UDC: 728.1:624.13.042.7]:550.34.042.4(497.75)
Original scientific paper

EXISTING RESIDENTIAL BUILDINGS AND FAMILY HOUSING FACILITIES IN THE POLOG VALLEY OF THE REPUBLIC OF NORTHERN MACEDONIA WITH MANDATORY SEISMIC RESISTANCE

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Abstract

Research on methodologies for seismic vulnerability assessment of existing buildings has been conducted. A procedure for assessing the seismic vulnerability of AB buildings is proposed. Applying nonlinear static pushover analysis, parameters of nonlinear behavior of the selected set of AB buildings are determined. Vulnerability indices are defined and calculated, as a measure of damage to each building, like a scaled linear combination of the state of nonlinear behavior of the components at the breaking point of the pushover analysis. The calculated values of the vulnerability indices obtained by the pushover analysis, in the range of 0.2-0.3, indicate satisfactory behavior of the analyzed buildings.

Recent earthquakes around the world have affected the formation of people's consciousness, especially in seismically active areas. Such projects of possible scenarios are realized today, which include various databases that are the basis for any research.

This paper deals with the current problem in the field of vulnerability of existing buildings during seismic actions.

Keywords*:* Polog valley, seismic vulnerability, ab buildings, pushover, vulnerability index

1 Introduction

This paper is an attempt to make an assessment of seismic risk on the territory of a selected region in RNM, namely the Polog Valley. The territory of the Republic of North Macedonia is actually one of the most seismically susceptible regions in Europe. Other seismically active areas include: Valandovo, Ohrid, Debar, Tetovo, Pehchevo and Skopje. The Polog region (Gostivar and Tetovo region) in the Republic of Macedonia is an active seismic area with a scale of 8 degrees according to the ICC, but according to the latest European research this area is quite active, so this zone should be considered the same as the Skopje Valley with seismic scale of 9 degrees according to MCS.

The paper shows a common procedure for forming a building stock database in a region, using standard forms. Finally, a template is proposed that could be applied to our cities.

Today's regulation in the field of seismic design in our country, not only has it not been renewed since 1981, when the last regulations for seismic design are adopted, it does not in any way treat the reliability of the constructed buildings. In the world today this is a very important field of research, so it is of great importance to take the initiative to collect data and establish a database necessary to understand the current situation.

Modern building vulnerability assessment procedures are primarily focused on the structural system, capacity, design and response parameters. These parameters would provide a more realistic assessment of

the expected behavior and to which extent the constructed building reflects the prescribed structural and architectural features and conditions.

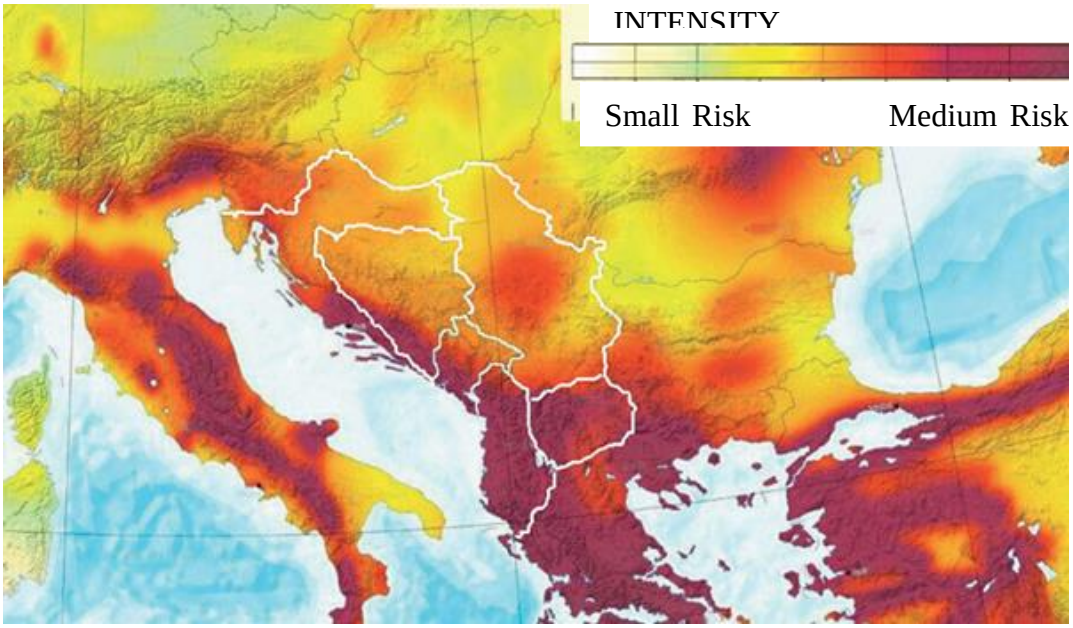

Figure 1: Seismic risk map of the Balkans (Euro-Mediterranean)
Book Vullnerabiliteti Sizmik nga kendveshtrimi i arkitektit (2014), Enis Rafet Jakupi, page 3

