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# Study of Repairs and Various Post-Seismic Interventions Carried Out in Ancient Sites in Algeria

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**Abstract**

Centuries of accumulated experience in construction during ancient times led to considerable expertise. Roman builders, for example, honed their engineering and construction skills to a high degree, even factoring in considerations for seismic hazards. Through an examination of the vestiges of Roman civilization, one can discern various parallels between the structures found in Europe and those in Roman Africa, particularly in the methods employed for repairs labeled by scholars as post-seismic restoration. The investigation took place across multiple historic locations in Algeria, including Djemila, Timgad, and Lambèse, aiming to examine the possible correlation between previous renovations and seismic activity. This was achieved through visual examination and comparative analysis with findings from Italian sites such as Pompeii and Ostia.

**Keywords:** earthquake, antiquity, construction, ancient sites, construction techniques and materials.

## 1 Introduction

Algeria, situated in North Africa along the Mediterranean coast, has long been susceptible to earthquakes owing to its geographical location. Its proximity to the meeting point of tectonic plates, namely the African and Eurasian plates, akin to neighboring countries in the Mediterranean basin, has resulted in significant and devastating seismic occurrences. Despite advancements in understanding contemporary earthquakes, historical seismic events in Algeria remain relatively under-documented and less comprehended.

The northern part of Algeria, which harbors several ancient cities, is located in a region prone to earthquakes. Historical records from the Algerian seismic database indicate numerous seismic occurrences in the area, some of which were significant in magnitude (for instance, Algiers in 1365 and 1716, Djijel in 1856, El Asnam in 1980 with a magnitude of 7.3, Constantine in 1985 with a magnitude of 6.0, and Zemmouri in 2003 with a magnitude of 6.8).

Due to its reputation for seismic activity, Northern Algeria presents an intriguing case for study, especially with its array of ancient sites.

The enduring presence of ancient artifacts today is testament to their resilience against natural calamities. This endurance is not coincidental; rather, it undoubtedly stems from a deliberate approach or careful planning by the builders of that era.

In pursuit of this goal, we analyzed various instances and sought to juxtapose them with prior research, including works by GIULIANI [1], RUGGIERI [2], DESSALES [3], and TOMASSINI [4], all of which delineated typological classifications of disorders observed on archaeological sites.

## 2 Methods

Using a comparative method, we will explore the behavior of ancient builders towards earthquakes. The following study will primarily focus on comparing indices - regarded by researchers as post-seismic repairs - between ancient sites in Algeria and those in Italy.

## 3 Ancient Earthquakes and current Seismicity

Historically, Algeria is renowned for being a highly seismic area. Through Latin accounts, we have gleaned some indications regarding the destruction caused to buildings and the restoration efforts on the structures affected by earthquakes as early as the 1st century BCE and CE. According to FERDI & HARBI, scant information about earthquakes in Algeria during antiquity has been found in epigraphic and literary sources, such as the earthquakes of Lambaesis in 267 and Sitifis in 419 [5]. Examples include the one in Ad Maiores, now Negrine, in 267 CE, where, according to an inscription, an earthquake was believed to have caused the collapse of an arch overnight. Another earthquake was recorded on July 21, 365; according to LEPELLEY, it likely affected a significant portion of the Mediterranean, including possibly the Roman city of Cuicul (Djemila) [6], as well as the earthquake in Sitifis (present-day Sétif) in 419, mentioned by GUIDOBONI, referencing St. Augustine's Sermons [7].

Presently, the CRAAG (Centre de Recherche en Astronomie, Astrophysique et Géophysique) possesses substantial data regarding seismic occurrences in Algeria. As per the findings of this research institution, seismic activity in northern Algeria persists without interruption. The surveillance system registers around 50 tremors monthly, predominantly of low magnitude, and largely distant from urban areas, comprising nearly 90% of the recorded seismic events.

