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# Compressive Strength of Masonry Units in Cagayan's Heritage Churches: A Reference for Sustainable Preservation and Seismic Vulnerability Assessment

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*Abstract: This study addressed a critical data gap concerning the mechanical properties of Unreinforced Masonry (URM) materials used in Cagayan's Spanish colonial-era heritage churches, which are significant cultural assets highly susceptible to seismic activity. The Philippines is an earthquake-prone country, ranked second globally for exposure to natural hazards. While historical accounts confirm that Cagayan's churches were extensively constructed with brick, a previous comprehensive national assessment of indigenous URM properties unintentionally missed collecting samples from this critical region, highlighting a continuing need for specific local scientific studies. Understanding the fundamental strength parameters of individual masonry units is crucial for accurate seismic vulnerability assessments, an indispensable first step in mitigation efforts for cultural heritage preservation. Therefore, this research aimed to comprehensively characterize the compressive strength of these masonry units to provide an essential reference for informed restoration measures and a proactive approach to mitigating the impact of possible earthquakes. By following minimal heritage protection guidelines, URM blocks were carefully retrieved as remnants from the ruins near St. Anne Church in Buguey, Cagayan. The gathered samples, taken from damaged areas, represent stonework that has been subjected to centuries of structural stress and environmental damage. Samples were subsequently prepared into 4" x 4" x 8" blocks. For compressive testing, a uniaxial compressive force was applied perpendicular to the bed surface to simulate the compression loads experienced by the block in situ. The meticulous methodology was crucial for obtaining representative data concerning the materials' structural integrity and seismic behaviour under axial stress. The analysed brick samples exhibited a mean compressive strength of 8.58 MPa, with individual strengths ranging from 8.44 MPa to 8.72 MPa. Critically, these measured values significantly exceed the ASCE. 41-17 default lower-bound strength of 1.96 MPa (285 lb/in²) typically specified for old unreinforced clay masonry with lime mortar. When compared to other indigenous URM materials found in the Philippines, the Cagayan bricks showed slightly higher strength than adobe (mean 7.49 MPa) and coralline limestone (mean 7.77 MPa), but were considerably weaker than sandstone (mean 37.12 MPa). These findings suggest that, if these bricks remain unreinforced, they would primarily limit structures to single stories, indicating a general need for further strengthening measures to sustain greater loads effectively. The study thus provides crucial foundational mechanical property data, essential for developing informed, low-invasive, and reversible conservation and retrofitting strategies for St. Anne Church and other heritage structures in Cagayan, contributing to their sustainable preservation and enhanced seismic resilience.*

*Keywords: Compressive Strength, Unreinforced Masonry (URM), Heritage Structures, Seismic Vulnerability*

***Abbreviations*:**
URM: Unreinforced Masonry
ASCE: American Society of Civil Engineers
GFDRR: Global Facility for Disaster Reduction and Recovery
FRP: Fibre-Reinforced Polymer
HBIM: Historical Building Information Modelling
NCCA: National Commission for Culture and the Arts

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## I. INTRODUCTION

The Philippines holds a rich heritage of church art from the Spanish colonial period, commonly referred to as 'Fil-Hispanic' churches [11]. These structures are far more than just buildings; they are significant carriers of historical and cultural memory, embodying the historical characteristics and national culture of a region [9]. Across the archipelago, churches, chapels, and convents stand as testaments to the country's diverse cultural lineage and architectural development. [21]. Studies highlight that numerous centuries-old churches in Cagayan function as crucial heritage sites, deeply connected with the community's spiritual, historical, and aesthetic values. In addition to preserving their inherent cultural importance, it is essential to preserve them for their economic contributions to the locality and their role in facilitating post-disaster community healing and rehabilitation [9], [15], [19].

The heritage churches in Cagayan, built mainly between the 15th and 19th centuries, were constructed using indigenous and locally sourced materials, which showcased the resources and building techniques standard at the time [4], [11]. A key characteristic of their construction is the use of Unreinforced Masonry fired clay bricks. Historical accounts confirm that every church in Cagayan, including those in Lallo and Buguey, was built from stone and brick [11]. The lime mortars from this period often had clay minerals mixed in, giving them hydraulic qualities that affected their hardening process. Over centuries, this URM material has significantly deteriorated in place, leaving these structures much more vulnerable, particularly during severe environmental events.

