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Seismic Vulnerability Assessment of Sid Maiza Mosque

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Abstract

The seismic vulnerability and risk assessment of monuments is really essential in rehabilitation programs and should not focus exclusively on recognized historic and heritage buildings but also related to current old masonry buildings highly valued in the urban environment. Moreover, because of their geographical, demographic or historical characteristics, certain ancient cities are particularly interesting and critical with regard to the reduction of seismic risks. For example, Ténès, a coastal town on the Mediterranean Sea, is one of the summer destinations. This fact explains the high seasonal flow of the population, combined with the high seismic risk of the region. Based on the elements presented, this article approaches the evaluation of the seismic vulnerability of old buildings by applying a simplified vulnerability method to the old Ténès city. This method is based on a vulnerability index, which makes it possible to assess the damage and create scenarios of human and economic losses in the broad sense (Vicente et al., 2011). A mosque and evaluated according to the targeted methodology. In this case, the seismic performance of a masonry mosque in the old city of Ténès was evaluated, selecting the approach considered most appropriate for the group and having chosen an analytical approach. The study was carried out by the GNTD II method. After analyzing the characteristics of the building and evaluating their seismic behavior, the capacity and fragility curves were produced according to the damage distributions.

Keywords: *Masonry Buildings; Old City; Seismic Vulnerability; Vulnerability Index; GNTD II.*

INTRODUCTION

Ténès is located in a region of strong seismicity in Algeria; it has been damaged by two earthquakes during the last century. Nationally recognized for its tourist visibility and has a substantial impact on the region's economy, despite its seasonality. The seismicity associated with this region results from the offshore seismic activity of the contact region of the Euro-Asian and African plates as well as from the activity of various local faults crossing the territory (Oliveira et al., 2004).

The evaluation of the seismic performance of a mosque in Ténès is made; the estimate of the building studied is carried out by applying the N2 method. The method used is applied to an isolated building and uses data from research on the characteristics of this building, then applied in digital modeling techniques.

Volume 63 | Issue 01 | January 2024
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PROPOSED METHODOLOGY FOR VULNERABILITY ASSESSMENT

There are a variety of methodologies proposed by different authors for the seismic vulnerability assessment of buildings. The choice of a certain assessment methodology depends on the following aspects: nature and objective of the study, available information, characteristics of the building or group of buildings studied, appropriate assessment methodology (qualitative or quantitative), and the organization that will receive the results of the study (eg government, scientific organizations, companies, etc.).

The formulation of the vulnerability index proposed in this chapter is essentially based on the GNDT II level approach, presented in GNDT-SSN (1994), for the assessment of the vulnerability of a masonry building. In this approach, the overall vulnerability is calculated as the weighted sum of 12 parameters (Table 1) used in the formulation of the seismic vulnerability index.

Table 1: Vulnerability Index (I_v)

Parameter group	Parameter	Class (K_i)				Weight (W_i)	Vulnerability index
		A	B	C	D		
1. Structural building system	P1 Type of resisting system	0	5	20	50	0.75	$I_v^* = \sum_{i=1}^{14} K_i W_i$ $0 \le I_v^* \le 650$ Normalized index $0 \le I_v^* \le 100$
	P2 Quality of the resisting system	0	5	20	50	1.00	
	P3 Conventional strength	0	5	20	50	1.50	
	P4 Maximum distance between walls	0	5	20	50	0.50	
	P5 Number of floors	0	5	20	50	1.50	
	P6 Location and soil conditions	0	5	20	50	0.75	
2. Irregularities and interactions	P7 Aggregate position and interaction	0	5	20	50	1.50	
	P8 Irregularity in plan	0	5	20	50	0.75	
	P9 Irregularity in elevation	0	5	20	50	0.75	
	P10 Wall façade openings and alignments	0	5	20	50	0.50	
3. Floor slabs and roofs	P11 Horizontal diaphragms	0	5	20	50	1.00	
	P12 Roofing system	0	5	20	50	1.00	
4. Conservation status and other elements	P13 Fragilities and conservation state	0	5	20	50	1.00	
	P14 Non-structural elements	0	5	20	50	0.50	

