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European Union
Humanitarian Aid

Rapid Multi-Risk Needs Evaluation and Planning Platform

101193586 - EMERGE - UCPM-2024-KAPP-PV

CBR Exposure, Resources and Capacity Portfolio

Basic Services and Transport Infrastructure Vulnerability Assessment
Prioritization of Interventions

Work package:	03
Deliverable Number:	3.3
Lead Beneficiary:	AUTH
Coordinator:	IZIIS
Contributing Beneficiaries:	EUCENTRE, AUTH, UPT-FCE, IUSS, CMC, PRD, AKMC, NOA, INFRATECH
Dissemination Level:	Public
Version:	1.0
Due Date:	November 30, 2025
Submission Date:	November 30, 2025



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WP-03 | D.3.3

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November 30, 2025

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Executive summary

This deliverable (D3.3) presents the results of the vulnerability assessment and prioritization of interventions for basic services and transport infrastructure within the EMERGE project. The work builds upon the harmonized regional exposure model developed in earlier project CRISIS (Comprehensive RISK assessment of basic services and transport InfraStructure) and update, accordingly, focusing on the territories of Albania, Greece, and North Macedonia. The objective of this activity is to refine and expand the exposure and vulnerability datasets to support evidence-based decision-making for risk reduction and to enhance regional disaster preparedness and emergency management capacities.

The report begins with an overview of the harmonized cross-border seismic and landslide hazard assessment, integrating national, regional, and European perspectives. The methodologies for earthquake and landslide hazard evaluation are summarized, with emphasis on their application to infrastructure systems across the three participating countries (CRISIS project).

Subsequently, the cross-border exposure model is described, covering two critical categories of infrastructure:

- Buildings providing basic services, i.e. schools and hospitals, and
- Transport infrastructure, i.e. road bridges and viaducts

For each country, data has been collected and harmonized according to a consistent methodology, enabling comparative assessment and regional synthesis. The analysis provides insight into the distribution, structural typologies, and age profiles of the exposed assets, with particular attention to their seismic and landslide vulnerability characteristics.

The following sections present regional fragility models that have been adapted or developed for each participating country to assess the vulnerability of object structures and infrastructures. Where local or national fragility curves were unavailable, established analytical models were calibrated to reflect the local construction practices and design standards. The models address both buildings for essential public services (schools and hospitals) and transport infrastructure elements.

1. Introduction

Exposure is a fundamental component of disaster risk assessment, representing the presence of people, assets, and infrastructure that may be affected by hazardous events (UNDRR, 2017). Reliable exposure data are essential for quantifying potential impacts, including property damage, economic losses, and human casualties, and for identifying effective measures to mitigate the risk (GAR, 2019). In this context, exposure modeling provides the spatial foundation for vulnerability and risk analysis by integrating geospatial, structural, and socio-economic information.

This deliverable (D3.3) is part of Work Package 3 (WP3) of the EMERGE project, which aims to enhance regional risk assessment capacity through the modeling of exposure, vulnerability, and capacity. It builds upon the harmonized regional exposure model for basic services and transport infrastructure developed within the CRISIS (Comprehensive RISK assessment of basic services and transport InfraStructure) project, refining and updating it to ensure improved accuracy, consistency, and interoperability across cross-border region (CBR).

The focus of Task 3.3 is to refine datasets for basic services (schools and hospitals), and transport infrastructure (road bridges and viaducts), and to support prioritization of interventions based on the exposure portfolio. Furthermore, it contributes to improving data sharing and coordination among National Civil Protection Authorities (NCPAs), enhancing collective capacity for multi-risk assessment and disaster preparedness in the CBR area.

This document presents the methodology and results related to the refinement of the regional exposure model, supporting the overall EMERGE objective of strengthening risk reduction and resilience-building across partner regions. In this framework, Section 2 briefly illustrates the main hazards considered in the EMERGE project, i.e. earthquakes and landslides, based on the harmonized multi-hazard approach set up within the CRISIS project for the CBR. Section 3 describes the exposure model of the CBR focusing on basic services (schools and healthcare facilities) and transport infrastructure (road bridges/viaducts). With reference to the above assets, Section 4 provides the key features of the fragility models adopted for assessing vulnerability to the considered seismic hazard. Finally, concluding remarks are summarized in Section 5.

2. Recap of the main features of the harmonized cross-border seismic and landslide hazard assessment

In this section, the harmonized approach for multi-hazard assessment in the CBR is briefly illustrated (Section 2.1). Then, Section 2.2 and Section 2.3 focus on the main addressed hazards, which are earthquakes and landslides, respectively.

2.1 Brief illustration of the methodology

A comprehensive risk assessment of critical infrastructure requires an integrated, multi-hazard approach combining advanced geospatial analysis, historical data, and modern probabilistic models. Previously concluded CRISIS project emphasized harmonization across the national borders among North Macedonia, Albania, and Greece and the regional context for seismic and landslide hazards, supporting resilient planning for buildings and transport routes (CRISIS D2.2, 2021 and CRISIS D2.3, 2021):

Key principles include:

- Reviewing national datasets, building codes and hazard mapping efforts for each country;
- Utilizing harmonized European and global hazard assessment tools (e.g., ESHM20 (the 2020 European Seismic Hazard Model) (Danciu et al., 2024) for seismicity, ELSUS v2 (Pan-European landslide susceptibility mapping for landslide susceptibility) (Wilde et al., 2018);
- Applying consistent probabilistic and scenario-based modeling to inform mitigation and planning;
- Cross-referencing infrastructure exposure and vulnerability for both natural hazards.

This methodology was framed by the need for zonation maps and susceptibility indices, scenario-based risk assessment and multi-criteria evaluation methods. In regions with complex terrain and incomplete inventories, harmonized large-scale approaches are recommended, supported by detailed local studies as available.

2.2 Earthquake hazard

Earthquake hazard assessment for critical infrastructure in the cross-border region is founded upon a rigorous review of available national, regional, and European models, culminating in the adoption of the state-of-the-art ESHM20 (European Seismic Hazard Model, (Danciu et al., 2024)) to ensure methodological harmonization.

2.1.1 National Perspective

In North Macedonia, seismic hazard assessment has evolved through several national models and seismotectonic zoning efforts since the 1960s, with contributions from the Institute of Earthquake Engineering and Engineering Seismology (IZIIS). These models incorporate historical seismicity, GPS-based tectonic measurements, and probabilistic mapping. Building codes have been updated over time towards Eurocode 8 (CEN, 2004-2006) compatibility - recent national annexes provide seismic zoning in acceleration units for modern design.

Albania's approach, while rooted in 1989's KTP-N2-89 code, has expanded through seismic microzonation of cities and regions. Hazard maps with return periods of 475 years have been produced by the Academy of Science and the Institute of GeoSciences,

Energy, Water and Environment (IGEWE). Eurocode-based seismic design is increasingly used, supplemented by historical catalogues and microzonation studies.

Greece implements zonal seismic hazard mapping reflecting extensive studies since the 1970s. Official seismic zoning divides the country into three zones (based on the updated 2003 code) with peak ground acceleration ranges of 0.16g, 0.24g and 0.36g for a 475-year return period. These reflect historic earthquake exposures and are integrated into engineering codes.

