the INFRA NAT project [29].

3.3.1. Seismic fragility and vulnerability of buildings - Schools and hospitals

Schools: According to the classification based on material type (Figure 22), 93.9% are masonry structures (M) and 6.1% are reinforced concrete (RC) structures.

Related to the classification based on lateral load resisting system, 66.7% of RC structures are moment resistant frame structures (LFM), and for the remaining 33.3% there is no information.

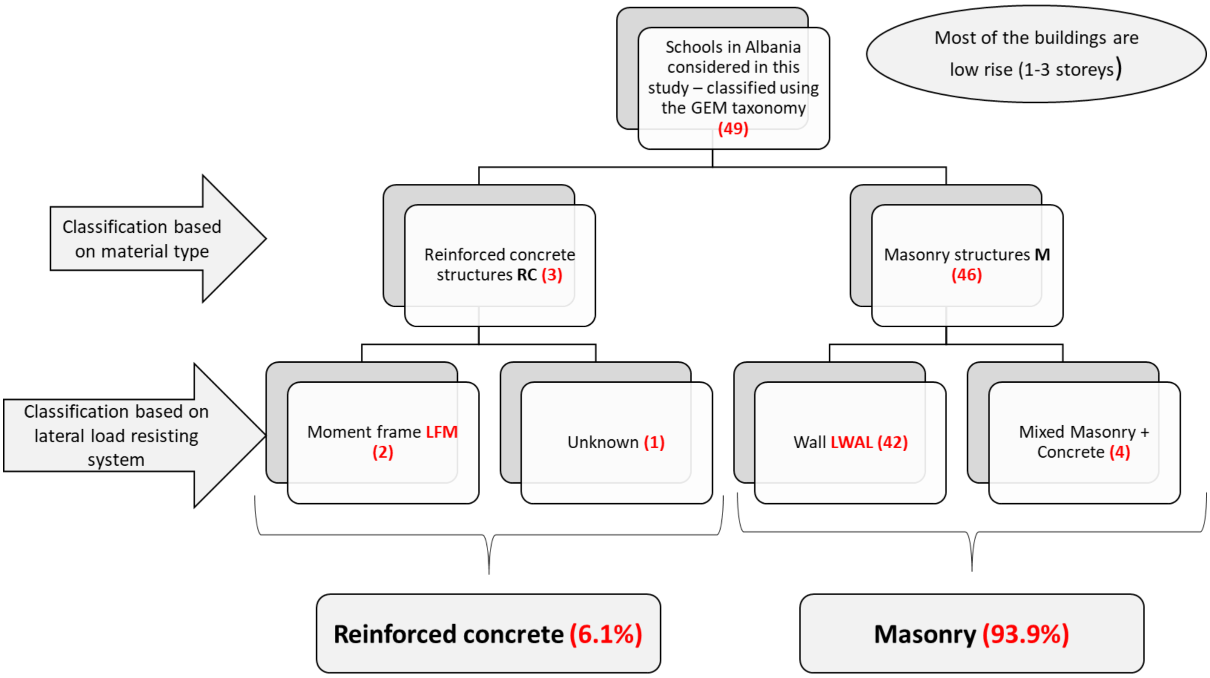


Figure 22 Exposure model of schools according to the GEM methodology (Albania)

Most of the structures constructed by use of the masonry technology represent unreinforced masonry structures (91.3%), while the remaining ones are constructed of mixed structure, unreinforced masonry + RC frame. According to the number of storeys of schools, 2% of them have one storey above ground, 20% have two storeys above ground, 61.2% have three storeys above ground and 16.8% have four storeys above ground, and each one of them does not have any storey below ground, meaning that most of these structures are low-rise [18].

Almost all of the school structures from the exposure model (98%) were built prior to the introduction of the currently valid national seismic regulations, KTP-N2-89. The remaining ones (2%) are designed and constructed according to these codes.