The Philippines is an earthquake-prone country, ranked second globally for exposure to natural hazards, and its heritage structures are highly susceptible to seismic activity. [17], [19]. Historical accounts reveal that Cagayan's churches have repeatedly suffered damage from strong earthquakes, including those in 1619 and 1688, as well as from recent events like the 2022 Abra earthquake, typhoons, and floods. [11], [17]. The rudimentary building techniques, poor quality of materials, and structural irregularities typical in these heritage buildings contribute to their inherent vulnerability to horizontal forces from seismic shaking [7].

The 2013 Bohol Earthquake serves as a stark reminder of the seismic vulnerability of heritage structures in the Philippines. This Magnitude 7.2 earthquake, with its epicentre near Sagbayan, Bohol, caused widespread and significant damage, resulting in 222 fatalities and displacing over 30% of Bohol's population. Critically, many of the island's historic churches, several of which were National Cultural Treasures or Important Cultural Properties, suffered severe damage or total collapse, including arch failures, wall collapses, façade failures, and, in some cases, destruction, such as the St. Vincent Ferrer Church in Maribojoc and the Our Lady of Light Church in Loon [18], [12]. The cultural and economic costs were immense, with their significance to the local community considered priceless [18]. In the aftermath, a multi-hazard vulnerability assessment of heritage structures in the Philippines was conducted, emphasizing the critical importance of a reliable inventory profile that defines the exposure and relevant building features affecting structural performance [5], [19]. This assessment, supported by the Philippines Department of Tourism, the World Bank, and the Global Facility for Disaster Reduction and Recovery (GFDRR), led to specific recommendations, conceptual designs, and cost estimates for structural strengthening and restoration of key cultural heritage sites [18]. Such an inventory, including the mechanical properties of URM, is crucial for understanding the inherent risks and prioritizing conservation efforts, especially in a country ranked second globally for exposure to natural hazards [17], [18].

A significant challenge identified in these assessments was the absence of local data for the mechanical properties of URM materials used in heritage structures in the Philippines [8], [22]. To address this limited literature and data gap, a study by Garciano et al. [8] aimed to assess the mechanical properties of in-situ URM fabric from selected heritage structures in the country. Their main objective was to determine, through experimentation, the range of in-situ values for the most available and abundant URM materials locally, specifically adobe, coralline limestone, and sandstone. For this purpose, URM blocks were gathered from specific regions in Luzon (adobe in Intramuros, Manila; sandstone in Pangasinan) and Visayas (coralline limestone in Samar, Southern Philippines), where these distinct masonry types are abundant. Their research also provided a map illustrating the spatial scatter of URM fabric, identifying coralline limestone as common in Visayas and some parts of Luzon and Mindanao, and adobe and clay bricks as abundant in Luzon. While the study by Garciano et al. [8] offered valuable local data, it notably excluded Cagayan's heritage churches from its sample collection. This is a significant oversight, especially since historical evidence confirms the extensive use of brick in their construction, symbolizing a unique regional architectural and material heritage [10], [11]. Therefore, there's a clear and ongoing need for localized scientific studies to gather mechanical property data for the indigenous Unreinforced Masonry blocks found in Cagayan's historic structures.

To accurately evaluate seismic vulnerability, it's essential to understand the strength characteristics of individual masonry units, as this offers vital insight into how structural components behave under various load conditions. This information is particularly crucial given that unreinforced masonry structures are inherently vulnerable to seismic forces; global seismic codes, in fact, frequently restrict their use to areas with low to moderate seismicity. For instance, the World Federation of Engineering Organizations, cited by Garciano et al. (2019), requires a minimum compressive strength of 2.94 MPa (30 kg/cm²) for unreinforced brick walls in single-story structures across Asia [8]. Likewise, in earthquake-prone countries such as Japan, masonry units must achieve an allowable compressive strength equivalent to one-third of sustained forces and two-thirds of temporary forces. Thus, a firm grasp of these fundamental material properties is necessary for effective structural analysis and the application of suitable strengthening interventions.

Therefore, this study intends to fully assess the compressive strength of masonry units found in Cagayan's Heritage churches, directly addressing a critical data gap identified in prior research. The findings will serve as an essential resource for guiding restoration efforts and developing a proactive approach to mitigate the effects of potential earthquakes. By providing fundamental mechanical data, this research contributes to the interdisciplinary field of heritage conservation, enabling more effective structural evaluations, rehabilitation planning, and ultimately, the lasting preservation and enhanced seismic resilience of these invaluable cultural assets [4], [9], [19]. This is particularly crucial because modern building codes, like the National Structural Code of the Philippines [2], frequently limit or do not fully apply to Unreinforced Masonry heritage structures. This highlights the necessity for tailored, evidence-based methods that respect their unique cultural and structural characteristics.

