Seismic Vulnerability and Risk of Losses Case Study Center of the City of Azogues

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Abstract Ecuador is located in the Pacific Ring of Fire, a country with high risk and seismic sensitivity, evidenced by the 6.8-degree earthquake in Ambato in 1949, which left approximately 6000 dead, the 7.8-degree earthquake in Manabí and Esmeraldas in the year 2016 with 663 victims and 29672 buildings without the possibility of use. Currently there is a problem about seismic performance in reinforced concrete buildings, since many were built with old regulations; so, it is necessary to assess their vulnerability. Quito, Guayaquil and Cuenca, large cities in Ecuador, have formal studies of seismic vulnerability, mostly carried out by university students and teachers. In contrast, most small cities do not have these studies; or, they need to be updated to validate their results. This is the case of the city of Azogues. The objective of this research is to evaluate the vulnerability of structures using the Hazus methodology, adapted to Ecuador, in the downtown area of the city of Azogues, in structures located around the Central Park, to establish the seismic performance in reinforced concrete buildings. The Hazus methodology, which determines the vulnerability of buildings from fragility curves, which are entered with inputs as the capacity, performance level and drift curves calculated through Ecuadorian models. The capacity curves, depending on various aspects such as: the material, number of floors, spans between columns, among others; they vary from building to building. In this sense, capacity curves were defined for sets of buildings with similar characteristics, coinciding with the Hazus methodology. The performance levels and the displacements were calculated with the ETABS computer package. For fragility curves, the model that most real simulates the response of a structure is the non-linear analysis, because it considers the decrease in stiffness in columns and beams, as well as the deterioration of the properties of the materials. In this sense, there are fragility curves of Ecuadorian buildings for four levels. The earthquake readings enable the construction of a demand spectrum, which, when contrasted with the capacity spectrum, leads to the performance point. Its position sometimes varies per the elastic demand spectrum, which is diminished by its inelastic behavior. As the demand spectrum decreases, the damage will increase. Once the coordinates of the performance point are known, the fragility curves are used; and, the possible damages are defined, quantifying them in percentage.

1. Introduction
Ecuador is located in the Pacific Ring of Fire, characterized by its high risk and seismic sensitivity, which has been evidenced in the 6.8-degree earthquake in Ambato in 1949, which left approximately...
6000 dead, the 7.8-degree earthquake in Manabí and Esmeraldas in 2016 with 663 fatalities and 29672 buildings without the possibility of use [1]. At present, a problem of seismic performance is denoted in reinforced concrete buildings, since a large number are built without the supervision of a professional technician in the field. Faced with this reality, it is necessary to assess the vulnerability of these structures using proven statistical or analytical methods.

Estimate the vulnerability of structures using proven statistical or analytical methods; as is the Hazus methodology, adapted to Ecuador, in zone 7-Central of the city of Azogues, specifically in the blocks located around the Central Park, to establish the percentage of damage, under seismic action, in the buildings of reinforced concrete.

Prepare an inventory of reinforced concrete buildings, through a survey of information on site, to establish the typology of buildings to be studied.

Determine capacity curves and performance points, through the application of computer programs and methodologies proven in Ecuador, to have parameters that allow an analysis of the buildings studied.

Estimate the percentage of damage, under seismic action, of the buildings analyzed, by using fragility curves, to know the magnitude of damage in the areas located around the Central Park, in the 7-Central zone of the city of Azogues.

2. Materials and Methods
2.1. Study baseline
2.1.1. Capacity curves
The capacity curve is an ordered set of points graphed in a rectangular coordinate system, which relates the basal shear (ordinate) with the lateral displacement (abscissa) of a structure, when crossing the border of the elastic range [2] [3]. A capacity curve is made up of two parts, one linear and the other non-linear. The linear part is made up of a straight line with a slope equal to the period of the fundamental mode of vibration of the structure. While the normalized non-linear part is adjusted through a cumulative lognormal function [4].

2.1.2. Fragility curves
The seismic vulnerability of a building directly affects its fragility, which can be quantified through fragility curves. These are understood as the probability of achieving or exceeding a defined boundary state, considering the response of the structure, in the face of an established earthquake. It is represented as a cumulative distribution function [5]. For the construction of the brittleness curves, the calculated displacements are used for the damage states, converted into spectral displacements [6].