2.1.2 Regional and European Perspective

Regional harmonization was enhanced by the BSHAP (Harmonization of Seismic Hazard Maps for the Western Balkan Countries) project (Salic et al., 2017) for the Western Balkans, using smooth-gridded seismicity with results in peak ground acceleration (PGA) for return periods aligned with Eurocode 8. The ESHM20 provides probabilistic hazard assessment for Europe and Turkey, incorporating a range of source models (area, fault/background, kernel-smoothed) and site conditions, spanning 5000 to 73 years return periods.

The SHARE Project (Seismic Hazard Harmonization in Europe, www.share-eu.org, Giardini et al., 2014) and EMME Project (Earthquake Model of the Middle East, www.emme-gem.org, Erdik et al., 2012) integrate region-wide catalogues and logic-tree frameworks, capturing aleatory and epistemic uncertainties in scenario modeling and ground motion prediction, with outputs accessible for site-specific and regional analysis.

2.1.3 Application to Infrastructure

Harmonized hazard maps (ESHM20), scenario-based analysis, and uniform hazard spectra are applied to characterize the seismic hazard levels affecting major towns and key transport corridors. PGA values typically range between 0.20–0.45g for the mean 475-year return-period hazard, with maximum values observed in southern Albania and western Greece, and substantial values in the Debar-Librazhd (AL-MK border) and Valandovo-Kilkis (MK-GR border) zones.

2.3 Landslide hazard

The assessment of landslide hazard for cross-border critical infrastructure follows a meticulous review of inventory maps, susceptibility zonation and probabilistic approaches at national, regional, and European level.

2.3.1 National Inventories and Susceptibility Mapping

In North Macedonia, the mountainous terrain (over 79% hills/mountains) results in frequent landslides triggered by rainfall, snowmelt, or seismic activity. Multiple partial inventories exist, but national-level coverage is incomplete. Key research contributions

identified GIS-based susceptibility and earthquake-induced landslide risk, emphasizing the critical need for national strategies integrating different triggering events for future hazard management (CRISIS D2.3, 2021, Bojadjeva et al., 2025).

Albania, similarly, mountainous, has compiled a landslide inventory and susceptibility mapping at scales of 1:150,000 (regional) and 1:1,200,000 (national) by the Geological Survey of Albania (GSA). The methodology combines heuristic and bivariate statistical methods, evaluating terrain slope, aspect, lithology, land cover, hydrology, precipitation and seismicity. Over 2900 landslides have been catalogued, with comprehensive forms documenting location, geomorphology, geology and hydrotechnical data (GSA, 2015).

In Greece, landslide susceptibility mapping uses extensive historic inventory data (over 1600 cases pre-2010), multivariate statistical analysis and digital thematic maps of geological, hydrological, climatic, land use and population factors. Zonation is expressed by the Landslide Susceptibility Index (LSI), with six classes from very low to extremely high (Sabatakakis et al., 2013). However, like its neighbors, no complete hazard map exists at the national level.

2.3.2 Regional and European Approach

Cross-border harmonization integrates national findings with large-scale European models. The ELSUS v2 Pan-European Landslide Susceptibility Map (Wilde et al., 2018) is adopted for harmonized assessment, using multi-criteria evaluation of terrain gradient, lithology, and land cover datasets. Statistical and expert-based confidence levels are assigned; up to 65% of the cross-border region is classified as having high or very high landslide susceptibility, reflecting the dominance of mountainous terrain.

Triggering mechanisms are summarized, with emphasis on rainfall, earthquakes, and anthropogenic activities (infrastructure construction, land use change). Susceptibility, while predicting where landslides may occur, does not account for timing or magnitude. Hazards are quantified by combining spatial, temporal and event magnitude probabilities.

3. Cross border exposure model

This section illustrates the exposure model of the CBR focusing on basic services and transport infrastructure.

3.1. Buildings for Basic Services

3.1.1 Schools

3.1.1.1 Albania

To obtain data on the essential service structures required for the project, the CRISIS D4.1 (2021) methodology was applied. In the cross-border region there are 100 primary schools, 263 mixed primary and secondary schools, 267 secondary schools and 36 high schools, allocated in the seventeen municipalities considered Table 1.

Table 1. Considered primary and secondary schools by municipalities in Albania

#	Municipality	No. of primary schools	No. of mixed (primary and secondary) schools	No. of secondary schools	No. of high schools	Total no. of schools
1	Bulqizë	6	21	28	1	56
2	Devoll	12	17	12	1	42
3	Dibër	7	61	43	3	114
4	Dropull	0	1	6	1	8
5	Finiq	3	10	3	0	16
6	Gjirokastër	7	9	17	4	37
7	Kolonjë	2	10	11	1	24
8	Konispol	3	1	4	0	8
9	Korçë	12	35	14	9	70
10	Librazhd	7	24	25	4	60
11	Libohovë	0	2	7	0	9
12	Maliq	9	28	22	3	62
13	Përmet	3	5	18	0	26
14	Pogradec	12	28	28	3	71
15	Prrenjas	9	8	19	3	39
16	Pustec	1	2	4	0	7
17	Sarandë	7	1	6	3	17
Total no.		100	263	267	36	666

The location of the schools considered is shown in Figure 1.

The school buildings examined are primarily constructed with unreinforced masonry and reinforced concrete, respectively 75.8% and 24.2%. In terms of height, the number of stories varies from 1 to 5, where most of the schools are 1 story high (50.2%), 38% are 2 story high, 9.9% are 3 story high and the rest (2%) are 4 and 5 stories.

Regarding the construction period, 9.3% of the school buildings are constructed before 1960 and can be considered to have been designed without seismic design code (no code), 66.5% of the school buildings are constructed between the period 1960÷1960 and can be considered to have been designed with the earliest seismic design codes (1963, 1978) (low-code), and the remaining 24.2% are constructed after 1990 and can be considered to have been designed with the latest seismic design code (1989) (moderate-code).

The type of lateral load resisting system for masonry buildings is unreinforced masonry, while for reinforced concrete buildings is frame system.

