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EARTHQUAKE DAMAGE ESTIMATIONS OF BUILDINGS IN A TYPICAL NORTH LEBANON VILLAGE

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Abstract

Bechmezzine is a typical village of Koura region in North Lebanon. As Lebanon is considered a seismic area, the earthquake hazard for the region was defined. Probabilistic hazard maps were digitized and presented. Moreover an adequate attenuation relationship for the Middle East region was implemented, and used to generate the deterministic hazard map of Beshmezzine for a specific scenario. A ground survey was led in order to gather the data of the village buildings, and then structural vulnerability functions were adequately chosen and assigned. The earthquake-induced building damage was modeled through Ergo platform after suitable needed files were prepared through the Geographic Information System. The earthquake building damage of Bechmezzine is assessed in terms of likely earthquake scenarios, and final results were offered. It was obtained that the unreinforced masonry structures type is the most vulnerable to earthquakes followed by the reinforced concrete frame structures type. It was recommended to reinforce masonry buildings, to add shear walls to concrete frame buildings, and to follow strictly seismic codes for the construction of new buildings. This prototype study aims helping adequate authorities and the Lebanese government to take possible risk-mitigating actions, and thus increase the resilience of Beshmezzine village.

Keywords: Earthquake damage estimations; Resilience; Buildings

1. Introduction

Even though the seismicity of the Lebanon region was very low in the last century; Lebanon fault system is considered to be capable of generating moderate to high earthquakes as it was mentioned by several studies addressing Lebanon seismicity [1, 2, 3, 4, 5, 6, 7, 8, 9]. However few researchers have tried to estimate earthquake damage in Lebanon, and fewer addressed inventories and fragility functions required to assess seismic losses.

In this paper, the evaluation of possible building damage of Beshmezzine village in the event of likely seismic scenarios was addressed.

1.2. Beshmezzine – a Lebanese typical village

Beshmezzine or Bishmizzine, a Lebanese village, its name is derived from Phoenician language and means «the place of pressing the grapes». Its history goes back to around 1000 BC. It is located approximately at an altitude of 275 m, and benefits from proximity to the Mediterranean Sea. It is a Northern village 67 kilometers far from Beirut. The village area is 5.44 km^2, and its population is approximately 4000.

This paper aims to assess the earthquake-induced building damage in the event of likely earthquakes for Beshmezzine, a typical Lebanese village. First Lebanon seismicity was detailed. Second assessment of seismic damage to Beshmezzine buildings was presented. To that purpose, seismic deterministic and probabilistic hazard maps were prepared, then building inventories were gathered, and adequate fragility functions were assigned. The obtained files, as well as hazards files for Lebanon were implemented and prepared in the Geographic Information System, GIS. Finally after modeling through Ergo platform, the building damage was obtained for several likely earthquake scenarios. Results, recommendations, and conclusions were offered to help adequate authorities and the Lebanese government to take possible risk-mitigating actions, and thus increase the resilience of Beshmezzine.

2. Lebanon seismicity

Lebanon is considered to be an active seismic region. The major active faults of Lebanon complex weaved fault system [1] (i.e., Lebanese Restraining Bend (LRB)) are: Yammouneh (YF), which is capable of generating earthquakes of magnitude greater than 7 with a return period of 1000 years; Seghraya (SF), which is capable of generating earthquakes of magnitude greater than 7 with a return period of 2000 years; the Mount Lebanon Thrust (MLT), which was lately discovered by the SHALIMAR marine geophysical campaign [10], is capable of generating earthquakes of magnitude greater than 7 with a return period of 1500-1750 years; Rachaya (RaF), and Roum (RF), smaller major faults, which are capable of generating earthquakes of magnitudes up to 6 and 6.5, as noted in [11].

2.1. Historical seismicity:

Earthquakes before 1900: Many have reported earthquakes which occurred along the Dead Sea Transform Fault from about 2000 BC until late 2000, such as in [12, 13, 7]. The earthquakes having a magnitude greater than 7, which were reported to have damaged greatly Lebanon region, occurred on: **2 April 306**, **9 July 551** [7, 14, 8]; **15 August 1157** [7]; **25 November 1759** [15].

