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IMPROVEMENT OF THE EXPOSURE MODEL AND PRELIMINARY PHYSICAL RISK ANALYSIS: A PILOT CASE MUNICIPALITY

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Abstract

Seismic risk encompasses the potential damage and losses resulting from earthquake events. Reliable risk assessment, apart from hazard assessment, requires precise and, as much as possible, accurate definitions of both the exposure and vulnerability models, as these components are interdependent and influence one another. This study focuses on developing an exposure model for the Aerodrom municipality in Skopje, partitioned into three subareas: Blocks A, B, and C. The model integrates data from three sources: Google Street View, the publicly accessible cadastral platform of North Macedonia, and field surveys conducted to fill data gaps not covered by the first two sources. These datasets serve as the foundation for constructing the exposure model and generating the input parameters required for seismic risk analysis. For each building asset, the model encompasses essential definitions, such as geographical coordinates and related taxonomy attributes. The developed exposure model is based on the GEM v2.0 taxonomy, which incorporates 13 attributes. Using the developed exposure model, selected vulnerability curves from the GEM database were applied to quantify the seismic response of different building typologies. The preliminary results highlight differences arising from the use of different vulnerability models and selected Ground Motion Models (GMMs). This study provides a comprehensive overview of potential damage in the pilot region, aiding in the further development of seismic risk input parameters. The results are displayed according to the various damage states identified in the assessment. Values are expressed as a percentage of the total number of buildings, providing insight into the potential impact on the building stock.

Keywords: Scenario calculator, Fragility, OpenQuake, Seismic risk.

1. Introduction

The assessment of seismic risk in urban areas is an active area, the results of which contribute to the definition of the degrees of damage and losses, whether economic or human. The components of seismic risk, i.e. their definition and parameterization, provide a comprehensive picture of the entire process. Components such as exposure, vulnerability curves, definition of seismic hazard and ground motion models are particularly influential in estimating the results arising from the seismic risk itself. This paper focuses on the selection of fragility curves based on a defined exposure model using modern tools and defined seismic conditions-scenarios such as a rapture plane with defined parameters that are associated with previous events that occurred on the territory of Macedonia. Based on the defined exposure model, i.e. part of the territory of the municipality of Aerodrom in Skopje, which consists of a total of 172 reinforced concrete buildings with various storeys. The model combines data from three sources: Google Street View, the publicly available cadastral platform of North Macedonia, and field surveys carried out to address data gaps not covered by the first two sources. Defined ground motion models using OpenQuake, by using 3 attenuation equations that are applicable and adaptable to the subject territory of exposure and the four seismic sources, namely the earthquakes in Skopje 1963, Skopje 2016, Debar 1967 and Pehchevo 1904. The results of the selected 3 fragility curves from the GEM database are presented and discussed. Their diversity indicates the need for classification of buildings according to storeys and development of a fragility function using various methods for nonlinear analysis [1]. In recent years, international codes and the scientific community have emphasized a performance-based design approach for structures. Performance can be measured in terms of mean annual frequency or by the probability conditioned on a specific 'earthquake scenario', which

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could be represented by the worst expected event or the event most likely to occur. Seismic performance should be regarded as uncertain, both in terms of earthquake occurrence and structural behavior [2].

2. Definition of the exposure model with GEM taxonomy

The exposure component describes the collected data on the assets (buildings, infrastructure, lifelines) that are susceptible to be damaged by seismic events [3]. In our case the exposure model is defined with data only for buildings using data sources from the following database:

- Google Street View
- The publicly accessible cadastral platform of North Macedonia
- Field surveys

Figure 1. Pilot case – exposure model

A total of 172 buildings in the subject area shown in Fig. 1 were parameterized, all reinforced concrete built in the eighties on the territory of the municipality of Aerodrom, according to Table 1, 14 reinforce concrete structure taxonomies (RCST) are defined, the number of buildings and their number of storeys are shown. The total estimate for residents of the analyzed exposure model is 15092 residents.

