THEORETICAL STUDY ON THE INFLUENCE OF OPENINGS AND OPENINGS SHAPES

IN

LOAD - BEARING MASONRY WALLS ON STRUCTURAL INTEGRITY

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Approval sheet of the Thesis

This is to certify that we have read this thesis entitled **"Theoretical study on the influence of openings and openings shapes in load - bearing masonry walls on structural integrity"** and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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ABSTRACT

THEORETICAL STUDY ON THE INFLUENCE OF OPENINGS AND OPENINGS SHAPES IN LOAD - BEARING MASONRY WALLS ON STRUCTURAL INTEGRITY

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Masonry constructions are the most common type for low to medium buildings in all Albania during mid-20th century. The performance of these constructions is primarily influenced by the inelastic phase and is very sensitive to a seismic risk. Additionally, a significant number of these structures have undergone structural modifications, such as the addition of apertures for doors or windows. These openings occur at various intervals and may be categorized as either formal, informal, or even spontaneous. The selection of the calculation model is crucial to provide the greatest degree of precision and accuracy in the study. The research used the finite element modeling, a computer model including macro-elements using MasterSeries Software, as described in the literature. This technique is quite popular in this sector because to its ability to provide results that closely resemble reality. It also allows for the modeling of nonlinear behavior of brickwork and is feasible for computer simulations. This approach will be implemented on a two-story structure that follows a widely used architectural style in Albania. The study will focus on the example of structural intervention, examining and comparing the performance of both the before and existing state of building.

Keywords: *load bearing masonry wall, openings, MasterSeries Software, structural modifications, structural integrity, microelement modeling, finite element modeling*

ABSTRAKT

STUDIM TEORIK MBI NDIKIMIN E HAPJEVE DHE FORMAVE TË HAPJEVE NË MURET ME TULLA MBAJTËSE NË INTEGRITETIN STRUKTUROR

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Udhëheqësi: Dr. Armando Demaj

Ndërtimet me konstruksion murature mbajtëse janë lloji më i zakonshëm për ndërtesat e ulëta dhe mesatare në të gjithë Shqipërinë gjatë mesit të shekullit të 20-të. Performanca e këtyre ndërtimeve ndikohet kryesisht nga faza joelastike dhe është shumë e ndjeshme ndaj rrezikut sizmik. Për më tepër, një numër i konsiderueshëm i këtyre strukturave kanë pësuar modifikime strukturore, si shtimi i hapjeve për dyer ose dritare. Këto hapje kanë ndhur vazhdimisht dhe mund të kategorizohen si formale, joformale apo edhe spontane. Zgjedhja e modelit të llogaritjes është thelbësore për të siguruar shkallën më të madhe të saktësisë në studim. Studimi përdor modelimin kompjuterik që përfshin makro-elemente nëpërmjet Softuerit MasterSeries, siç përshkruhet në literaturë. Kjo teknikë është mjaft e popullarizuar në këtë sektor për shkak të aftësisë së saj për të ofruar rezultate që i ngjajnë shumë realitetit. Kjo qasje do të zbatohet në një strukturë dykatëshe që ndjek një stil arkitekturor të përdorur gjerësisht në Shqipëri. Studimi do të fokusohet në shembullin e ndërhyrjes strukturore, duke shqyrtuar dhe krahasuar performancën si të gjendjes së mëparshme ashtu edhe të asaj ekzistuese të ndërtesës.

Fjalët kyçe: *mure mbajtëse, hapje, MasterSeries Softuer, modifikime strukturore, integritet strukturor, modelim i mikroelementeve, modelim i elementeve të fundme*

To my family, father, mother and my sisters, whose continuous support and encouragement have been the fundamental foundation of my path. To my mentors and lecturers, whose guidance and wisdom have influenced every step of my journey. To the many engineers and academics whose work serves as a source of inspiration and pushes me to pursue greatness in the area of structural engineering.

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CHAPTER 1

INTRODUCTION

1.1 Background and Significance of Openings in Load-Bearing Masonry Walls in Tirana, Albania

Load-bearing masonry walls are an integral part of the architectural story of civilizations, serving as the foundation for a wide range of structures across history and cultures. One of the earliest building materials is the masonry block, which has been widely and customarily utilized for ages all throughout the world. These walls have been essential in forming the built environment because of their capacity to sustain vertical loads and offer stability [1].

Historically, the Albanian constructed environment has been dominated by unreinforced masonry (URM) buildings used for varied purposes, with houses and places of worship being the most common. After 1945, the frequency of multi-story houses increased, peaking between 1961 and 1980. Previously, single-story buildings were more common. The cities with the most URM buildings in Albania are Tirana, Korça, Elbasani, Durresi, Berati and Shkodra [2]. A typical example widely used in Albania is shown in the *Figure 1,* which is captured in Tirana city.

Figure 1. Unreinforced masonry walls with openings in Tirana, Albania

Masonry is the oldest building material and one of the widely used construction method around the world. It is still utilized today because to its inexpensive material prices, excellent sound and heat insulation, local availability, attractiveness, and ease of building [3]. The building technique of stacking bricks, stone, or block units, either dry or bound with mortar, has been used for thousands of years. It is simple, effective, and beneficial. The constructions that still exist today have shown to be resilient and were built without the need for any specific skills.

Openings change the structural dynamics by nature; hence it is important to comprehend how the load distribution, stress distribution, and overall stability are affected. Although openings are common in masonry constructions, there is still a crucial gap in the literature that necessitates a thorough examination of the precise impact of openings and their various forms on the structural behavior of masonry load-bearing walls [4].

Prior to 1990, buildings in Albania mostly used brick walls. The building was carried out using low-strength masonry units, such as fired clay or silicate bricks, blocks, or stones. Masonry was a prevalent construction technique throughout the era. During the period of 1945 to 1990, which included the era of a centralized economy, there was a notable increase in construction activity [2]. URM walls were often constructed using multiperforated clay blocks and solid clay bricks until the 1990s. Single-story masonry constructions typically consist of a roof and a lightweight ceiling.

Contemporary buildings often have floors made of composite concrete and masonry, prefabricated hollow core slabs, partially prefabricated slabs with joists, or monolithic reinforced concrete solid slabs [5].

Moreover, a considerable proportion of these buildings have seen diverse structural alterations throughout the years, particularly the inclusion of openings for doors or windows. These unplanned changes are usually motivated by urgent necessities or conveniences, sometimes ruining the structural stability of the structures. Comprehending the characteristics and consequences of these alterations is essential for evaluating the present condition of the structure and devising efficient methods for restoration and strengthening [6].

1.2 Objectives and Scope of the Theoretical Study

This thesis' main goal is to investigate the effects of load-bearing masonry wall openings in Tirana, Albania, with a particular emphasis on stability and structural integrity. The purpose of this research is to present the architectural and historical context of Tirana's load-bearing brick walls while highlighting the importance of apertures.

The investigation will use both theoretical models and actual data to evaluate how different apertures affect how load-bearing brick walls behave under different loads. The objective is to comprehend how stress patterns and load distribution are impacted by apertures.

This work aims to describe moment capacity in load-bearing masonry walls. To make sure local procedures are in line with worldwide best practices, it will explain pertinent EUROCODE 6 standards and compare them with local practices.

The process will lay out a theoretical foundation and describe the macro-modelling technique. To provide precise and trustworthy analysis, the finite element modeling technique utilizing MASTERSERIES software and the digitalization procedure will be explained.

Structural integrity evaluation will present theoretical analysis results, comparing the impact of different opening shapes on stability and load distribution. The analysis will identify weaknesses and failure points.

Findings will be interpreted in the context of the case study, with recommendations for optimal opening shapes to enhance structural integrity. Best practices for design will be suggested based on the analysis.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Load-Bearing Masonry Walls and Their Structural Integrity

The earliest cultures are known for their use of brick and stone in masonry construction, as seen by the Roman Colosseum and the Egyptian pyramids. In his architectural work "De Architectura," Vitruvius laid down load-bearing masonry concepts that are still relevant in modern building [8]. The knowledge of load-bearing masonry walls has grown throughout time due to developments in engineering principles and building materials.

Many ancient stone structures have been constructed with the weight of the floors and immense walls to balance the tensile stresses caused by moments from the irregularity of vertical loads and lateral loads. It has been known that achieving lateral stability by gravity sets a realistic economic limit on the scale of loadbearing masonry constructions. Designers and builders have been looking for solutions to reduce the thickness of these large bearing walls while retaining their structural integrity [9].

