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THE CRISIS PLATFORM: A CROSS-BORDER PLATFORM FOR RISK ASSESSMENT AND MANAGEMENT

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Abstract

This paper aims to describe the CRISIS web-based platform (WBP) in all its parts and functionalities. The platform is the main result of the two-year EU-funded project CRISIS (Comprehensive RISk assessment of basic services and transport InfraStructure). It has been developed by EUCENTRE (European Centre for Training and Research in Earthquake Engineering) using the most up-to-date web programming frameworks and technologies. The CRISIS WBP is a user-friendly tool intended to support disaster and emergency management authorities in case of earthquakes and/or seismo-induced landslides in the cross-border region of Albania, North Macedonia, and Greece. It has been designed to collect, organise, and visualise for the project target area: i) the exposure data of educational facilities, health facilities, and bridges; ii) the seismic and landslide hazard data; iii) the earthquake damage scenarios (calculated both for selected historical events and in real-time); and iv) the landslide risk scenarios related to the considered exposure dataset. The tool also allows the identification of alternative routes to the nearest available safe facilities, if the main one cannot be used due to damage to the transport infrastructure following a seismic event. This feature can be particularly useful for rescuers who have to intervene promptly after damaging earthquakes. In addition to supporting emergency management, the CRISIS platform can also be used to identify the most vulnerable assets and prioritise actions to increase the resilience of the project target area. As a case study, two earthquakes that affected the cities of Ohrid and Valandovo in 1911 and 1931, respectively, have been simulated. The results of these simulations, also in terms of emergency management (e.g., how to get to the nearest hospitals in the cross-border areas), are presented in detail hereinafter.

Keywords: Earthquakes, Landslides, Risk Assessment, Emergency Management.

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1. Introduction

Disasters know no national borders and often emergency conditions require rescue action even from neighbouring countries. It is therefore important to minimise as far as possible all disruptions, even temporary ones, that could significantly alter cross-border flows. This was the primary goal of the CRISIS (Comprehensive RISk assessment of basic services and transport InfraStructure) project, which aimed to increase the resilience of critical infrastructure in emergencies after catastrophic events through preventive measures, effective resource management, and risk assessment of basic services, i.e., health and educational facilities (hospitals and schools) as well as transport infrastructure (bridges and viaducts).

CRISIS was a two-year EU-funded project that started in November 2020 and focused on the cross-border region (henceforth CBR) of North Macedonia, Albania, and Greece. This target area, consisting of eighteen municipalities in North Macedonia, eleven districts in Albania, and twelve municipalities in Greece, has been affected by destructive earthquakes in the past (Mw≥6). Moreover, this region is also susceptible to landslides, mainly due to its topography, lithology, vegetation cover distribution, and weather conditions. Hence the need to develop cross-border harmonised hazard models and a common platform for sharing risk data/information. This paper focuses on the second objective, i.e., to describe the CRISIS web platform (henceforth WBP), developed by EUCENTRE (European Centre for Training and Research in Earthquake Engineering) within the framework of the project.

The CRISIS WBP is a georeferenced tool that provides rapid risk for educational and health facilities and transport infrastructure in case of potential earthquakes or landslides. It aims to collect, organise, and visualise: i) the exposure data on cross-border basic services and transport infrastructure; ii) the cross-border hazard data; iii) the earthquake damage scenarios, and iv) the landslide risk scenarios. Once an earthquake damage scenario has been calculated, the tool also allows the identification of possible alternative routes to the nearest available safe facilities (i.e., *routing*). As designed and developed, the CRISIS WBP is a user-friendly tool intended to support disaster and emergency management authorities in the event of an earthquake or landslide emergency.

2. Cross-border exposure and vulnerability model for basic services and transport infrastructure

The CRISIS project aimed to improve disaster and emergency management by creating a harmonised and efficient system for risk assessment of basic services and transport infrastructure in the target CBR. For the project purposes, only facilities located in largely populated areas, connected to border crossings and serving a significant number of users have been considered. This is because they can ensure greater cross-border cooperation and coordination in disaster risk management. For these facilities, a harmonised risk exposure model has been created.

For schools and hospitals, it has been used the *Global Earthquake Model (GEM) - Direct Observation Tool* [1]. Afterwards, buildings in the database have been grouped into taxonomies based on the criteria adopted by the *GEM Building Taxonomy* [2]. In particular, the latter classifies buildings according to thirteen attributes, ranging from their intended use (i.e., occupancy) to the building's construction and structural characteristics, which allow their seismic behaviour to be assessed.

For bridges in the CBR network, each neighbouring country has gathered all possible and useful data for a seismic assessment of their structural behaviour, following a common data collection method established beforehand. Afterwards, bridges have been grouped into taxonomies based on construction material, static scheme (e.g., arch bridges, continuous girder bridges, simply-supported bridges), and geometric characteristics (e.g., span length).

Table 1 reports the final exposure model defined for the CRISIS project, divided by the number of educational and health facilities as well as road infrastructure in each of the three neighbouring countries of the target CBR. This exposure model has been implemented in the CRISIS WBP, which allows it to be visualised by activating dedicated layers in the “Exposure layers” tab (see Figure 1). Once one or more layers have been activated and a specific item has been selected, the corresponding information collected in the exposure database can be viewed through a pop-up window, as shown in Figure 1.