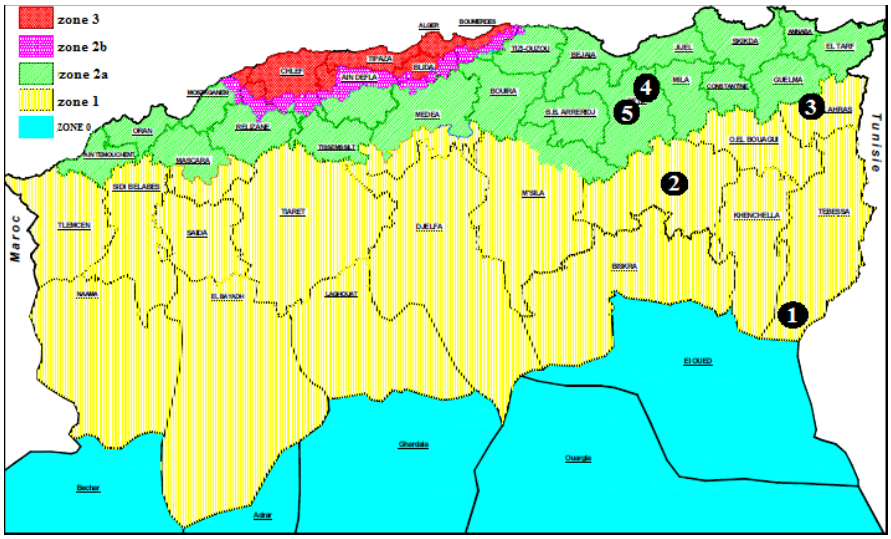


Figure 1: Distribution of ancient earthquakes on the seismic zoning map (source: CGS - RPA99 version 2003). Number 1: Negrine earthquake in 267, Number 2: Lambèse and Timgad earthquakes in 267, Number 3: Khemissa earthquake in 355, Number 4: Djemila earthquake in 365, Number 5: Sétif earthquake in 365.

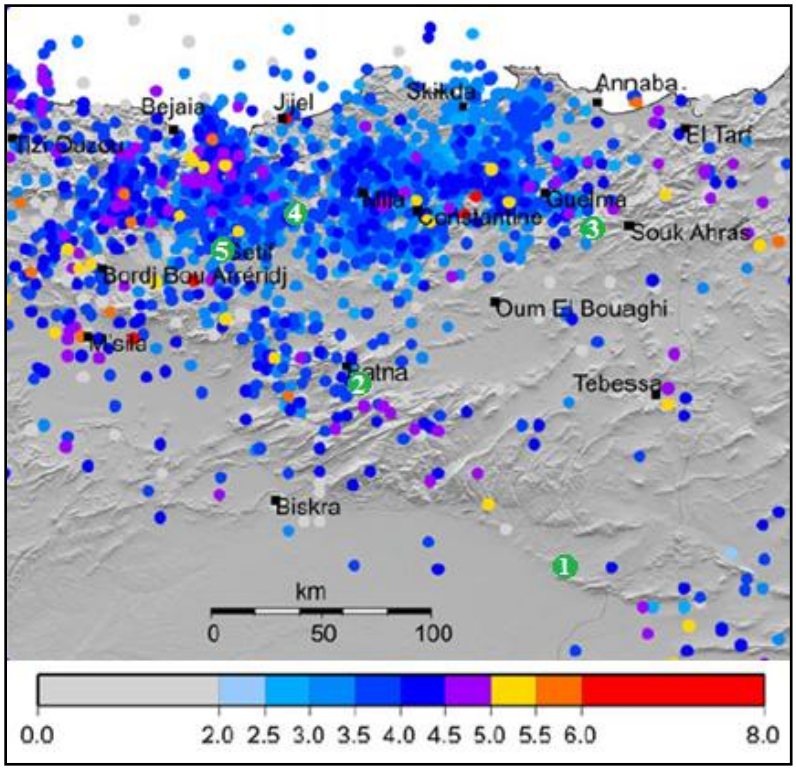


Figure 2: Ancient seismic activity distribution compared to recent seismic events and their magnitude (source: HARBI & AL.) [8]. Colored points represent recent earthquakes according to their magnitude. Number 1: Negrine earthquake in 267, Number 2: Lambèse and Timgad earthquakes in 267, Number 3: Khemissa earthquake in 355, Number 4: Djemila earthquake in 365, Number 5: Sétif earthquake in 365.

Table 1: Key earthquakes recorded from antiquity to the 20th century in eastern Algeria, particularly in the Sétif-Batna study area (reported by the author).