Reinforced concrete frame structures are the most commonly used types of structural systems in reinforced concrete buildings in this region. Although current seismic regulations allow for satisfactory behavior of reinforced concrete buildings, there are still a number of seismically weak-inadequate structures that are not approved by these regulations. Identifying weak structures is of great importance in assessing losses in the event of a possible strong earthquake in the future and setting priority criteria for strengthening these structures.

2 The Polog Valley in the Republic of North Macedonia

The Republic of North Macedonia as a mountainous region is divided into eight regions or subdivisions. The Polog valley as a region extends to the southeast and north-east, at a length of 55.5 km and a width of 8-10 km, surrounded by mountains: Shar Planina, Suva Gora and Zheden. The administrative divisions of the municipalities: Gostivar, Tetovo, Mavrovo and Rostusha, Vrapchishte, Bogovinje, Brvenica, Tearce, Zhelino and Jegunovci, fall under this region.

The Polog Valley is known as a seismically active area.

The construction and the representation of certain types of buildings are described and the selected constructions of buildings are analyzed.

Geological characteristics of the Polog Valley:

The terrains of the municipality are made up of strapaleological rocks; philitoids, metadiabases, green shale, quartz shale and quartzite. Triassic sediments are found in faces of clay, sandstones, limestone, whereas from the Cretaceous, sediments are represented by upper-cretaceous. The youngest quaternary sediments are alluvial-proliferating sediments and moraine materials in the high-mountainous areas.

From the geotectonic point of view, the Polog Valley has highly complex tectonics and the largest part of it is the zone between the mountains Shar Planina –Pelister (Korapska zone).

Figure 2. Planning Region in the Republic of Macedonia

Figure 3. Planning Region Polog with the Municipalities

BookVullnerabilitetiSizmikngakendveshtrimiiarkitektit (2014), EnisRafetJakupi, page 11 and 12

3 Description of the research

Recommendations are given in the design based on displacements, procedure steps, and methods used in the analysis. The nonlinear static pushover analysis is described as a procedure for assessing the seismic response of reinforced concrete buildings with an illustration of an example developed using SAP2000 software.

An overview has been given of the current research on the vulnerability of reinforced concrete frame structures in seismic regions, modeling, as well as analysis required for damage assessment. The current situation in the considered region is discussed and an approach for defining damage assessments is described with an example from the literature. The uncertainties are also shown, the manner and substrates used in the modeling of the buildings, the characteristics of the materials, the calibration of the stiffness parameters and the procedure for assessing the vulnerability by the pushover analysis. The analyzed constructions are described and the selected objects in the Polog Valley are categorized by identifying the key elements on which the behavior of the objects in seismic conditions depends. The conducted analysis and the way of calculating the index of vulnerability of the buildings are described.

The paper presents the results of the research on the vulnerability of existing reinforced concrete residential buildings and family housing in settlements and rural and urban, in the Polog valley and proposes a simplified methodology for determining the seismic resistance of these buildings.

The proposed methodology is a combination of micro and macro approach in the analysis of seismic vulnerability of existing structures. Namely, at the level of integral construction, a nonlinear static analysis of the behavior of the selected set of 20 characteristic constructions is performed. This approach belongs to the group of methods that can be included in micro-modeling.

On the other hand, after providing the answer to the selected representative structures, the results of the nonlinear static analysis of the structures are applied to the general conclusions made about the level of seismic vulnerability of a whole class of buildings provided in the design according to current regulations. This approach is a typical example of a macro approach in seismic vulnerability analysis.

The proposed methodology, which is a combination of micro and macro modeling, is an innovative approach in providing relevant data for a whole class of buildings from a narrower region, treating the

specific characteristics of the buildings from the considered class of buildings, in this case reinforced concrete residential buildings and family housing, both rural and urban, in the Polog Valley.

