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Structural Characterization and Seismic Vulnerability Analysis of Buildings Located in the Historic Center of Sincelejo

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Abstract

This manuscript presents a detailed inventory of the buildings, their state of conservation and their potential performance against seismic risk is presented. The information was obtained from surveys, geotechnical zoning investigation and seismic vulnerability. The evaluated area is located in the urban area of the municipality of Sincelejo in the department of Sucre, north of Colombia. The data show the Structural Typology of the buildings in the central and historical area of the city, as an essential input to carry out the Seismic Risk studies. Among the relevant information obtained from the survey carried out, there is the age of the buildings, the type of material used for their construction, the types of finishes, the structural system used, the type of roof, the type of walls, the height of the structure, the state of conservation, the type of the buildings, among other information. On the other hand, a study of the seismic vulnerability of these buildings was carried out, making use of the survey data and using the geotechnical investigations that was performed through geotechnical surveys in various sites in the historic center. For this purpose, the Vulnerability Index method was used, through which the expected damage for buildings was obtained and different scenarios of seismic damage were modelled.

Keywords: Structural typology, geotechnical investigation, seismic vulnerability, seismic risk, seismic damage

I. INTRODUCTION

Historic centers are places with monuments to history, art, and architecture, and they are established as the heritage of a country, and even as world heritage sites [1]. The conservation and rehabilitation of these sites is a necessary activity to preserve history and culture, thereby safeguarding an invaluable legacy for new generations [2]. Then, it is essential to know the conformation of the historic centers and verify their state of conservation, which seeks to have a complete knowledge of each of the structures that make up the historic center and their individual characteristics [3]. This allows taking timely action against possible threats that threaten the integrity of cultural heritage, such as environmental phenomena, which can endanger the stability of these structures.

This work focuses on obtaining the structural typology, as well as determining the seismic vulnerability of buildings located in the central and historical area of the city of Sincelejo. According to the classification established for the degree of conservation of buildings, about 75% are in good condition, 22% are in poor condition, while about 3% are in fair condition. The vulnerability index of the structures is determined and the structures are evaluated with three damage scenarios (Aa = 0.065, 0.125 and 0.150).

II. EXPERIMENTAL DESIGN, MATERIALS AND METHODS

II.I Study area description

Sincelejo, the capital of the department of Sucre, is located on a set of low hills in the Serranía de San Jerónimo, which in this area is called Sierra Flor. The municipality of Sincelejo has a total area of 28,410 Ha. The composition of the land of the municipality is given by a landscape of mountains, hills and foothills. The climate is hot dry, with an average rainfall of 500 to 1200 millimeters; the vegetal formation according to Holdridge is the tropical dry forest. Regarding the landscape of the hills, this is the most important in the municipality, which extends from the mountain landscape to the limits with the plain, both in the north and in the south, these hills being moderately undulating to strongly ravines, with slopes between 7% and 50% and with slight to moderate erosion [4]. Sincelejo is localized in intermediate seismic hazard site [5], which is why it is important to conduct seismic risk studies.

In terms of cultural heritage, Sincelejo has 87 conservation properties and 39 heritage properties, which will be valued to the extent that public training strategies are also made effective towards the appreciation of architectural art, cultural integration and acceptance by the diversity. The tangible and intangible heritage of Sincelejo, according to the Land Use Planning, must be inventoried, in terms of architectural legacies, the city in its historic center has a republican-style urban construction, represented in 39 buildings [6].

In Fig. 1 the location of the study area is presented. The perimeter that borders the historic center of the city of Sincelejo is observed.