Table 1. RCST assets for exposure model

GEM id.	No. of buildings	Stories	Residents
RCST1	4	2	112
RCST2	9	3	378
RCST3	34	4	1904
RCST4	16	5	1120
RCST5	21	6	1764
RCST6	11	7	1078
RCST7	45	8	5040
RCST8	17	9	2142
RCST9	7	10	140
RCST10	4	11	616
RCST11	1	12	168
RCST12	1	14	196
RCST13	1	15	210

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RCST14	1	16	224

The aim of the Global Earthquake Model (GEM) Building Taxonomy, which is used for the exposure model is to describe and categorize buildings in a standardized way as a crucial step in assessing their seismic risk. The criteria for developing the GEM Building Taxonomy included ensuring its relevance to the seismic performance of various construction types; being comprehensive yet simple; allowing for flexibility; adhering to principles familiar to a wide range of users; and ultimately being adaptable to non-buildings and other hazards. The taxonomy is structured as a series of expandable tables that contain information about various building attributes. Each attribute outlines a specific characteristic of an individual building or a group of buildings that could impact their seismic performance. Typical attributes include materials, lateral load-resisting systems, building height, and more. The proposed taxonomy is adaptable and offers the possibility of adding or modifying attributes based on the level of detail needed and new knowledge gathered through the data collection process, which is a benefit over alternative taxonomy models given the global scope of the GEM initiative. This taxonomy differs from most existing structural taxonomies used for seismic risk assessments [4].

The GEM Building Taxonomy v2.0 characterizes a building or building typology using the following 13 attributes, each linked to specific characteristics that could potentially impact seismic performance:

- Direction - this attribute is used to describe the orientation of building(s) with different lateral load resisting systems in two principal horizontal directions of the building plan which are perpendicular to one another.
- Material of the lateral load-resisting system
- Lateral load-resisting system - the structural system that provides resistance against horizontal earthquake forces through vertical and horizontal structural components
- Height - building height above ground in terms of the number of storeys; this attribute also includes information on number of basements (if present) and the ground slope.
- Date of construction or retrofit - identifies the year when the building construction was completed.
- Occupancy - the type of activity (function) within the building; it is possible to describe a diverse range of occupancies
- Building position within a block - the position of a building within a block of buildings
- Shape of the building plan
- Structural irregularity - a feature of a building's structural arrangement, such as one story significantly higher than other stories, an irregular building shape, or change of structural system or material that produces a known vulnerability during an earthquake.
- Exterior walls - material of exterior walls
- Roof - this attribute describes the roof shape, material of the roof covering, structural system supporting the roof covering, and roof-wall connection.
- Floor - describes floor material, floor system type, and floor-wall connection
- Foundation system – shallow/deep foundation

As a characteristic example of the adopted GEM taxonomy, the example of RCST4, which is for RC buildings with a height of 5 stories, is taken. Table 2 indicates the meaning of each taxonomy component individually.

Table 2. RCS GEM taxonomy

CR+CIP/LFM+DUC/HEX:5+HFEX:3+HD:1/YEX:1983/RES+RES2E/BPD/PLFR/IRRE/EWMA/RSH2+RMT6+RWO+RTDP/FC+FC2+FWCP/FOSSL			
CR	Concrete, reinforced	PLFR	Rectangular, solid
CIP	Cast-in-place concrete	IRRE	Regular structure
LFM	Moment frame	EWMA	Masonry exterior walls
DUC	Ductile	RSH2	Pitched with gable ends

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HEX	Exact number of storeys above ground	RMT6	Metal or asbestos sheets
HFEX	Exact height of ground floor level above grade	RWO	Wood
HD	Slope of the ground	RTDP	Roof tie-down present
YEX	Exact date of construction or retrofit	FC	Concrete floor
RES	Residential	FC2	Cast-in-place beam-supported reinforced concrete floor
RES2E	20-49 Units	FWCP	Floor-wall diaphragm connection present
BPD	Detached building	FOSSL	Shallow foundation, with lateral capacity

3. Ground motion models generated from raptures for a range of magnitudes from past events

For the estimation of the seismic risk of the exposure model defined in this way, four earthquake scenarios shown in a Table 3 have been defined based on earthquakes that have occurred in the territory of Macedonia. The same sources are generated as point sources with defined earthquake parameters and a rapture plane associated with the point source itself.