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Table 1 – Educational facilities, health facilities, and road infrastructure in the harmonised CBR exposure database

Country	Educational facilities	Health facilities	Road infrastructure
North Macedonia	57	15	166
Albania	49	12	190
Greece	19	7	16
Total	**125**	**34**	**372**

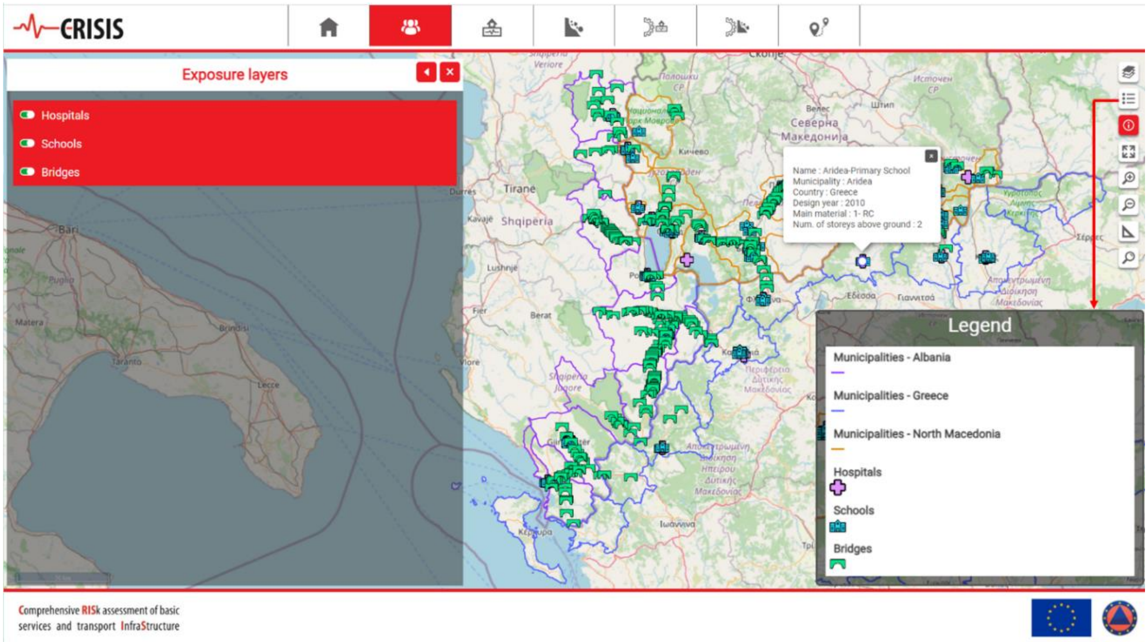

Figure 1. “Exposure layers” tab: visualisation of the harmonised CBR exposure database and corresponding legend

In addition to the exposure model, the calculation of seismic damage scenarios (see section 4.1) requires the earthquake behaviour of each structure and infrastructure in the database to be defined. This was done by associating appropriate fragility curves with each taxonomy of educational and health facilities and road infrastructure. In particular, for educational and health facilities, each neighbouring country of the project CBR proposed sets of fragility curves from the literature that best describe the seismic behaviour of its buildings, also according to their construction characteristics. Each of these sets is composed of five fragility curves, one for each damage level (DLi) as defined by the European Macroseismic Scale 98 (EMS98; [3]). For road infrastructure, instead, the fragility curves defined by EUCENTRE have been associated with reinforced concrete and masonry bridges with continuous and supported decks ([4], [5]) as well as with masonry and slightly reinforced arch bridges ([6], [7]). Fragility curves in [8] have been used for frame bridges. Finally, unlike structures, only two damage levels have been considered for road infrastructure, i.e., slight damage and collapse.

3. Cross-border multi-hazard assessment

3.1 Seismic hazard cross-border harmonization and mapping

The target area of the CRISIS project has been selected because of its high seismicity. In the past, several earthquakes occurred in this region, causing considerable damage as well as numerous deaths and injuries (see Figure 2). To estimate in this area the probability of a certain earthquake occurring in a given time interval, a review of the different seismic hazard models available in the literature has been carried out for each country and/or region involved in the project CBR, as well as for various European projects. In the end, the ESHM13 (2013 European Seismic Hazard Model, [9]) hazard model has been selected because it has resulted in the most up-to-date and the only one to consider all three countries

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of the project area. The hazard maps in Peak Ground Acceleration (PGA) referring to the ESHM13 [9] mean hazard model have thus been implemented in the CRISIS platform for three return periods (RTs), i.e., 102 years (39% probability of exceedance in 50 years), 475 years (10% probability of exceedance in 50 years), and 975 years (5% probability of exceedance in 50 years). These maps are available in the "Seismic Hazard" tab together with the Vs30 (the time-averaged shear-wave velocity to 30 m depth) map proposed by the United States Geological Survey (USGS, earthquake.usgs.gov/data/vs30). The latter was implemented in the platform to take site effects into account in the calculation of real-time damage scenarios (see section 4.1).

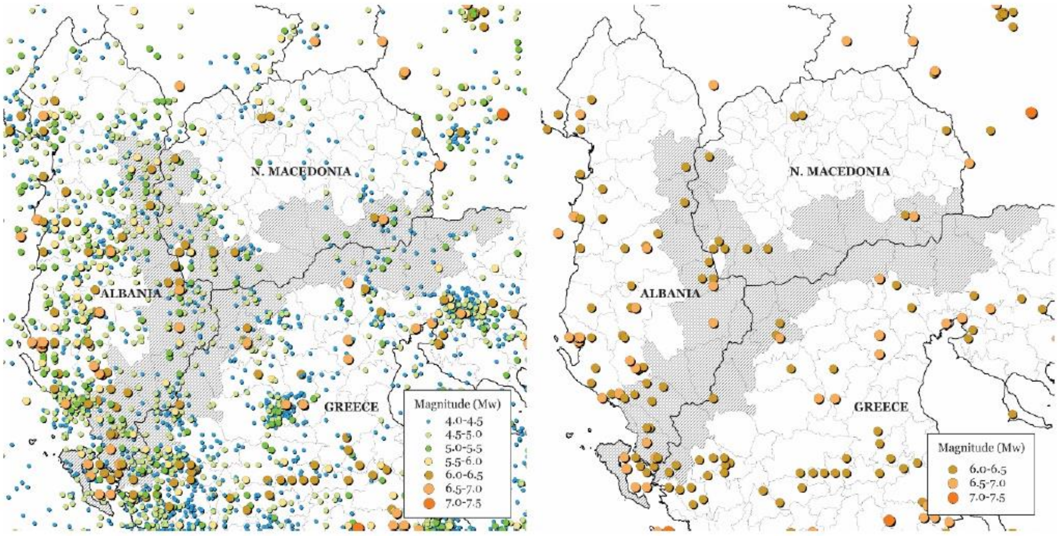

Figure 2. Seismicity data for the target CBR related to the period 1000 A.D.-2006 A.D. from the SHARE European Earthquake Catalogue (SHEEC; [9], [11], [12])