2.1.3. Performance point
Represents the maximum capacity demand of the structure compared to the request of the earthquake; that is, it is the response of the building, in its fundamental mode of vibration, considering pseudo-acceleration and pseudo-spectral displacement with respect to the maximum displacement. The performance point is identified as the crossing point of the capacity and demand spectra [7].

2.1.4. Seismic Risk
It can be considered as the loss probability function of the damage to an element or set of elements as a consequence of the action of earthquakes.

2.1.5. Seismic vulnerability
Vulnerability can be conceived as a component of internal risk, which corresponds to its internal preference to be exposed to receive a deterioration. It manifests itself as the possibility that the structure is affected by the earthquake or earthquake. On the other hand, we currently speak of vulnerability when referring to risk [8] [9]. The level of wear of a footing, column, beam or its set, in the event of an earthquake of a given magnitude or intensity is what defines Vulnerability [10]. That is, the vulnerability depends on the behavior of the structure in the event of an earthquake [11].
The urgency of evaluating the seismic vulnerability in buildings, to determine corrective measures, is greater in urban areas that have inventories of buildings constructed without seismic design [12].

2.1.6. Vulnerability studies - seismic risk.

The seismic hazard, the level of exposure and the vulnerability to which the buildings are exposed are the triggers of the seismic risk. The development of a city may be conditioned to the seismic risk to which it is exposed. So its study becomes a serious and decisive challenge for the current century. A variety of studies related to vulnerability, danger, and seismic risk have been developed, both in Ecuador and outside of it. The city of Quito, capital of Ecuador, has been the object of the development of several master's and doctoral theses at local and European universities. One of them carries out the evaluation of seismic vulnerability of the city of Quito, developed with the Hazus and Perpetuate methodologies, complemented with Ecuadorian models used for the elaboration of capacity curves, fragility curves and performance points. 2066 buildings were involved in this study. It was concluded that the capital of Ecuadorians is highly vulnerable due to its construction and design procedures, in addition to the existing faults and its type of soil [13].

In Azogues, the evaluation of its seismic vulnerability has been developed, based on the vulnerability index methodology, based on the European macro seismic scale EMS-98, defined and tested by Sonia Giovinazzi and Sergio Lagomarsino. Its results are alarming, 98% of the buildings are identified as highly vulnerable. [14].

Several buildings located in the center of developed cities, are old and are still in service, however, they were not conceived under seismic codes or under construction regulations. In this context, the promotion of optimal models that improve the performance of the structure will be important in reducing risk. Such is the case of the study developed to evaluate the seismic safety of reinforced concrete buildings [15], which used the Rapid Visual Screening method and tested the effectiveness of the Machine Learning method in predicting damage. It was tested with four earthquakes, including the one that occurred in Ecuador, on April 16, 2016. One of its main conclusions establishes that existing buildings show poor construction, poor maintenance and damage, which increases even more, if they are related to an earthquake. In addition to the fast methods, methods such as incremental dynamic analysis can be applied, which requires high-performance equipment [16].

In addition to earthquakes, a critical component involved in the vulnerability of reinforced concrete buildings is the soil, and even more critical, if it is soft. In this regard, a study has been carried out on the seismic fragility of reinforced concrete structures in soft soils, considering the aftershocks that may occur. His model was developed with finite elements. His contribution was the determination of the consequences in the face of a sequence of earthquakes, of a 7-story building. The reference earthquake was the Northridge of 1994 [17].

2.2. Case study

The canton Azogues, capital of the province of Cañar, is located in the south-central sector of the Republic of Ecuador, at 2350 meters above sea level. It limits to the north with the province of Chimborazo, to the south and east with the province of Azuay and to the west with the cantons of Biblián and Delég.

The city of Azogues is located at coordinates 2.75 ° south latitude and 78.85 ° west longitude. Its urban limits are: to the north, from the Tocanchón hill to the Uchupucún sector; to the south, with the urban parish of Borrero (Charasol); to the east, with Chaquimayllana; and, to the west with the hill of Shishiquín.

The urban area of the city of Azogues is small, it has around 11,000 buildings, with an area of 613 km². It is divided into 7 planning zones: Bayas, Charasol, Bellavista, La Playa, Chacampamba, Uchupucún and Central. The study was carried out in the Central zone (Fig. 1), specifically for the 8 blocks that are located around the Parque del Trabajo (Central Park), in which there are 131 properties registered [18].
2.3. Methodology
2.3.1. Primary - Secondary Information
The information used in this study was primary and secondary. Regarding the type of structure, dimensions and materials of the buildings, it was primary. This was obtained from 2 inspections. The first for gathering information and the second for validation. Regarding the fragility curves, the existing ones were used, related to cities with characteristics similar to that of the city of Azogues [19].