Table 3. Earthquake scenarios, earthquake and fault parameters

No.	**Name**	**Magnitude Mw**	**Depth (km)**	**Lon (◦)**	**Lat (◦)**	**Strike (◦)**	**Dip (◦)**	**Rake (◦)**
1	Skopje EQ1963	6.01	4.8	21.43	42.02	290	70	-55
2	Skopje EQ2016	5.28	15	21.5	42	247	61	-99
3	Debar EQ1967	6.38	20	20.43	41.42	52	60	-155
4	Pehchevo EQ1904	7.58	30	23	41.71	230	55	-105

The point source is the type of elemental source used in the OpenQuake-engine for modeling distributed seismicity. The OpenQuake engine always carries out calculations assuming finite ruptures, even when dealing with point sources. Here are the fundamental assumptions used to generate ruptures with point sources:

- Ruptures take a rectangular form
- The hypocenter of the rupture is positioned at the center of the rupture
- The rupture is constrained at the top and bottom by two planes parallel to sea level, located at two characteristic depths known as the upper and lower seismogenic depths, respectively

Based on the adopted scenarios for scenario damage assessment, 4 attenuation equations applicable to the specified territory [5] with an identical weighting factor of 0.25 have been selected:

- Akkar et al. 2014 GMPE [6]
- Bindi et al. 2014 GMPE [7]
- Boore et al. 2014 GMPE [8]
- ChiouYoungs2014 GMPE [9]

In relation to local soil conditions, a reference Vs30 value was taken to be 520 m/s.

4. Damage distribution and selection of fragility curves

Fragility curves highlight the probability of exceeding a certain level of damage in relation to a certain intensity measure. In our case, fragility curves from the GEM database with the intensity measure peak ground acceleration PGA were used. Three fragility curves [10, 11, 12] were selected, for low, medium and high-rise buildings, as follows:

- Ahmad et al (2010) - CR_,_DUC_,_IRRE_Low-rise (2storeys)
- Ahmad et al (2010) - CR_,_DUC_,_IRRE_Mid-rise (5storeys)
- Ahmad et al (2010) - CR_,_DUC_,_IRRE_High-rise (8storeys)
- Kappos et al. (2003) - CR_,_LFM LowRise HighCode
- Kappos et al. (2003) - CR_,_LFM MidRise HighCode
- Kappos et al. (2003) - CR_,_LFM HighRise HighCode
- Liao (2006) - Reinforced Concrete, Moment Frame, High Code (1-3 stories)
- Liao (2006) - Reinforced Concrete, Moment Frame, High Code (4-7 stories)
- Liao (2006) - Reinforced Concrete, Moment Frame, High Code (8+ stories)

To carry out scenario damage calculations, it is essential to define a fragility function for every building type present in the exposure model. A fragility model consists of a series of fragility functions, which describe the probability of exceeding a set of limit, or damage, states. These fragility functions can be specified in either a discrete or continuous format, and the fragility model file can contain a combination of both types of fragility functions. The presentation of the fragility curves and their comparative difference are shown in Fig. 2. Regarding the differences, it can be determined that there are differences both in the intensities and in the probabilities of exceeding.