Figure 3 shows the activation of the seismic hazard map for an RT equal to 475 years (mean hazard model and to rock site conditions) with the relative legend in the CRISIS platform. Figure 3 highlights the high seismicity of the project CBR, where PGA estimates can range from 0.20g to 0.45g. In particular, the area with the highest seismic hazard is in the southwestern part of the CBR where PGA is reaching values of 0.45g (dashed red box in Figure 3), followed by the one at the border between Albania and North Macedonia where the PGA values can reach 0.40g (dashed orange box in Figure 3).

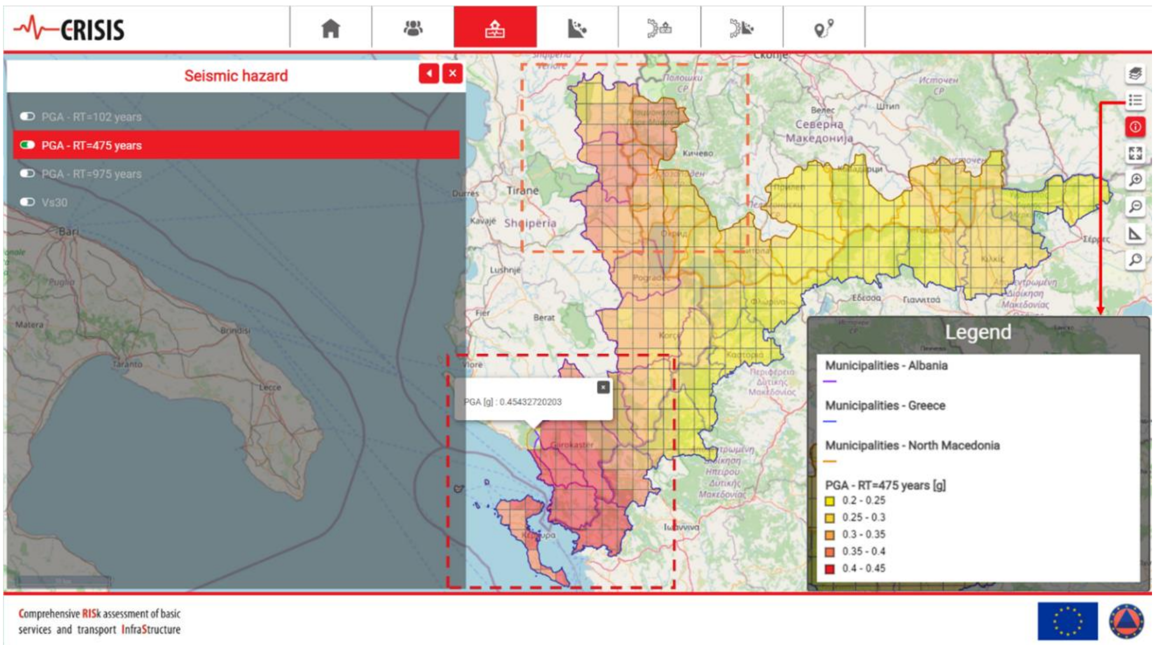

Figure 3. "Seismic hazard" tab: seismic hazard map for RT=475 years and corresponding legend

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3.2 Landslide hazard cross-border harmonization and mapping

The project CBR is prone to a high landslide hazard due to its topography, lithology, vegetation cover distribution, and meteorological conditions. As with the seismic hazard, all available data and studies on landslides in each of the three CBR countries have been reviewed to produce landslide hazard maps for the project target area. This review has also been extended to European projects from which the European Landslide Susceptibility Map version 2 (ELSUS v2, [13]) approach has been selected. Indeed, the latter has turned out to be the most suitable methodology for the harmonised assessment of landslide susceptibility and hazard in the project CBR.

As reported in section 3.1, this region is highly earthquake-prone. So, it is not possible to decouple seismic phenomena from landslides. Seismically induced landslides are triggered when the critical acceleration a_c causes the factor of safety to fall below 1. A_c is commonly determined from pseudo-static analyses of slope stability and/or empirically from observations of slope behaviour during past earthquakes. In the CRISIS project, a_c values have been deduced from ELSUS v2 [13] and engineering judgements. The hazard maps for seismically induced landslides have instead been derived in terms of permanent ground displacements (PGD) triggered by earthquake scenarios with RTs of 475 years and 975 years according to the following relationship [14]:

$$Ln(PGD)=-2.965+20217\times ln(PGA)\ -6.583\times k_y+0.535\times M\pm\varepsilon\times 0.72 \tag{1}$$

where: (i) PGA is the peak ground acceleration at the ground surface in g for RT=475 years and RT=975 years derived from the ESHM13 hazard maps [9] and amplifications due to site effects according to USGS Vs30 map; (ii) k_y is the yield coefficient, commonly used to represent the overall resistance of the slope in displacement-based approaches; (iii) M is the earthquake magnitude, i.e., M=6 (RT=475 years) and M=7 (RT=975 years); and (iv) ε is the standard normal variant with zero mean and unit standard deviation. More details on the harmonised approach for mapping the earthquake-induced landslide hazard in the project CBR can be found in [15].