Earthquakes after 1900: In the last century, the seismic activity of Lebanon region was relatively low. Few earthquakes were reported to have occurred with a magnitude greater than 5: The earthquake of **29 September 1918**, with surface magnitude, Ms, of approximately 6.3 [16, 4], the one of **20 April 1921** with Ms of 5.38, the one of **16 March 1956** with surface magnitude Ms of 6. The double earthquake event of **26 March 1997**, with magnitudes Ms of approximately 5.6 and 5 [13]; on **15 February 2008** a series of earthquakes struck Lebanon and the largest one was reported to have a body magnitude Mb of 5.1 [12]; on **11 May 2012**, an earthquake with magnitude Mb of 5.3 hits the eastern Mediterranean Sea between Cyprus and Lebanon as reported by the United States Geological Survey's website.

3. Assessment of seismic damage to Bechmezzine buildings Methodology

As presented in [17], the earthquake loss estimation procedure followed, in this paper, to model the damage to buildings of Bechmezzine village is based on four main modules: Seismic hazard, Building inventory, Structural vulnerability, and Earthquake damage estimations. First a local data repository was created in Ergo platform, which was chosen to model Byblos seismic damage to buildings. In this repository were ingested and stored: Lebanon map, seismic hazard, building inventory, fragility, fragility mapping, and default sets among others. Second, seismic hazards were created with; the scenario hazard using attenuation function or probabilistic hazard by probabilistic data (hazard map). Third building dataset was created using appropriate tools (GIS data in this study), then the data was exported to ESRI shapefile, finally the required building dataset was ingested into Ergo Platform as input for the modeling. Forth adequate fragility curve dataset and a fragility mapping dataset were ingested. As noted in [17], «*Building Attributes will determine the Fragility Mapping, i.e. Mapping rules determine which fragility curves to use based on details of the inventory dataset*». Fifth, once all previous steps achieved, the building damage analysis can finally be execute based on the chosen inputs of ingested data. The methodology is explained with further details in the following sections.

4. Seismic hazard

Two studies have developed hazard maps for Lebanon: the study of [7], and the one of [9]. Lately the Earthquake Model Middle East region project, EMME [18], has proposed hazard maps which were developed on regional scale, therefore not of great interest to our study. Nevertheless EMME project has proposed more suitable attenuation relationships for Middle East region than the ones used in [7, 9].

In this paper the uniform hazard map of Lebanon, in terms of peak ground acceleration (PGA) for 2500-year return period earthquake from [7] and the one for 950-year return period earthquake from [9], were used in the modeling of the damage for Beshmezzine buildings. Those maps were fed into the Geographic Information System, GIS, and were prepared in form of raster files for whole Lebanon surface and then fed into Ergo to evaluate the damage of the building stock in Beshmezzine. Those hazard maps fed and prepared in Ergo are shown in Fig.1 and Fig.2 respectively. Furthermore the Akkar et al. (2014) in [19], one of the attenuation relationships recommended by EMME project [18] was implemented, specifically to model Lebanon region, using java in the hazard plugin in Ergo platform. This attenuation was used to simulate the scenario of the 551 AD earthquake which occurred at a latitude of 34.14 and a longitude of 35.46 [16] with a moment magnitude, Mw of 7.5. The generated scenario was then ingested as deterministic hazard and used to model an additional scenario of earthquake damage of Beshmezzine building. The generated deterministic hazard map in Ergo is shown in Fig.3. Moreover Fig.1, Fig.2 and Fig.3 show the location of Beshmezzine village on the map, and the coordinates of the village location at the right lower corner of the figure, in addition to the legend of the generated hazard in term of PGA. Furthermore Fig.2 shows the coordinates of the lower point at the left lower side of the Map.

5. Building inventory

Beshmezzine village inventory encompass mainly two building typologies: the traditional unreinforced masonry which are considered to be of historical value and were built previous to 1970; and the reinforced concrete frame buildings which are mainly residential buildings relatively new since the majority was built after 1970.