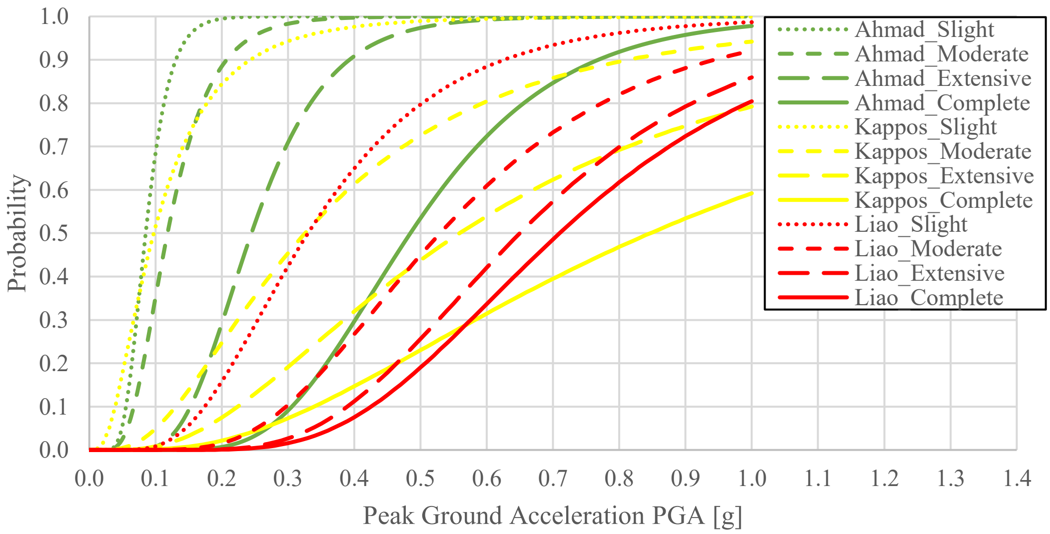

Figure 2. Contribution of fragility curves

The scenario damage calculator used with OpenQuake determines damage distribution statistics for all assets in a given exposure model based on a single specified rupture. These statistics include the mean and standard deviation of damage fractions for various damage states. To operate, this calculator

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requires the definition of a finite rupture model, an exposure model, and a fragility model. An example of the job.ini.file from the scenario damage calculator is shown in Fig. 3. The primary outputs are the damage distribution statistics per asset, aggregated damage distribution statistics per taxonomy, overall damage distribution statistics for the region, and collapse maps, which show the spatial distribution of the number or area of collapsed buildings across the region of interest.

```
[general]
description = Scenario calculation Skopje 1963 ahmad
calculation_mode = scenario_damage
random_seed = 113

[Rupture information]
rupture_model_file = earthquake_rupture_Skopje_1963_cat.xml
rupture_mesh_spacing = 2

[Hazard sites]
region_grid_spacing = 2
region = 18.660643 43.597828, 23.453487 43.441627, 23.588118 40.061431, 18.831175 40.013329

[Exposure model]
exposure_file = exposure_model_Block_A_kor.xml
asset_hazard_distance = {'default': 200}

[Fragility model]
structural_fragility_file = fragility_model_Block_A_kor so ahmad.xml

[Site conditions]
reference_vs30_value = 520
reference_vs30_type = inferred
reference_depth_to_2pt5km_per_sec = 2.0
reference_depth_to_1pt0km_per_sec = 100.0

[Calculation parameters]
gsim_logic_tree_file = gmpe.xml
ground_motion_correlation_model =
truncation_level = 3.0
maximum_distance = 200
number_of_ground_motion_fields = 1000
```

Figure 3. Example of job.ini flie

Based on the conditions defined in this way and the calculation models defined in OpenQuake, a total of 12 analyses were run using the scenario damage calculator. The results are shown in Fig. 4,5,6. The values of the results from the seismic risk estimation are expressed in percentages. The results clearly show the contribution of the fragility curves in the estimation of the distribution of damage levels.