The hazard maps in PGD are available in the CRISIS WBP in the "Landslide Hazard" tab together with all those maps defined for the CBR in the project for the landslide phenomenon (see Figure 4). Figure 4 shows the PGD map for RT equal to 475 years. This map identifies the southern part of the Albanian-Greek border region as having the highest seismically induced landslide risk, with PGD values ranging from approximately 14.5 cm to 18 cm. These values can reach up to 60 cm in the case of seismic events with an RT of 975 years.

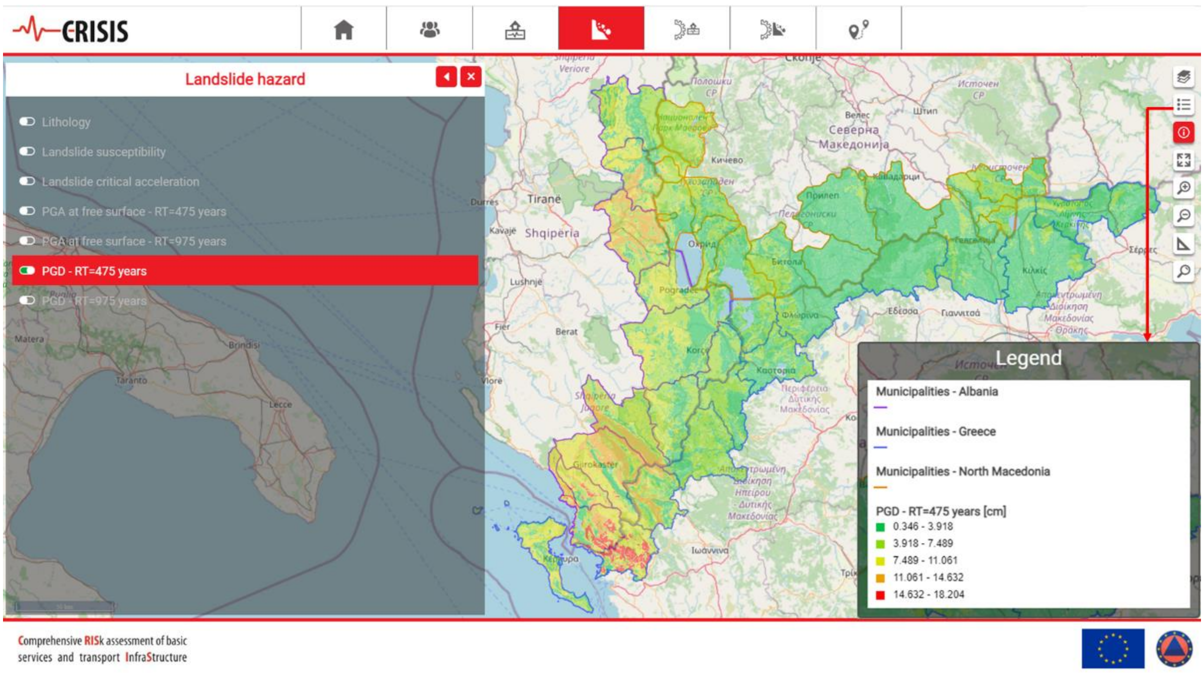

Figure 4. "Landslide hazard" tab: PGD map for RT=475 years and corresponding legend

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4. Cross-border risk assessment

4.1 Earthquake damage scenario

Due to its peculiarity of calculating seismic damage scenarios, the CRISIS WBP represents a valuable support tool for both emergency management and policymakers. Indeed, the former can use the tool in the immediate aftermath of an earthquake to assess which structures/infrastructure are usable, while the latter can use it to plan seismic interventions on the most vulnerable structures in peacetime.

Under the "Earthquake scenario" tab, the CRISIS WBP allows viewing damage scenarios calculated for selected historical events. These scenarios are important for estimating the impact in terms of damage (and thus economic losses) that would be incurred in the territory if an event of the same or similar characteristics were to occur again. In particular, eleven significant historical events affecting the project CBR have been considered. These events with their respective characteristics (magnitude, epicentre depth/longitude/latitude, fault type, and date) are listed in Table 2. Figure 5 shows the damage scenario calculated for the historical earthquake event E06 and DL5. In particular, the legend associated with the scenario for DL5 in Figure 5 reveals that bridges around the epicentre might reach the considered DL with a probability of about 30%. The probability might increase by 10% in the case of schools.

Table 2 – Selected earthquake scenarios from the SHARE European Earthquake catalogue (SHEEC; [9], [11], [12]) and corresponding characteristics

Events	Mw	Depth	Longitude	Latitude	Fault type	Date
E1	7.0	-	20.30	39.20	Reverse	05.02.1786
E2	6.6	-	20.00	39.50	Reverse	01.01.1674
E3	6.7	-	20.00	40.30	Normal	04.12.1866
E4	6.3	10	20.70	40.10	Right Lateral Strike-Slip Fault	22.12.1919
E5	6.7	-	20.10	41.10	Right Lateral Strike-Slip Fault	--.--.1380
E6	6.8	21	20.70	40.85	Normal	18.02.1911
E7	6.5	-	21.30	40.50	Normal	29.05.1812
E8	6.1	15	20.66	41.72	Normal	07.12.1922
E9	6.0	12	21.19	41.10	Normal	01.09.1994
E10	6.7	-	22.20	40.90	Normal	--.10.1395
E11	6.7	-	22.51	41.32	Normal	08.03.1931