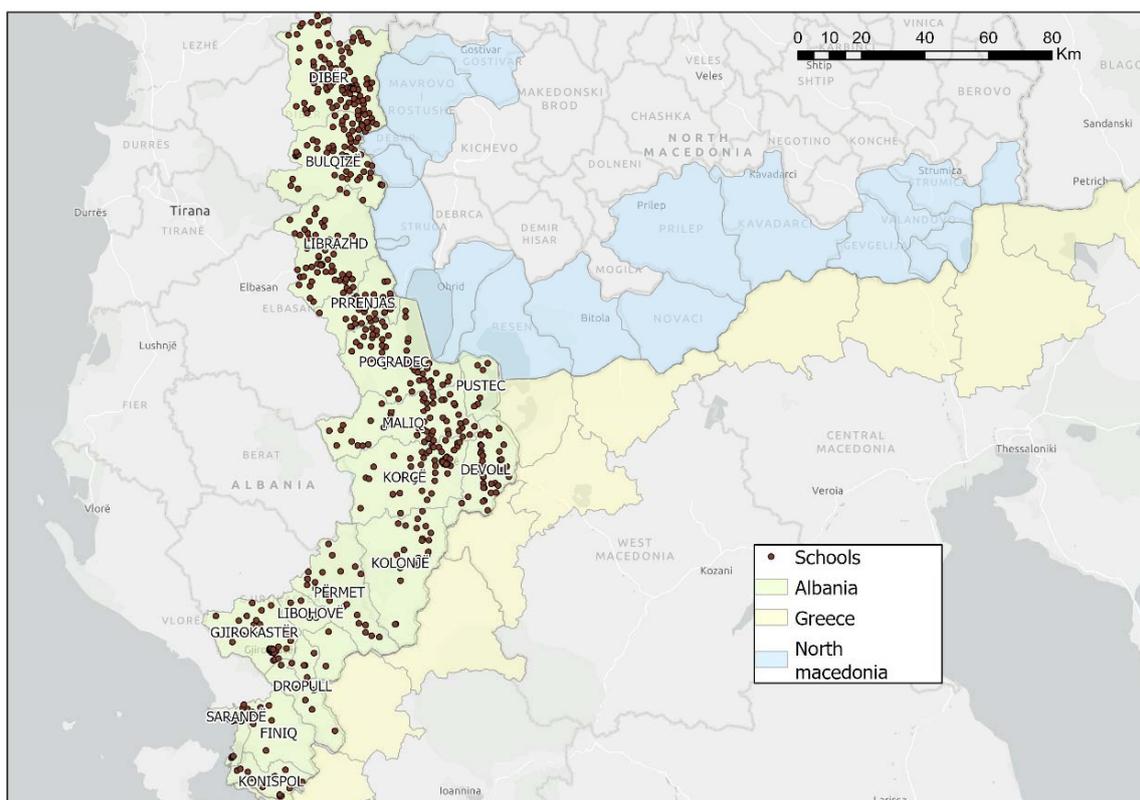


Figure 1. Location of the schools within the Albanian part of the CBR considered in this project

3.1.1.2 Greece

To develop the exposure model of the school buildings located in the Greek part of the EMERGE cross-border region, the respective database developed in the framework of the CRISIS project was updated using additional data from the national project RiskSchools (<https://riskschools.gr/>, Karafagka et al., 2024). The developed database consists of 63 schools, compared to 20 buildings in the CRISIS database. These 63 buildings are distributed to different municipalities according to Table 2.

Table 2. Considered primary and secondary schools by municipalities in Greece

#	Municipality	No. of primary schools	No. of secondary schools	Total no. of schools
1	Almopia	14	5	19
2	Florina	0	3	3
3	Kastoria	0	5	5
4	Kilkis	20	10	30
5	Konitsa	0	2	2
6	Paionia	2	2	4
Total no.		36	27	63

The location of the schools considered is shown in Figure 2.

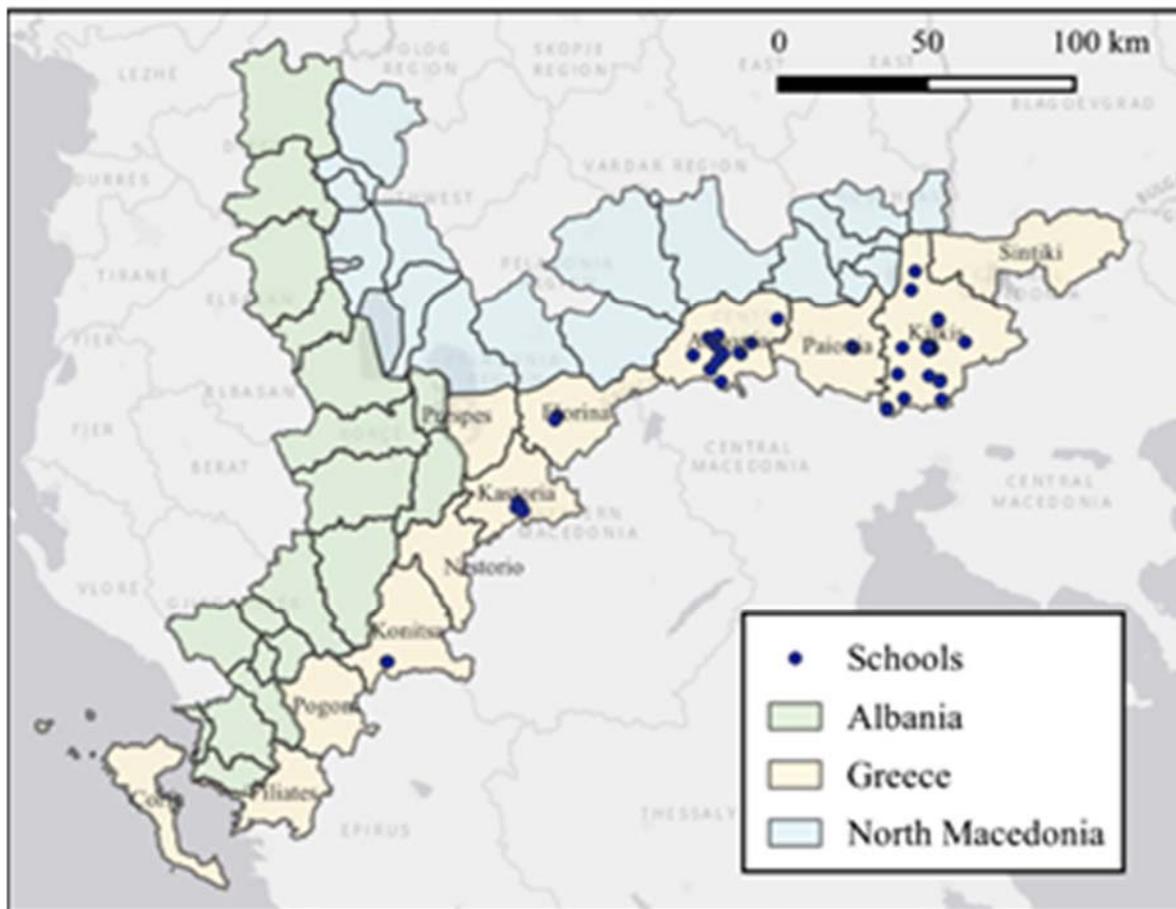


Figure 2. Location of the schools within the Greek part of the CBR considered in this project

The school buildings examined are primarily constructed from reinforced concrete (RC) and masonry, accounting for 65% and 27% of the sample, respectively. The rest consists of precast reinforced concrete structures.

In terms of height, most schools (57%) have two stories above ground, while 30% are single-story and 13% have three stories.

Regarding construction age, 25% of the buildings were built before 1959 and therefore lack seismic design. Another 40% were built between 1960 and 1995, reflecting low to moderate ductility standards and remaining 30% were constructed after 1995 under modern seismic codes. Finally, for three out of the 63 school buildings there was no information available on the exact construction period.

The type of lateral load resisting system was available for 39 out of the 41 RC buildings. Among them, 18 (46%) are frame systems. 20 (49%) are dual systems (with walls and frames), while there is only one building with wall system.

3.1.1.3 N. Macedonia

To obtain data on the essential service structures required for the project, the CRISIS D4.1 (2021) methodology was applied. The data collection process was conducted following the established procedure and the database has been updated with new available data on newly built schools.

According to the State Statistical Office of the Republic of North Macedonia, the total number of primary and secondary schools across the country amounts to 1,119, comprising 979 primary and 130 secondary schools (Statistical review 2017/2018).