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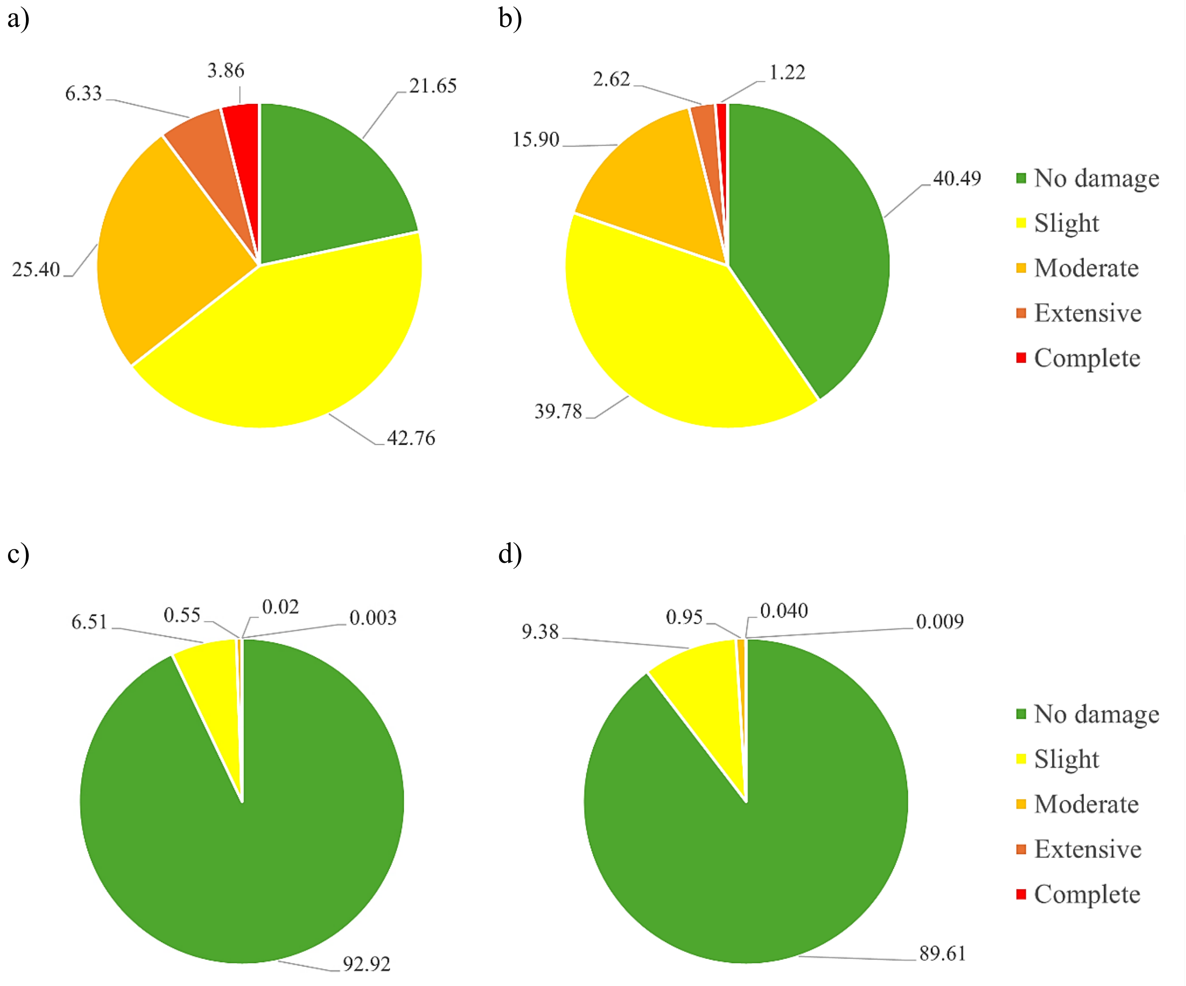
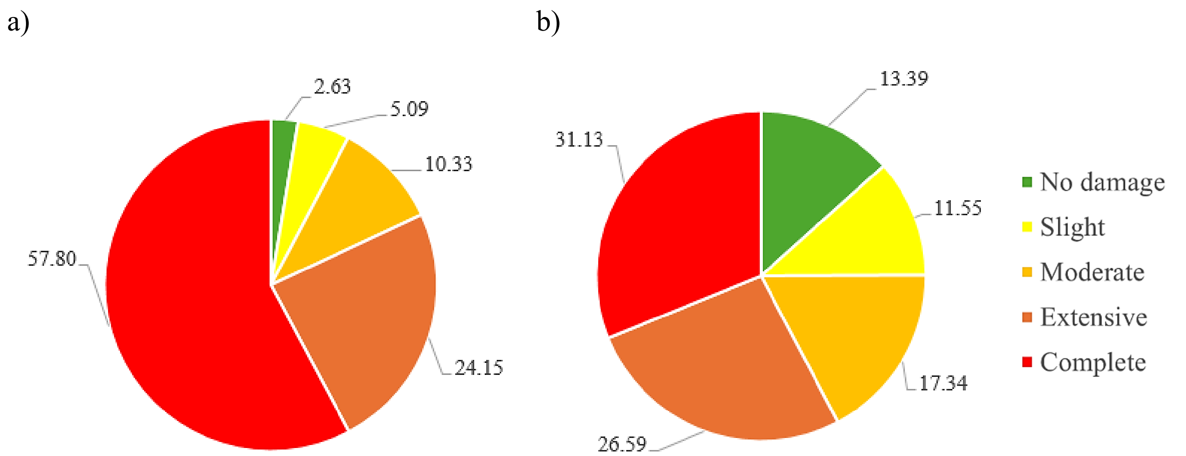