In locations with minimal seismic activity, unreinforced masonry has been widely employed in low and medium-rise buildings. Plain masonry elements are the easiest to build since they have no reinforcement other than the possibility of adding modest joint reinforcement to minimize shrinkage cracking [10]. To resist weights, they rely only on the strength of the brickwork. Because masonry is strong in compression but weak in tension, unreinforced masonry offers excellent resistance to compressive loads but only moderate resistance to tensile stresses.

Significant innovations in masonry materials and production have helped to establish masonry construction as a competitive and cost-effective contemporary building method. High-strength units are now available in a wide range of forms, colors, and textures.

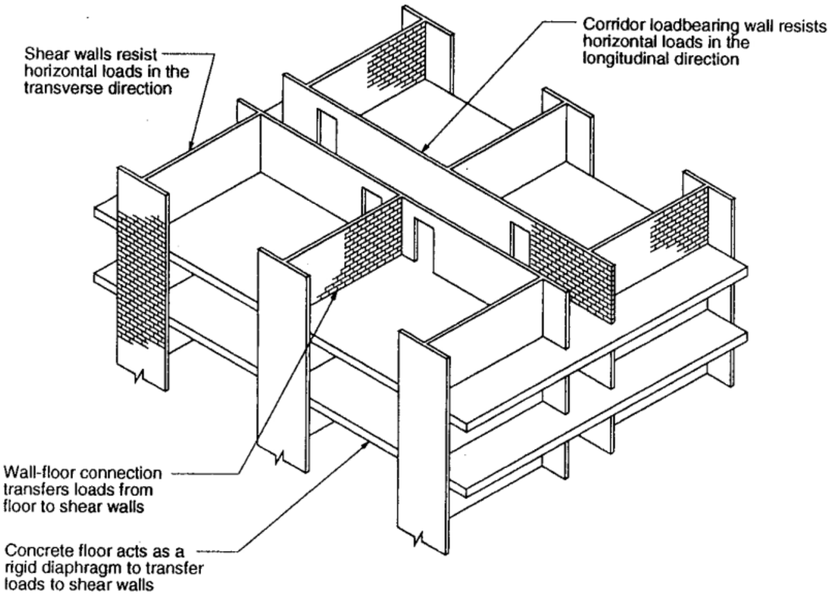

Figure 2. Multistory Wall System *[11]*

Many typical low- and high-rise masonry structures were planned and built with self-weight to mitigate tensile strains caused by lateral loads. The highest structure was the Monadnock Building in Chicago, which was built between 1889 and 1891 [11]. This 16-story structure has an unbraced pin-jointed iron frame within and strong load-bearing masonry walls on the outside. It was distinguished by the simplicity of its architectural elevational treatment. A typical scheme of this system is also presented in *Figure 2*.

The general design of the building, construction methods, and material qualities are some of the elements that affect the structural integrity of load-bearing masonry walls. The longevity and compressive strength of the wall are largely dependent on the selection of materials, such as stone or brick. The bonding between masonry units has increased as a result of recent developments in mortar technology, improving the overall structural performance [7].

Tensile stresses in unreinforced masonry must be designed to be less than the tensile strength, otherwise the section may crack. The activities of unreinforced brickwork under axial compressive loads and lateral loads are discussed in turn in the following paragraphs. A schematic illustration of how loads impact the masonry wall is presented in *Figure 3* [11].

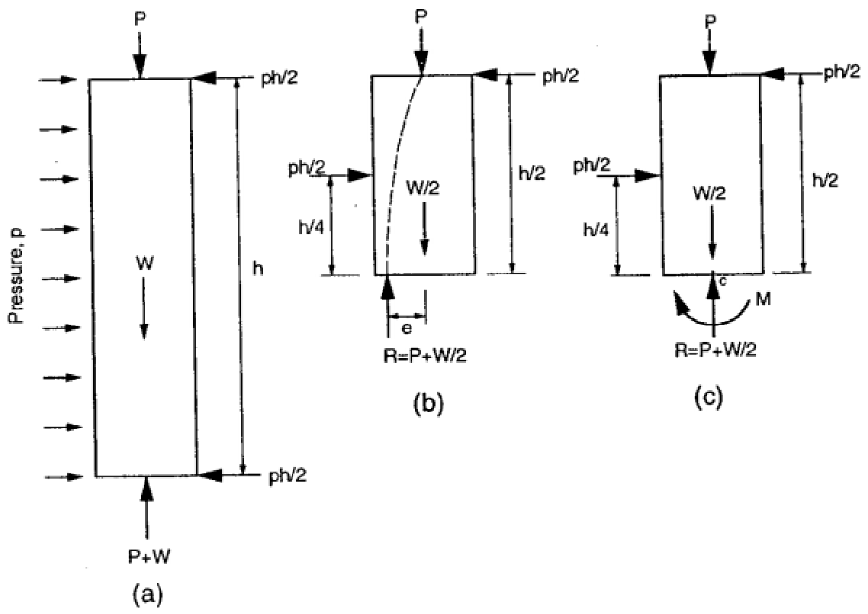

Figure 3. Masonry wall under axial load and lateral wind pressure *[11]*

The literature review concludes by highlighting the complexity and structural integrity of load-bearing masonry walls. Achieving structurally stand and aesthetically pleasing structures requires the combination of engineering and architectural ideas. Building on this basis, the subsequent portions of this thesis will add to the growing body of knowledge by concentrating on the theoretical analysis of openings and their forms in load-bearing masonry walls.

2.2 Review of Previous Studies on the Influence of Openings on Structural Integrity

Elevations are the most visible aspects of a building and often provide the first and enduring impression. The height of a structure has a significant impact on its elevation. In general, the most cost-effective building is one with as few stores as feasible while meeting the owner's floor-area needs. This, of course, must be countered by the cost of the land, and in general, the greater the cost of the land, the taller the building must be to be economically feasible [12]. Examples of these openings are doors and windows and are more analytically shown in *Figure 4*.

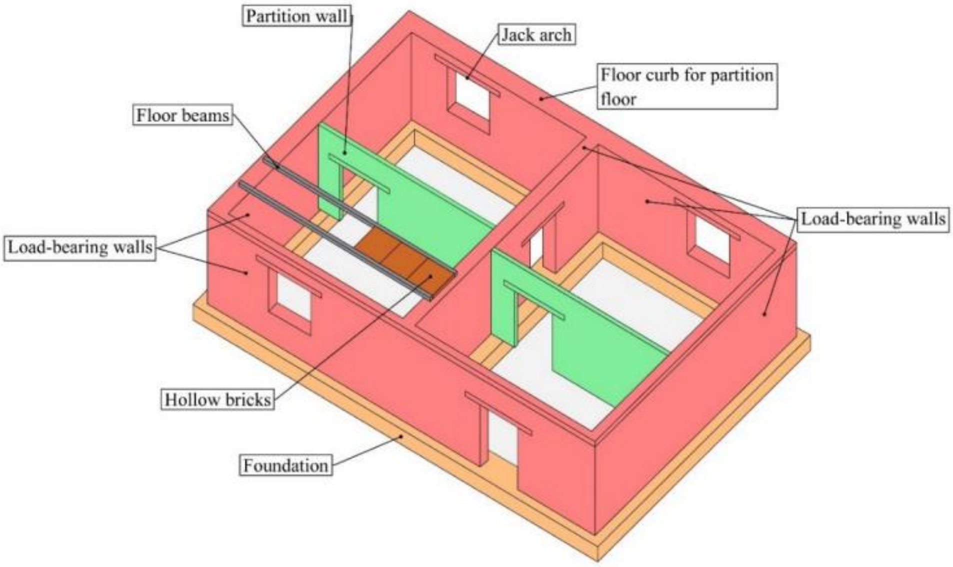

Figure 4. Load-bearing walls building scheme (drawing by G.B) *[13]*.

Along the years, a lot of research has been done on the impact that apertures have on the structural integrity of load-bearing masonry walls [14]. The conceptualization of load redistribution with the introduction of apertures, such doors and windows, was the main emphasis of these investigations. Even though these early efforts offered valuable insights, they frequently relied on oversimplified mathematical models, which calls for additional research.

The utilization of experimental studies has been essential in enhancing analytical methodologies. Scientists, such as Stephen P. Timoshenko, carried out experiments by simulating actual conditions with physical models and scale copies. For example, Timoshenko looked at how various opening forms affected stress concentrations and load distribution [15]. This helped to validate analytical predictions with empirical data and gave researchers a more sophisticated knowledge of how openings affect brick walls. They usually follow these studies with illustrations which enrich their research as it is presented in *Figure 5*.