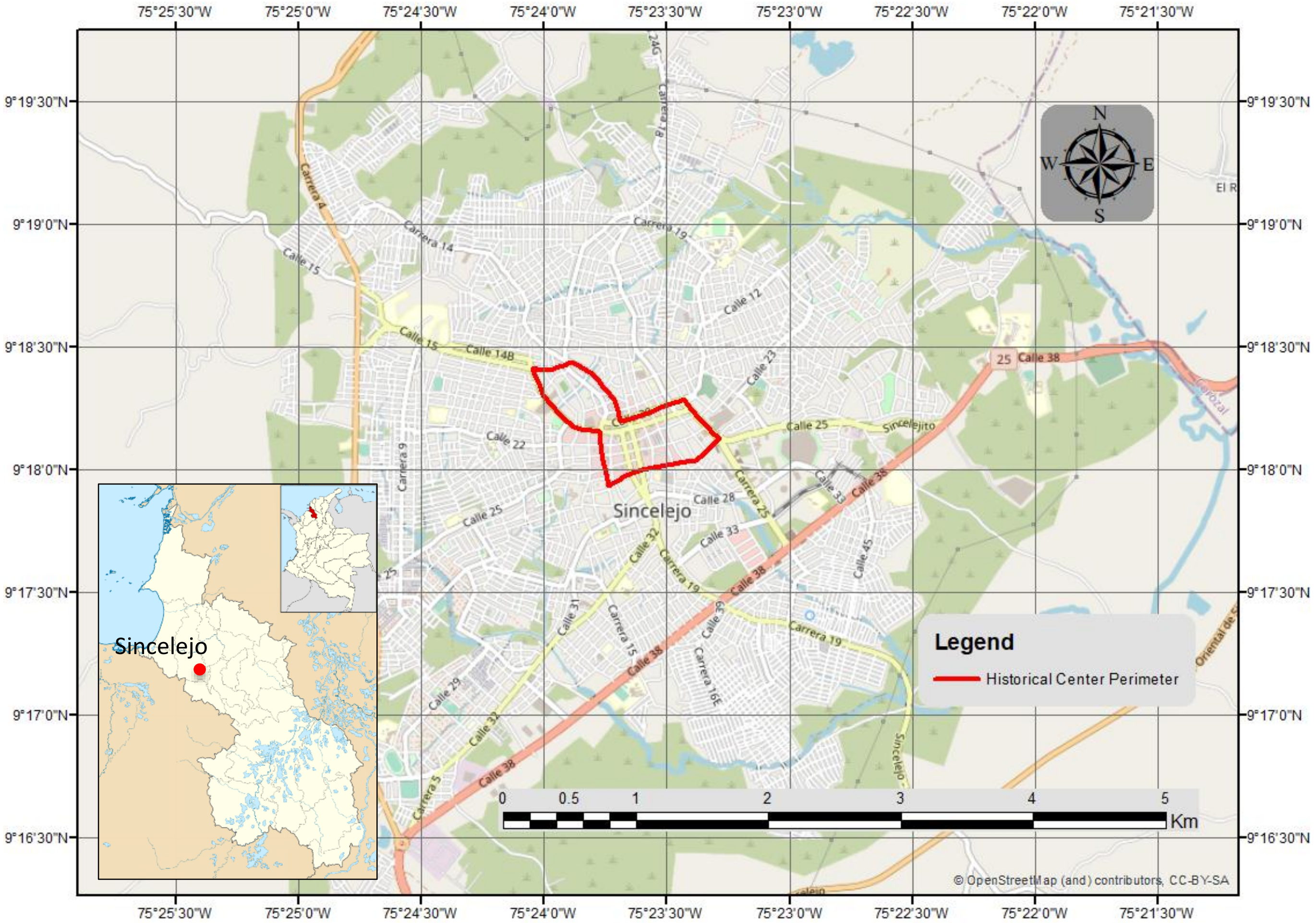

Fig. 1. Location of the historic center of the city of Sincelejo (research zone).

II.II Material and methods

For the development of the structural typology study and seismic vulnerability assessment of the structures that make up the historic center of the city of Sincelejo, techniques and tools were followed that led to obtaining the required information. The study was broadly divided into three phases: first, a survey was carried out to obtain data about the structural typology of buildings, information about their current use and their state of conservation. In the second phase, field tests and soil laboratory tests were carried out to generate the geotechnical profiles for the area. In phase 3, the Vulnerability Index method was used to obtain the seismic risk of the buildings. For this purpose, the information from Phases 1 and 2 was used, as well as the documentation regarding the structural and architectural design of the structures. Each of the aspects considered is detailed below.