Figure 4. Aggregate Risk Statistics in Percentage FCS1 Kappos et al. 2003 a) Skopje 1963; b) Skopje 2016; c) Debar 1967; d) Pehchevo 1904.



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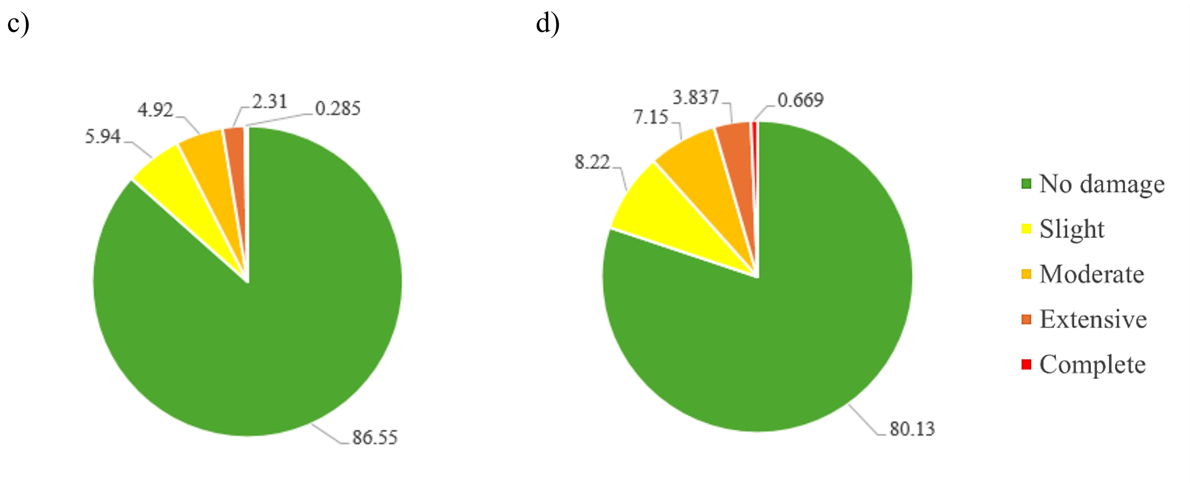

Figure 5. Aggregate Risk Statistics in Percentage FCS2 Ahmad et al. 2006 a) Skopje 1963; b) Skopje 2016; c) Debar 1967; d) Pehchevo 1904.