These 14 parameters are grouped into four groups. The first group includes parameters, characterizing the strength system of the building and the type and quality of masonry, starting from the material (size, shape and type of stone), masonry fabric and layout and quality of the connections between the walls, of the shear resistance capacity of the structure, evaluates the slenderness ratio of the structures and the soil foundation conditions. The second group of parameters focuses primarily on the relative location of buildings and its interaction with other buildings, assesses the irregularity of plan and elevation, and identifies the number, size and location of wall openings, due to its importance in the charge path. The third group of parameters evaluates horizontal structural systems, namely the type of connection of wooden floors and the impulsive nature of pitched roof systems. Finally, the fourth group of parameters evaluates the structural fragilities and the level of conservation of the structures, as well as the negative influence of non-structural elements with poor connection conditions to the main structural system.

Volume 63 | Issue 01 | January 2024
DOI: 10.5281/zenodo.10472686

The City of Ténès

Ténès is a coastal city on the Mediterranean Sea, located in northern Algeria, in the north of Chlef. In a region of strong seismicity, it was devastated by two earthquakes during the 21st century. The seismicity associated with this region results from the offshore seismic activity of the contact region of the African and Euro-Asian plates as well as from the activity of various local faults crossing the territory (Oliveira et al, 2004).

Figure 1: View of the Old City of Ténès

As for the old Ténès, Ténès El-Lahdar' created in the 9th century, with successive occupations, the Punics, the Berbers, the Romans, the Vandals, the Byzantines, the Arabs, the Turks and the French. Around the 8th century, the Phoenicians founded in Ténès a trading post with the Berber population. The tombs exist to this day on the coast of the city. From then on, the city bore the name of Cartenna. In the 3rd century, located west of eastern Numidia, it was placed under the command of Syphax. Under the Carthaginian domination, it was delivered by Massinissa at the end of the century. In the year 30, according to the Roman historian Pliny the Elder, Augustus installed the soldiers of the second Roman legion there. Today are discovered the vestiges dating from this time such as the mosaics with the Roman inscriptions: Caius, Fulcinius, Optatus, soldier of the second legion, or that of Victoria.

Sidi Maïza Mosque

As for the mosque in the old city of Tennis in the province of Chlef, is one of the oldest mosques in Algeria. It was listed as the third oldest mosque in 1905 after the Sidi Okba Mosque in Biskra and the Sidi Bou Mediene Mosque in Tlemcen. It is located on the northeast side, away from its center, and occupies an estimated position at a height of 46m above sea level, which allows it to monitor all the buildings below. The height of the minaret serves as a guide for visitors to the city from outside and inside. It is difficult to determine the date of the construction of this mosque because no written document indicates it, the only date that can be determined in this regard is that it was present at the time of al-Bakri (d. 1094/ 487 AD), when he says as part of his description of the city and it has a mosque. According to Marçais and J. Berque, it dates back to the 4th century of the Hegira corresponding to the 9th century of our era.

Volume 63 | Issue 01 | January 2024
DOI: 10.5281/zenodo.10472686

It was known as the "Sidi Ma'iza 'Sidi Ahmed Boumaza' Mosque", and despite its association with that name, anyone who referred to it when describing the city or studying it did not mention it or mentioned that a mosque, the Jami Mosque, or the old Mosque of Ténès in the architectural and archaeological study carried out by 'Dosso Lamar' in 1924: it was called 'The Mosque of old Ténès'.

It occupied a completely irregular space due to the emergence of some of its architectural elements, such as the minaret, the doors and the mihrab in the projection of the minaret. As for the open courtyard adjoining it, it is located to the north, and its dimensions are irregular in width, starting with 6.90 m on the west side and gradually decreasing to reach 1.00 m at its eastern edges, while that its length reaches its maximum extension at 31.50 m, which is the length of the mosque itself, and reduced at the bottom to 23.20 m.