Within the scope of CRISIS D4.1, only structures situated in larger settlements associated with border crossings were considered, for which relevant data were available. The same selection criteria have been applied in the present analysis, ensuring consistency with the previous study (CRISIS D4.1).

A summary of the number of schools included in the analysis by municipality is presented in **Error! Reference source not found..**

Table 3. Considered primary and secondary schools by municipalities in N. Macedonia

#	Municipality	No. of primary schools	No. of secondary schools	Total no. of schools
1	Mavrovo i Rostuše	0	1	1
2	Debar	2	1	3
3	Centar Župa	1	0	1
4	Struga	2	1	3
5	Vevčani	1	0	1
6	Debarca	0	0	0
7	Ohrid	3	2	5
8	Resen	1	1	2
9	Bitola	8	0	8
10	Novaci	0	0	0
11	Prilep	6	1	7
12	Kavadarci	5	3	8
13	Gevgelija	4	1	5
14	Valandovo	3	0	3
15	Bogdanci	1	2	3
16	Dojran	1	0	1
17	Strumica	3	4	7
18	Novo Selo	0	0	0
Total no.		41	17	58

The location of the schools considered is shown in Figure 3.

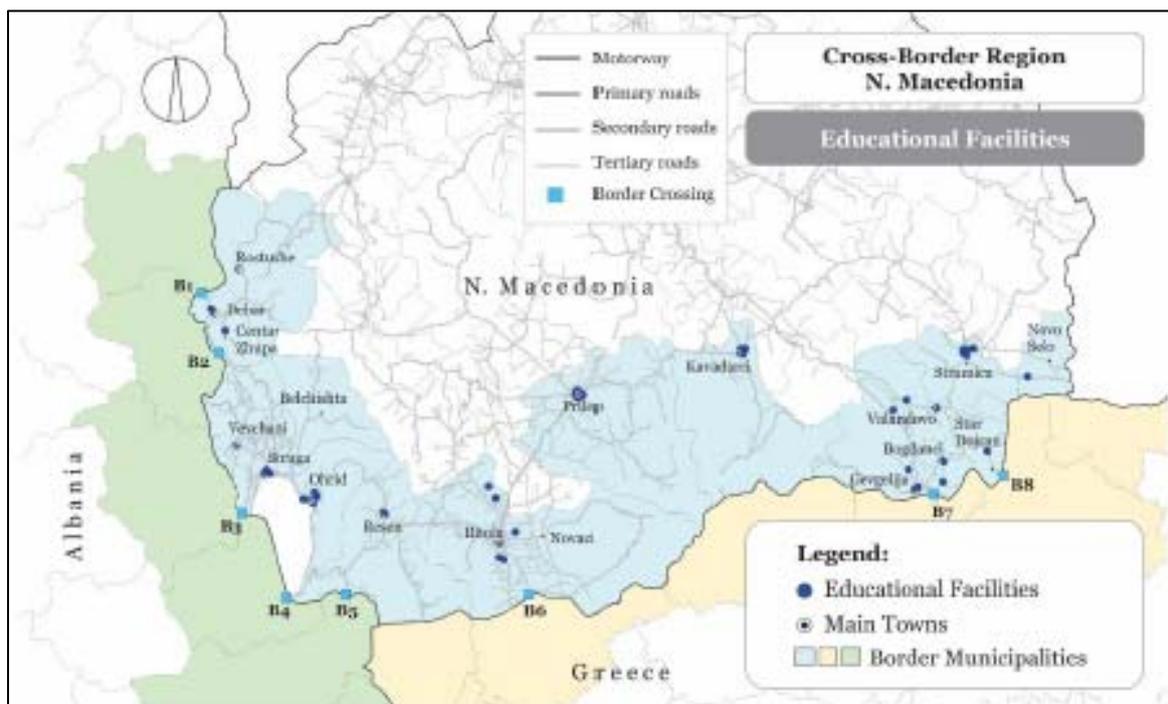


Figure 3. Location of the schools within the N. Macedonian part of the CBR considered in this project

According to structural material technology, most of the assessed school buildings are constructed using cast-in-place reinforced concrete, representing 43.9% of the total sample. Structures built with fired clay solid bricks constitute 40.4%, indicating a significant reliance on traditional masonry construction. A smaller proportion, 3.5%, was found to utilize alternative masonry unit technologies. The remaining buildings are characterized by using materials and techniques that could not be clearly identified, including stone masonry accounting for 5.3%, unclassified masonry with 5.3%, and unclassified concrete structures representing 1.8% of the total.

Based on the previously presented data, it can be observed that all structures built using cast-in-place technology are composed of reinforced concrete, accounting for 43.9% (CR) of the total. Among the structures employing masonry construction, the majority are confined masonry, representing 26.3% (MCF), while unreinforced masonry constitutes 15.8% (MUR). A smaller proportion of the masonry structures are reinforced masonry, comprising 1.8% (MR). The type of reinforcement is unspecified for 10.8% of the masonry structures (M99) and 1.8% of the concrete structures (C99).

With respect to the number of stories, most schools have two to three above-ground levels, and either one or no subterranean levels. Regarding the construction period, the oldest primary school in the database is located in Strumica and was built in 1926, whereas the most recently constructed school is the primary school in Bitola, completed in 2015.

A significant portion of the schools considered in this database (60.7%) were constructed prior to the implementation of seismic regulations, while the remaining 39.3% were designed and built in accordance with these codes.

The average story height of the school buildings is 350 cm. Based on the available data, the majority of the structures exhibit regular configurations (62.8%), whereas 30.2% are structurally irregular. The regularity of 7% of the buildings could not be determined.

3.1.2 Hospitals

3.1.2.1 Albania

The same data collection methodology applied to the schools has been employed for the hospitals (CRISIS D4.1).

The buildings considered for basic services in this study are healthcare facilities, encompassing general hospitals, clinics, and specialized hospitals. In the cross-border region, there is a total of 31 hospitals. Their distribution across municipalities is presented in Table 4.

Table 4. Healthcare facilities by considered municipalities

#	Municipality	Total no. of hospitals
1	Bulqizë	0
2	Devoll	1
3	Dibër	0
4	Dropull	0
5	Finiq	0
6	Gjirokastër	0
7	Kolonjë	2
8	Konispol	0
9	Korçë	4
10	Librazhd	5
11	Libohovë	0
12	Maliq	0
13	Përmet	6
14	Pogradec	11
15	Prrenjas	1
16	Pustec	0
17	Sarandë	1
Total no.		31

The location of the health care structures considered is shown in Figure 4.