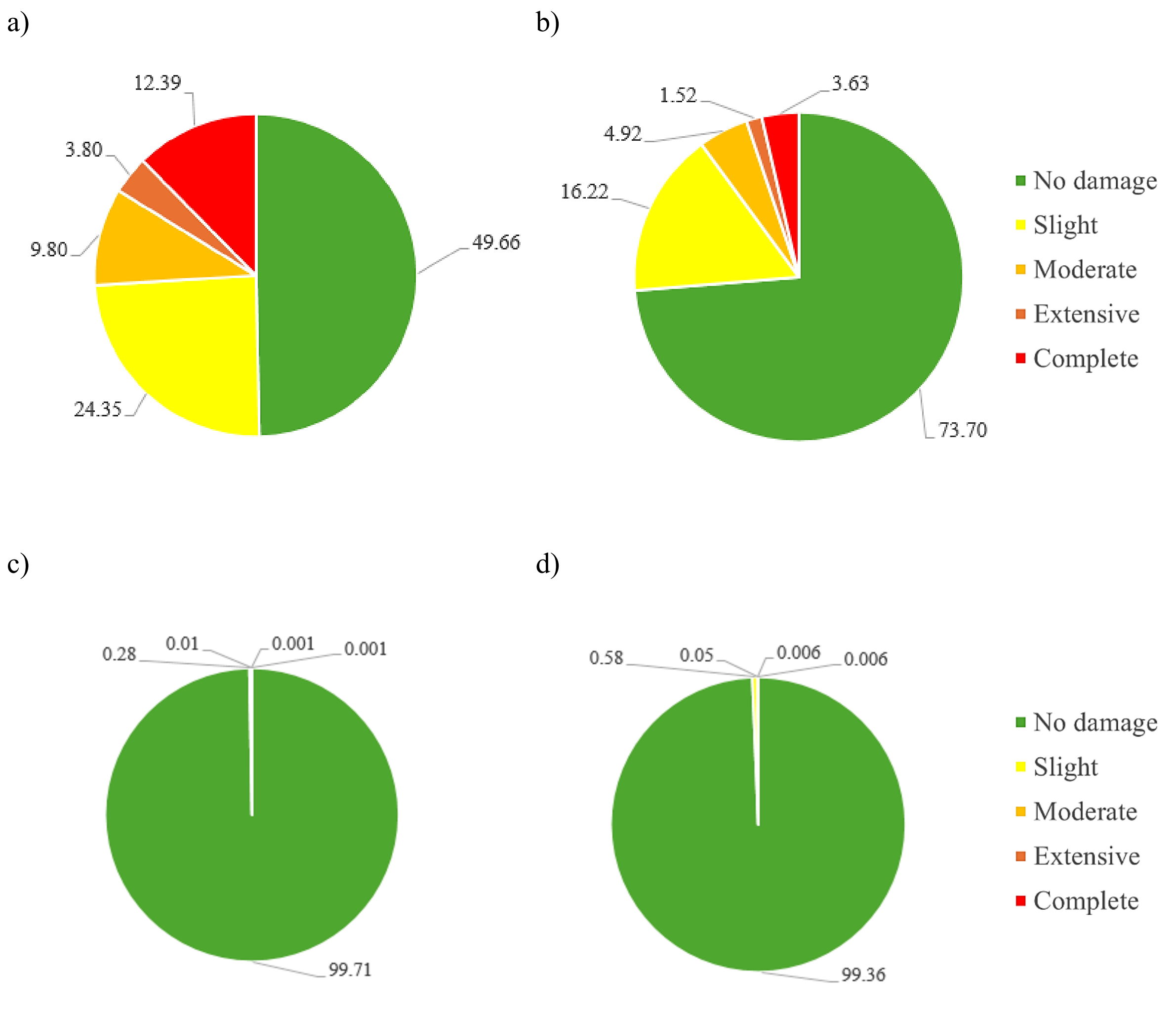

Figure 6. Aggregate Risk Statistics in Percentage FCS3 Liao et al. 2007 a) Skopje 1963; b) Skopje 2016; c) Debar 1967; d) Pehchevo 1904.

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5. Conclusions

The paper generalizes and shows the differences in the selection of fragility curves in relation to the estimation of seismic risk based on a defined exposure model created by obtaining data from three sources. A total of 12 earthquake scenarios were used, four for each of the selected fragility curves. In terms of the results, the most conservative estimate of the damage degrees was obtained with the curves of Ahmad et al. (2010). The curves of Kappos et al. (2003) and Liao (2006) are more uniform despite the fact that all curves are adopted from the GEM database for reinforced concrete structures, moment frame ductile structures.

The differences that originate from the selection of fragility curves indicate the fact that for the estimation of seismic risk, the best results would be obtained by developing fragility curves based on the typology of buildings such as 1 to 3 stories, 4 to 7, over 8 stories. To generate these curves, using various types of nonlinear static and dynamic analyses, curves would be realistically obtained that would be representative of the structures shown in the exposure model.

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