The mosque consists of a group of sections distributed in this space, accessed by a door that connects it to the street, and from there the prayer hall which contains the qibla wall consisting of the opening of the mihrab and a small adjacent opening to the east serves to place the pulpit and two secondary doors. The smallest of these provides access to the women's prayer hall and in the wall opposite the qiblah wall, there is a minaret in the northwest corner, and a door leading to the open back yard. The roof of the mosque is raised on a group of columns interconnected by arches through which horizontal parallel rows are formed which intersect in the central area and on both sides with vertical rows.

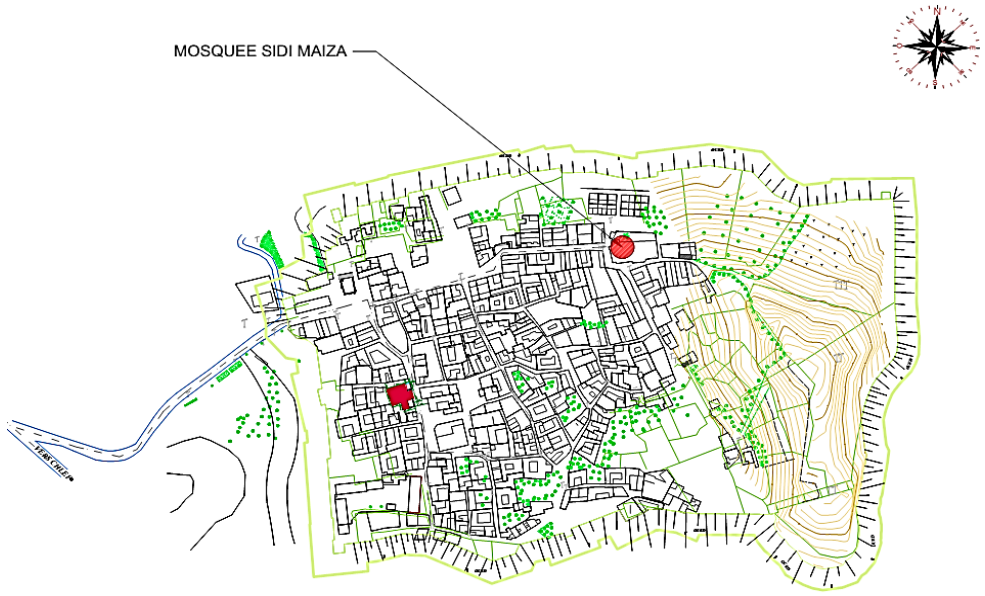

Figure 2: Location Map of the Sidi Maïza Mosque

Although it suffered significant damage during the great earthquake of 1954, which required rehabilitation works, which modified the original plan, the mosque was once again damaged following the earthquake of 1980. A study temporary protection was then carried out, but it was not until 1996 that the National Archaeological Agency carried out rehabilitation work.

Considered by Pr R. Bourouiba as the oldest mosque in Algeria still intact, the Sidi Bou-Maïza Mosque was built in a style inspired by the Great Mosque of Damascus. This religious building “by its naves parallel to the wall of the qibla is similar to the first mosque

Volume 63 | Issue 01 | January 2024
DOI: 10.5281/zenodo.10472686

of Medina that the Prophet would have helped to build with his own hands and whose model was taken up in Damascus (705-715)".

Figure 3: The Sidi Maïza Mosque in Old Ténès dates from the 9th Century the National Agency for Antiquities and the Protection of Monuments and Historic Monuments - Agence Chlef.

When one enters the interior of this secular building, one finds attached to the north facade of the mosque an ablutions room and a small courtyard in which is the tomb of Sheikh Sidi M'ammar. Then, by taking a small, slightly diagonal entrance, you reach the prayer room. This resembles in style to that of the mosques of Damascus, Cordoba, Kairouan or the al-Hassan Mosque in Rabat.

In addition to its five naves parallel to the qibli wall, divided into eleven bays, four of which support arches perpendicular to the qibla wall, the mosque has a mihrab on a polygonal plan with an octagonal niche. A model that can be found in all the medieval mosques of western Algeria and which strongly resembles that of the great mosques of Kairouan and Cordoba. With the only difference that the mihrâb of Ténès is "shifted by one nave towards the east and is preceded by a dome which emerges from the roof with a crushed cap and four corner merlons". According to R. Bourouiba, "this shift would have been intentional originally for the sake of respecting the Medinese type".