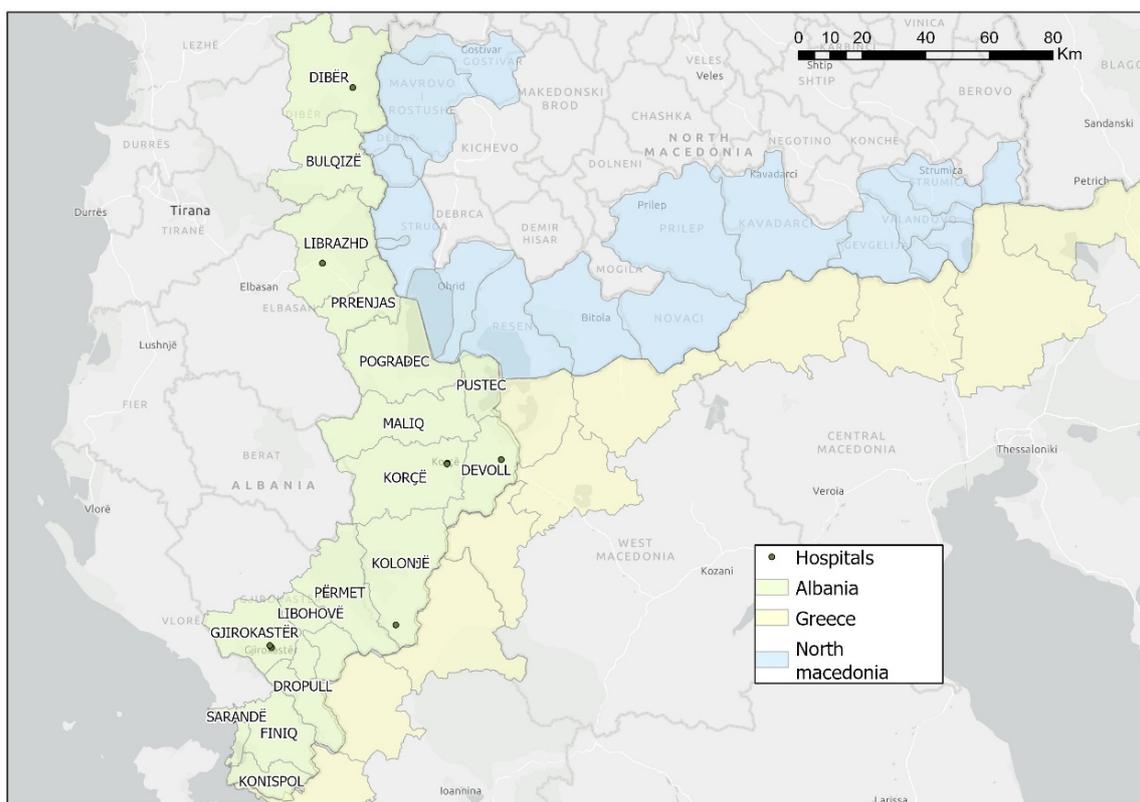


Figure 4. Location of the health facilities within the Albanian part that have been considered with this project

The majority of the hospitals are constructed using masonry structures, or mixed structures of masonry and reinforced concrete.

With respect to the number of stories, hospitals with 1, 2 and 4 stories account for 25.8% of the total stock each; 16.1% are with 3 stories and the rest (6.5%) are with 5 stories.

Regarding the construction period, 6.5% of the school buildings are constructed before 1960 and can be considered to have been designed without seismic design code (no code), 90.3% of the school buildings are constructed between the period 1960÷1960 and can be considered to have been designed with the earliest seismic design codes (1963, 1978) (low-code), and the remaining 3.2% are constructed after 1990 and can be considered to have been designed with the latest seismic design code (1989) (moderate-code).

3.1.2.2 Greece

To develop the exposure model of the hospitals located in the Greek part of the EMERGE cross-border region, the respective database developed in the framework of the CRISIS project was updated. The developed database consists of nine (9) hospitals, compared to six (6) hospitals in the CRISIS database. These 9 hospitals are distributed to different municipalities according to Table 3.

Table 5. Considered hospitals by municipalities in Greece

#	Municipality	Total no. of hospitals
1	Almopia	1
2	Florina	1
3	Kastoria	1
4	Kilkis	1
5	Konitsa	1
6	Paionia	2
7	Corfu	1
8	Filiates	1
Total no.		9

The location of the hospitals considered is shown in Figure 5.

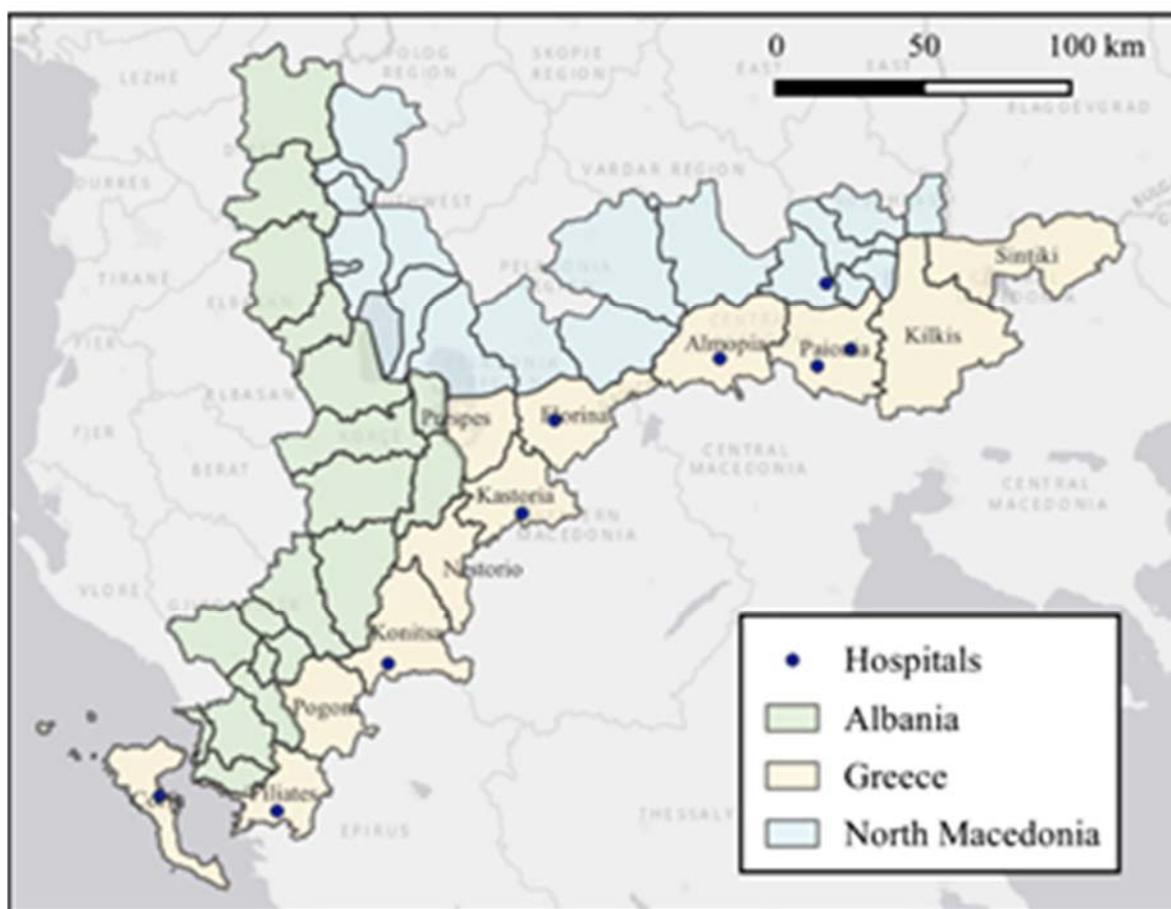


Figure 5. Location of the hospitals within the Greek part of the CBR considered in this project

Eight out of the nine hospital buildings included are primarily constructed from reinforced concrete, while one combines reinforced concrete with masonry.

In terms of height, the majority are low-rise structures, consisting of one to three stories above ground, while only one has six stories.