Hospitals: According to the classification based on material type (Figure 23), 66.7% are masonry (M) structures, and 33.3% are reinforced concrete (RC) structures.

Related to the classification based on lateral load resisting system, all of the RC structures are moment resistant frame structures (LFM), while 75% of masonry structures are structures with confined masonry and 25% are confined masonry + RC frame.

According to the number of storeys above and below ground, 33.4% have two storeys above ground, 33.3% have three storeys above ground, and 33.3% have four storeys above ground.

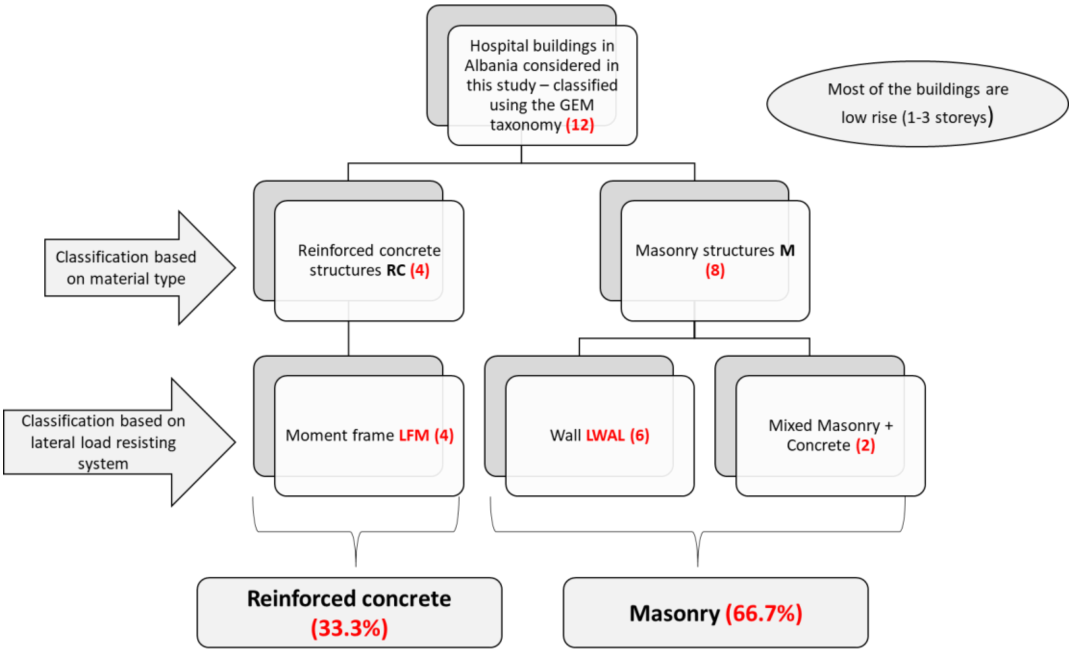


Figure 23 Exposure model of hospitals according to the GEM methodology (Albania)

More than 84% of the considered hospitals were built prior to the introduction of the national seismic regulations (1989) [42].

According to the building typology of the exposure model, the fragility curves developed for the RC structures have been selected based on recent studies [2], while the fragility curves for masonry structures have been selected based the seismic vulnerability model published on EFEHR (The European Facilities for Earthquake Hazard and Risk), [50], [45], and the doctoral thesis of Baballëku M. [5].

The reinforced concrete structures considered in the investigation were built between 1967-2001. Half of them were built according to the current national seismic regulations, after 1989; and the other half were built in the period between 1967-1987.

Regarding the number of storeys, 33.4% reinforced concrete structures are with 2 storeys, 33.3% are with 3 storey, 33.3% are with 4 storeys. The fragility curves for reinforced concrete structures is given below.