The research conducted within the doctoral thesis should be seen in the light of the situation in the construction and design practice in the past two decades after the independence of the Republic of Macedonia. Namely, due to the institutional changes, the adoption of the law on construction has been with a serious delay in the general public, and there is a serious concern about the level of seismic resistance of the buildings built in that period. The choice of the topic of research, residential buildings in the Polog Valley, resulted primarily from the expansive growth of these settlements in the indicated period.

During the research, serious attention is paid to the study of the existing construction fund in the selected region, where typification of characteristic constructive solutions is made, and for the selected constructions detailed information is provided on the constructive and non-constructive elements that ensure authenticity, originality and above all reliability of the conclusions drawn.

4 Analyzed structures

During the transition period of rapid development and socio-economic development in the Polog region, the last decade saw the construction of a large number of individual family houses, collective buildings, business and commercial buildings with different heights for a short relevant period. Therefore, such studies for the Polog Valley can be considered as a real basis for possible interventions in the construction of buildings, with all the adequacy to be strengthened or reconstructed, by reducing the seismic risk in acceptable limits as well as taking a stand on how to proceed during the design and construction of facilities in this region of the Republic of Northern Macedonia, in the Polog Valley.

The paper examines individual residential buildings for family housing and collective residential buildings. A total of 50 buildings were analyzed, and 20 buildings in different municipalities of the Polog region were described in detail. Some of the buildings on the ground floor have business premises with different purposes. Most of the analyzed facilities are located in the cities of Gostivar and Tetovo and some in rural areas. The analyzed buildings have different floors and are located in different locations. According to the number of floors, the buildings are divided into 3 categories: up to P + 3, up to P + 5 and from P + 5 to P + 10 floors.

Table 1 Buildings examined (analyzed), by municipalities.
Enis JAKUPI, doctoral dissertation "Determination of seismic vulnerability of existing residential buildings and family housing facilities in the Polog Valley R.M" University Cyril and Methodius, Faculty of Civil Engineering Skopje, 2012.

Floors	Municipality of Gostivar – number of examined buildings	Municipality of Tetovo – number of examined buildings	Rural Municipalities – number of examined buildings
Up to P+3 floors	12	6	10
Up to P+5 floors	8	6	
Up to P+10 floors	2	6	

Each building is identified by a serial number, address / location, investor, date of construction, description of the type of construction, floors and the construction system.

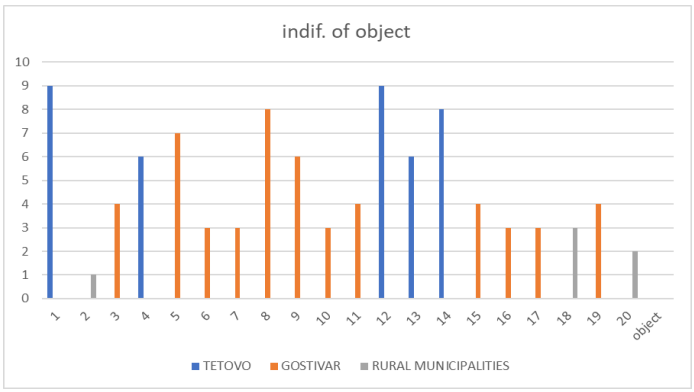

Figure 4. Marked buildings by municipalities

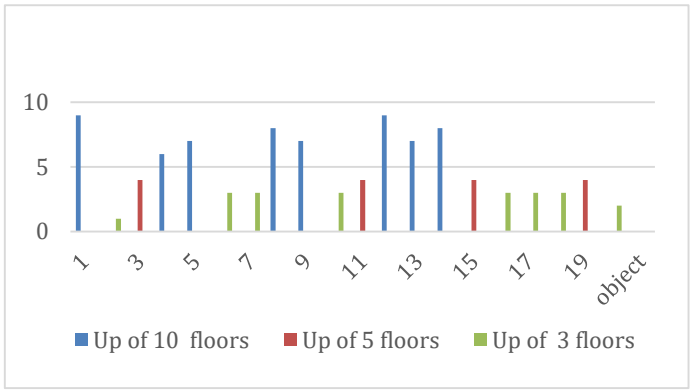

Figure 5. Marked buildings by floors

Enis JAKUPI, doctoral dissertation "Determination of seismic vulnerability of existing residential buildings and family housing facilities in the Polog Valley R.M" University Cyril and Methodius, Faculty of Civil Engineering Skopje, 2012.