| Seismic location | Date of the earthquake | Source of information |
|---|---|---|
| Ad Maiores | 267 | - BALLU [9].<br>- LEPELLEY [6].<br>- FERDI & HARBI [5].<br>- HARBI & AL. [10]. |
| Lambaesis | 267 | - BALLU [11].<br>- LEPELLEY [12].<br>- FERDI & HARBI [5].<br>- HARBI & AL. [10]. |
| Thamugadi | 267 | - BALLU [9].<br>- LEPELLEY [12, 6]<br>- LAPORTE & DUPUIS [13]. |
| Thubursicu Numidarum | 355 | - LEPELLEY [12, 6]<br>- FERDI & HARBI [5]. |
| Cuicul | 365 | - ALBERTINI [14].<br>- REBUFFAT [15]. |
| Setifis | 419 | - GUIDOBONI [7].<br>- FERDI & HARBI [5].<br>- HARBI & AL. [10]. |
| Lambaesis | October 13th, 1893 | - HARBI & AL. [10]. |
| Lambaesis | December 27th, 1893 | - HARBI & AL. [10]. |
| Setif Region | 1850 – 1852 – 1855 – 1863 – 1867 – 1877 – 1875 – 1881 – 1885 – 1886 – 1887 – 1888 – 1889 – 1890 – 1893 – 1895 – 1898 – 1902 – 1909 – 1913 – 1930 – 1931 – 1938 – 1953 – 1963. | - HARBI & AL. [10]. |
| Batna Region | 1856 – 1858 – 1866 – 1869 – 1870 – 1875 – 1879 – 1882 – 1892 – 1893 – 1895 – 1898 – 1901 – 1904 – 1907 – 1911 – 1924 – 1925. | - HARBI & AL. [10]. |

## 4 Study area and earthquakes

Algeria's earthquake-prone regions predominantly lie adjacent to the Tell Atlas Mountains, encompassing locales like Kabylie and the Aurès mountains. We selected our study area due to its history of seismic events and the accessibility of pertinent indices central to our research focus. Figure 3 provides a depiction of earthquake occurrences within this study region.

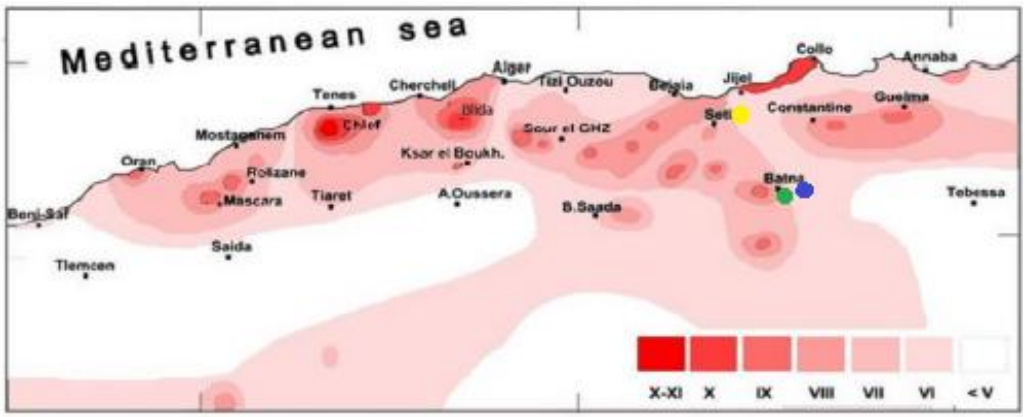


Figure 3: Localization of ancient sites - case study - on the map of macroseismic intensities in Northern Algeria (source: CRAAG 1999). Green point: Lambaesis, Blue point: Timgad, Yellow point: Djemila.

Algeria boasts a wealth of archaeological sites bearing witness to its ancient history. Among them, we will examine three sites:

• **Tazoult (Lambèse or Lambeisis):** A Roman city initially established as a military camp by the Third Legion of Augustus, located 10 kilometers from Batna.

• **Timgad (Thamugadi):** A well-preserved ancient Roman city situated in the province of Batna.

• **Djemila (Cuicul):** Another UNESCO World Heritage Site, a Roman archaeological site located in the province of Sétif.

Certainly, these ancient sites have been affected by several seismic events with varying magnitudes, as evidenced by Figures 2 and 3, as well as Table 1.

## 5 Antique sites - case studies - and work carried out over time

The well-maintained excavation reports serve as essential resources for analytically studying archaeological sites. They provide invaluable insights into the excavation and restoration efforts undertaken at different historical locations, enabling a deeper understanding of these endeavors.

### 5.1 Tazoult (Lambèse or Lambeisis)

Founded in 81 AD as the camp for the III Augustan Legion, Lambèse evolved into the principal city of the Numidia province under Septimius Severus, reigning from 198 to 208 AD. Though the excavation efforts have only partially revealed its remnants, Lambèse retains immense importance in the region's historical landscape. As documented by Albert BALLU, the primary focus of Lambèse's restoration work has centered on excavation endeavors and upkeep tasks, including the repair of wall coping stones damaged by weather in 1926 [16].