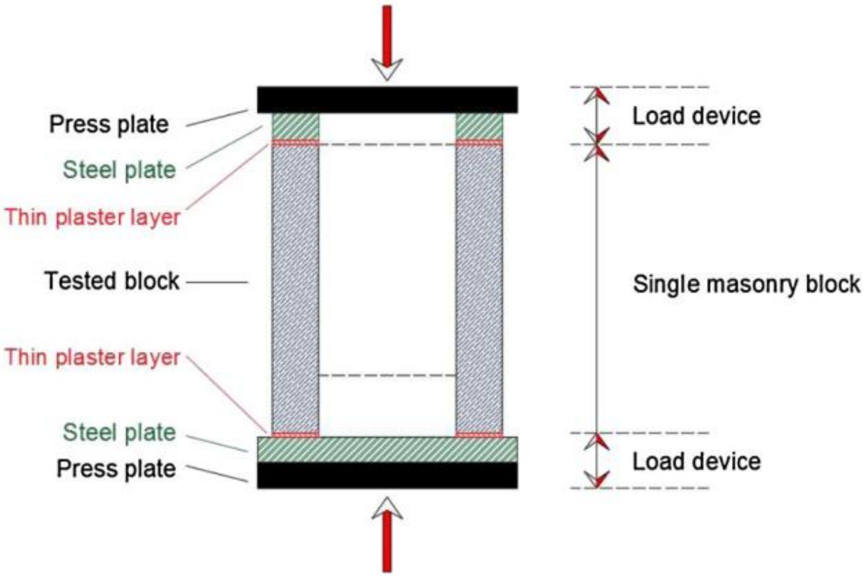

Figure 5. Illustration of Loads *[15]*

Developments in computer modeling have greatly broadened the field of study in this area. Comprehensive parametric studies are made possible by the application of Finite Element Analysis (FEA) and other numerical simulation techniques, as shown by modern researchers such as X. Liu and Y. Li. These investigations examine how several factors, like the size, form, and location of openings, affect the structural behavior of brick walls, allowing for a more thorough examination and a wider variety of design options.

The seismic susceptibility of masonry structures has also been the subject of recent research, with a focus on apertures. Researchers that have studied the dynamic behavior of masonry walls during seismic events, such as S. Pampanin and G. Magenes, have focused on the relationship between openings and seismic forces. This line of research aids in the creation of seismic design guidelines and retrofitting plans, which are crucial for earthquake-prone areas. A clearer prespective of that is shown in *Figure 6.*

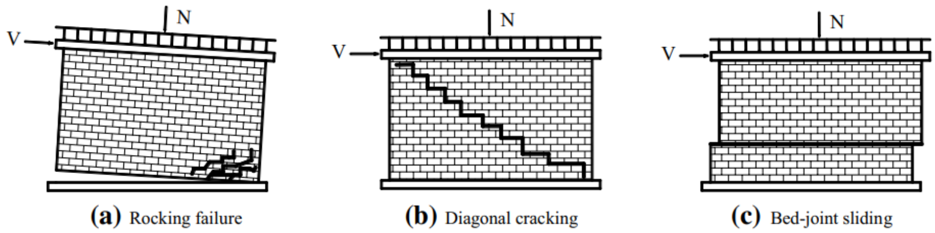

Figure 6. Failure patterns of masonry walls *[16]*

Research has recently begun to incorporate ideas from the fields of architecture and design into the investigation of openings. Architects like A. Sayyad and A. Ahmad have studied how openings affect a building's visual and spatial features in addition to its structural issues. This all-encompassing method recognizes the dual function of openings and advances an integrated design philosophy that takes structural and aesthetic factors into account.

To sum up, the collection of studies examined here represents the development of knowledge on how openings affect the structural soundness of masonry walls that support loads. Researchers have made major contributions ranging from early analytical investigations to complex computational modeling and concerns of seismic damage and architectural design. As the discipline develops, it is anticipated that further research will deepen and broaden our understanding, improving design methodologies and assisting in the construction of more durable and aesthetically beautiful masonry structures.

2.3 Masonry Wall Openings, Detailed Description of Different Types and Shapes of Openings in Tirana, Albania

Openings in the walls which are usually in the form of doors and windows have the task of connecting them with the spaces between themselves and with the outside, especially to bring light and air in spaces. The shape and size of the openings depends on the purpose of the openings, on the material from which was realized opening and from the architectural and aesthetic requirements.

An important part of investigating how openings affect the structural aspect of load-bearing masonry walls is closely examining the many kinds and forms of openings. In this part, the various forms and combinations of the apertures used in Tirana are thoroughly described and some shapes are illustrated in *Figure 7*.

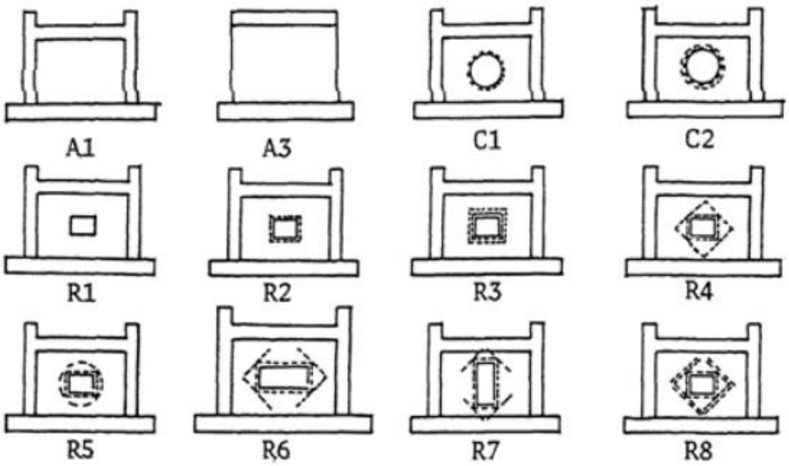

Figure 7. Wall Specimens with different types of Openings and Reinforcement *[17]*

The main focus is on rectangular openings because of its simplicity and ease of incorporation into architectural projects. These apertures, which are frequently seen in Tirana as seen in *Figure 8,* offer beneficial advantages while presenting intriguing difficulties for the masonry walls' structural behavior [18].

Figure 8. Rectangular opening in masonry walls in Tirana, Albania

Arched openings, which are well-known for their elegant architecture and visual appeal, bring special challenges. The way that arches curve introduces different load routes and redistributions, which affects how stone walls respond structurally [19].

Round apertures, which are symmetric about the radial direction, are another group that is being studied [20]. These apertures are frequently used for both decorative and practical reasons usually in specific positions in the Church of the city. Compared to its rectilinear counterparts, the study examines how circular holes transfer loads and cause stress concentrations. Since the circular shape introduces a consistent force distribution, its effect on the overall structural integrity should be investigated.

The study includes non-standard shapes including trapezoidal and triangular arrangements in addition to regular openings. These unusual entrances pose a challenge to accepted design conventions and offer creative avenues for architectural expression. The analysis investigates the effects of these irregular forms on load-bearing capacities and stress distribution, offering insights into the flexibility of brick walls to accommodate various opening shapes [13].

Additionally, the study takes into account differences in opening sizes within each category of shapes. Through a methodical manipulation of dimensions, from tiny to massive apertures, the study seeks to identify the ways in which size impacts structural reactions. This study offers a comprehensive knowledge of the findings' scalability as well as useful implications for designing masonry walls with varying-sized holes [5].

By means of this comprehensive examination of diverse forms and shapes of apertures, the research aims to enhance not only the conceptual comprehension of their influence on weight-bearing masonry walls but also offer pragmatic perspectives for designers and engineers. The results will hopefully add value to design considerations by allowing structures to be optimized to suit various opening configurations while maintaining structural integrity and visual coherence [5].

This section's examination essentially aims to decipher the subtleties of how various opening shapes and types affect the behavior of load-bearing masonry walls. In order to provide a comprehensive understanding that connects theoretical discoveries with real-world applications, the research will look at load distribution, stress concentrations, stability, and the impact of size and proportion.

Openings are often included into load-bearing walls to accommodate windows, doors, and other utilities. It is vital for individuals to have knowledge about the behavior of walls with openings. It is essential to comprehend the influence of various opening criteria, such as the dimensions, location, and kind of failure characteristic, on load-bearing walls. The advantages of this wall system are succinctly outlined as follows: It eliminates load-bearing elements like as beams and columns, hence decreasing the need for foundations and footings. Reduces construction time by minimizing structural requirements and manpower use. Facilitates quicker and more convenient design. Results in cost savings due to the aforementioned factors.

There are several factors contributing to the disuse of load-bearing masonry construction. It lacks effectiveness in mitigating the impact of earthquakes. Most earthquake-related deaths globally have occurred in load-bearing masonry buildings. Due of the potential for significant destruction, earthquakes are drawn to massive buildings. Significant exertion is required due to the fact that a substantial portion of the brickwork was crafted manually. Currently, humanity have not yet achieved the capability to construct a machine that is capable of producing bricks. Furthermore, the building process is much slower in comparison to more automated contemporary techniques.