## II. METHODOLOGY

### A. Study Site and Material Acquisition

For this investigation, unreinforced masonry (URM) blocks were explicitly gathered from the adjacent ruins beside St. Anne Church, Buguey, in Cagayan Province, a province recognised for its numerous historical religious sites. The primary mampostería (rubblework)


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and brick walls of both the church and its adjacent convento are estimated to date between 1623 and 1640 [21].

The availability of debris from the heritage structures themselves strictly limited the collection of samples. This was a necessary approach to avoid any damaging impact on the standing structures and to maintain the principles of minimal invasiveness in heritage conservation [8], [9], [22]. This practice aligns with the methodology employed by Garciano et al. (2019) [8] URM blocks for mechanical property assessment were collected as debris from the heritage structures themselves, specifically to address limitations in sample availability and prevent damage to existing buildings. Similarly, Cayme (2022) [4] obtained lime mortar samples for chemical characterization by gently extracting from a wall partition that was partially damaged by a strong earthquake, facilitating removing without further harm to the historical structure. Guidelines for evaluating cultural qualities also stress the need for strict control over any disruptive sampling, where even small interventions need to be discussed and justified beforehand to maintain the artistic value [14], [9].

The specific sampling points included the ruins beside St. Anne Church, particularly the remnants of its convento at the rear of the church complex. These walls, constructed from irregularly cut stone with areas of rubblework and brick overlays, offered accessible fragments. Additionally, remnants of a quadrangular rubblework structure behind the brick espadaña (bell-gable), potentially an earlier bell tower base, served as a source of debris [21]. The materials recovered from these ruined sections are valuable because they represent masonry exposed to centuries of structural stress and environmental weathering. This exposure provides critical information on material deterioration, which is vital for long-term preservation.

### B. Sample Preparation and Testing

For the mechanical performance assessment of the collected masonry, three samples for each block were prepared for compression testing. The block samples for compression had a minimum length-to-width ratio of 2, as prescribed by section 14.7.4.11 of the 2015 *New Mexico Earthen Building Materials Code* [13] used for masonry blocks in general testing and the Technical Standards in masonry specifications [20]. The samples were partitioned and cut into 4''x4''x8'' blocks for compression tests by using a grinder machine. The rough surfaces were smoothed to ensure even load distribution on the block surface.

During the compressive testing, the uniaxial compressive force was applied perpendicular to the bed surface to simulate compression loads experienced by the masonry block in situ. Understanding the structural integrity and seismic behaviour of these historical materials requires representative data on their behaviour under axial stress, which can only be obtained through careful preparation and targeted sampling.

The results from compression testing are vital for establishing reliable parameters for seismic vulnerability assessments. Previous studies on standard URM blocks in the Philippines, such as adobe, coralline limestone, and sandstone, have indicated that their inherent compressive strengths might limit their application to only single-story structures if not adequately reinforced [8].

Therefore, determining the specific compressive strength of the brick from the Church is essential for establishing appropriate and effective preservation and retrofitting strategies.

**[Fig.1: URM Block Specimens]**

## III. RESULTS AND DISCUSSION

To evaluate the structural integrity and seismic vulnerability of heritage structures, it is necessary to understand the compressive strength and other mechanical properties of historical masonry. Moreover, it is crucial for developing sound engineering solutions and sustainable preservation strategies, especially for unreinforced masonry (URM) buildings typical in Heritage churches. Furthermore, restoring these heritage buildings is a complex, interdisciplinary process that requires thorough preliminary research as well as the integration of scientific knowledge with traditional craftsmanship. These initiatives ensure the sustainability of these invaluable historical assets [6], [9].