Figure 4: The Sidi Maïza Mosque in Old Ténès

Volume 63 | Issue 01 | January 2024
DOI: 10.5281/zenodo.10472686

MODIFICATION OF THE SIDI MAÏZA MOSQUE

The Mosque before 1954:

Originally, this room was covered with terraces, a way of covering that some authors refer to Roman times; while others see there that, the roof of the Sidi Maïza mosque is of the same style as the roof of the mosque. Of Omar Ibn El Khatab in Tenes. The roof has undergone several modifications and restorations since the occupation of the city by the French in 1842.

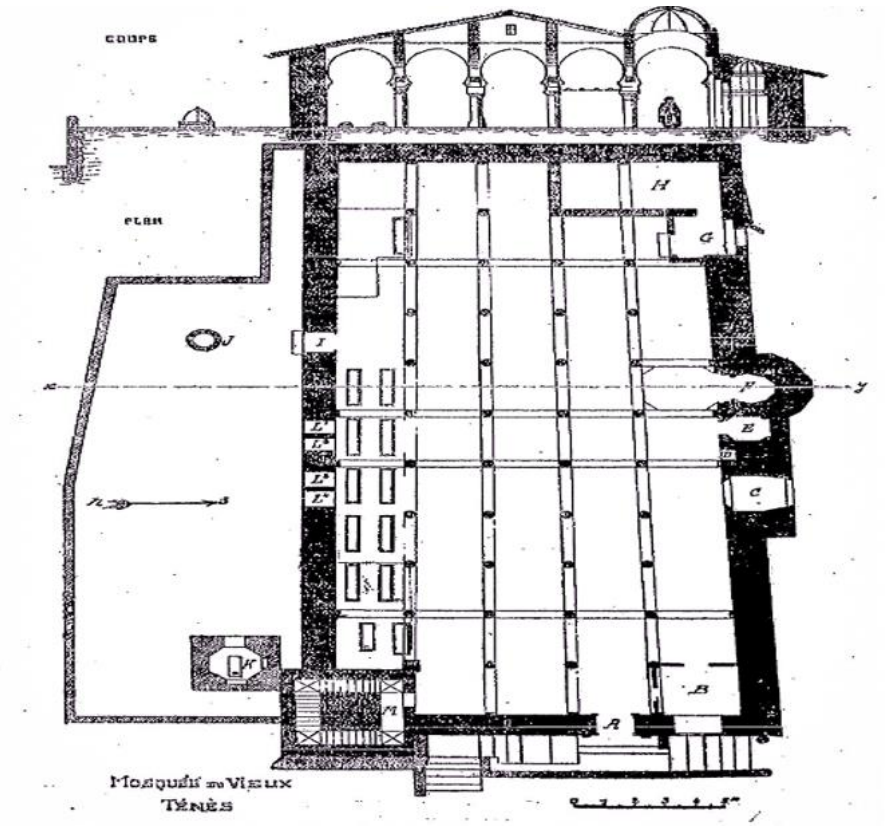

Figure 5: Plan and Initial Section of the Sidi Maïza Mosque. (The National Agency for Antiquities and the Protection of Monuments and Historic Monuments - Agence Chlef)

Indeed, from the middle of the 19th century, the mosque saw its first restoration, however the sources do not indicate on which parts of the building the interventions were carried out. The 1924 study indicated that the roof was tiled and pyramidal in shape and following the earthquake of September 9 1954; it was destroyed and replaced by flat roofing during restorations. It therefore appears that the roof has lost its authenticity and new constituent elements dating from the 20th century alter the historical and archaeological reading.

The Mosque after 1954:

In 1954, after an earthquake, the mosque underwent major work that modified the original plan and the initial volume. After the 1980 earthquake, a temporary protection study was carried out. In 1996 a development operation (cleaning and stripping of the capitals) by the National Archaeological Agency.