Construction age was available for seven out of the nine buildings. Of those two were built prior to 1959 and therefore lack seismic design, one was built in 1955 and later expanded in 1988, two hospitals were built between 1960 and 1995, reflecting low to moderate ductility standards, while two more were constructed after 2010 under modern seismic codes.

The type of lateral load resisting system was available for four hospitals, with three having dual systems (walls and frames) and one having frame system.

3.1.2.3 N. Macedonia

The same data collection methodology applied to the schools has been employed for the hospitals (CRISIS D4.1).

The buildings considered for basic services in this study are healthcare facilities, encompassing general hospitals, clinics, specialized hospitals, and health care centers. These facilities are defined as those capable of providing the necessary medical care and hospitalization for injured individuals.

Due to limited access to detailed design documentation for some of the structures, only a subset of the available data could be utilized for this study. Specifically, information was obtained for a total of 16 healthcare buildings. Their distribution across municipalities is presented in Table 6.

Table 6. Healthcare facilities by considered municipalities

#	Municipality	Total no. of hospitals
1	Mavrovo i Rostuše	-
2	Debar	1
3	Centar Župa	-
4	Struga	3
5	Vevčani	2
6	Debarca	-
7	Ohrid	1
8	Resen	2
9	Bitola	1
10	Novaci	-
11	Prilep	-
12	Kavadarci	2
13	Gevgelija	2
14	Valandovo	1
15	Bogdanci	-
16	Dojran	-
17	Strumica	1
18	Novo Selo	-
Total no.		16

The location of the health care structures considered is shown in Figure 6.



Figure 6. Location of the health facilities that have been considered with this project

The majority of the healthcare facilities for which data were available are constructed using reinforced concrete (CR), accounting for 68.8% of the total. Approximately 13% are masonry structures with unspecified reinforcement (M99), while 6.3% are unreinforced masonry (MUR). An equal proportion, 6.3%, consists of reinforced masonry (MR) and concrete structures with unknown reinforcement (C99).

With respect to the number of stories, approximately half of the healthcare facilities have two above-ground levels and one subterranean level.

In contrast to the school buildings, the healthcare facilities in the study region are generally older, with the earliest constructed in 1925 and the most recent in 1989. Over 85% of the hospitals included in the dataset were built before the introduction of seismic regulations in 1981, while the remaining were designed and constructed in accordance with these codes.

Based on the available data, the majority of these structures exhibit regular structural configurations. It should be noted that the analyses and presentations are based solely on the subset of buildings for which information is available, as no data exists for the remaining facilities.

3.2. Transport Infrastructure

3.2.1 Albania

The data collection for the bridge database was carried out in accordance with the CRISIS D4.1 methodology, encompassing bridges located along the primary road network within the cross-border area between Albania, North Macedonia, and Greece. A total of 190 bridges were included in the analysis. Their locations are shown in Figure 7. For some of these bridges, complete data have been available, while for some of them, there have been only basic data. Most of the bridges are situated along roads running to the border crossings on these two countries.