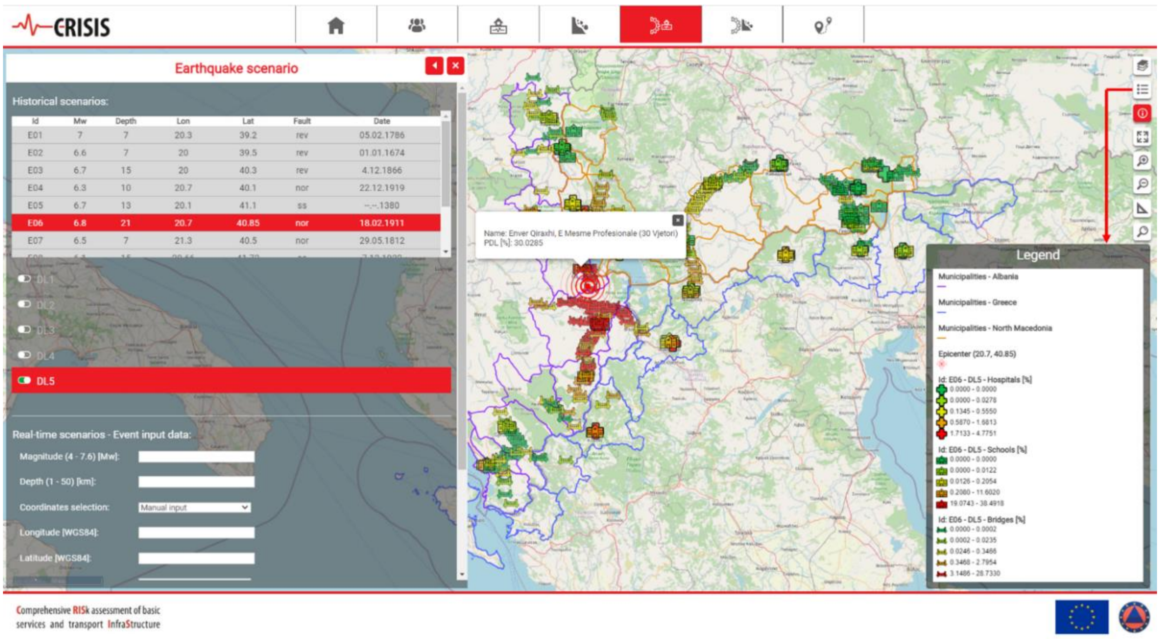

Figure 5. "Earthquake scenario" tab: scenario for the historical seismic event E6 and DL5 and corresponding legend

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In addition to damage scenarios of historical events, in the same tab real-time damage scenarios can be calculated by providing the following information in the "Real-time scenarios - Event input data" section:

- Magnitude (Mw). The damage scenario calculation works for 4≤Mw≤7.6.
- Depth of the epicentre (D). The damage scenario calculation works for 1 km≤D≤50 km.
- Coordinates of the epicentre. The epicentre can be located by entering its longitude and latitude according to the WGS84 (World Geodetic System) or by positioning it directly on the map. In the latter case, the longitude and latitude fields will be filled in automatically.
- Fault type. The fault type can be defined in a drop-down menu, by choosing among *Normal*, *Reverse*, and *Lateral Strike-Slip*.

After clicking on the "Calculate" button, the calculation of the scenario is launched. Simultaneously, the launched scenario is loaded into the "Calculated real-time scenarios" table (see Figure 6), where it is also possible to check the status of the calculation. Once completed, the performed scenario can be selected to be viewed for each of the five DLs. Figure 6 shows the real-time damage scenario for DL1 calculated by considering an Mw6 earthquake with epicentre at the border between North Macedonia and Greece (i.e., Lon.=21.72422 and Lat.=40.9176) and a normal type of fault. Figure 6 shows that for the considered event a large number of bridges in all three neighbouring countries might reach the DL1 with a probability of about 30 %, thus causing problems for the network of possible rescue aid. This probability might even increase to 40% for schools and hospitals and only decrease moving away from the epicentre.

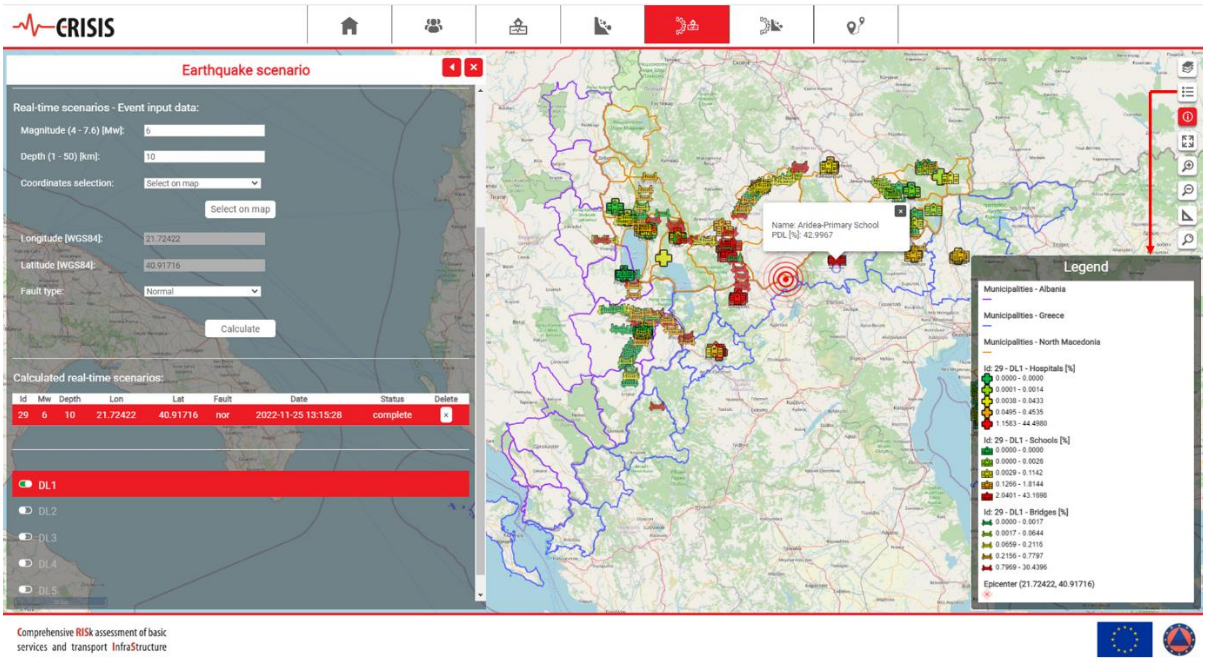

Figure 6. "Earthquake scenario" tab: real-time damage scenario for DL1 and corresponding legend