2.4 Analysis of The Impact of Load-Bearing Masonry Wall Behavior

Examining how different opening forms and types affect the way load-bearing masonry walls behave structurally is a procedure that entails a thorough examination of numerous important factors. The purpose of this section is to explore the subtle reactions that stone walls display to various opening configurations, illuminating important elements including load distribution, stress concentrations, general stability, and the impact of size and proportion.

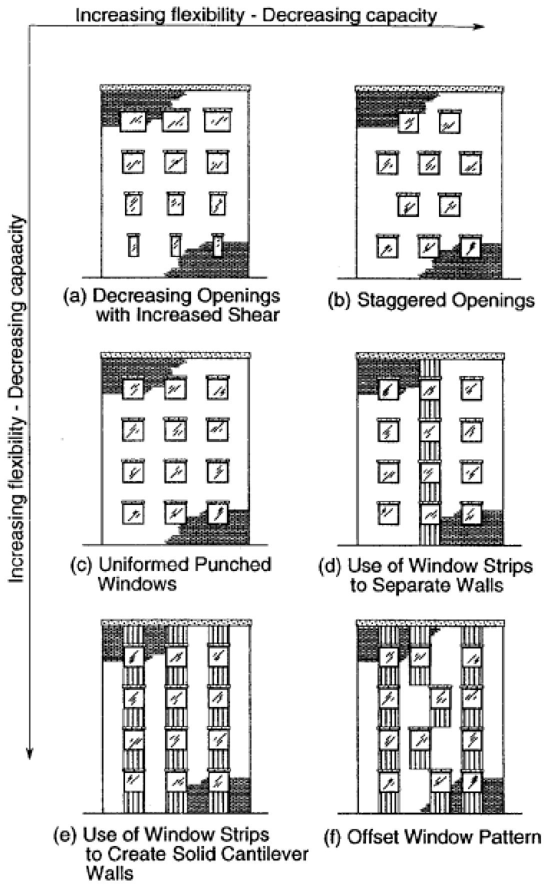

Figure 9. Placement of windows and its effect on wall flexibility *[11]*

Windows in exterior walls have varied degrees of effect on the wall's structural activity. When tiny punched windows are used, as shown in *Figure 9* (c), the entire wall can operate as a monolith to withstand lateral racking stresses. Critical regions include window corners and horizontal beam sections beneath or above windows. Because the cumulative shear stress increases from top to bottom, these effects can be mitigated by utilizing smaller windows in the lower floors, as seen in *Figure 9* (a). Staggering apertures, as shown in *Figure 9* (b), as opposed to aligned openings, increases vertical section coupling, increasing the wall's stiffness and strength for lateral resistance.

Using structurally independent infill panels above and below the window opening, as shown in *Figure 9* (d) and (e), effectively separates the wall into uncoupled shear walls. Although lateral strength gradually decreases from *Figure 9* (a) to *Figure 9* (e) (for unreinforced or equally reinforced sections), stress concentrations at windows are eliminated in *Figure 9* (e), and increased flexibility has the desirable effect of eliminating stiff beam elements, which are prone to brittle shear failure. Such cantilever structures have shown to be effective in resisting lateral stresses, including earthquakes, without severe cracking. The discontinuities generated by the offsetting windows in *Figure 9* (f) severely weaken the shear wall, and such walls frequently experience significant earthquake damage at changes in section.

For economic considerations, the clear height from floor to ceiling of a multistory structure is typically set at or near the minimum appropriate for the application. The vertical spacing of horizontal building components (floors and roofs) is then defined by the necessity for clear space, the depths of the floor or roof elements, and the need (if any) to accommodate mechanical and electrical services in ceiling spaces.

When it comes to load distribution, the existence of apertures is crucial in determining the manner in which both vertical and lateral loads are conveyed inside masonry walls. Since the research covers a variety of opening shapes from the simple rectangular to the visually complex arched and circular forms the goal is to identify the unique load routes that each arrangement introduces. Through the analysis of force redistribution and identification of possible locations of load concentration, the study aims to offer significant insights into the intricate relationship between opening geometry and internal forces encountered by the masonry structure, using calculations as shown in *Figure 10* [5].

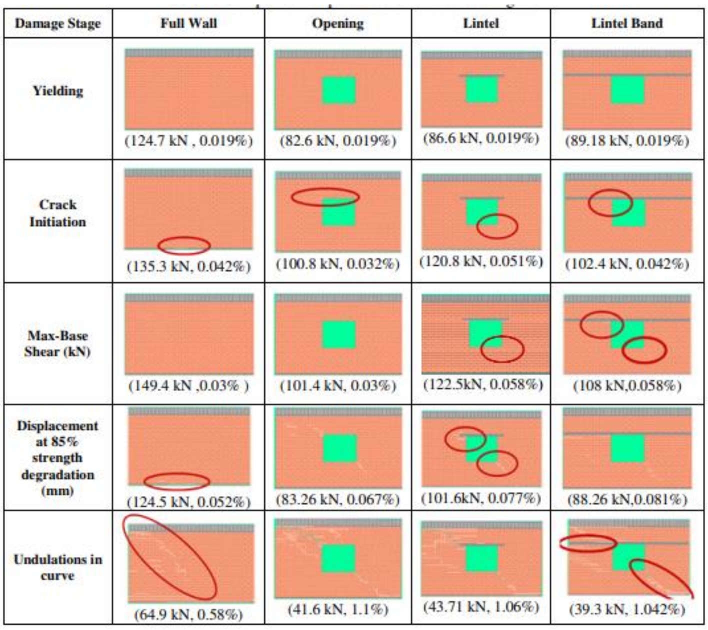

Figure 10. Comparison of parameters for load bearing wall *[5]*

The way that stress concentrations appear around various aperture shapes is another important factor that is being examined. Different aperture layouts might cause localized stress concentrations when loads pass through the brickwork material. This analysis will explore the evolution and manifestation of these stress concentrations, identifying possible weak points and areas of concern within the masonry wall. Optimizing structural designs requires an understanding of the stress patterns surrounding openings to make sure that the added openings do not reduce the masonry structure's overall strength and longevity [21].

The primary concern when adding openings to the structural system is the overall stability of load-bearing masonry walls. This study attempts to evaluate how various opening shapes contribute to or ameliorate potential stability difficulties. Each form of opening presents different opportunities and challenges regarding stability. The project will provide a thorough assessment of how different opening configurations impact the structural integrity of brick walls using sophisticated computational modeling and analytical techniques. This comprehensive evaluation guarantees a sophisticated comprehension of the dynamic connection between opening geometry and the general stability of load-bearing masonry constructions [22].

The study broadens its scope to investigate the impact of size and proportion on the behavior of brick walls, going beyond the form of openings. The systematic variation of opening sizes, from tiny too big, within each shape category facilitates an in-depth examination of the ways in which size affects load-bearing capability and stress distribution [23]. This part of the research offers insightful information about how discoveries can be scaled up or down, giving engineers and architects useful direction for creating brick walls with varying-sized openings.

A crucial component of the entire research are parametric studies, which involve the methodical variation of important factors including opening size, wall thickness, and material qualities. This thorough investigation guarantees that the research is applicable to a wide range of real-world situations and is both informative.

2.5 Moment Capacity of Load Bearing Masonry Walls, Detailed Definition and Explanation

An important concept in structural engineering is moment capacity, which is the most bending moment a structural member can withstand before failing [24]. It is defined as the maximum bending moment that a structural component is capable of withstanding is known as its moment capacity.

For the calculation of moment capacity of load bearing masonry walls are taken in consideration some points [1]. Firstly, are determined the properties of the section, the width of the wall (w), which is usually its horizontal length and the vertical distance between the centroid of the tensile reinforcement and the extreme compression, which is known as the effective height (d).

Secondly, the material characteristics are important too, since they can perform different based on their properties. Masonry Compressive Strength (f_m), which represents the masonry's overall compressive strength, taking into account both the mortar and the masonry components.

Thirdly, the strain compatibility and equilibrium are taken in consideration. This means that internal forces are balanced and that the strain distribution throughout the wall section is consistent with the behavior of the material.