Figure 6. The category of objects and the number surveyed with the expression ups and downs

Enis JAKUPI, doctoral dissertation "Determination of seismic vulnerability of existing residential buildings and family housing facilities in the Polog Valley R.M" University Cyril and Methodius, Faculty of Civil Engineering Skopje, 2012.

A nonlinear static pushover analysis of reinforced concrete buildings was performed using the computer program SAP2000. The location of the plastic joints is chosen in the cross-sections of the structural elements where the initial achievement of the static quantities that cause leakage is expected. Under the action of horizontal loads, such cross-sections are usually located at the ends of the structural elements. Thus, the plastic joints are placed at the ends of all the beams and at the ends of all the pillars of the structure, as places where the limit moments would be reached first [2].

The vulnerability index determined by pushover analysis is a measure of building damage. It is defined as a scaled linear combination (weight average) of the measures of behavior of the plastic joints formed in the elements and are calculated from the levels of behavior of the elements at the point of behavior

(performance point) or at the moment of interruption of the push-over analysis. The building vulnerability index is calculated according to the following mathematical expression:

$$V_{I3rp} = \frac{1.5\sum N_i^c x_i + \sum N_i^h x_i}{\sum N_i^c + \sum N_i^h}$$

where N_i^c and N_i^h represent the number of formed plastic joints in the columns and beams, respectively, for the i-th level of behavior (i = 1,2,….., 6), [2].

The force-deformation curve for plastic joints is divided into 6 levels of behavior: B-IO, IO-LS, LS-CP, CP-C, DE, and > E. At the end of the analysis, from the output results for the deformed state, the level of deformed condition can be noticed for each joint. Each level of behavior is assigned a weight factor, xi as given in Table 3. The results also show the number of joints formed in the beams and columns of the structure. The columns are treated as elements of greater importance for the global safety of the building, due to which they are assigned a weight factor of 1.5 versus 1.0 for the beams.

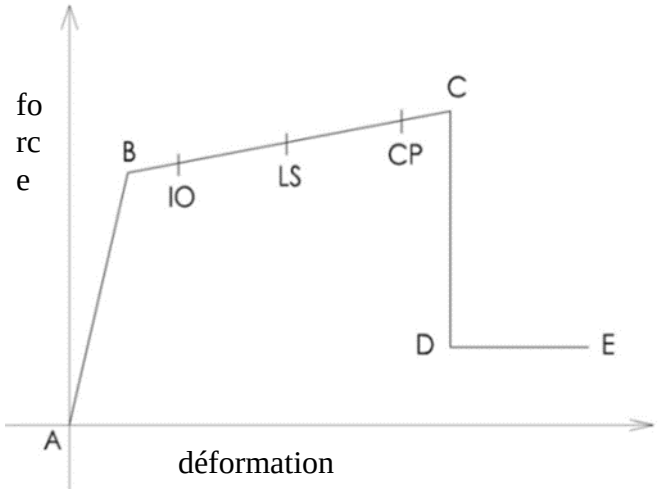

Figure 7. Force-displacement curve for plastic joints

Range	Factor x_i
<B	0
B to IO	0.125
IO to LS	0.375
LS to CP	0.625
CP to C	0.875
C-D, D-E, >E	1

Table 2.

Enis JAKUPI, doctoral dissertation "Determination of seismic vulnerability of existing residential buildings and family housing facilities in the Polog Valley R.M" University Cyril and Methodius, Faculty of Civil Engineering Skopje, 2012.

From the analysis, the capacity curves of the buildings have been obtained (dependence of the total seismic force in the foundation and the maximum horizontal displacement of the top) from which the behavior of the structures, their minimum estimated seismic load, the rigidity of the structure and the maximum displacement can be estimated.

The obtained pushover curves also show the values of seismic forces for the buildings designed according to the current seismic regulations of VII, VIII and IX degrees, which are relevant for the considered region of the Polog Valley [1].

For all buildings, we can observe a significant reserve in the load capacity estimated by the nonlinear analysis, which indicates the conservatism of the current regulations.