As can be seen from Figure 5 and Figure 6, all items considered in the calculated scenarios take on a different colouring, depending on the probability of reaching the selected damage level reported in the "Legend" tab. Also, the platform allows checking the probability of reaching the activated DL for a specific element by clicking on it and reading the required information in a label on the screen. As already specified in section 2, five DLs have been accounted for school and hospital buildings according to the EMS98 scale [3] while slight damage and collapse have only been considered for bridges. Consequently, bridges are only included in the calculation of the historical and real-time damage scenarios for DL1 and DL5.

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The damage scenarios for historical events and those calculated in real-time have inherent differences that make them not comparable. The first concerns the used calculation engine. In fact, the damage scenarios of the historical events have been calculated using the *Scenario Damage Calculator of the OpenQuake Engine* [16], while those in real-time are determined with an ad hoc tool developed by EUCENTRE. This leads to a second difference, i.e., the adopted ground motion prediction equation (GMPE) and how site effects are accounted for. In particular, damage scenarios for historical events have been calculated according to what [17] and [18] define for the GMPE and site amplification effects, respectively. Instead, the GMPE in [19] and the Vs30 map proposed by USGS have been used in the real-time damage scenario tool.
Finally, contrary to the damage scenarios of historical events, the real-time damage scenarios only include in the calculation those elements of the exposure database for which the PGA assumes a value greater than 1%g.

4.2 Landslide risk scenario

In addition to seismic damage scenarios, the CRISIS WBP enables the visualisation of landslide risk maps calculated for schools, hospitals, and bridges. In particular, the landslide risk for educational and health facilities has been defined according to a semi-quantitative procedure fully implemented in a GIS environment based on [20]. Instead, the landslide risk for bridges has been defined using the fragility curves due to ground failure proposed by HAZUS [21] and considering seismic events triggering landslides with RTs equal to 475 and 975 years, respectively. The landslide risk has not been calculated for all bridges in the exposure database but for a part of them, selected based on their position and importance in terms of cross-border connection.
Figure 7 shows the landslide risk scenario for schools, hospitals, and bridges. For the latter, the landslide risk scenario refers to slight damage and a seismic event with an RT of 475 years triggering the landslide.

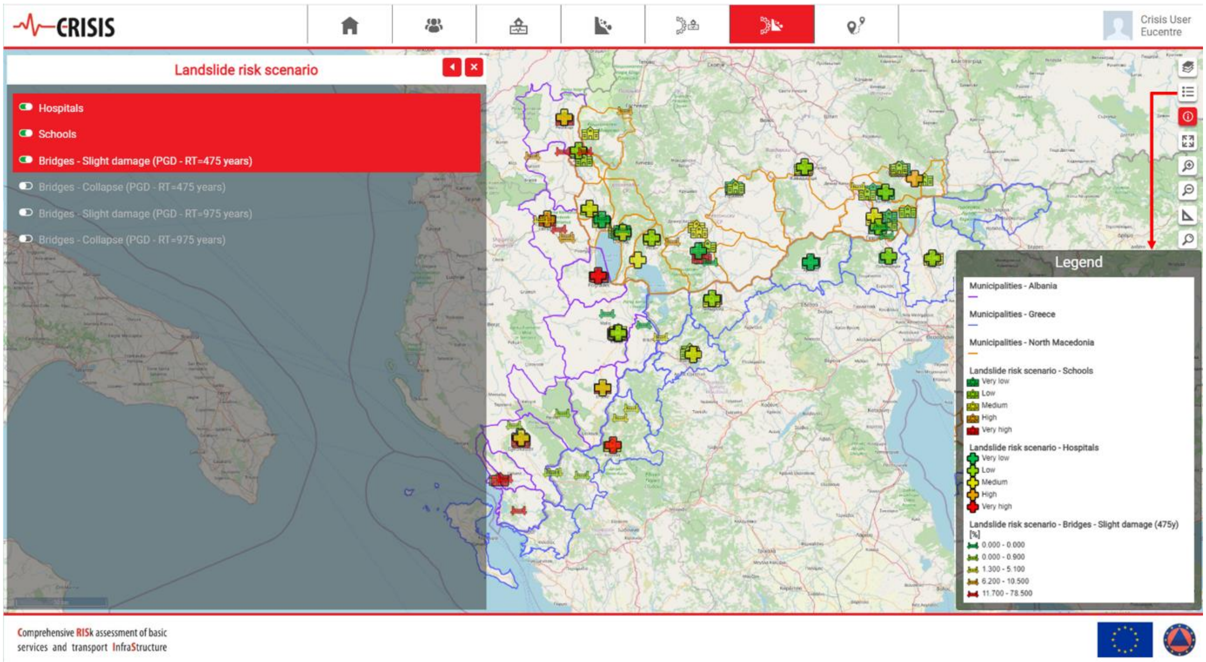

Figure 7. "Landslide risk scenario" tab: landslide risk scenario for schools, hospitals, and bridges. For bridges, the activated layer refers to slight damage and an earthquake with an RT of 475 years triggering the event

5. The routing: a cross-border disaster management

The CRISIS WBP features a tool that provides information on possible routes to follow in an emergency to avoid potentially unusable bridges due to a seismic event. The tool is available under the "Routing"

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tab and is important for cross-border disaster management. In fact, disasters know no national borders and the affected areas often require immediate rescue interventions even from neighbouring countries. As shown in Figure 8, the route needs to be identified by start and end points on the map through the "Add start point" and "Add destination point" buttons, respectively. To check whether the route has damaged infrastructure due to a seismic event, a scenario previously calculated in the "Earthquake Scenario" tab has to be loaded in the "Scenario ID" field. Then, the "Create route" button needs to be clicked. If there are no damaged bridges in the defined route, the platform will return the fastest route for rescue teams to follow. Otherwise, it will provide the shortest alternative route, as in Figure 8.