From the findings of this study, the compressive strength of the brick's ranges from 8.39 MPa to 8.72 MPa. In addition, the mean compressive strength of the samples is 8.52 MPa. In comparison to the study of Garciano et al. (2018) [8] It can be observed that the compressive strength of the brick samples from this study is slightly above that of the adobe and coralline limestone and significantly below that of the sandstone. According to the survey by Garciano et al. (2018), the mean compressive strength of adobe was found to be 7.49 MPa, with values ranging from 6.49 MPa to 8.95 MPa. On the other hand, for the coralline, the mean compressive strength is 7.77 MPa. A higher mean compressive stress was recorded for sandstone units, ranging from 32.06 MPa to 40.33 MPa, with an average of 37.12 MPa (Garciano et.al, 2018). These findings emphasizes that there are varying material properties of indigenous masonry used in Philippine heritage structures. This also highlights the necessity of site-specific material characterisation for accurate assessments.

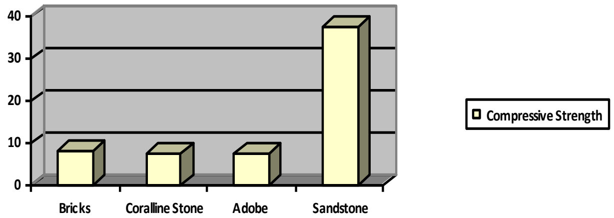
**Table I: URM Brick Samples in Cagayan**

| Specimen | Compression Test | |
|---|---|---|
| | Maximum Load (KN) | Maximum Strength (Mpa) |
| A | 87.11 | 8.44 |
| B | 90 | 7.72 |
| C | 86.56 | 8.39 |

Although the compressive strengths of the brick samples appear to be higher compared to some materials, they are still only suitable for use in unreinforced structures up to a single story. Their strength limits their application beyond this, so unreinforced designs should be restricted to single-story buildings for safety. This is mainly because these blocks are inadequate to sustain greater loads, specifically when used as structural members or walls [8]. Overall, the masonry fabric requires additional strengthening measures to resist forces, as indicated by its strength parameters.

**Table II: URM Brick Samples in Cagayan**

| Specimen | Compressive Strength |
|---|---|
| | Maximum Strength (Mpa) |
| Bricks | 8.52 |
| Coralline Stones | 7.77 |
| Adobe | 7.49 |
| Sandstone | 37.12 |




**[Fig.2: Mean Compressive Strength of URM Blocks]**

The data found aligns with the default material properties for unreinforced masonry referenced from Table 11-2c with respect to condition assessment outlined in Section 11.2.2 of ASCE 41-17. Specifically, for solid unreinforced masonry (URM) constructed with lime mortar, ASCE 41-17, Table 11-2c, specifies a default lower-bound compressive strength of 285 lb/in.$^2$ (approximately 1.96 MPa). This default value applies to masonry classified in Good or Fair condition, as defined in Section 11.2.2 of the standard. Masonry in good condition has a severity of damage not exceeding insignificant or slight, while masonry in fair condition has a seriousness of damage not exceeding moderate. Mortar that can be easily scraped away by hand with a metal tool is considered lime mortar. This provides a standardized context for evaluating the performance of historical masonry units, especially when actual material properties are unknown or need verification through a condition assessment.

ASCE 41-17 [16] outlines procedures for the seismic evaluation and retrofit of existing buildings, adopting a performance-based design methodology. For Tier 2 evaluations and retrofits, default material properties specified in Chapters 8 through 12, including for masonry, are permitted if design drawings or material test records are unavailable. However, a comprehensive condition assessment, including destructive and nondestructive investigation, is required to supplement incomplete or nonexistent information. The scope of condition assessment for masonry includes identifying details and overall condition, with specific inspection requirements to determine the availability of drawings. The level of data collection performed also determines a knowledge factor (κ) used in capacity evaluation, with different factors applied based on the source and completeness of material property information (e.g., usual tests, design drawings, comprehensive tests).

The data derived from these compressive strength tests is invaluable for conducting seismic vulnerability assessments for St. Anne Church and other Heritage structures in Cagayan. Mechanical properties are vital for understanding how structural components behave under excessive loads and for establishing parameters for seismic vulnerability assessments. Such assessments are a crucial first step in mitigation efforts for cultural heritage [7].

The restoration of cultural heritage buildings emphasizes principles of low invasiveness, reversibility, and compatibility with existing surfaces to preserve architectural, artistic, and historical values. ASCE 41-17 outlines various retrofit strategies, including local modification of components, removal or reduction of existing irregularities, global structural stiffening, global structural strengthening, mass reduction, seismic isolation, and supplemental energy dissipation. Materials for restoration can be enhanced in terms of compressive strength, shear strength, and bonding strength through changes in preparation, fibre modification, or component replacement. New technologies, such as Fibre-Reinforced Polymer (FRP) materials, are promoted for reinforcement as an alternative to metal components, offering highly concealed repair effects and improving strength and stiffness. Modern tools like Historical Building Information Modelling (HBIM) and image recognition technology also aid in the non-contact diagnosis and evaluation of damage patterns.