For the elaboration of the database on the structural typology of the area, surveys were used (annexed in the Supplementary data). In total, 1,392 buildings that are part of the perimeter surrounding the historic center of the city of Sincelejo were evaluated. The information collected in the survey was the following: number of floors of the building, height of the building, areas of the building (lot area, built area), date of construction (age of the structure), structural system, type of materials of the roof, materials of the facade, materials of the floor, materials of the walls and the type of slab (if applicable). Additionally, questions were asked about the current use of the buildings and the number of people who make use of them at different times of the day (morning, afternoon and night). Additionally, structural and architectural plans were obtained for 28 non-structural masonry buildings and 42 reinforced concrete buildings.

Geotechnical investigations was carried out, which allowed characterizing the foundation soils of the buildings in the historic center of the city. This step is essential to be able to apply the Vulnerability Index method. A total of 64 geotechnical surveys were performed, conveniently distributed within the study area, which were taken to different depths, the maximum depth being 7 meters. The information was organized using the Excel spreadsheet. The characterization was carried out by soil strata at each depth meter, taking the parameters of the collected sample, such as: depth, type of soil, consistency, number of number of blows of the SPT test [7], natural humidity, Atterberg limits (liquid limit, plastic limit and plasticity index) [8], percentage that passes the No. 200 sieve, USCS classification [9], bearing capacity [10], and presence of the water table.

The seismic vulnerability assessment depend on the characteristics of the structures and the location of the same, for which the elements resistant to seismic loads and the non-structural elements are taken into account. These studies are essential in disaster prevention and mitigation programs resulting from earthquakes, since they allow adequate measures to be taken in the areas where they have been carried out [11]. In this way, the seismic risk or degree of damage expected for a structure or area of interest that is subjected to an earthquake is obtained. For the vulnerability analysis, the Vulnerability Index method [12] was chosen, because according to experience, good results have been found to be applied in projects in different countries, including Colombia [13]. This method has been developed to be applied in non-structural masonry structures and in reinforced concrete structures [14], which makes it a versatile tool to evaluate areas where this type of structure predominates, as is the case of the evaluated area, in which the structures of this typology represent approximately 96% of the total.

Next, the Vulnerability Index method [15] is presented, which identifies the most important parameters that control the damage caused by an earthquake in buildings. In each of the types of structures, eleven parameters are evaluated, with their respective importance coefficients, in which at the end, by means of some equations, the seismic vulnerability of the structure is determined. As this value is higher, the building is more vulnerable. Below is shown the Equation 1, used to determine the Vulnerability Index for non-structural masonry structures:

$$I_v = \sum_{i=1}^{11}(K_i * W_i) \quad (1)$$

The analysis of this type of structures, yielded results between 0% (the least vulnerable), and 382.5% (the most vulnerable), so it was necessary, to work in the same range to the different types of structures, standardize it between 0 % and 100%.

To determine the Vulnerability Index to reinforced concrete structures, the Equation 2 is used:

$$I_v = 10 * \left[\frac{\sum_{i=1}^{11} K_i * W_i + 1}{4}\right] \quad (2)$$

In this equation, the vulnerability indices give results between 0% and 100%, so it is not necessary to standardize it.

Finally, the software ArcGIS (GIS tools) was used in order to extrapolate the results of the vulnerability analysis to all the structures in the historic center of Sincelejo, thus obtaining the seismic risk values for all the buildings; the scale chosen to present the ranges of the damage states is the one proposed by ATC-13 [13].

III. RESULTS

In Fig. 2 the state of conservation of the buildings in the historic center of the city of Sincelejo is shown. Fig. 3 shows the distribution by year of the number of buildings built. Fig. 4 presents the current uses that are given to the buildings in the historic center. In Fig. 5 the types of foundation soils found in the geotechnical investigations are presented, discriminated into sands, silts and clays, and stratified every meter.

Fig. 6 presents the Seismic Vulnerability Index calculated for the buildings in the historic center, and Fig. 7, Fig. 8, and Fig. 9 show the possible seismic damage scenarios of the buildings for accelerations of 0.065, 0.125 and 0.150, respectively.

Table 1 shows the damage levels obtained through modeling for different seismic accelerations.