Lastly, it's critical to follow applicable design norms and standards for determining moment capacity, such as Eurocode 6 Design of Masonry Structures [1]. When all of these points are considered, there is also a formula for the calculation of moment capacity of unreinforced masonry wall. The formula is shown in *Equation 1.*

$$\boldsymbol{M_u = \frac{f_m bd^2}{2}}$$

Equation 1. Formula for Moment Capacity

Where $\mathbf{M_u}$ is the moment capacity, the maximum bending moment the wall can withstand, $\mathbf{f_m}$ is the compressive strength of the masonry, **b** is width of the wall section, **d** is the effective height of the wall section.

2.6 The EUROCODE 6 Standard for Masonry Wall Openings in Load-Bearing Structures

Detailed recommendations for the construction of masonry buildings, including load-bearing walls with openings, are provided by EUROCODE 6 (EN 1996-1-1:2005) [1]. Doors, windows, and service duct openings may all have a major effect on a masonry wall's structural stability. The regulation specifies requirements and factors to make sure these apertures don't affect the walls' stability and ability to support weight.

The location and size of apertures inside a wall affect how stresses are distributed and how stable the structure is overall. Symmetric placement of openings is recommended to reduce eccentric loading. To make sure there is still enough wall area to support the imposed loads, the size of apertures should be kept to a minimum.

According to EUROCODE 6 [1], the remaining wall width must be at least 600 mm, or one-sixth of the wall length, whichever is larger. It's important to provide enough space between the wall's edge and the opening's edge. Maintaining structural integrity and efficient weight distribution are aided by this distance. A minimum horizontal gap of 600 mm or one-sixth of the wall's length, whichever is larger, shall exist between any two openings or between an opening and the wall's end.

To transmit weights from above to the masonry next to the opening, lintel or beams should be installed above apertures [5]. It is essential that lintels be designed to withstand loads without experiencing undue deflection or failure. Furthermore, to preserve the integrity of the wall and to provide strength and restrict the spread of cracks, reinforcing may be needed around apertures.

Both horizontal and vertical load transmission are disrupted by openings in masonry walls. As a result, the design has to guarantee that vertical and horizontal loads are distributed appropriately. To move loads from the regions above the apertures to the sides and below, proper detailing is required. This entails figuring out load routes and making sure the structure can sustain the loads that have been transferred efficiently.

The brick wall's overall stability is enhanced by the openings, which shorten the wall's effective length. To lower the chance of buckling, the slenderness ratio the height to thickness of the wall segments has to be monitored to make sure it stays within allowable bounds. This is essential to preventing structural instability, either locally or globally.

In order to guarantee the structure's comfort and functioning, deflection and vibration requirements must be satisfied. In order to protect the finishes around the apertures and non-structural components from damage, the design should contain tests for permissible deflections. Ensuring the wall's serviceability guarantees that it will continue to be both visually beautiful and useful over time.

The effective cross-sectional area that can support loads is decreased by apertures, which causes greater stress concentrations to surround the openings. This decrease in load-bearing capacity may make it more difficult for the wall to sustain structural loads [23].

Furthermore, tensile stresses and cracking may result from the disturbance of the load path that openings produce, particularly in the vicinity of opening corners. Differential movement or settlement around openings may provide more strains that might lead to structural failure. It might be difficult and need the use of extra reinforcement or structural components like lintels and beams for the structural system to effectively disperse loads around openings.

Additionally, apertures may weaken the stability of brick walls by creating weak areas that, if left unchecked, might result in regional or even global instability. These weaknesses highlight how crucial it is to adhere to EUROCODE 6 requirements in order to guarantee the continued safety, stability, and functionality of masonry walls with openings [1].

CHAPTER 3

METHODOLOGY

3.1 Theoretical Framework for the selected Case Study

This section provides the theoretical background and methods for numerically modeling a specific structure in a case study. The main objective is to assess the structural soundness and evaluate the effects of prior modifications on the selected building via the use of finite element analysis. Through the analysis of the building's construction materials, geometrical qualities, and historical alterations, our goal is to get a thorough understanding of its present structural performance and use this knowledge to guide future preservation efforts. Conducting this examination is essential for preserving the structural integrity and historical significance of the building while making necessary updates to meet modern requirements.

As it is discussed at previous chapters, Tirana city is characterized by the usage of clay and calcium silicate brick masonry load bearing walls during a significant period of time. Since masonry is so inexpensive, it has been the material of choice for structures up to five or six stories, particularly during the communist era. These types of walls are based usually on KTP-78 [3].

In this case is taken in a typical building with clay bricks. The building is located in Tirana city in neighborhood named "Komuna e Parisit". A clearer representation of the building is illustrated in *Figure 11* and *Figure 12*.

Figure 11. Selected Building located in Tirana City Façade 1

Figure 12. Selected Building located in Tirana city, Facade 2

3.2 Mechanical characteristics of the building

The chosen case study is a brick masonry structure built throughout the 20th century, namely from 1945 to 1950. This era is distinguished by the use of conventional building materials and methods, which mirror the architectural customs of that age. Throughout the years, the building has seen many modifications, such as the installation and sealing of apertures, which might have greatly impacted its structural performance [24].

The materials and techniques used during this period were mostly manual, with a focus on robustness and skillful workmanship. This phase of construction was characterized by a dependence on materials obtained from nearby sources and the use of conventional building methods. The building's construction primarily utilizes brick and mortar, each of which possess distinct physical and mechanical features that impact the overall performance of the structure. The selection of these materials was based on their accessibility, cost-efficiency, and compatibility with the prevailing building methods.

The bricks used are solid clay bricks with dimensions of 225 mm x 112 mm x 75 mm. They have a density of 1800 kg/m³ and a compressive strength of 11 N/mm2 [24]. The qualities of these bricks make them excellent for load-bearing applications, since they possess the required strength and rigidity to sustain the building. The bricks' durability and compressive strength are crucial factors in determining the building's capacity to endure vertical loads and environmental stressors in the long run. The building's geometrical features are essential for its load-bearing mechanism, since they determine how loads are distributed and transported throughout the structure. The structural efficiency and load resistance of a building are determined by the size and design of its walls and openings.

The building's walls have a thickness of 500 mm and are built utilizing a double brick wall method. The wall height on each story is 3.5 meters, although the lengths of the walls vary depending on the building's unique layout. The dimensions of the walls, namely their thickness and height, play a crucial role in their capacity to support vertical stresses caused by the weight of the building and its occupants, as well as lateral pressures resulting from external elements like wind and seismic activity. The use of a double brick wall structure offers improved thermal insulation and soundproofing, while simultaneously enhancing the building's durability and stability. The design of the walls guarantees effective transmission of loads to the base, hence preserving the structural integrity even under different load circumstances.

The building incorporates various apertures, such as windows and doors, which affect the structural robustness by generating zones of diminished strength. The dimensions of the windows are normally 1.2 meters in width and 1.5 meters in height, whilst the doors are usually 1.0 meter wide and 2.1 meters tall. The arrangement of the entrances and windows significantly impacts the visual and historical significance of the structure, requiring a careful approach to any alterations. The building has undergone several alterations during its existence, resulting in significant impacts on its structural stability and overall functionality. These interventions include the act of adding or closing apertures.

3.3 Modelling Approach: Macro-Modelling

In order to examine the structural characteristics of the masonry structure, we will use a macro-modelling methodology. This methodology guarantees a thorough comprehension of the building's performance under different loads and opening configurations throughout time.

Macro-modelling is a method that considers the masonry building as a continuous material, without specifically representing each individual brick and mortar joint. This streamlines the computational procedure and is well-suited for examining the overall behavior of expansive structures [11].

The masonry walls will be represented as homogenous, anisotropic materials, which accurately depict the combined characteristics of bricks and mortar. The properties of density, modulus of elasticity, Poisson's ratio, and compressive strength will be determined for the bricks and mortar, and then allocated as homogenized properties. A mesh will be created for the whole structure, with a finer resolution in areas where stress concentrations are anticipated. The appropriate boundary conditions and load scenarios, including dead loads, live loads, wind loads, and seismic loads, will be implemented [4].

Macro-modelling offers a comprehensive view of the stability, distribution of loads, and patterns of deformation in a structure.

3.4 Digitalization of the selected building

The act of digitizing the chosen building is a crucial stage in the structural analysis procedure. The first phase of the digitization process involves collecting all accessible paperwork and doing on-site measurements to assure precision. The process starts with gathering extant architectural drawings, blueprints, and historical documents of the building, which are provided by the property's occupants. The papers consist of floor plans depicting the initial architectural layout of the building as well as any future alterations made to it [21].

Conducting measurements at the location is essential for confirming and revising the current documentation. The measures include the lengths and thicknesses of walls, the sizes and placements of apertures, as well as specifics about any modifications or damages. Precise on-site measurements guarantee that the digital models accurately represent the actual condition of the structure, collecting all essential elements for a dependable study.