5.1. Data collection

The data were gathered on a building-by-building basis survey, using GPS tools and GIS maps. The data regarding structural typology, usage and other characteristics of buildings were gathered as recommended by [20]. After the data for Beshmezzine buildings were gathered, they were fed into the Geographic Information System (GIS) to prepare the adequate «shapefiles», which are needed to model earthquake damage estimations of Beshmezzine buildings through the Ergo platform.

5.2. Building stock

The total number of investigated buildings was 307. The total number of the structural typology « reinforced concrete frame » (C1) was 246, and the total number of the structural typology «unreinforced masonry» (URM) was 61. The number of buildings constructed before 1900 is 6, the number constructed between 1900 and 1970 is 95, and the number constructed after 1970 is 206. Table 1 shows structural type versus year built. The number of buildings constructed in the last 46 years is nearly twice the number of those constructed before 1970; which reflects the rapid urbanization of Beshmezzine village. Table 2 shows structural type versus number of stories; all buildings in Beshmezzine are low-rise buildings with the exception of 5 buildings of 4 stories height.

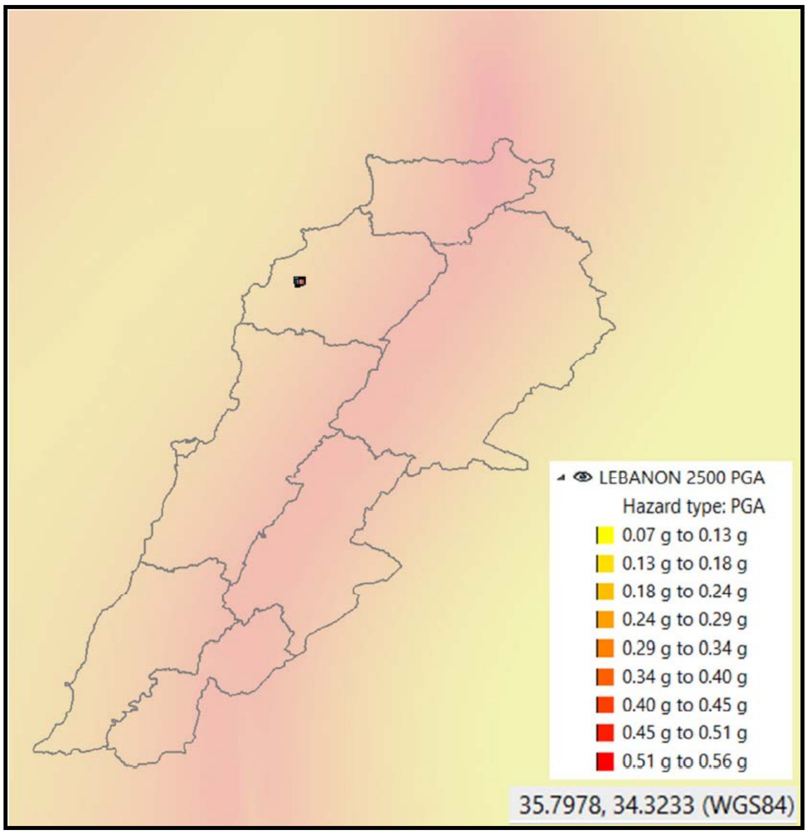

Fig. 1 – Uniform hazard map of Lebanon, in terms of peak ground acceleration (PGA) for 2500-year return period earthquake from [7]

5.3. Fragility functions

Fragility functions are needed to obtain damage that might be encountered in the event of an earthquake. The fragilities of Turkey were used; since no fragility functions are available for Lebanon: the few centuries of history shared and the geographic proximity justify some resemblance in construction site procedures. The Turkish fragility functions were derived using the Parameterized Fragility Method (PFM) by [21].