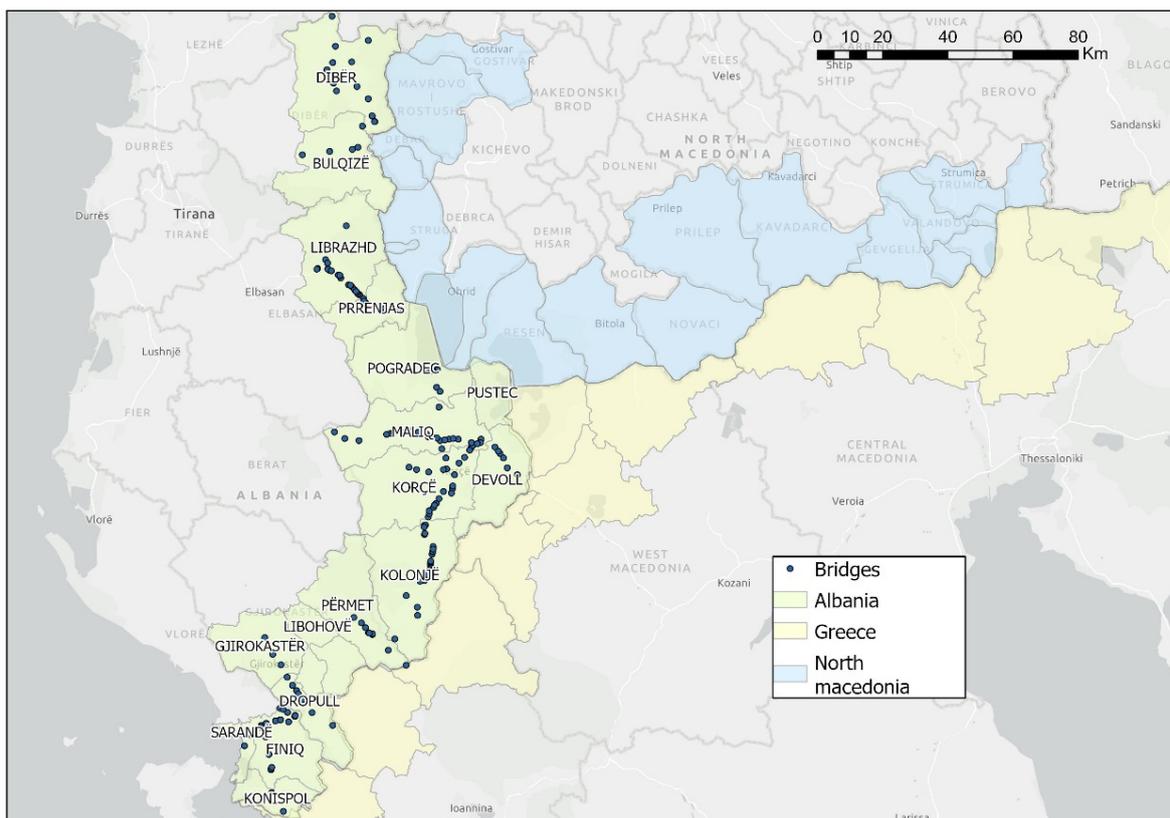


Figure 7. Location of the bridges considered in this project

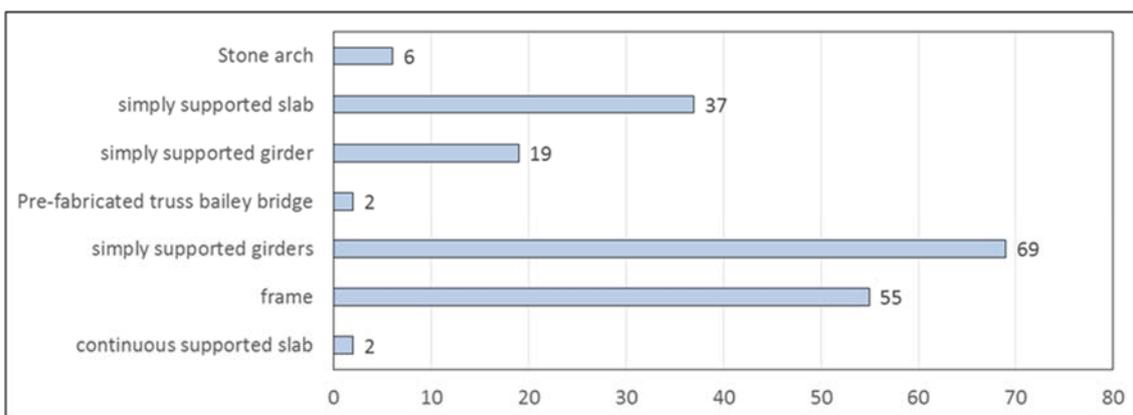


Figure 8. Number of bridges from the aspect of structural type

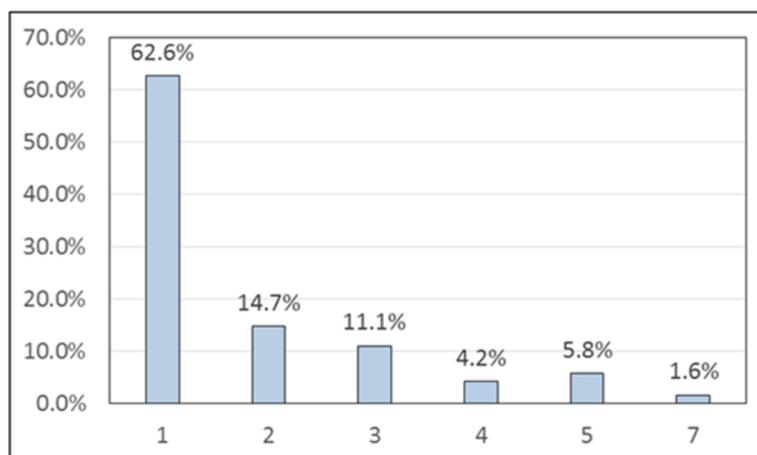


Figure 9. Percentage of bridges from the aspect of number of spans

For most of these bridges, there are only basic data, i.e. construction material, total length, number of spans, and structural system. In respect of structural system, the most common bridge type in this region is the simply supported girder, followed by frame bridges, while continuous supported slab and Bailey bridges represent the least frequent category (Figure 8).

Regarding the number of spans, data show that 62.6% of the bridges have 1 span, about 14.7% have 2 spans, while the greatest number of spans in this region is 7 (Figure 9).

The number of bridges in cross-border municipalities is shown in Table 7.

Table 7. Number of bridges by municipalities

#	Municipality	Total no. of bridges
1	Bulqizë	5
2	Devoll	8
3	Dibër	14
4	Dropull	7
5	Finiq	22
6	Gjirokastër	3
7	Kolonjë	29
8	Konispol	2
9	Korçë	26
10	Librazhd	24
11	Libohovë	-
12	Maliq	22
13	Përmet	9
14	Pogradec	6
15	Prrenjas	9
16	Pustec	-

17	Sarandë	4
Total no.		190

3.2.2 Greece

The developed exposure model for bridges located in the Greek part of the EMERGE cross-border region relies on the respective database developed in the framework of the CRISIS project, which was the result of an on-site investigation in the CBR. The database consists of 16 bridges, shown in Figure 10.

The main construction material for all bridges is reinforced concrete. Thirteen out of the sixteen bridges are characterized as overpass/culvert and are single-span, while the remaining three are multi-span bridges. The length of the bridge’s ranges between 5m and 210m, while the height of the piers ranges between 4m and 20m.



Figure 10. Location of the bridges within the Greek part of the CBR considered in this project

3.2.3 N. Macedonia

The data collection for the bridge database was carried out in accordance with the CRISIS D4.1 methodology, encompassing bridges located along the primary road network within the cross-border area between North Macedonia, Albania, and Greece. A

total of 128 bridges were included in the analysis. This number is slightly lower than that of the original CRISIS database, primarily due to the unavailability of certain required information for a subset of bridges. Their locations are shown in Figure 11. For some of these bridges, complete data have been available, while for some of them, there have been only basic data. Most of the bridges are situated along roads running to the border crossings on these two countries.



Figure 11. Location of the bridges considered in this project

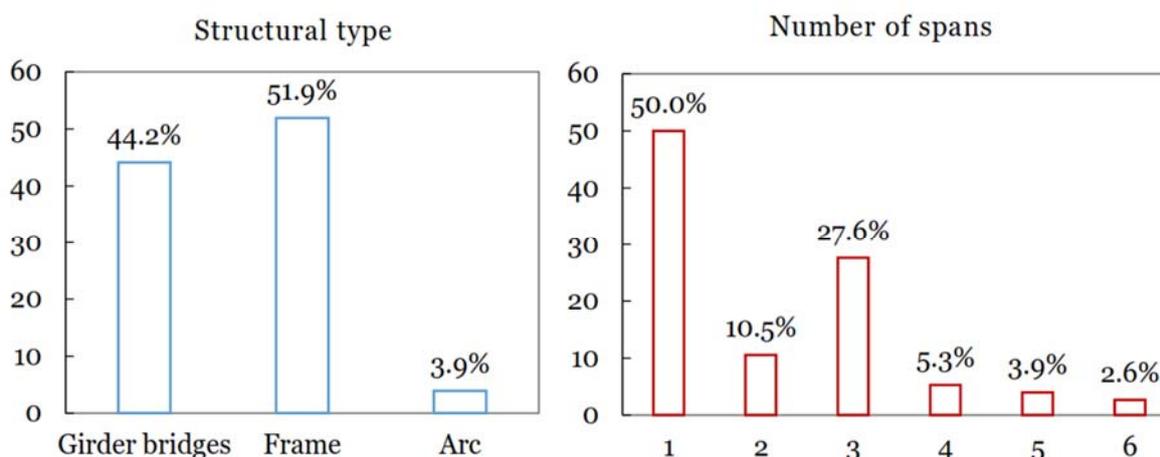


Figure 12. Percentage presentation of number of bridges from the aspect of structural type (left) and number of spans (right)

For most of these bridges, there are only basic data, i.e. construction material, total length, number of spans, and structural system. In respect of structural system, the most common bridge type in this region is the frame bridge, followed by girder bridges (with

beam and slab main girders), while arch bridges represent the least frequent category (Fig. 12 left).

As regards the number of spans, data show that half of the bridges have 1 span, about 28% have 3 spans, while the greatest number of spans in this region is 6 (Fig. 12 right).

The number of bridges in cross-border municipalities is shown in Table 8.

Table 8. Number of bridges by municipalities

#	Municipality	Total no. of bridges
1	Mavrovo i Rostuše	4
2	Debar	-
3	Centar Župa	-
4	Struga	3
5	Vevčani	-
6	Debarca	10
7	Ohrid	11
8	Resen	7
9	Bitola	23
10	Novaci	-
11	Prilep	17
12	Kavadarci	11
13	Gevgelija	31
14	Valandovo	-
15	Bogdanci	2
16	Dojran	-
17	Strumica	5
18	Novo Selo	4
Total no.		128

4. Fragility models for assessing seismic vulnerability of the buildings for basic services and infrastructures

This section provides the main features of the fragility models adopted for assessing the vulnerability of the buildings for basic services and transport infrastructure located within the CBR, presented in Section 3 above.

4.1 Buildings for Basic Services

Seismic vulnerability of the exposure models for basic services in CBR, as presented in Section 3 above, is assessed in accordance with the CRISIS D4.2 (2022) methodology and the updated SP-BELA fragility curves (Borzi et al., 2008; Faravelli et al., 2023).