The next stage after gathering the data is to generate intricate digital models using AutoCAD. The first step is importing the gathered data into AutoCAD as represented in *Figure 12*. This serves as a basis for constructing precise digital renderings of the architectural blueprints. Precise floor plans are generated for every level of the structure, providing a realistic depiction of all walls, openings, and structural components. This entails accurately recording the precise positions and measurements of doors, windows, and any other notable characteristics.

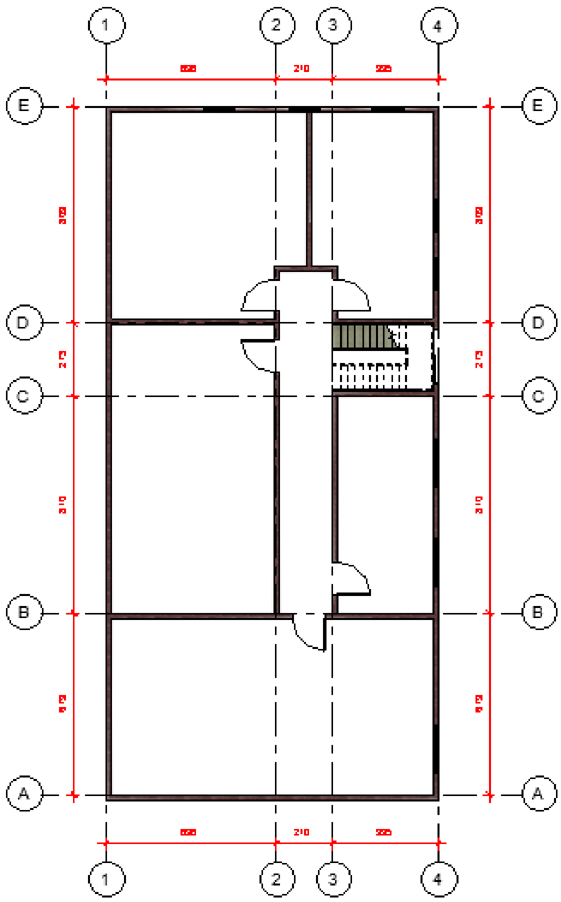

Figure 13. Generated Building Plan using AutoCad Software

AutoCAD is used to import elevation data and on-site measurements in order to initiate the development of elevation views. Comprehensive elevation views of all exterior surfaces of the structure are generated, documenting features such as windows and doors as illustrated in *Figure 14*, *Figure 15* and *Figure 16*.

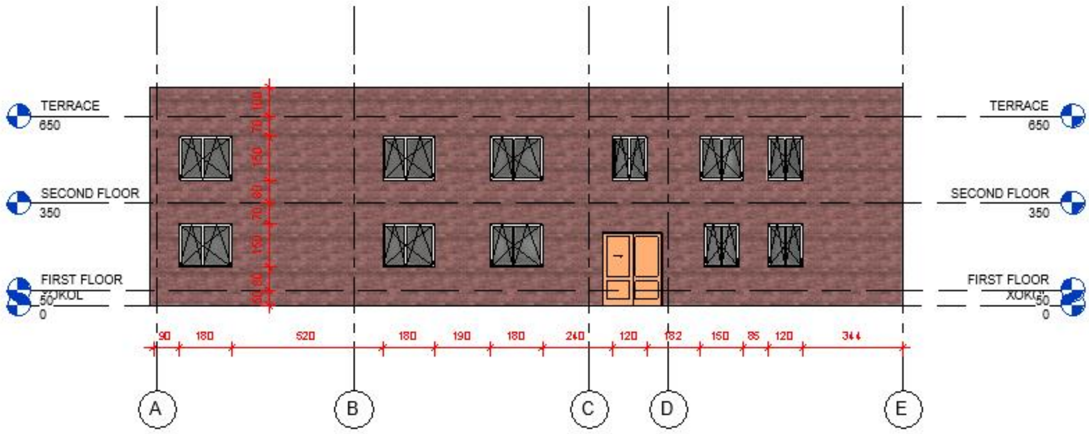

Figure 14. Elevation 1 of the Building

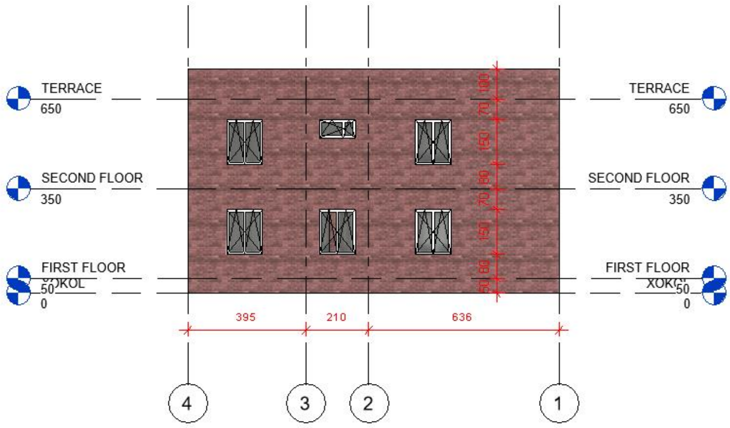

Figure 15. Elevation 2 of the Building

Figure 16. Axonometry of the Building

The expansion of windows and doors in different areas has created additional points of stress and changed the way the load is distributed inside the walls. These alterations are often motivated by functional requirements, such as enhancing illumination and airflow, but they may have a substantial effect on the structural performance. The windows pointed with red are the ones which have been expanded as illustrated in *Figure 17*.

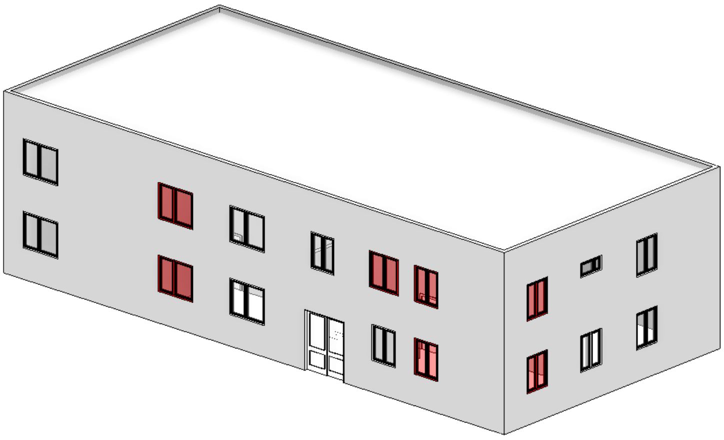

Figure 17. Openings which have been expanded

Certain windows and doors have been closed off in order to rearrange the layout of the interior space, which may have an impact on how the weight is distributed and the general stability of the building. The ones which have been closed are shown in *Figure 18*. This procedure sometimes entails substituting the initial aperture with infill materials that can possess distinct mechanical characteristics compared to the original construction.

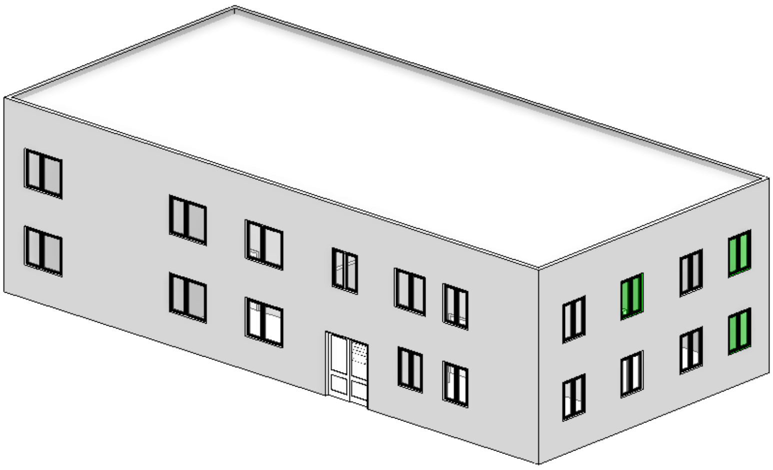

Figure 18. Openings that have been filled partly or closed totally

3.5 Finite Element Modeling using MASTERSERIES

Finite Element Modeling is an effective analytical technique used to simulate and study the structural response of structures under different loading circumstances [25]. This section provides a detailed explanation of the analytical techniques used to analyze the structural integrity of a load-bearing brick masonry wall with openings. MasterSeries is an extensive software for structural engineering that is specifically created for the examination, planning, and specification of buildings structures. The program enables precise modeling of geometries, material characteristics, and boundary conditions, making it well-suited for our research [26].