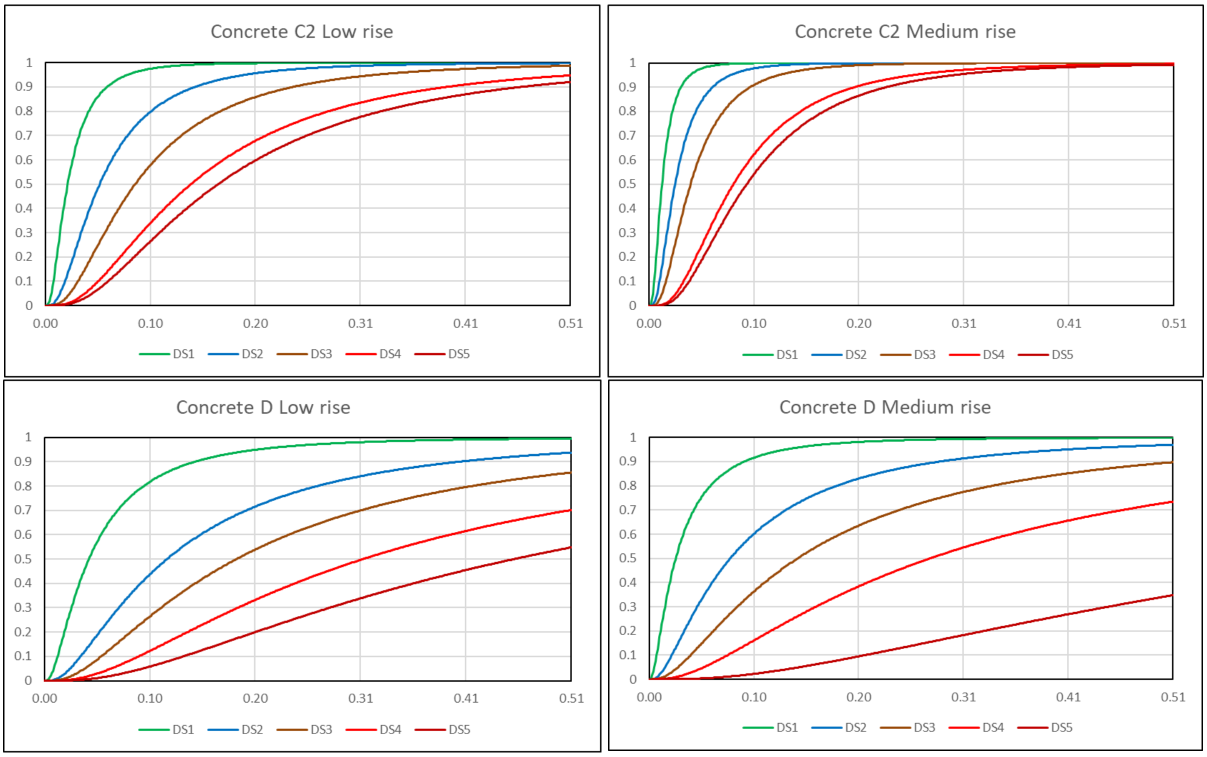


Figure 24 Fragility curves of low rise and medium rise RC frame buildings of vulnerability class C2 and D

Table 15 Median and standard deviation β of the fragility curves for five damage levels

Vulnerability class	DS1		DS2		DS3		DS4		DS5	
	Median	β	Median	β	Median	β	Median	β	Median	β
C2-Low rise	0.213	0.790	0.5118	0.790	0.857	0.790	1.388	0.790	1.646	0.790
D-Low rise	0.422	0.951	1.163	0.951	1.822	0.951	3.024	0.951	4.458	0.951
C2-Medium rise	0.126	0.693	0.250	0.693	0.397	0.693	0.806	0.693	0.931	0.693
D-Medium rise	0.253	0.995	0.774	0.995	1.417	0.995	2.682	0.995	7.386	0.995

D1- light damage, D2-moderate damage, D3-extensive damage, D4-complete damage, and D5 collapse

The masonry structures in the exposure model were built in the period 1923÷1993. According to the number of storeys 20.3% are two storeys, 50.2% are three storeys and 29.5% are four storeys. All of the masonry school structures are constructed with unreinforced masonry, and all of the masonry hospital structures are constructed with confined masonry. According to the number of storeys and the main construction material the fragility curves based on [50], [45] are given in Figure 25.