Table 1 – Buildings type versus year of construction

	TOTAL	YEAR INTERVALL		
		1850 < Year ≤ 1900	1900 < Year ≤ 1970	Year > 1970
C1	246	0	41	205
URM	61	6	54	1
SUM	**307**	**6**	**95**	**206**
TOTAL	**307**	**307**		

Table 2 – Buildings type versus number of stories

	TOTAL	NUMBER OF STORIES			
		1	2	3	4
C1	246	89	125	27	5
URM	61	30	29	2	0
SUM	**307**	**119**	**154**	**29**	**5**
TOTAL	**307**	**307**			

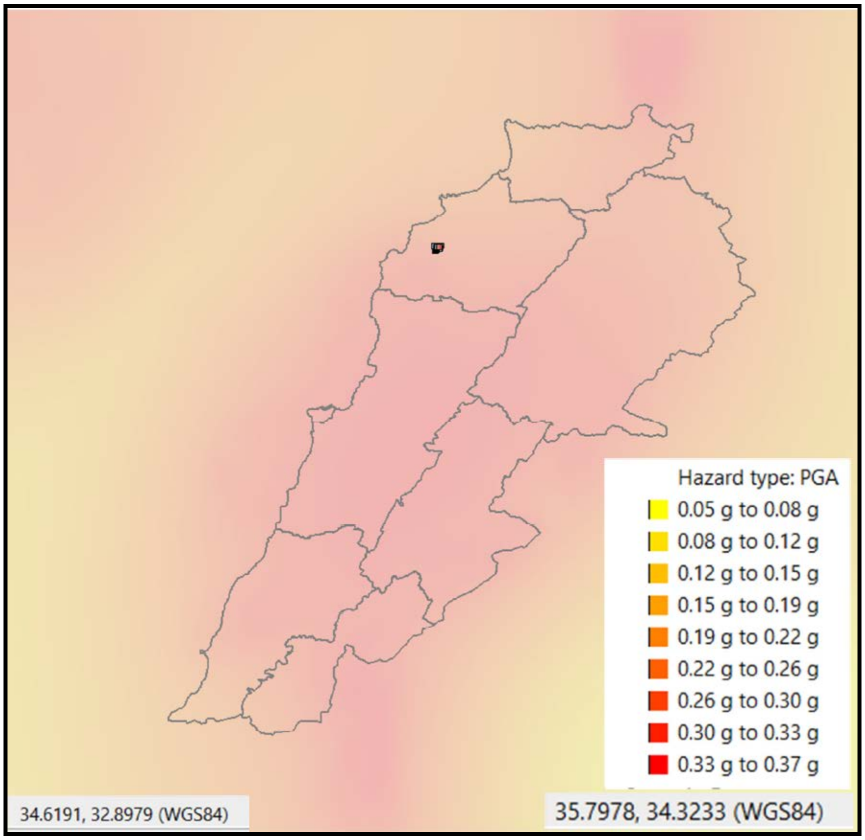

Fig. 2 – the uniform hazard map of Lebanon, in terms of peak ground acceleration (PGA) for 950-year return period earthquake from [9]

6. Model development

6.1. Ergo – a modeling platform

Ergo platform was used to assess building damage of Beshmezzine. The open-source software was developed by NCSA at the University of Illinois at Urbana Champaign (it was previously called m-HARP or MAEviz). It is a «*Hazard (primarily Seismic) Risk Assessment tool, based on Consequence-based Risk Management (CRM) to help coordinate planning and event mitigation, response, and recovery*» [22], and it benefits from the global initiative work of a developer community through a consortium of at least a dozen countries. Ergo is undergoing continuous development in order to assess multi-hazards at a global level and to consider relationships and interactions between hazards if occurred simultaneously. It has received a positive review by the Global Facility for Disaster Reduction and Recovery (GFDRR), in the World Bank Report 2014 [23].

6.2. Beshmezzine model

Earthquake damage estimations of Beshmezzine buildings were obtained through the Ergo modeling platform, after performing the following steps: Buildings data were gathered and implemented in GIS; hazard maps (the 2500-year return period earthquake of [7], the 950-year return period of [9]) were prepared in GIS; the adequately obtained shapefiles were imported into the Ergo platform; the 551 earthquake scenario file was prepared in Ergo; the fragility functions were assigned; and finally, the analysis was achieved to evaluate Beshmezzine building damage. The obtained results are discussed in Part 7.