The first stage in finite element modeling is creating an accurate and comprehensive model of the building's load-bearing wall, which includes any apertures. The building's geometric data, which has been digitized using AutoCAD, is loaded into MasterSeries. This includes precise measurements of the walls, openings, and structural components. software and the facades represented in are generated.

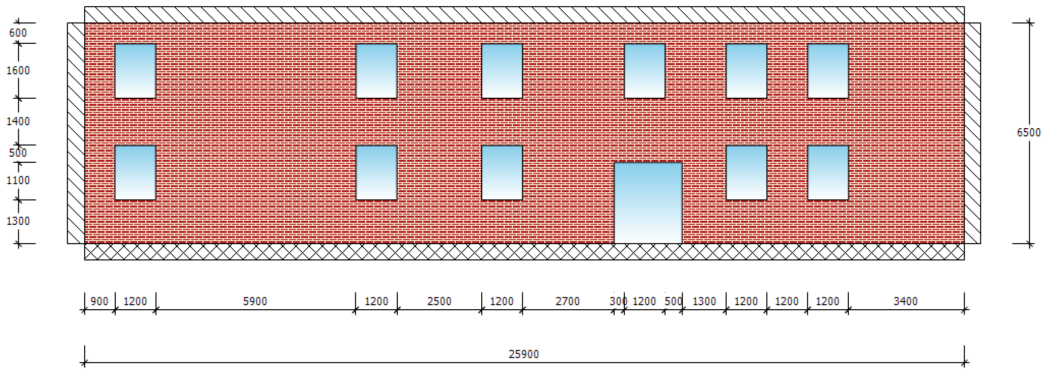

Figure 19. Facade 1 with openings using Masterseries Software

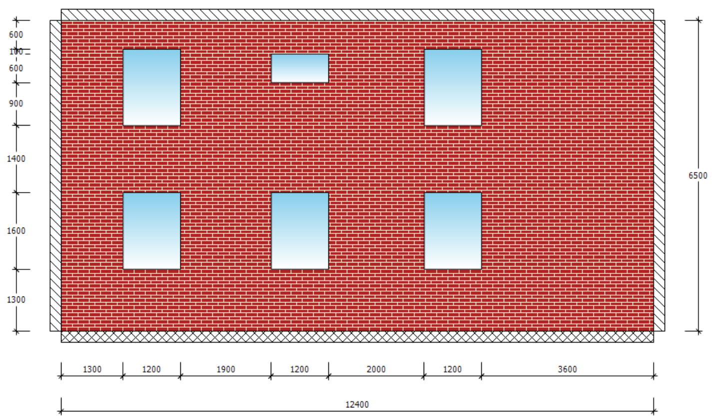

Figure 20. Facade 2 with openings using Masterseries Software

The fundamental attributes for modeling masonry structures are [6]:

-Compressive strength of masonry f_k

- The elastic modulus of compression and tension E

-Shear elastic modulus G

Value suggestions are provided based on the relationships between the mechanical qualities of all masonry materials. These concepts are derived from the literal interpretation of the words "brick" and "mortar". The following text outlines the parameters and calculation procedure as per the guidelines for analyzing the performance of masonry structures with and without structural intervention, in accordance with EC and other codes [1], [24], [27], [28] and [29].

Since the building is been constructed times ago the materials aren't homogeneous. This means that they have been changing over time so in this case we will use some hypothetical parameters when doing the analysis since the focus here is the effect of openings.

The following factors were taken into account when doing the modeling and analysis:

- The masonry used is Clay.
- The water content of clay bricks is 7%-12%.
- The class and category of the brick is secondary.
- The compressive strength is taken 11 N/mm^2.
- The density is taken 1800 kg/m^3.
- The dimension of clay brick is 225x112x75 mm.
- The Dead Loads are 15 kN.
- The Live Loads are 7 kN.
- The Masonry Mortar type is M2.
- Walls don't have reinforcements.
- Linear elastic analysis refers to a method where both the reinforcement and materials have linear behavior.
- The investigation focused on determining the critical stress in brick, supposing it to be a homogenous substance.

CHAPTER 4

STRUCTURAL INTEGRITY EVALUATION

4.1 Presentation of Theoretical Analysis Results on Structural Integrity Considering Different Opening Shapes

This part provides a detailed overview of the theoretical study carried out to assess the structural stability of the chosen structure. The analysis specifically examines the influence of various opening forms and interventions. Apertures such as doors and windows in load-bearing walls have a substantial impact on the weight distribution and overall stability of the structure.

The main geometrical forms analyzed in this investigation were rectangular openings, which are often seen in standard windows and doors. The selection of these forms was based on their widespread occurrence in both past and present architectural designs. The investigation sought to comprehend the impact of these apertures on the structural strength and distribution of stress inside the walls.

Analyzed was the load distribution over the masonry walls with various opening forms, which was a crucial component examined. Sharp edges in rectangular apertures can lead to the formation of stress concentrations. Stress concentrations arise when the load routes are disrupted by the corners, resulting in a redistribution of stresses that might produce localized weaknesses.

It is crucial to comprehend stress concentrations as they may serve as focal locations for the start and propagation of cracks, which may ultimately result in structural collapse. Rectangular apertures exhibited a heightened susceptibility to producing elevated stress concentrations at their corners.

Every alteration has a distinct effect on the structural dynamics of the structure. For example, when new openings are created, it may lead to the formation of new areas of stress concentration and change the way loads are distributed. On the other hand, if apertures are closed properly, it has the ability to partially restore the original load-bearing capacity of the wall.

4.2 Evaluation of Structural Behavior and Load Distribution

This research included an examination of facade modifications using the MasterSeries program. The emphasis was on two main facades that have been elaborated in previous chapters.

The Façade 1 which was characterized by the expansion of the windows' during time. The simulation with the previous openings is shown in *Figure 21*. These openings were done in order to enhance the presence of natural light and airflow inside the internal areas. From the simulation are clearly visible the possible cracks in the corners of the apertures. The moment capacity here is 0.886 kNm.

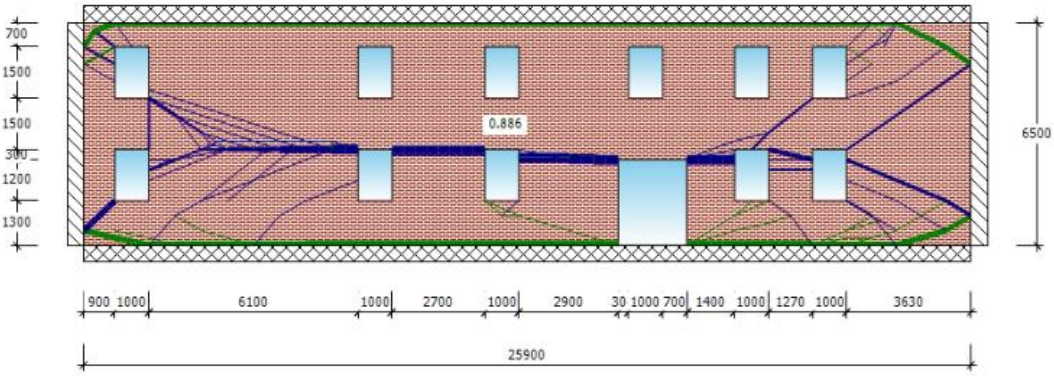

Figure 21.Simulation of Facade 1 with previous openings

In the *Figure 22* is shown the simulation of the existing state of Façade 1. From the image is visible the addition of possible cracks in the corners of the apertures compared when the openings were smaller. The moment capacity here is 0.945 kNm.

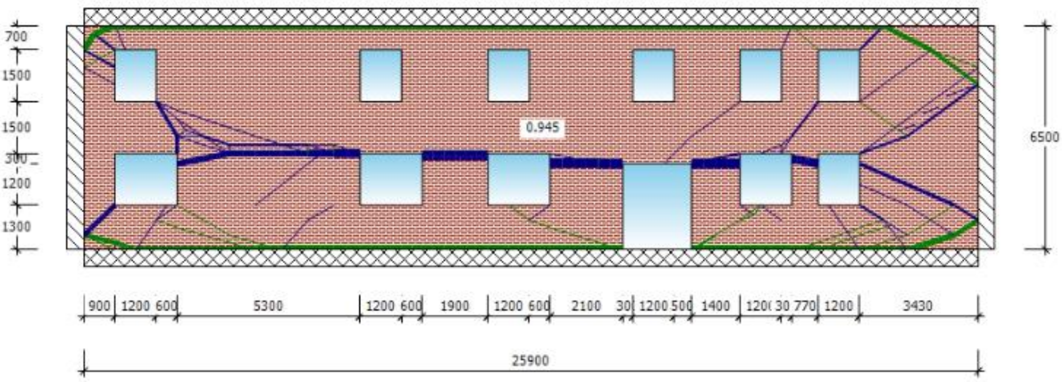

Figure 22.Simulation of Facade 1 with expanded openings

The Façade 2 was characterized by the closure of two windows and an intervention on partly closing of one other window The simulation with the previous openings is shown in *Figure 23*. The objective of this renovation was to improve the building's structural integrity and thermal performance. The moment capacity here is 0.092 kNm.