The Philippines faces significant seismic hazards, with most cities susceptible to liquefaction and other earthquake-related ground failures. Historical earthquake records show a rise in reported liquefaction events from 1851 onwards [3], coinciding with more systematic documentation and an increase in town foundations. This underscores the critical need for robust structural assessments and appropriate preservation strategies for heritage structures in the country.

## IV. DISTRIBUTION OF URM HERITAGE STRUCTURES IN CAGAYAN

The assessment of strength parameters and significant features of unreinforced masonry (URM) blocks in heritage structures in the Philippines provides crucial insights into their vulnerability during extreme environmental events like earthquakes. To further complement the study, the distribution of masonry was illustrated in a Map containing points that indicate the location of Heritage Churches in the Province. These heritage structures in the Philippines, exemplified by numerous churches, chapels, convents, and bell towers across the province, showcase the state-of-the-art materials and construction methods from the 15th to 19th centuries, predominantly utilising URM and other indigenous materials.

Specifically for Cagayan, there are 18 identified century-old churches, with ten currently functional and eight existing as ruins [11]—three of these ruined churches —St. Michael of Archangel Church in Gattaran, San Jacinto de Polonia Church in Camalaniugan, and St. Vincent Ferrer in Lallo were considered no longer significantly traceable or visibly recognisable due to the absence of major structural components and were thus excluded from detailed consideration in one study. However, St. Vincent Ferrer

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Church is still listed with assessed values. The churches often display resemblances in design, materials, and structure, characterised by high and thick walls supported by buttresses. Some, like the church of Iguig, feature flying buttresses. A common feature is the *palitada*, a lime mixture applied to walls for protection. However, its removal in some churches to reveal authentic stone walls has led to deterioration [11]. Bricks, or ladrillo, were widely used, with their manufacture dating back to 1587 during the Spanish colonial period. Most of the century-old churches were constructed using bricks, river stones, and lime.

**[Fig.3: Map of Heritage Churches in Cagayan (Source: Google Earth)]**

The functional churches in Cagayan, which generally exhibit a Spanish baroque architectural style, include:

St. Philomene Church (Iglesia de Sta. Filomena) in Alcala, Cagayan, built in 1881, is notable for its massive dimensions (approximately 25m wide and 67.5m long internally) and is considered the widest church in the Archdiocese of Tuguegarao. It features bricks, river stones, and lime, with prominent round pilasters and angel statues. Its roofing was replaced with steel trusses and pre-painted galvanised iron sheets over 15 years ago [11].

St. Hyacinth of Poland Chapel (Ermita de San Jacinto) in Tuguegarao City, Cagayan, originally from 1604 and reconstructed in 1724, had its wooden roof framing replaced with steel frames and was retrofitted with reinforced concrete columns. This church, along with Buguey, is one of two in Cagayan where wooden retablos have survived in a relatively complete state [11].

St. Raymund of Peñafort Church (Iglesia de San Raimundo de Peñafort) in Rizal, Cagayan, with its cornerstone laid in 1617, is a Spanish baroque-inspired National Cultural Treasure that retains its original retablo and pulpit [11]. It was previously known as Malaueg. St. Catherine of Alexandria Church (Iglesia de Sta. Catalina de Alejandria) in Gattaran, Cagayan, was built in 1877. It features a rectangular plan with side niches, an original side retablo, and a silver-plated carroza. It was constructed for us [23] ing sandstone, bricks, and pebbles. Its original retablo is still present.

St. James the Greater Church (Iglesia de Santiago Mayor) in Iguig, Cagayan, was built between 1765 and 1787 and stands on a hill overlooking the Cagayan River. It is a Spanish baroque-inspired church with a rectangular plan, retaining its original retablo and a relocated steel pulpit. Distinctive flying buttresses are found at its rear, and stepped buttresses on its sides, all constructed from vernacular materials like bricks and river stones.