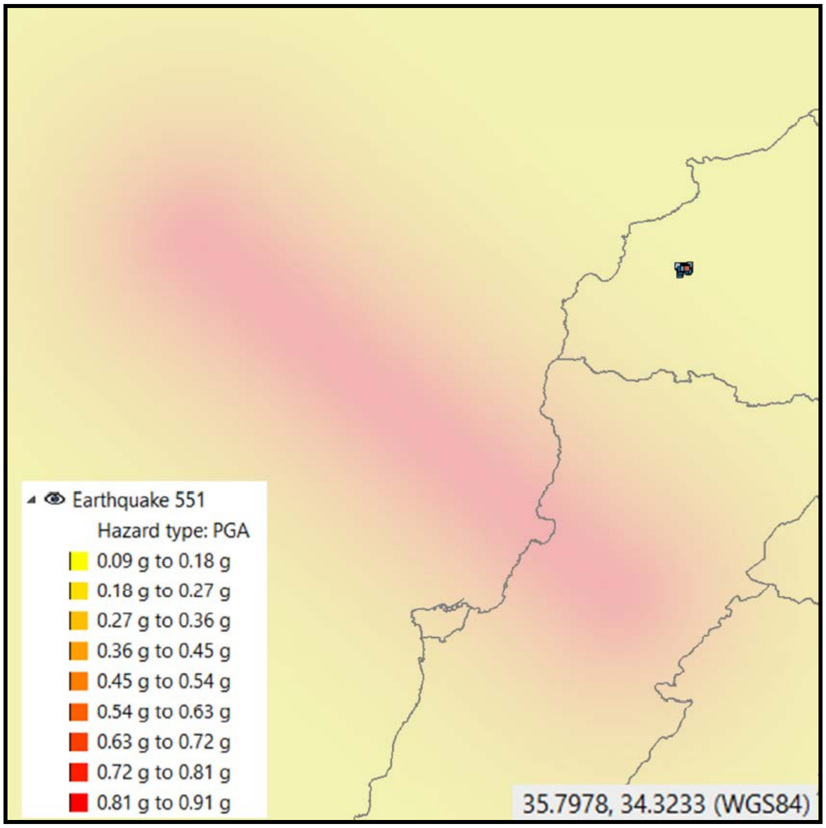

Fig. 3 –The deterministic hazard map obtained from the generated scenario of the 551 Earthquake, using the ground motion attenuation equation of Akkar et al. (2014) [19]

7. Results and recommendations

Modeling through Ergo platform allowed us to obtain the following results for the 2500-year return period of [7], the 950-year return period of [9], and the 551 earthquake scenario.

The structures that suffered greater damages were the unreinforced masonry followed by the reinforced concrete frame structures. Fig.4 compares the results in terms of mean damage to Beshmezzine building typologies obtained through Ergo using the 2500-year return period of [7], the 950-year return period of [9], and the 551 earthquake scenario. Fig.5 shows the results of damage to Beshmezzine building typologies obtained through Ergo using the 950-year return period of [9].

The results for the 2500-year return period earthquake of [7] were the following: 70% of reinforced concrete frame structures, and 45% of unreinforced masonry structures would suffer insignificant damage; 25% of reinforced concrete frame structures, and 28% of unreinforced masonry structures would suffer moderate damage; 5% of reinforced concrete frame structures, and 17% of unreinforced masonry structures would suffer heavy damage; 1% of reinforced concrete frame structures, and 8% of unreinforced masonry structures would suffer complete damage. Table 3 shows Beshmezzine buildings structural damage for 2500-year return period earthquake of [7].

The results for the 950-year return period earthquake of [9], were the following: 71% of reinforced concrete frame structures, and 46% of unreinforced masonry structures would suffer insignificant damage; 24% of reinforced concrete frame structures, and 28% of unreinforced masonry structures would suffer moderate damage; 5% of reinforced concrete frame structures, and 17% of unreinforced masonry structures would suffer heavy damage; 1% of reinforced concrete frame structures, and 8% of unreinforced masonry structures would suffer complete damage. Table 4 shows Beshmezzine buildings structural damage for 950-year return period earthquake of [9].