2.3.2. Universe – Sample
The urban area of the canton Azogues has around 11,000 buildings, however, the investigation included only those belonging to the 8 indicated areas, which are 131, of which only 45 were selected that are made of reinforced concrete.

2.3.3. Methods
A vulnerability assessment consists of individually analyzing its essential phases, identified as: input data, methods and results [20]. One of the options is to use mechanical methods. Among these we have the linear and non-linear procedures, considering static and dynamic loads. The static nonlinear is considered in several methodologies such as: capacity spectrum, developed in ATC-40 [21], FEMA displacement coefficient [22]; and, Hazus [23], which bases its evaluation on a static non-linear model with variation of the earthquake and capacity of the structure. In the present study, the Hazus alternative was used.

2.3.4. Software
For the determination of the capacity spectra, the ETABS program was used.

2.3.5. Process
In the present study, directed exclusively for buildings with a reinforced concrete typology, the Hazus methodology adapted to Ecuador was used. This option determines the vulnerability of buildings from fragility curves, which were entered with inputs from the capacity curves, performance points and drifts calculated through Ecuadorian models [13].
The capacity curves, depending on various aspects such as: the material, number of floors, spans between columns, among others; they vary from building to building. In this sense, capacity curves were defined for 2 sets of buildings with similar characteristics, coinciding with the Hazus methodology. It works with 36 structural shapes, for which it has defined its corresponding capacity curves. The capacity curves, the capacity spectrum and the displacements were calculated with the ETABS computer package.

Regarding the generation of brittleness curves, the main methods used are: techniques based on field observations, experimental alternatives, variants considering the opinion of experts and analytical alternatives. All of them differ fundamentally in the input inputs and the way of calculating the probabilities of each type of damage [9]. At present, the model that most real simulates the response of a structure is the nonlinear analysis, because it considers the decrease in stiffness in columns and beams, as well as the deterioration of the properties of the materials. In this sense, there are fragility curves for Ecuadorian buildings for four levels of seismic damage [19]; which were used in the present study.

The readings of an earthquake allow the construction of a demand spectrum, which, when contrasted with the capacity spectrum, leads to the performance point [24]. Its position varies at times according to the elastic demand spectrum, which is diminished by its inelastic behavior. As the spectrum decreases further, the damage will increase. Once the coordinates of the performance point are known, the brittleness curves are used; and, the possible damages are defined, quantifying them in percentage.

3. Results and discussions

3.1. Building inventory

The buildings in the study area of the city of Azogues present different typologies, among which we find masonry, adobe and reinforced concrete structures, the latter corresponds to 34% of the 131 existing ones, for which the methodology is used by Hazus.

Hazus establishes 36 structural systems [24], under these parameters, the buildings studied are classified as:

| Cod | Description | Range | # Structures |
|-----|-------------|-------|--------------|
|     |             | Spec  | Story        |
| C1L | Reinforced concrete beam and column frames. Old and modern buildings are included | Low   | 1-3 | 22  | 49 |
| C1M | Medium      | 4-7   | 22  | 49 |
| C1H | High        | 8+    | 1   | 2  |

3.2. Capacity curves - Performance points

3.2.1. Soil type

To determine the type of soil, a refraction seismic geophysical test - MASW Method was carried out in the area under study. The dominant formation is the Guapán (MG), which consists of dark brown to black shales and even creams. It is characterized by alteration to limonite films. Locally it is observed tuffs and tuff sandstones, as well as bentonites and gypsum strata. There are abundant fossil plants. It has a power in the area close to 350 m.

The formation of strata is as follows: from 0.00 m to 14.00 m, soil type D, rigid soil profiles that meet the criteria of shear wave velocities between 360m / s &gt; Vs ≥ 180m / s; and, from 14.00 m to 30.00 m, type C soil, very dense soil profiles to soft rock, which meet the shear wave velocity criteria between 760m / s &gt; Vs ≥ 360m / s. From this information we proceeded with the calculation of the Dominant Period of the soil [25].
$$T_s = \frac{4}{5} \sqrt{\left(\sum_{n=1}^{N} \frac{h_n}{g_n}\right) \left(\sum_{n=1}^{N} \gamma_n h_n (W_{n}^2 + W_{n-1} W_{n-1})\right)}$$

(1)

The calculated value of $T_s$ was 0.428 s. The data used for its calculation: $h_1=14$ m, $h_2=16$ m, $g=9.807$ m/s$^2$, $\gamma_1=1800$ kg/m$^3$, $\gamma_2=1800$ kg/m$^3$, $V_{s1}=320$ m/s, $V_{s2}=580$ m/s, $W_0=0$, $W_1=1$, $W_2=1$.