### 5.2 Timgad (Thamugadi)

Founded in 100 AD under Emperor Trajan and the III Augusta Legion, Timgad stands out for its remarkably intact ancient remnants. Spearheading the excavation and restoration initiatives at Timgad was Albert BALLU. His endeavors encompassed archaeological excavations to deepen insights into the city's history and layout, alongside restoration projects aimed at safeguarding and reviving existing architectural marvels. The primary goal was the stabilization of structures, occasionally involving partial reconstructions to recapture the site's initial allure [16].

### 5.3 Djemila (Cuicul)

The remnants of the former city of Cuicul, known today as Djemila, represent a settlement established by Emperor Nerva (96-98) for Roman veterans. Deserted in the 7th century, the city's remains were unearthed during the 19th century. Cuicul, akin to numerous other meticulously excavated urban centers, stands as an archaeological marvel, boasting remarkably preserved Roman architecture despite pockets of unexplored terrain.

Efforts to excavate and restore the significant historical site have been initiated to record, safeguard, and improve its condition. These endeavors play a vital role in comprehending the region's history. Key components of the excavation and restoration work at Djemila involve refurbishing dilapidated buildings and structures to halt their ongoing decay. This encompasses rebuilding walls, columns, and other architectural features [16].

Claude LEPELLEY argues that there is no explicit or implicit acknowledgment of the alleged widespread earthquake that supposedly occurred on July 21, 365. Optatus of Milevus, Augustine, and even Ammianus Marcellinus do not make any mention of it [6]. Similarly, despite the abundance of inscriptions in the epigraphic record, there is no reference to this event.

R. REBUFFAT examined signs of seismic events in Africa, drawing from findings in Cuicul, Numidia [15]. This researcher tended to associate the aftermath of this earthquake with the various demolitions, constructions, and repairs of structures witnessed across Africa in the approximately two decades following 365.

DRICI notes the presence of 76 epigraphic texts documenting construction or restoration efforts on municipal public monuments. These texts span the twenty-year period from the reign of Valentinian I starting in February 364 to the passing of Gratian in August 383 [17]. This suggests a significant surge in building endeavors during this era. Scholars posit that the emphasis on restoration (33 or 34 instances, as opposed to 15 or 16 new constructions) reflects the imperative to address the aftermath of the 365 earthquake, which left African cities in a state of disrepair.

Numidia emerged as the province primarily impacted by the surge of public construction projects from 364 to 367. It inaugurated 15 projects, indicative of its proactive approach towards revitalizing the monumental legacy of its urban centers.

# 6 Comparison of repairs and various post-seismic interventions carried out in ancient sites in Algeria with those in Italy

Throughout history, humans have attempted to distance themselves from the impact of earthquakes, often striving to erase their memory altogether. This explains the scarcity of information about ancient earthquakes in literary and epigraphic records, despite their likely occurrence. Unlike people, buildings retain the evidence of seismic activity and any efforts made by humans to mitigate its consequences, making them invaluable sources for understanding the history of earthquakes.

After the Pompeii earthquake of 62 AD, various mechanisms designed to counteract lateral forces had to be incorporated into repairs and reconstruction endeavors to enhance building resilience [4].

Pompeii's inhabitants prioritized the interconnection of structural components as the main strategy to mitigate the earthquake risk of their buildings [4]. A plethora of instances, spanning from minor fixes like patching small fissures to comprehensive constructions, underscore the utilization of technical mechanisms designed to unite different segments of the edifice.

Numerous integrated measures were implemented to preserve masonry coherence and prevent the need for excessive hammering between distinct masonry sections. These interventions involved utilizing modern materials intricately connected via recesses crafted within the preexisting wall.

Moreover, special attention is paid to the alignment of chainages at building corners, leading to a significant enhancement in the coordination between adjacent perpendicular panels [3].

Figure 4: Brick corner of a building in Timgad (source: Author 2023).

After the 62 earthquake, certain buildings saw improvements in their seismic resilience through reinforcement interventions. Additionally, in Pompeii, employing construction methods like brickwork might have contributed to the favorable performance of buildings [3].

Additionally, employing a brick structure, even if confined solely to the outer wall, enhances shear resistance. It demands more energy to collapse compared to a disorderly masonry with

identical constraints and geometric features, especially under seismic forces perpendicular to the panel.