The results for the 551 earthquake were the following: 87% of reinforced concrete frame structures, and 62% of unreinforced masonry structures would suffer insignificant damage; 12% of reinforced concrete frame structures, and 23% of unreinforced masonry structures would suffer moderate damage; 1% of reinforced concrete frame structures, and 10% of unreinforced masonry structures would suffer heavy damage; 0% of reinforced concrete frame structures, and 3% of unreinforced masonry structures would suffer complete damage. Table 5 shows Beshmezzine buildings structural damage for the 551 earthquake scenario.

Tables 3, 4 and 5 report the probability of performance level (Immediate Occupancy, life Safety, Collapse Prevention), and probability of damage state (insignificant, Moderate, Heavy, Complete and Mean damage). Table 6, shows the comparative results of Beshmezzine building structural mean damage for the 2500-year return period earthquake of [7], the 950-year return period earthquake of [9], and the 551 earthquake scenario.

It is noticed from Table 6 that the damage obtained from the 2500-year return period of [7], was very similar to the one obtained from the 950-year return period of [9], while damage for the 551 earthquake were less since the event occurred at Mount Lebanon Thrust near Byblos city [8] and which might have been attenuated while reaching Beshmezzine 35 km far from Byblos; as it was also evidenced by the generated deterministic hazard map presented in Fig.3.

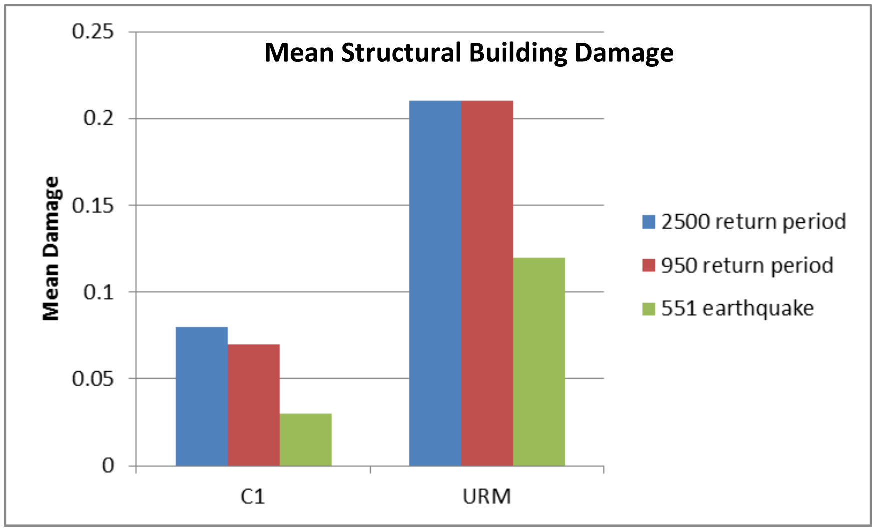

Fig. 4 – Damage for Beshmezzine buildings typologies obtained through Ergo for the 2500-year return period earthquake of [7], the 950-year return period earthquake of [9], and the 551 earthquake scenario

Obviously, as noted above, unreinforced masonry buildings would suffer the most in Beshmezzine; therefore, it is recommended to strengthen the unreinforced masonry buildings while preserving their historical aspect. The concrete frame buildings are recommended to be strengthened by adding shear walls whenever possible. New buildings to be constructed in the future are required to be dual system structures or at least have some shear walls. Nevertheless, all new buildings to be constructed in the future are required to strictly follow the seismic codes.