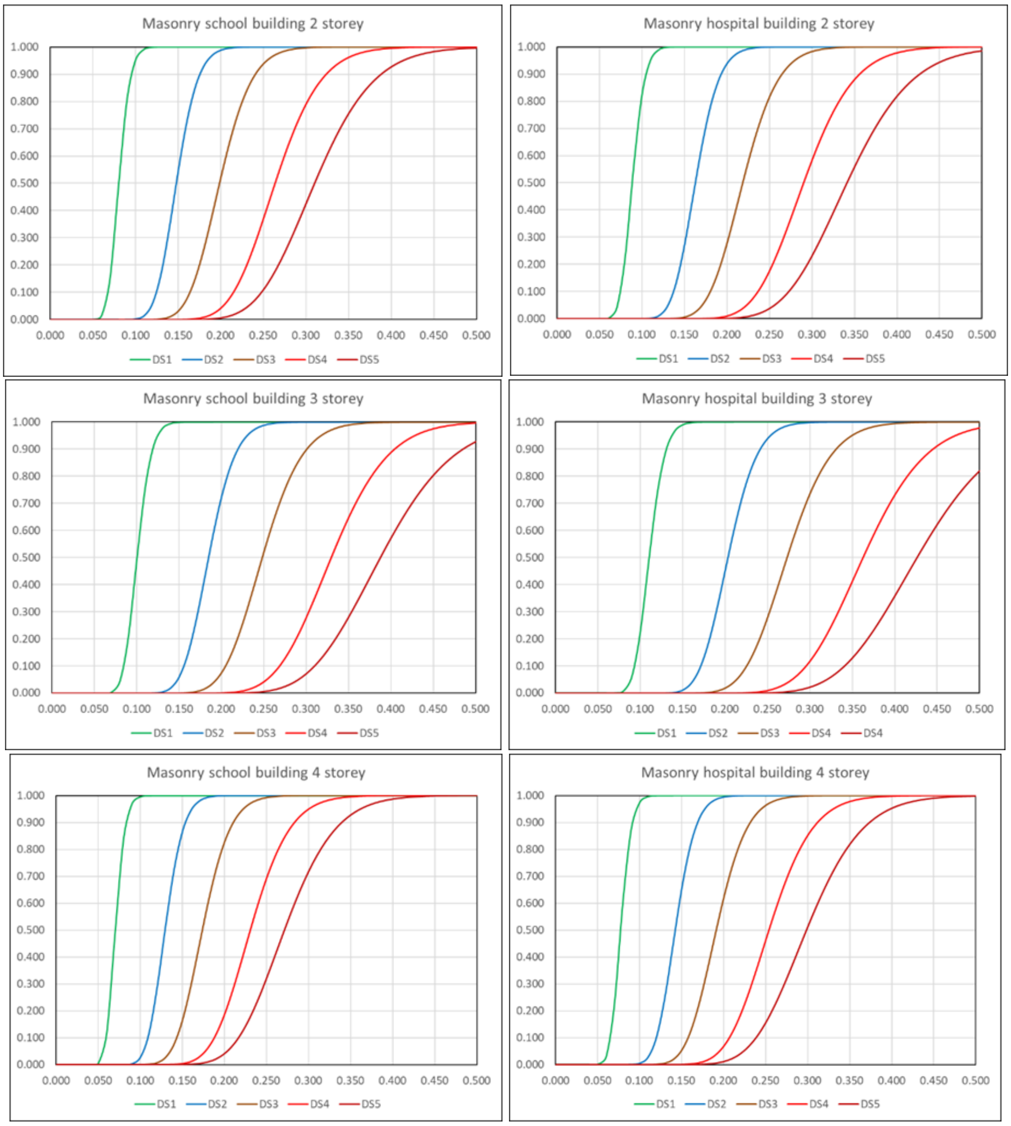


Figure 25 Fragility sets (from DS1 to DS5)