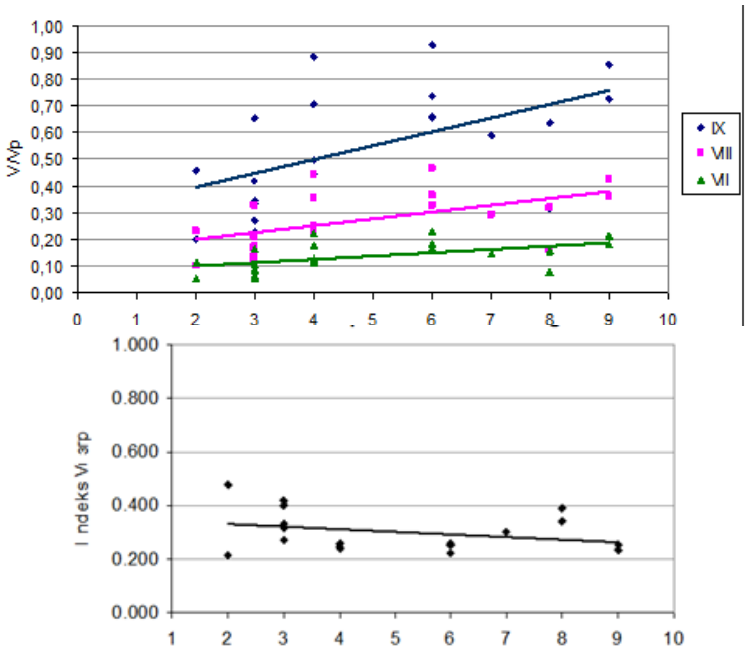

Figure 8. Relation of projected seismic load and estimated load with push-over analysis for seismicity of VII, VIII and IX degree

Figure 9. Vulnerability indices of buildings

Enis JAKUPI, doctoral dissertation "Determination of seismic vulnerability of existing residential buildings and family housing facilities in the Polog Valley R.M" University Cyril and Methodius, Faculty of Civil Engineering Skopje, 2012.

Table 3. Buildings examined, by municipalities

Enis JAKUPI, doctoral dissertation "Determination of seismic vulnerability of existing residential buildings and family housing facilities in the Polog Valley R.M" University Cyril and Methodius, Faculty of Civil Engineering Skopje, 2012.

building	floors	V_{IX} /Vp	V_{VIII} /Vp	V_{VII}/Vp
1	9	0,46	0,23	0,11
2	1	0,20	0,10	0,05
3	4	0,65	0,33	0,16
4	6	0,35	0,17	0,09
5	7	0,33	0,17	0,08
6	3	0,27	0,13	0,07
7	3	0,42	0,21	0,10
8	8	0,22	0,11	0,06
9	6	0,70	0,35	0,18
10	3	0,50	0,25	0,12
11	4	0,88	0,44	0,22
12	9	0,45	0,22	0,11
13	6	0,73	0,37	0,18
14	8	0,66	0,33	0,16
15	4	0,93	0,46	0,23
16	3	0,58	0,29	0,15
17	3	0,31	0,16	0,08
18	3	0,63	0,32	0,16
19	4	0,73	0,36	0,18
20	2	0,85	0,43	0,21

It can be noticed that the calculated values of the vulnerability index are quite even and there are no significant deviations**.**

5 Conclusion

By applying the proposed methodology and behavioral analysis of 20 selected representative structures, from two to nine floors, the following conclusions from the research are defined:

- Most of the reinforced concrete buildings with 2 to 9 floors are behaving satisfactorily. The load-bearing capacity of buildings, assessed by pushover analysis, indicates the existence of significant reserves in relation to the forces calculated according to current regulations.

- The obtained values for the vulnerability indices of the buildings are in the range of 0.2 to 0.4 with the exception of the buildings with irregularities in the base and height where the values of the indices greater than 0.45 are obtained.

- The nonlinear behavior of the structures takes place primarily through the formation of plastic joints in the beam elements.

- From the analysis of the deformed condition of the joints formed in the beams, it can be concluded that the condition of these joints is in the region between B and IO. Until the appearance of the first plastic joints in the columns, the condition of the joints in the beams is in the range between IO-LS. The end of the analysis occurs when the condition of the joints formed in the columns is in the region between the LS-CP, which corresponds to an effective displacement of about 2-3% of the height of the buildings.

- A simple assessment method has been developed that enables the assessment of the seismic vulnerability of existing AB buildings. The method is based upon taking into account the capacity for nonlinear deformation of buildings in conditions of seismic action.

- The proposed method is a useful tool for achieving this goal because it allows analysis of the vulnerability of ordinary buildings in a given territory including data from different sources and accuracy.

It remains to be pointed out that all the above stated conclusions should be taken with reservations, which arises from the fact that all conducted analyzes are mostly based on data obtained from the project documentation, and any deviations from that in the construction process is a situation that cannot be excluded. Hence, when applying the indicated methodology to individual buildings, it is necessary to pay special attention to the adequacy of the project documentation and the performed condition of the building.

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