Table 3 – Results of Beshmezzine building structural damage for 2500-year return period earthquake of [7]

2500 RETURN PERIOD EARTHQUAKE								
	Probability of Performance Level			Probability of Damage State				
Structure Type	Imm Occup	Life Safety	Coll Prev	Insignific	Moderate	Heavy	Complete	Mean Damage
C1	0.30	0.06	0.01	0.70	0.25	0.05	0.01	0.08
URM	0.53	0.25	0.08	0.45	0.28	0.17	0.08	0.21
	0.47	0.10	0.02	0.64	0.25	0.07	0.02	0.10

Table 4 – Results of Beshmezzine building structural damage for 950-year return period earthquake of [9]

950 RETURN PERIOD EARTHQUAKE								
	Probability of Performance Level			Probability of Damage State				
Structure Type	Imm Occup	Life Safety	Coll Prev	Insignific	Moderate	Heavy	Complete	Mean Damage
C1	0.29	0.05	0.01	0.71	0.24	0.05	0.01	0.07
URM	0.52	0.24	0.08	0.46	0.28	0.17	0.08	0.21
	0.46	0.09	0.02	0.66	0.24	0.07	0.02	0.10

Table 5 – Analysis results of Beshmezzine building structural damage for the 551 earthquake scenario

551 EARTHQUAKE								
	Probability of Performance			Probability of Damage State				
Structure Type	Imm Occup	Life Safety	Coll Prev	Insignific	Moderate	Heavy	Complete	Mean Damage
C1	0.14	0.01	0	0.87	0.12	0.01	0	0.03
URM	0.36	0.13	0.03	0.62	0.23	0.1	0.03	0.12
	0.18	0.04	0.01	0.82	0.14	0.03	0.01	0.05

Table 6 – Comparative results of Beshmezzine building structural mean damage for 2500-year return period earthquake of [7] and for 950-year return period earthquake of [9], and the 551 earthquake scenario

	EARTHQUAKE SCENARIO		
	Elnashai et al.(2004)	Huijer et al. (2010)	551 Earthquake
	2500 return period	950 return period	
Structure Type	Mean Damage	Mean Damage	Mean Damage
C1	0.08	0.07	0.03
URM	0.21	0.21	0.12
	0.1	0.1	0.05

Table 7 – Comparative results of Beshmezzine building structural mean damage, presented function of number of stories for structural typologies C1 and URM, for the 2500-year return period earthquake of [7] and for the 950-year return period earthquake of [9], and the 551 earthquake scenario

		Probability of Damage State		
Earthquake		**950 Return Period**	**2500 Return Period**	**Year 551 scenario**
Structure Type	**Number of stories**	**Mean Damage**	**Mean Damage**	**Mean Damage**
C1	**1**	0.08	0.08	0.03
	2	0.07	0.07	0.03
	3	0.08	0.08	0.03
	4	0.07	0.06	0.02
URM	**1**	0.22	0.21	0.13
	2	0.22	0.21	0.13
	3	0.22	0.21	0.13