This approach enables a consistent classification of the assessed RC structures according to their seismic design level, namely:

- non-earthquake-resistant design buildings
- earthquake-resistant design buildings

For masonry structures, three categories are defined, correlated are correlated with the five different construction periods.

- High-vulnerability masonry structures
- Medium-vulnerability masonry structures
- Low-vulnerability masonry structures

The SP-BELA fragility functions provide an empirically calibrated relationship between structural damage probability and ground motion intensity expressed via PGA. Figure 13 shows the adopted fragility curves for two-story masonry and three-story reinforced concrete buildings.

Furthermore, the corresponding fragility parameters for RC and masonry RC buildings with one, two, three, and four stories are summarized in Table 9. These parameters serve as the fundamental input for the subsequent seismic vulnerability assessment.

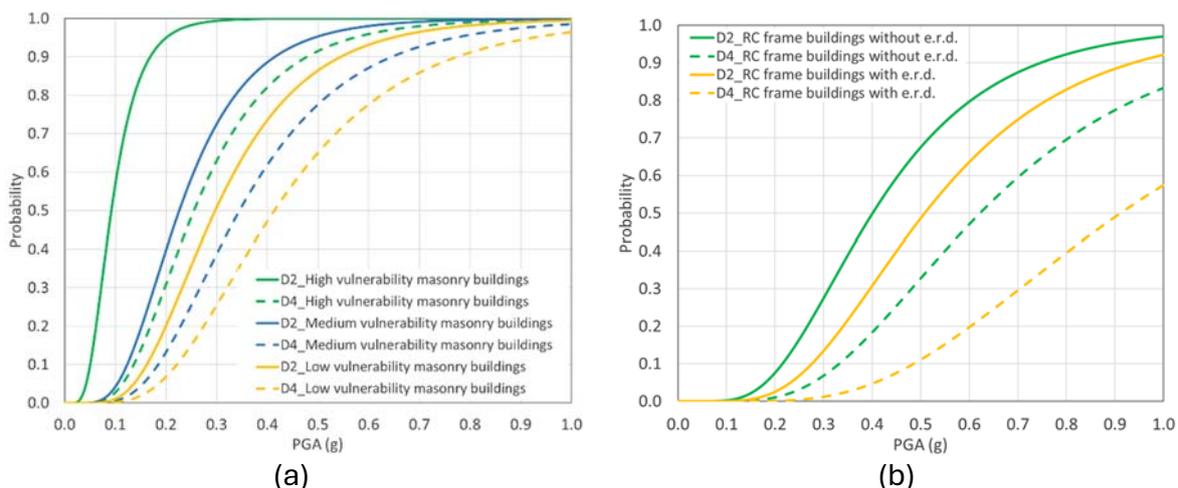


Figure 13. Fragility curves of 2-storey masonry (a) and 3-story RC buildings (b) (Faravelli, 2023)

4.2 Transport Infrastructure

Most bridge structures in the considered region are constructed of reinforced concrete. The most common bridge types in this area are those with a girder structural system (including beam and slab main girders), followed by bridges with a frame system, while arch bridges represent the smallest proportion. Regarding the number of spans in structures with available data, approximately half have a single span, a considerable share has three spans, and a small percentage have six spans, which is the highest number of spans observed in this region.

To assess the seismic risk of bridge structures, fragility curves will be applied in the same manner as those employed in the CRISIS project.

Table 9. Fragility curve parameters (median and β) for five damage levels for reinforced concrete and masonry structures by number of stories

Typology	N. of storeys	α_{D1} (g)	β_{D1} (-)	α_{D2} (g)	β_{D2} (-)	α_{D3} (g)	β_{D3} (-)	α_{D4} (g)	β_{D4} (-)	α_{D5} (g)	β_{D5} (-)
High vulnerability masonry buildings	1	0.053	0.603	0.145	0.603	0.210	0.603	0.389	0.580	0.486	0.580
	2	0.033	0.473	0.092	0.473	0.133	0.473	0.255	0.489	0.319	0.489
	3	0.030	0.519	0.083	0.519	0.121	0.519	0.225	0.531	0.282	0.531
	≥ 4	0.030	0.506	0.082	0.506	0.120	0.506	0.219	0.516	0.273	0.516
Medium vulnerability masonry buildings	1	0.202	0.603	0.358	0.603	0.404	0.603	0.525	0.580	0.750	0.580
	2	0.128	0.473	0.226	0.473	0.256	0.473	0.345	0.489	0.493	0.489
	3	0.116	0.519	0.205	0.519	0.232	0.519	0.304	0.531	0.434	0.531
	≥ 4	0.115	0.506	0.204	0.506	0.230	0.506	0.295	0.516	0.422	0.516
Low vulnerability masonry buildings	1	0.309	0.603	0.469	0.603	0.526	0.603	0.630	0.580	1.050	0.580
	2	0.196	0.473	0.297	0.473	0.332	0.473	0.414	0.489	0.690	0.489
	3	0.177	0.519	0.269	0.519	0.301	0.519	0.365	0.531	0.608	0.531
	≥ 4	0.176	0.506	0.267	0.506	0.299	0.506	0.354	0.516	0.591	0.516
RC frame buildings without e.r.d.	1	0.522	0.642	1.741	0.642	2.350	0.642	2.474	0.636	3.535	0.636
	2	0.179	0.515	0.597	0.515	0.807	0.515	0.889	0.511	1.269	0.511
	3	0.120	0.486	0.401	0.486	0.542	0.486	0.622	0.490	0.889	0.490
	≥ 4	0.110	0.498	0.368	0.498	0.496	0.498	0.611	0.528	0.873	0.528
RC frame buildings with e.r.d.	1	1.369	0.624	1.685	0.624	2.190	0.624	2.391	0.616	4.782	0.616
	2	0.535	0.507	0.658	0.507	0.855	0.507	1.026	0.498	2.053	0.498
	3	0.413	0.477	0.508	0.477	0.661	0.477	0.912	0.492	1.824	0.492
	≥ 4	0.386	0.476	0.475	0.476	0.618	0.476	0.935	0.499	1.871	0.499

5. Concluding remarks

The following points summarize the harmonised CBR risk exposure model for basic services and transport infrastructure, along with the corresponding fragility curves:

- Harmonization of the CBR exposure model for basic services (schools and hospitals) has been carried out using the GEM taxonomy. The bridge exposure model has been harmonised based on the classification of reinforced concrete bridge structures according to their structural system and number of spans.
- Only structures located in or near larger cities within the CBR—serving a significant number of users—have been considered.
- For the CBR area between North Macedonia, Greece, and Albania, the following assets have been mapped:
 - 787 school buildings (58 in North Macedonia; 63 in Greece; 666 in Albania)
 - 56 health care structures (16 in North Macedonia; 9 in Greece; 31 in Albania)
 - 334 bridges (128 in North Macedonia; 16 in Greece; 190 in Albania)
- Fragility models for assessing seismic vulnerability of the buildings for basic services are cross-border harmonized and based on CRISIS D4.2 (2022) methodology and the updated SP-BELA fragility curves (Borzi et al., 2008; Faravelli et al., 2023).
- Fragility models for seismic vulnerability assessment of transport infrastructures will be the same as those used in the CRISIS project (D4.2, 2022).

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