Figure 2. Wave speeds.

By: Author

3.2.2. Analyzed frames

For the analysis of the buildings, they were classified into 3 groups, as indicated in Table 2. Average frames were defined, these being the following:

Portico 1: Corresponds to an average building of the C1L code, with three floors with two openings. Columns of 30 cm x 30 cm and beams of 30 cm x 20 cm. Column height of 3 m and spans length of 3m. Regarding the reinforcing steel of the columns, we worked with a quantity of 1%, $f_y = 4200$ kg / cm$^2$ and $f_c = 210$ kg / cm$^2$.

Portico 2: Corresponds to an average building of the C1M code, with 4 floors with two openings. Columns of 25 cm x 35 cm and beams of 30 cm x 30 cm. Column height of 3.10 m and spans length of 3.7 m and 3.5 m. Regarding the reinforcing steel of the columns, we worked with a quantity of 1%, $f_y = 4200$ kg / cm$^2$ and $f_c = 210$ kg / cm$^2$.

3.2.3. Capacity curves and performance points

For the analysis, a type D soil was considered, as well as an earthquake characterized as rare in the NEC (Ecuadorian Construction Standard), whose spectrum (Demand) is as follows:
3.3. Building damage estimation

3.3.1. Fragility curves
Those developed by Roberto Aguiar and Carlos Bobadilla [19] are used, which obey their geometry, assembly and materials of structures as they are built in Ecuador. They are developed for mild, moderate, extensive and complete seismic damage levels.

3.3.2. Determination of percentage of damage by using brittleness curves
With the value of the global floor distortion, we enter the brittleness curves and determine the percentages of damage to the structure.
Figure 5. Fragility curves – percentage of damage – C1L.

Curves results: Mild = 100%, Moderate = 95%, Extensive = 14% y Complete = 5%.

Figure 6. Fragility curves – percentage of damage – C1M.

Curve results: Mild = 100%, Moderate = 79%, Extensive = 6% and Complete = 3%.

4. Conclusions
The present work had a series of restrictions, due to Covod-19, the entrance to the buildings was very restricted, because their owners objected. However, it was determined that the typology of the reinforced concrete buildings studied are very different, their design does not obey a serious structural study, so it is necessary to carry out detailed studies of these to reduce their vulnerability.

For the C1L group of buildings, there is 100% slight damage, which means that all of its structural elements would present visible cracks smaller than 0.3 mm. In the case of moderate damage, the percentage of damage is 95%, that is, cracks smaller than 1mm and the steel stress around the yield point. The level of extensive damage with 14%, the elements lose coating and the cracks are in the order of 1 and 2 mm. Finally, at the complete damage level, we have 5%, with cracks greater than 2 mm.

For the C1M group of buildings, there is 100% slight damage, which means that all its structural elements would present visible cracks smaller than 0.3 mm. In the case of moderate damage, the percentage of damage is 79%, that is, cracks smaller than 1mm and the steel stress around the yield point. The level of extensive damage with 6%, the elements lose coating and the cracks are in the order of 1 and 2 mm. Finally, in the level of complete damage we have 3%, with cracks greater than 2 mm.
The calculated dominant period of the soil, which was 0.428 seconds, indicates that probably the buildings between 4 and 5 floors (C1M) are the most affected; and, indeed, it is confirmed with the data presented in the previous paragraph.

The C1L group of buildings has a better performance than those of the C1M, since its period of vibration is less than that of the ground. It is important to note that C1M buildings are taller.

The results presented should alert the authorities of the city of Azogues, as we are in time to take preventive measures and reinforcement of buildings.

On the other hand, this study confirms what is expressed in the conclusions of the study of the evaluation of its seismic vulnerability, based on the vulnerability index methodology, based on the European macro seismic scale EMS-98, defined and tested by Sonia Giovinazzi and Sergio Lagomarsino. In which it is indicated that 98% of the buildings are identified as highly vulnerable.

Finally, it is recommended that this study, which can be taken as a pilot study, be extended to the entire city, once the pandemic has been overcome; and, in this way, there is complete information on the structural reality of the buildings.

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