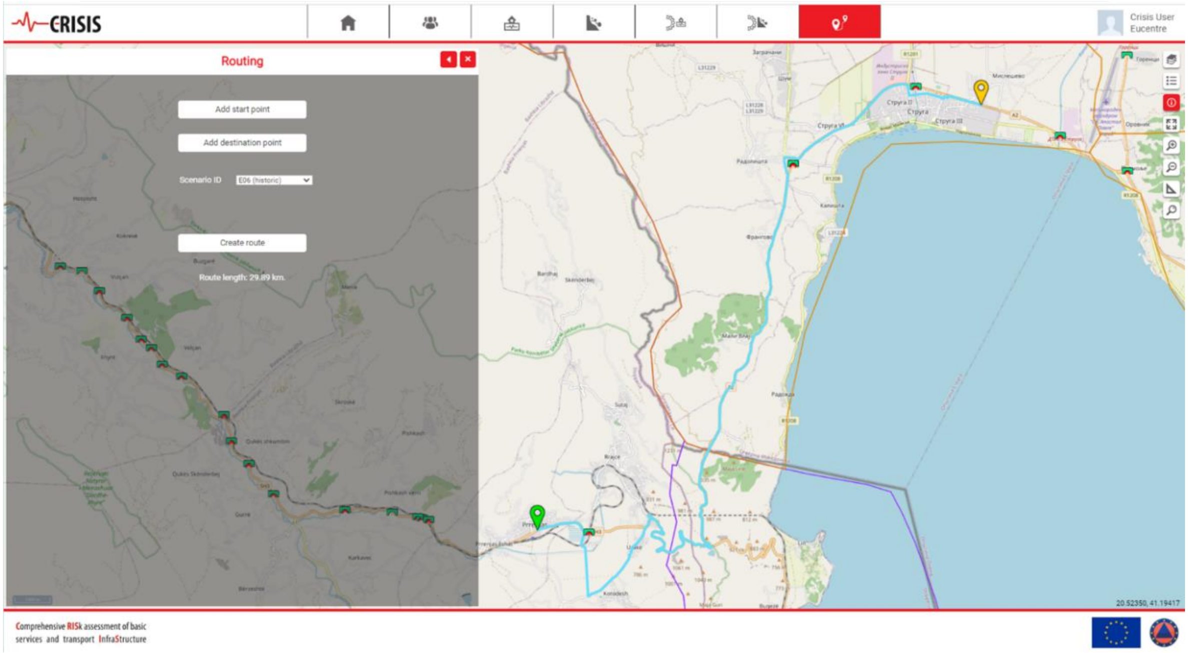

Figure 8. "Routing" tab: alternative route to the main one to bypass bridges damaged by the considered event

To demonstrate the usefulness of the routing tool, two earthquakes that occurred in the regions of Ohrid (M_W=6.4, May 1960) and Valandovo (M_W =6.7, May 1931) are considered as case studies (see Figure 9).

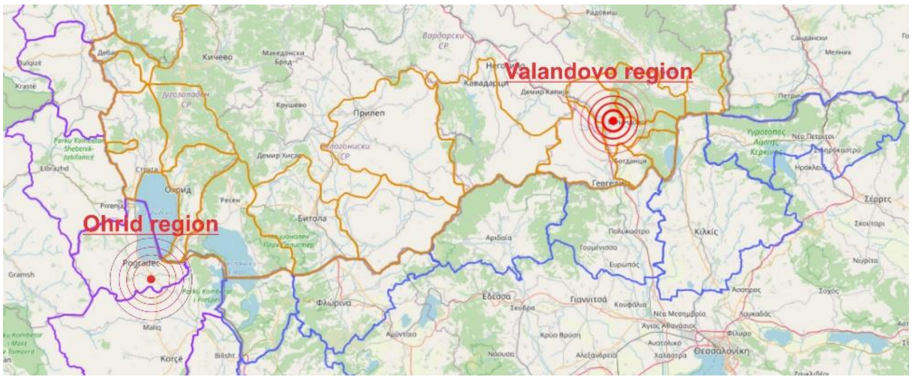

Figure 9. Locations of the earthquakes in the Ohrid and Valandovo regions considered as case studies

For citizens living in these seismically active regions, it is very important to have access to the nearest hospital facilities in case an earthquake occurs. As shown in Figure 10, the hospital facility chosen for the earthquake simulation in the Ohrid region is located in the city of Librazhd (Albania) and is a 4-storey building capable of accommodating a large number of patients. The route calculated under non-emergency conditions is 68.9 km and consists of a large number of bridges. To understand whether this route is usable even after an earthquake like the one in the Ohrid region (Mw6.4), it is necessary to calculate the corresponding damage scenario with the real-time damage scenario tool in the "Seismic

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scenario" tab and load it into the routing tool. Figure 11 shows that most of the bridges along the route might be damaged by the event. Therefore, the tool suggests an alternative route that, although longer, allows bypassing the damaged bridges.