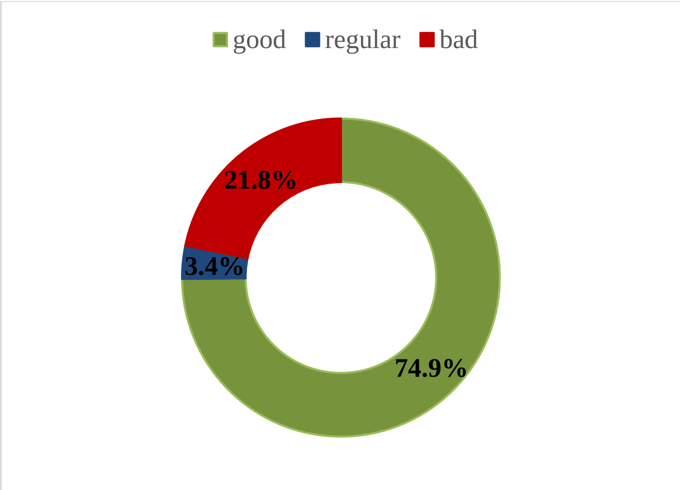

Fig. 2. Conservation state of the structure

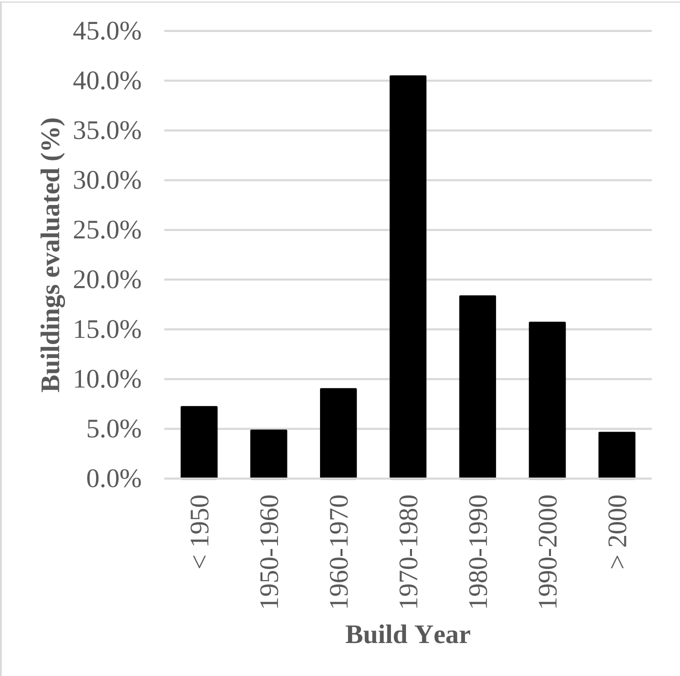

Fig. 3. Distribution of buildings by built year

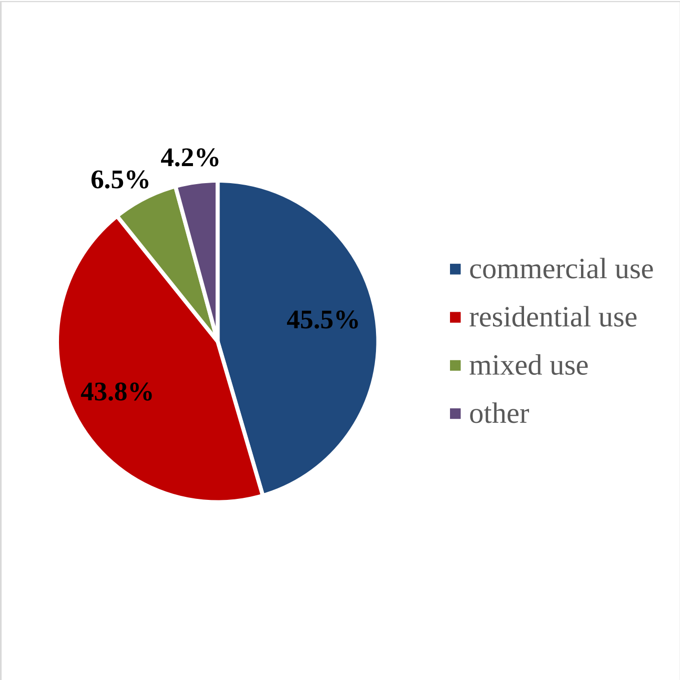

Fig. 4. Types of buildings of the historic center

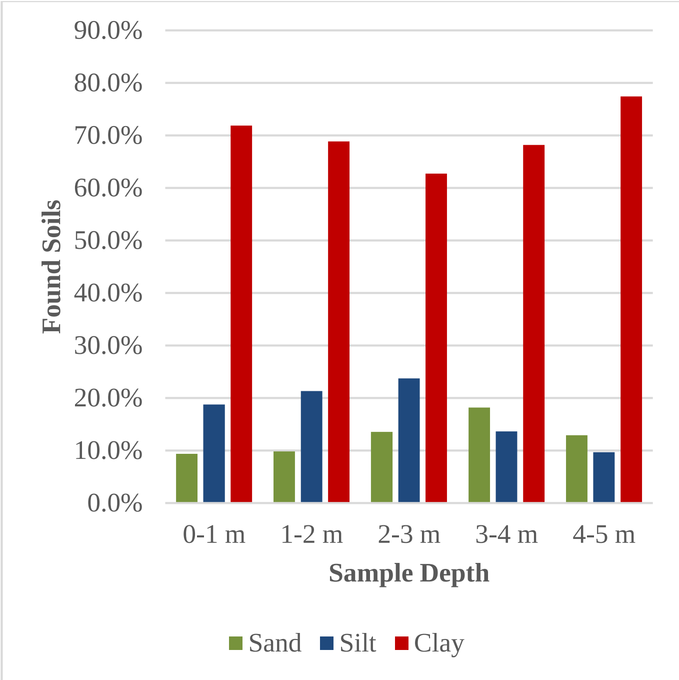

Fig. 5. Types of soils by strata

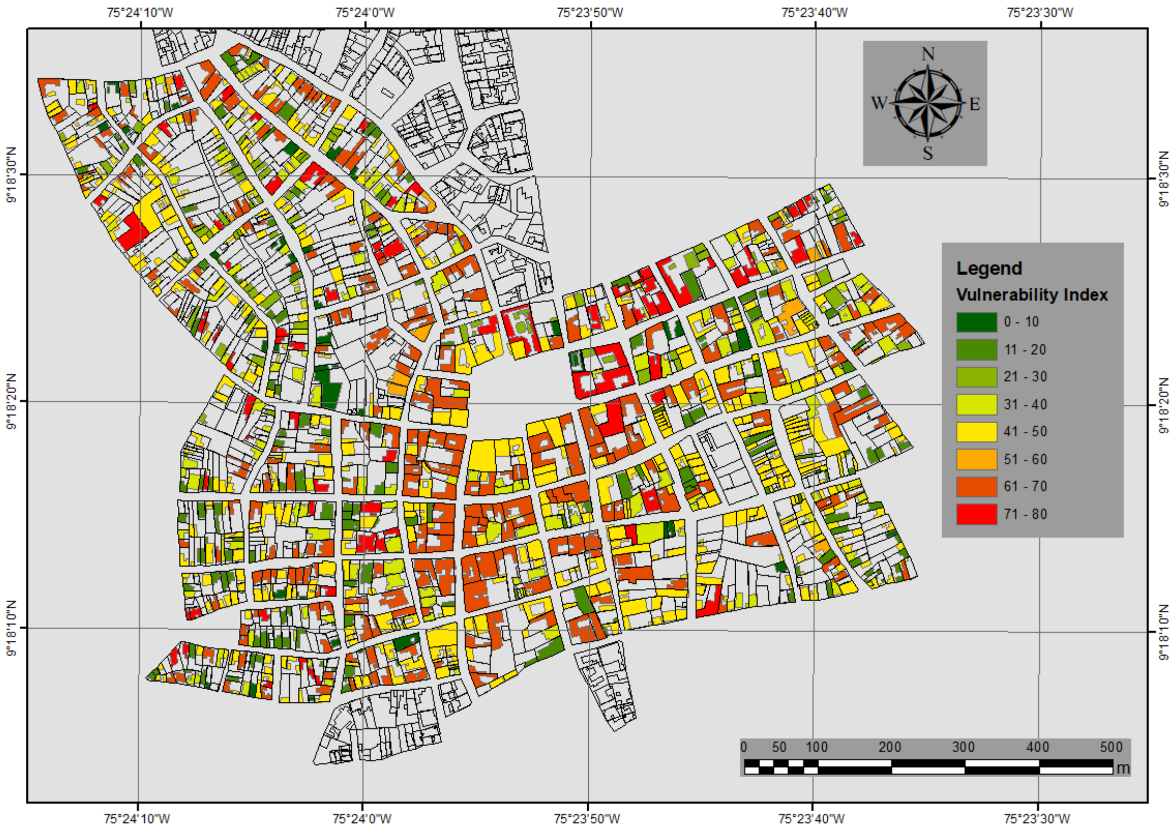

Fig. 6. Vulnerability Index of the buildings

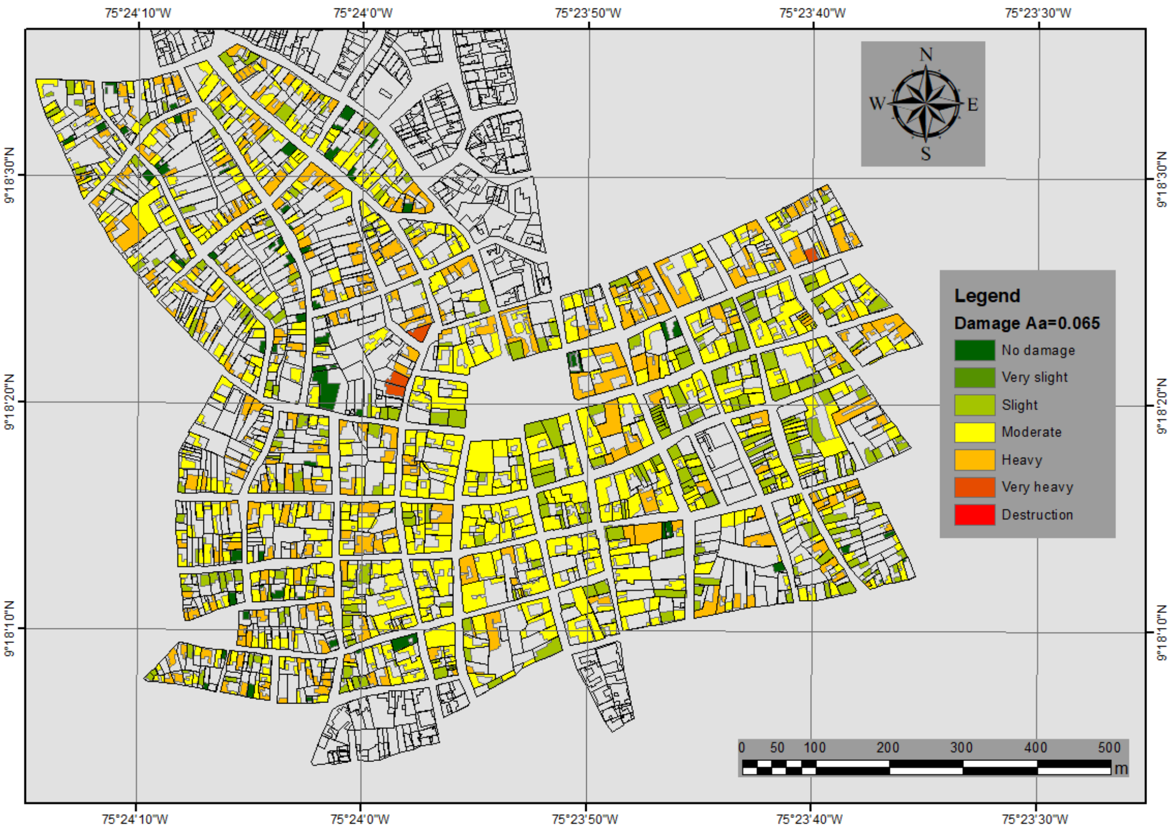