St. Anne Church (Iglesia de Sta. Ana) in Buguey, Cagayan, built in 1610 and reconstructed in 1732, has a cruciform plan with Spanish baroque-inspired design. Its façade is notably tilted, not perpendicular to the nave, and the church features an altar of molave and narra, retaining its original retablo and wooden trusses. Its rubblework walls potentially date between 1623 and 1640, with the façade dating between 1689 and 1708. It showcases an inverted stepped pyramidal window base, suggesting a transfer of artistic ideas between Dominican posts.

St. Peter the Martyr Church (Iglesia de San Pedro Martir) in Pamplona, Cagayan, was built between 1614 and 1617, damaged by a 1721 earthquake, and subsequently repaired. It was constructed with bricks, sandstones, and lime, and features visible side buttresses. It still possesses its original retablo.

St. Dominic De Guzman Church (Iglesia de Sto. Domingo de Guzman) in Lallo, Cagayan, was recently renovated under the supervision of the National Commission for Culture and the Arts (NCCA). It is one of the earliest Dominican houses in Cagayan, established in Nueva Segovia in 1596. It suffered damage from earthquakes in 1619, 1688, and 1721, and floods in 1687 and 1753, with subsequent repairs and renovations. The church still retains its original palitada lime plastering on the north wall. The Our Lady of Snow Church (Iglesia de Nuestra Señora de las Nieves) is in Enrile, Cagayan. It was built in the barrio of Cabug (the present-day municipality of Enrile) in 1877 under the supervision of Fr. Francis Bueno.

The St. Peter Metropolitan Cathedral is located in Tuguegarao City, Cagayan. It was founded as a mission in 1604, with Fray Tomas Villa, O.P., as its first vicar. The construction of the current cathedral was initiated and supervised by Fr. Antonio Lobato, O.P., beginning on January 17, 1761, and was completed in 1768. It is constructed using vernacular materials such as bricks, river stones, and lime, and adheres to a Cruciform plan and a Spanish baroque-inspired design. It is recognized as the largest Colonial Era church in Cagayan.

There are noticeable, distinct patterns in the distribution of standard URM blocks across the Philippines, excluding Cagayan. Among the materials, coralline limestone is the most abundant in the Visayas and also exists in parts of Luzon and northern Mindanao. Another is clay brick, which ranks as the second most common masonry material. It is distributed across all major island groups. Lastly, the adobe, which is particularly abundant in Luzon, has been widely used in construction since the Spanish era [1], [8]. In addition to those mentioned above, riverstone and sandstone are frequently found in areas like Iloilo and Pangasinan. This regional variability of URM blocks gives rise to the need for localised studies of material properties for practical preservation efforts.

## V. CONCLUSION

The objective of this study was to analyse the masonry units' compressive strength in Cagayan's heritage churches, serving as a significant reference for seismic vulnerability assessment and sustainability. The results of the study, detailing the findings for unreinforced masonry (URM) blocks, are shown in the table below. The tested URM blocks exhibited a mean compressive



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strength of approximately 8.58 MPa, with individual sample strengths ranging from 8.44 MPa to 8.72 MPa. These values are considerably higher than the default lower-bound strength of 1.96 MPa (285 lb/in²) typically associated with old unreinforced clay masonry with lime mortar, as referenced in ASCE 41-17 [1], [8]. When compared to other masonry materials used in heritage structures, the Cagayan URM blocks fall within a similar strength range as adobe (5.32-10.56 MPa) and coralline limestone (6.15-10.56 MPa), though significantly lower than sandstone (32.06-40.33 MPa).

**Table III: Compressive Strength Results of Masonry Units**

| Specimen | Compression Test | |
|---|---|---|
| | Compressive Strength Range (MPa) | Mean Compressive Strength (MPa) |
| Fired Brick | **8.44 – 8.72** | **8.58** |
| Adobe | 5.32 – 10.56 | 7.49 |
| Coralline Limestone | 6.15 – 10.56 | 7.77 |
| Sandstone | 32.06 – 40.33 | 37.12 |

The study has shown that, when compared with various literature, the masonry fabric can be further improved. Strengthening measures are necessary for heritage structures that, despite being aesthetically preserved, might have deteriorating structures. This deterioration could pose a potential long-term risk to both human lives and the cultural significance of these structures. This underscores the critical importance of understanding material properties for practical seismic vulnerability assessments and developing appropriate, low-invasive, and reversible strengthening interventions to safeguard these invaluable cultural assets against future seismic events.

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After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

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- **Author's Contributions:** The authorship of this article is contributed equally to all participating individuals.

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