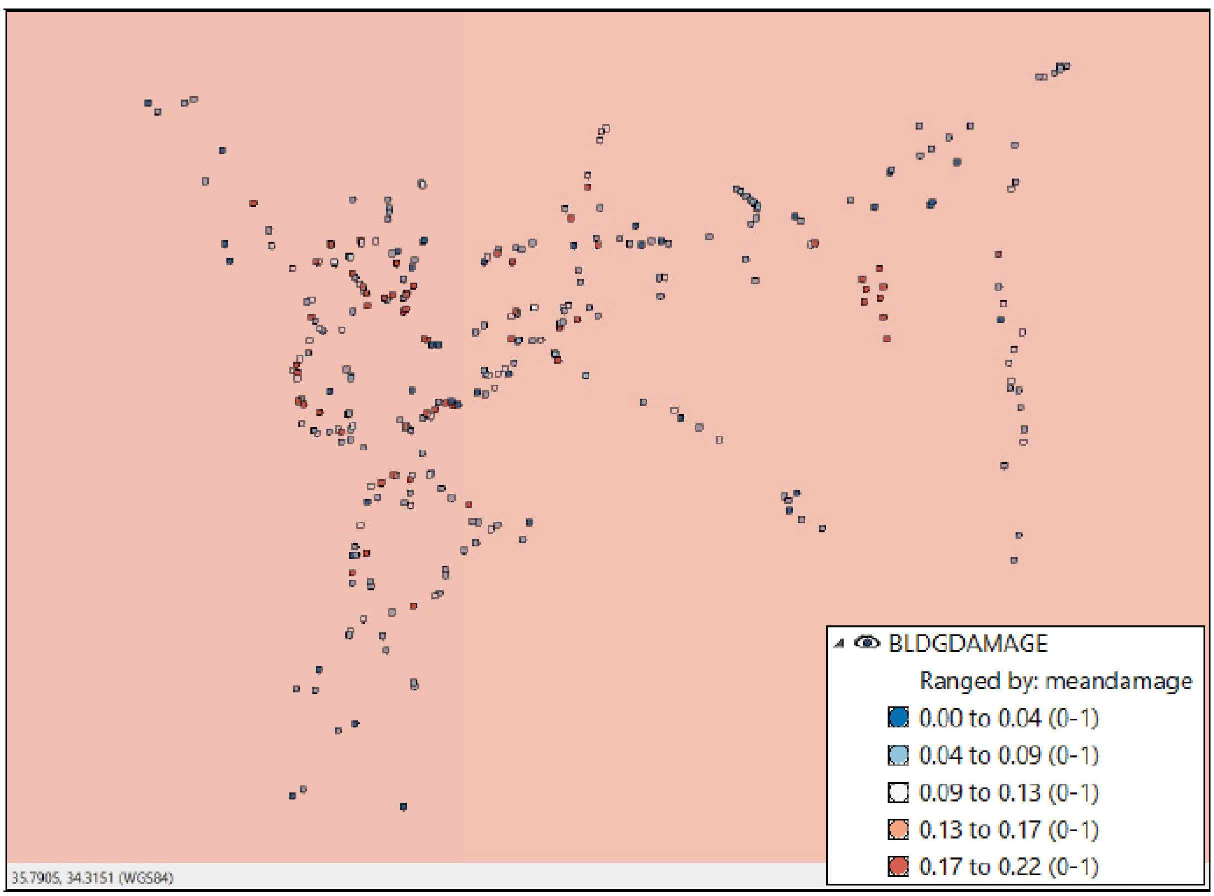

Fig. 5 – Results of Beshmezine building damage in term of mean damage obtained through Ergo for the 950-year return period earthquake of [9]

Moreover Table 7 compares results of Beshmezzine building structural mean damage, presented function of number of stories for structural typologies C1 and URM, for the 2500-year return period earthquake of [7] and for the 950-year return period earthquake of [9], and the 551 earthquake scenario. It was noticed few differences in the mean damage as function of the number of stories, since the considered buildings typologies C1 and URM are low rise buildings (number of stories less or equal to 4). The mean damage of the URM was almost constant, while the mean damage of C1 was slightly different; mainly it decreased 1% for the building with 4 stories.

8. Conclusions

In this article Beshmezzine, building damage was assessed in the event of severe earthquakes which are likely to occur in Lebanon region. Seismic hazards were detailed, and a ground survey of Beshmezzine building was completed to gather needed data. The data was fed in Geographic Information System, then the prepared files were fed in Ergo, and adequate structural fragility functions were assigned. Moreover the ground motion attenuation equation Akkar et al (2014) [19] was specifically implanted in Ergo, and deterministic hazard map was generated for the 551 AD Earthquake scenario. Finally, after modeling, results of earthquake-induced building damage in the event of likely earthquake scenarios were offered. It was obtained that the unreinforced masonry structures type is the most vulnerable to earthquakes followed by the reinforced concrete frame structures type. In case building owners are willing to invest in additional safety measures, it was recommended to reinforce the masonry buildings and to add some shear walls to the concrete frame buildings, while preserving the lovely architectural aspect of Beshmezzine residential houses and buildings. New buildings to be constructed in the future need to strictly follow the codes. This study helps understanding the extent of potential damage in Bishmezzine village in the event of likely severe earthquakes in Lebanon, and allows the establishment of an earthquake preparedness strategy and recovery plan for a typical Lebanese village.

9. Acknowledgements

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