Fig. 7. Damage scenarios for Aa = 0.065. Service earthquake

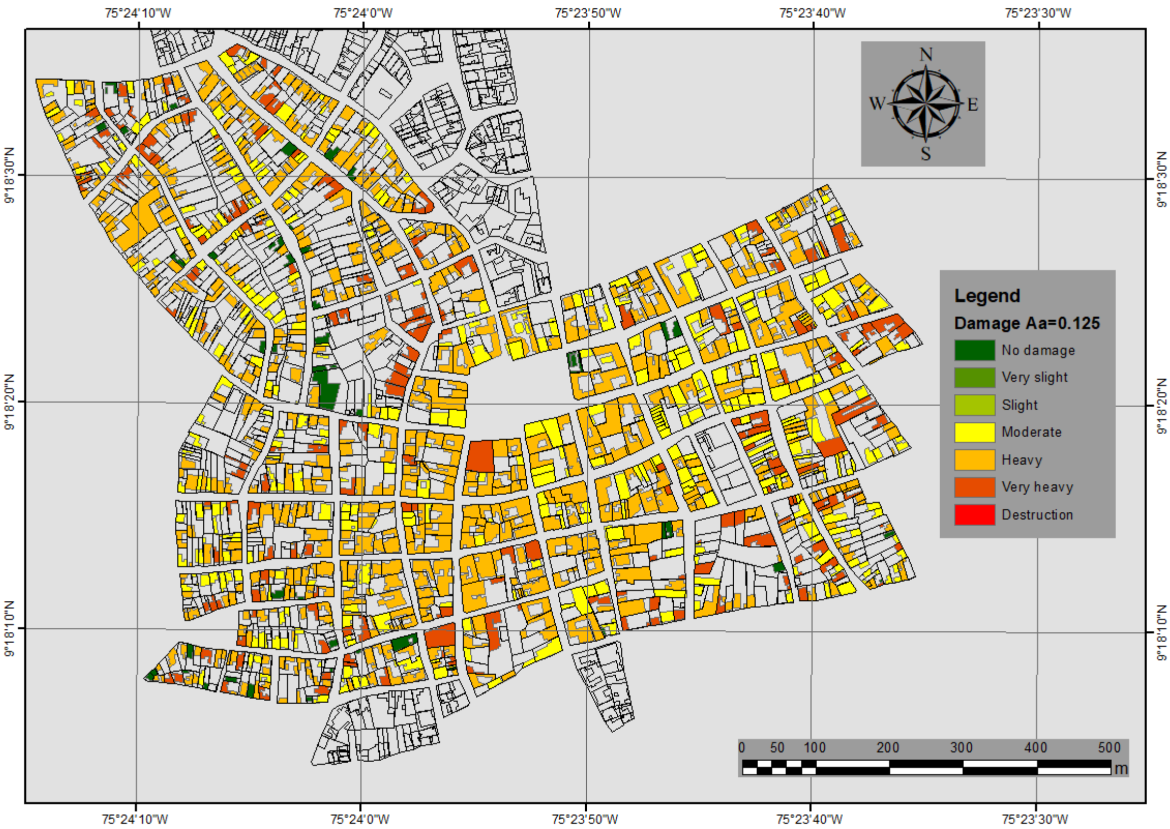

Fig. 8. Damage scenarios for Aa = 0.125. Design earthquake

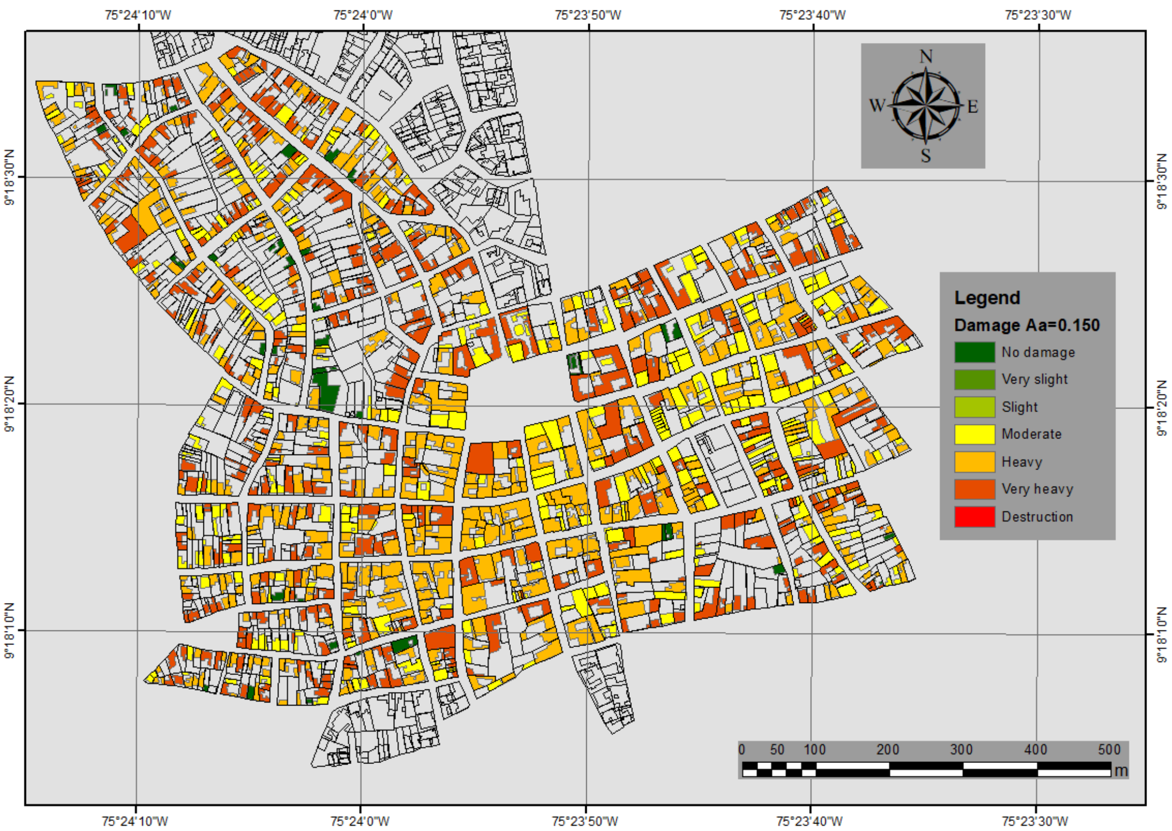

Fig. 9. Damage scenarios for Aa = 0.15. Severe earthquake

Table 1. Damage levels expected for different seismic accelerations

Damage level	Damage range (%)	Seismic Damage for Aa = 0.065	Seismic Damage for Aa = 0.125	Seismic Damage for Aa = 0.150
No damage	0	10.6%	9.3%	8.7%
Very slight	0-1	0.0%	0.0%	0.0%
Slight	1-10	14.9%	0.0%	0.0%
Moderate	10-30	52.0%	29.2%	25.1%
Heavy	30-60	14.1%	45.3%	20.7%
Very heavy	60-100	8.4%	16.2%	45.5%
Destruction	100	0.0%	0.0%	0.0%

VI. CONCLUSIONS

In accordance with what was developed in this work, it has been possible to establish the structural typology and the results of the seismic vulnerability analysis of the structures located within the historic center of the city of Sincelejo. The information obtained is very useful, because through it is possible to know the properties of the soil characteristic of the area under study, identify and delimit seismically vulnerable areas and reduce the uncertainty in the knowledge of the seismic risk in buildings in the study area. Additionally, the information can provide entities and conservators of historical monuments with valuable data to carry out conservation and reinforcement work, in order to carry out prevention and mitigation programs that make buildings safer.

As relevant data it was established that in the event of the expected design earthquake (Aa = 0.150), about 46% of the buildings considered in the present study would suffer a high level of damage (very heavy), which shows the urgent need for an intervention in the buildings identified as most vulnerable in order to prevent material losses and human lives.

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