Volume 63 | Issue 01 | January 2024
DOI: 10.5281/zenodo.10472686

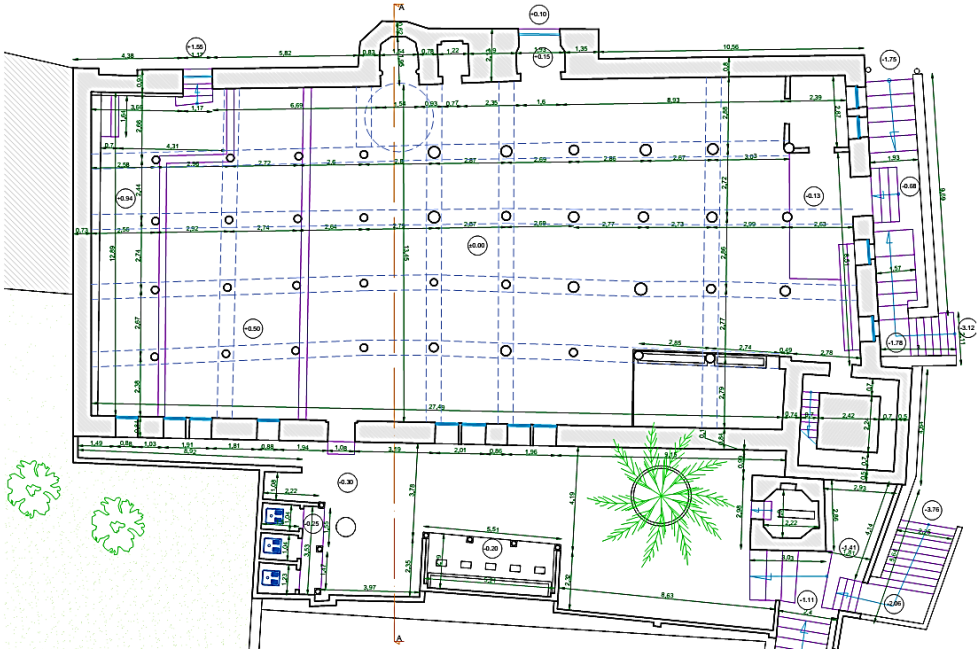

Figure 6: Plan of the Sidi Maïza Mosque

SEISMIC VULNERABILITY ASSESSMENT OF THE MOSQUE

A vulnerability index Iv and assign the Sidi Maïza mosque. The average I_v value is between 40 and 41, corresponding the old masonry construction typology and vulnerability classes A–B adjusting the constructive description described by Giovinazzi and Lagomarsino (2004), referring to the EMS-98 scale (Grunthal 1998).

While a detailed evaluation of the mosque resulted in an average value of the vulnerability index of $I_{v,mean}$ = 40.89. The mosques have a vulnerability index greater than 40 (equivalent to vulnerability class B according to EMS-98). The maximum and minimum I_v values obtained for the mosque evaluated are respectively 72.31 and 9.47

Analysis of the Parameters Evaluated For the Calculated Vulnerability Index

The assignment of vulnerability classes to each parameter is considered reliable, given that the inspection of all mosques was carried out in detail and that precise geometric information was available. Consequently, the uncertainty of the value of the assessed vulnerability index I_v is considered to be low.

Vulnerability Curves

After resolving incompleteness using probability theory, ambiguity and overlapping linguistic definitions are then addressed using fuzzy set theory (Giovinazzi, 2005), in which upper bounds and Lower values of the correlation between the macro seismic intensity and the mean degree of damage (μ_D) of the distribution are defined and derived for each building typology and vulnerability. The average damage degree (μ_D) allows us to know the expected distribution of the damage level, where it represents a quantitative interpretation of the consequences caused by the earthquake on the structural and non-structural elements (Lagomarsino et al, 2004). For the operational implementation of the methodology, an analytical expression proposed by Lagomarsino and Podestà (2004) for churches and taken up by Curti (2007) and Balbi et al. (2005) for the tower is adopted. This expression correlates