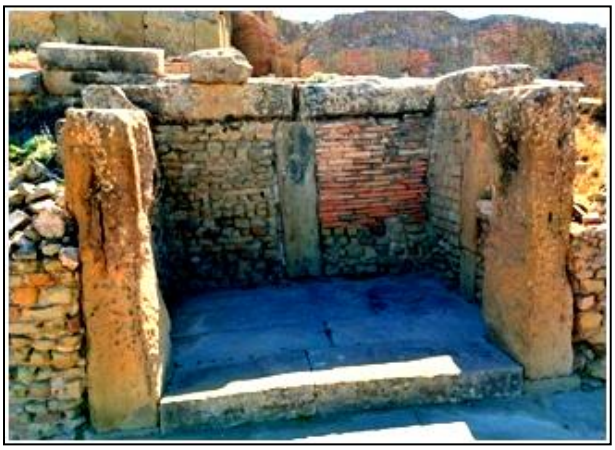

Figure 5: Example of brick usage in the repair of a wall in Timgad (source: Author 2023).

Following the 62 earthquake, additional evidence has surfaced regarding reinforcement measures. By examining the previously noted structural shortcomings, particularly the toppling of masonry, potential strategies emerged for Pompeians to lessen the seismic vulnerability of their buildings. Notably, various buttresses were constructed, featuring specific geometries and materials to enhance stability [4]. These buttresses ranged from modest masonry structures positioned against existing walls to more extensive interventions. It appears these efforts were aimed at counteracting the prevalent issue of wall overturning, exacerbated by the elongated spans of walls in public buildings lacking intermediate supports.

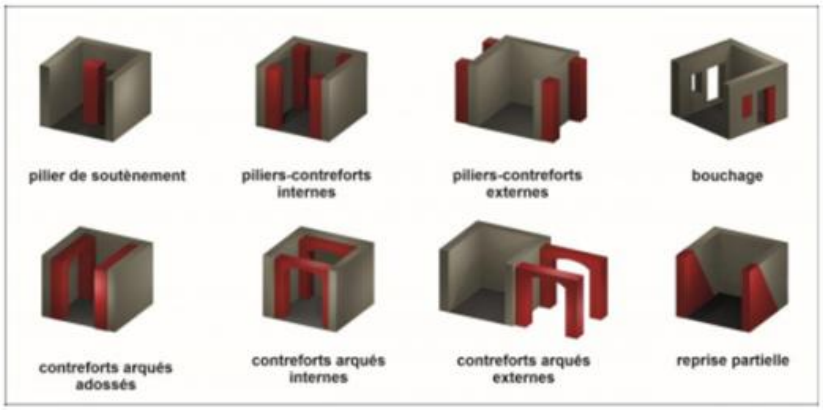


Figure 6: Schematic representation of the repair and reinforcement interventions identified in Ostia (source: TOMASSINI) [4].


Figure 7: Buttresses (source: Author 2023). Numbers 1 & 2: External buttress pillars at Timgad, Numbers 3 & 4: Reinforcement wall at Djemila.

One of the most common interventions found in various ancient sites is the blocking of openings, which can be seen as an acknowledgment that doors are vulnerable points (especially arches and keystones).

Figure 8: Blocking of openings at Djemila (source: Author 2023).

Additionally, intermediate pillars are incorporated to reinforce the arches. This reinforcement is primarily attributed to the occurrence of fallen vault keys, which are commonly regarded as the most dependable indication of earthquake damage [18]. When subjected to horizontal shaking without substantial vertical load, the vault keys tend to collapse, while the load typically maintains the cohesion of the masonry blocks through intense friction at their interfaces.

Figure 9: Support pillars at Djemila (source: Author 2023).

## 7 Results and conclusions

This contribution does not aim to claim that every structural intervention spotted in these historic sites can be solely attributed to an earthquake, as relying on a single piece of evidence is not definitive. Nevertheless, the multitude of correlations does raise the possibility for this hypothesis to merit further examination. Only through comprehensive and meticulous scrutiny of each building can we gain additional insights and determine whether alternative interpretations are viable.

Prudence is certainly warranted, but by comparing the restoration and various interventions carried out after earthquakes between ancient sites in Algeria (Djemila, Timgad, and Lambèse) and those in Italy (Pompeii and Ostia...), we can confirm:

- The hypothesis of the occurrence of one or multiple earthquakes in antiquity in Algeria.
- The reaction of builders of the time to adapt to earthquakes.
- The transmission of knowledge (non-punctuality), perhaps through the movement of builders.

Improving our comprehension of previous seismic events allows us to not only assess regional seismic hazards but also to reconstruct the historical records of specific locations.

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