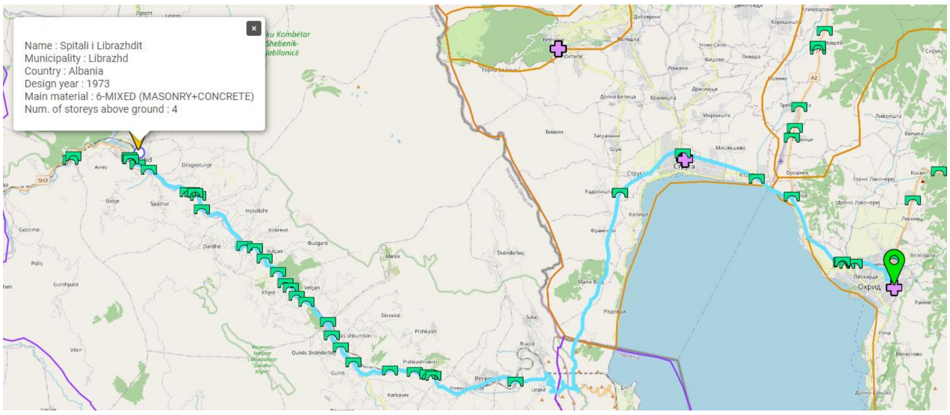

Figure 10. Route to the hospital in Librazhd (Albania) from the Ohrid region under non-emergency conditions

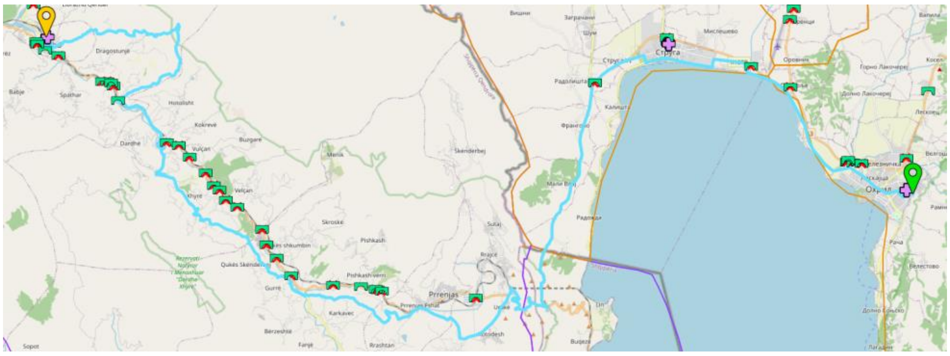

Figure 11. Alternative route to the hospital in Librazhd (Albania) from the Ohrid region to bypass damaged bridges on the main road due to an earthquake like the one in the Ohrid region (Mw6.4)

The situation is much different if we simulate an earthquake such as the one that occurred in the Valandovo region (Mw6.7). In fact, as shown in Figure 12, the connection between the region and neighbouring Greece appears to suffer no damage to the infrastructure along the considered route linking four hospitals. This is because the infrastructure in the region has undergone significant structural renovation and seismic retrofitting in the past.

Both simulations carried out with the "Routing" tool highlight that areas considered in the case studies appear to be functional even in the case of damaging earthquakes since viable routes are guaranteed to quickly transport patients to the nearest hospitals.

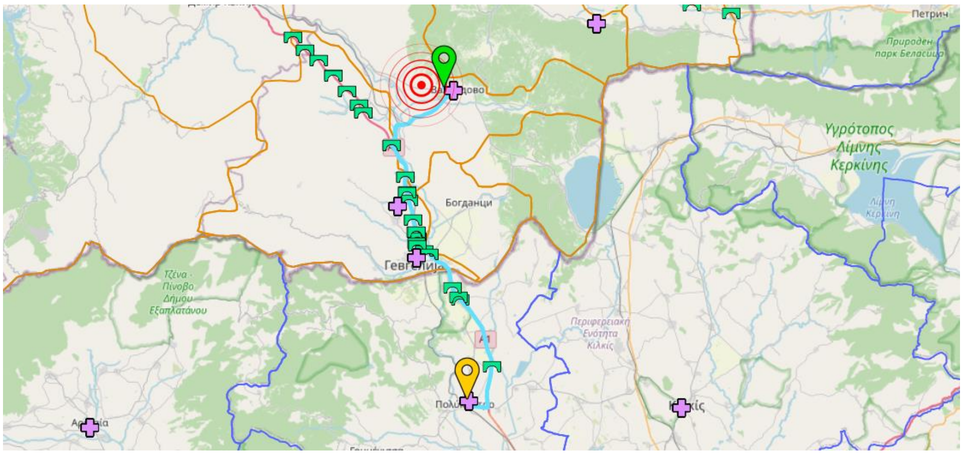

Figure 12. Route to reach a hospital in Greece after an earthquake like the one in the Valandovo region (Mw6.7)

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6. Conclusion

This article describes the geo-referenced WBP developed within the CRISIS project to support policymakers as well as disaster and emergency management in the CBR of North Macedonia, Albania, and Greece. The CRISIS WBP contains, organises, and enables the visualisation of all cross-border health and educational facilities (i.e., hospitals and schools) and transport infrastructure (i.e., bridges) data collected within the project. In addition to the exposure database, the tool displays the harmonised seismic and landslide hazard models defined for the target CBR. Rapid information is also available on the level of damage that hospitals, schools, and bridges in the reference area could suffer in the event of an earthquake. Specifically, the platform allows displaying damage scenarios calculated for selected historical events that occurred in the project CBR but also to calculate real-time scenarios using a proper tool implemented in it. Furthermore, it is possible to identify which areas of the CBR are most susceptible to landslides and consequently which assets are most at risk in the event of seismic-induced landslides. No less important is the routing tool, which is useful in the emergency conditions caused by earthquakes to identify alternative routes to be followed by the rescue teams if the main ones are unusable due to damaged road infrastructure.

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