Volume 63 | Issue 01 | January 2024
DOI: 10.5281/zenodo.10472686

hazard with the average damage level (0<μD<5) of the damage distribution (discrete beta distribution) in terms of vulnerability value, as shown in equation (1).

$$\mu_D = 2.5 * \left[1 + tanh\left(\frac{I+2.4375*V-8.9125}{Q}\right)\right] \quad (1)$$

Figure 2.24 shows the comparison of the vulnerability curves plotted for the maximum, average and minimum possible values of the vulnerability index using the methodology proposed for masonry structures with the values of the vulnerability index presented by Giovinazzi & Lagomarsino (2004) for the topology of EMS-98 buildings. Although there may be a difference between the values of vulnerability index between masonry structures and other building topologies, it has been adopted due to the lack of sufficient information on vulnerability assessment for masonry structures. However, the vulnerability index values of Giovinazzi & Lagomarsino (2004), which closely resemble the masonry type of the structures, were considered (i.e., unreinforced brick and stone masonry). Moreover, the average value adopted here is very similar to the value presented by Lagomarsino et al. (2004) for towers. However, the average value used here is slightly lower than the value presented by Curti (2007).

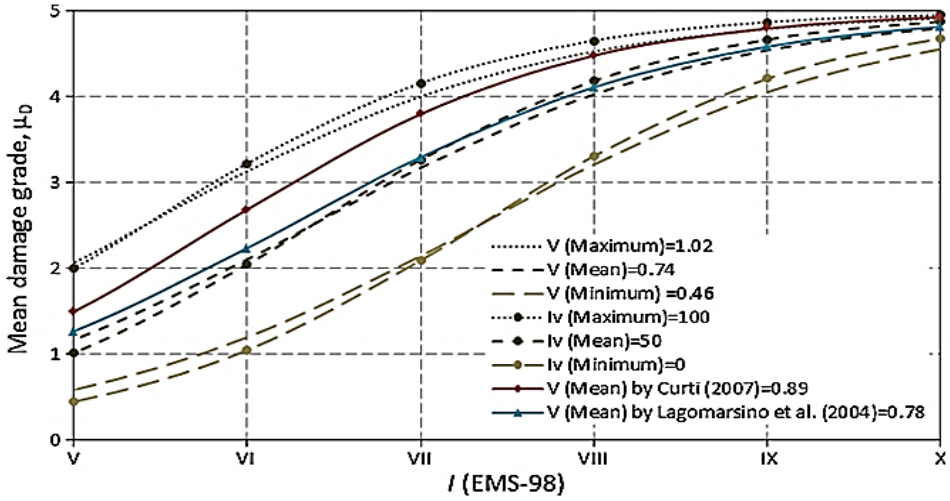

Figure 7: Correlation between the Vulnerability Curves for the Maximum, Average and Minimum Value of I_v

CONCLUSION

The seismic vulnerability assessment methodology adopted in this case study is specially developed for masonry structures. However, the uncertainties associated with the empirical vulnerability curves and the quality of the vulnerability classification data remain issues that need to be investigated with regard to post-seismic data collection to obtain even more reliable results.

The correlation of this vulnerability assessment methodology with the macroseismic method has enabled the development of damage and loss scenarios for seismic risk reduction and management. The analysis of the deterministic scenarios of damages and losses created in this study makes it possible to verify the relationship of these scenarios with the identified structural fragilities and the construction characteristics of the mosque.

Volume 63 | Issue 01 | January 2024
DOI: 10.5281/zenodo.10472686

The city Ténès is located in a region with high seismic risk. Therefore, the level of damage associated with seismic events is moderate to high. The level of damage estimated for these mosques is an indicator of their low resistance to seismic actions, and the moderate to high values of damage and losses obtained for intensities VI and IX are a consequence of the high vulnerability of these mosques.

In this sense, studies based on macro seismic approaches have an important role in assessing the seismic vulnerability of cultural heritage in earthquake-prone regions. This research enables the development of a comprehensive database and guidance tool for local authorities responsible for the rehabilitation and restoration of mosques.

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