Table 16 μ and β values

Building macro-typologies	DS1		DS2		DS3		DS4		DS5	
	μ (g)	β (–)	μ (g)	β (–)	μ (g)	β (–)	μ (g)	β (–)	μ (g)	β (–)
Masonry school structure 2 storey	0.0802	0.132	0.1478	0.134	0.1985	0.15	0.2636	0.16	0.31	0.175
Masonry school structure 3 storey	0.1003	0.132	0.1847	0.134	0.2481	0.15	0.3296	0.16	0.3875	0.175
Masonry school structure	0.0702	0.132	0.1293	0.134	0.1737	0.15	0.2307	0.16	0.2713	0.175

Building macro-typologies	DS1		DS2		DS3		DS4		DS5	
	μ (g)	β (–)	μ (g)	β (–)	μ (g)	β (–)	μ (g)	β (–)	μ (g)	β (–)
4 storey										
Masonry hospital structure 2 storey	0.0882	0.132	0.1625	0.134	0.2183	0.15	0.29	0.16	0.341	0.175
Masonry hospital structure 3 storey	0.1103	0.132	0.2032	0.134	0.2729	0.15	0.3625	0.16	0.4263	0.175
Masonry hospital structure 4 storey	0.0772	0.132	0.1422	0.134	0.191	0.15	0.2538	0.16	0.2984	0.175

The fragility curves for masonry structures were taken also from the doctoral thesis of [5]. The fragility curves are given below. Based on the abovementioned study, it should be noted that typified school buildings with masonry structure built after the '60s show only slight differences in lateral capacity, although the seismic intensity scale is different for different places where these school buildings are situated. This conclusion is also experienced during damage data collection after the November 2019 Durrës Earthquake.

Table 17 μ and β values

Building macro-typologies	DS1		DS2		DS3		DS4	
	μ (g)	β (–)	μ (g)	β (–)	μ (g)	β (–)	μ (g)	β (–)
Masonry school structure 2 storey	0.2385	0.6069	0.5260	0.6069	0.7598	0.6069	0.9577	0.6069
Masonry school structure 3 storey	0.2192	0.7429	0.5065	0.7429	0.7603	0.7429	0.9843	0.7429
Masonry school structure 4 storey	0.2303	0.8593	0.5138	0.8593	0.7804	0.8593	1.0231	0.8593
Masonry hospital structure 2 storey	0.3297	0.5286	0.7195	0.5286	1.0157	0.5286	1.2588	0.5286
Masonry hospital structure 3 storey	0.2940	0.6514	0.6697	0.6514	0.9853	0.6514	1.2571	0.6514
Masonry hospital structure 4 storey	0.2910	0.7917	0.6592	0.7917	0.9967	0.7917	1.2999	0.7917

3.3.2. Seismic fragility and vulnerability of bridges

Most of the bridge structures in the considered region are constructed of reinforced concrete. According to the type of structural system, the most frequently found bridge types in this region are bridges with a girder system (with beam and slab main girders), then bridges with

a frame structural system, while pre-fabricated truss bridges account for the least number of bridges. As to the number of spans of structures for which there are data, more than half of them have 1 span (66.49%), about 14.14% have 2 spans, 8.38% have 3 spans, 3.66% have 4 spans, 5.24% have 5 spans and 1.05% have 7 spans.
There are no studies of Albanian bridge typology and fragility functions available. Therefore, seismic fragility and vulnerability of bridges in Albania follows the description of 2.1.2.

3.3.3. Seismic fragility and vulnerability of bridges

In Albania, landslide-related fragility and vulnerability is estimated according to the general methodology presented in 2.2.1 and 2.2.2. Both sections cover landslide hazard and the corresponding fragility curves for the Albanian building and bridge stock may be utilized.

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