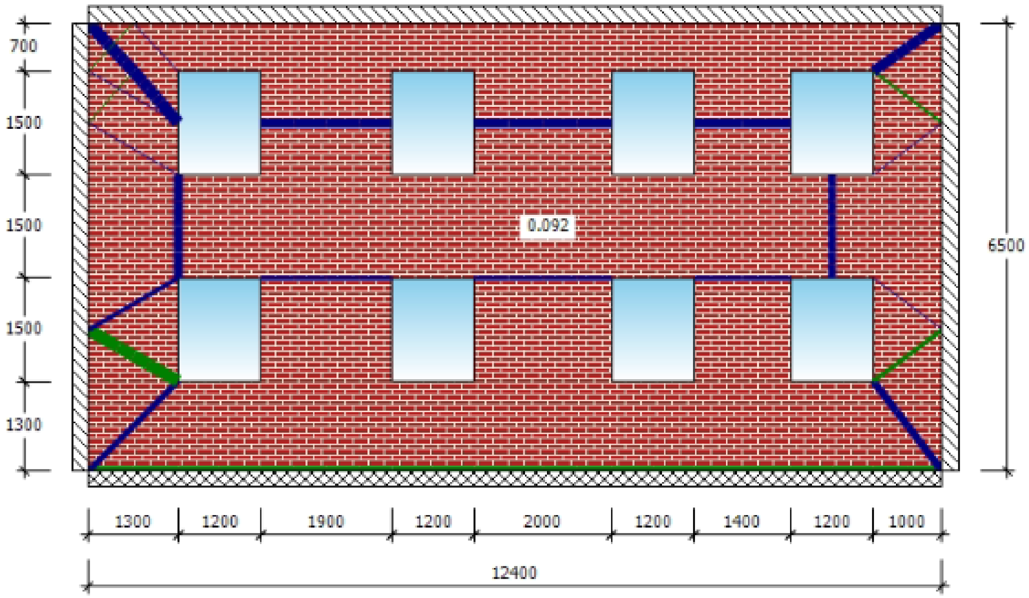

Figure 23.Simulation of Façade 2 with previous openings

In the *Figure 24* is shown the simulation of the existing state of Façade 2. Even though the wall was closed still it has possible big cracking. The moment capacity here is 0.089 kNm.

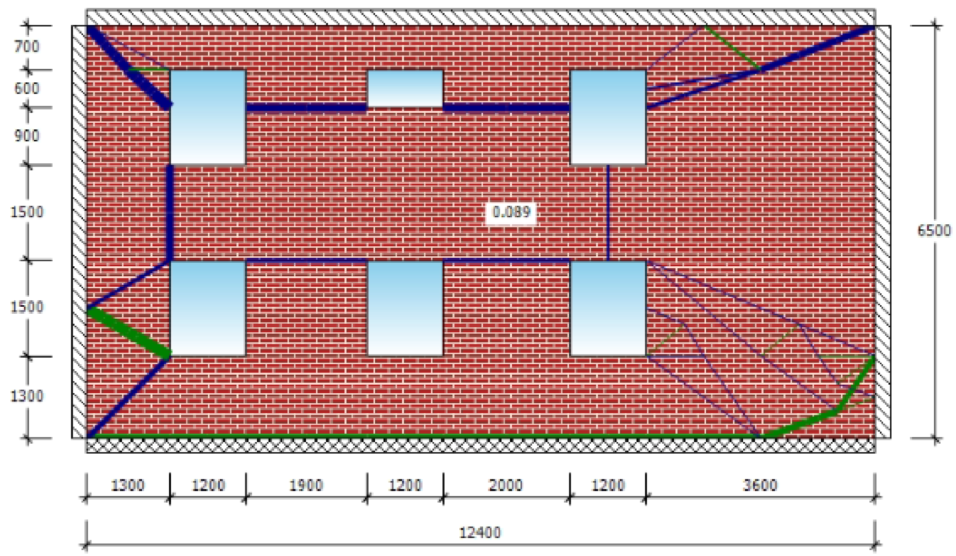

Figure 24. Simulation of Facade 2 with closed openings

This research enabled us to assess the structural and environmental consequences of the changes on both facades. Through a comparison of the initial and final conditions, we were able to make inferences on the efficacy and possible drawbacks of both shutting and enlarging openings in building facades.

The corners of rectangle holes showed high amounts of stress. This is because the shape changed quickly, which messed up the load path and made stress stems.

There are bigger displacements around the holes, which shows that they might bend when they're loaded. It was found that the sides of rectangular holes could be places where cracks start, especially when loads change quickly, like when there is wind or an earthquake. Interventions like making new openings or shutting down old ones, affected things.

Making new openings messed up the original load paths, which caused more stress to build up around the new openings. To lessen the bad effects, new spaces often needed extra supports like steel frames or lintels.

When old holes were closed, the stress distribution inside the wall changed. The filled holes could either make the wall stronger or weaker, depending on the method used. To avoid uneven movement and possible cracking, it was very important to make sure that the filler material was properly mixed with the original brickwork.

Adding supports like steel lintels, concrete beams, or extra layers of brickwork around holes made the structure work much better.

The reinforcements helped spread the loads more widely, which decreased stress concentrations and the chance of breaking.

The theoretical study using finite element modeling in MasterSeries gave useful information about how different opening forms and past changes to the building affected its structural stability. The building's structural stability had to be carefully thought out and reinforced after previous changes, especially when new openings were made. These results show how important it is to do a thorough structural study before trying to save and fix up old brick buildings.

CHAPTER 5

ANALYSIS OF FINDINGS

5.1 Interpretation of Theoretical Analysis Results

This research included analyzing facade modifications using the MasterSeries program. The emphasis was on two separate exteriors of a building: one with extended openings and another with closed apertures. This research enabled us to assess the structural and environmental consequences of the changes on both facades.

The chosen software beside the simulation which were explained in previous chapter, also represents a report paper which for Façade 1 that had expansion of the opeings, is shown in *Figure 25.*

Two Way Spanning, Vertically and Laterally Loaded, Cavity Wall
Design to BS 5628 : 1992
EAST M

Summary of Design Data			
Wall Dimensions	h=6.500 m, hef=6.500 m, L=25.900 m, Lef=25.900 m		
Support Conditions	Bottom Cont., Top Cont., Left Simple, Right Simple		
Lateral Loads	Wx=1.0 kN/m²		
Opening load span direction	opening at X = 15.6, Y = 0 - Two way spanning		
	opening at X = 0.9, Y = 1.3 - Two way spanning		
	opening at X = 8, Y = 1.3 - Two way spanning		
	opening at X = 11.7, Y = 1.3 - Two way spanning		
	opening at X = 19, Y = 1.3 - Two way spanning		
	opening at X = 21.27, Y = 1.3 - Two way spanning		
	opening at X = 0.9, Y = 4.3 - Two way spanning		
	opening at X = 8, Y = 4.3 - Two way spanning		
	opening at X = 11.7, Y = 4.3 - Two way spanning		
	opening at X = 19, Y = 4.3 - Two way spanning		
	opening at X = 21.27, Y = 4.3 - Two way spanning		
	opening at X = 15.9, Y = 4.3 - Two way spanning		
Cavity Wall (mm)	t1=250, t2=250, tef=333.3		
Limiting Dimensions	λ=19.5<=λ_{lim}=27, L.h<=2025 tef², L>50 tef, h<=50 tef	1.554	Warning
Outer-Leaf Design			
Partial Safety Factor (γmc/γmf)	Construction Normal, Unit Manufacture Normal	3.5/3	Table4a/4b
Unit Material	Clay water absorption7% to 12%, Standard Bricks, γ=17.66 kN/m³		
	Designated compressive strength 11 N/mm²		
Mortar Material	M2/(iv), 2 N/mm²		
Compressive Strength (fk)	Standard Bricks	3.68 N/mm²	Table 2
Loads from above	Dead Load=12.0 kN/m, Live Load=1.6 kN/m		
Section Properties	Area=2500 cm²/m, Zp=10417 cm³/m		
Flexural Strength fkp (Perpendicular)		1 N/mm²	Table 3
Flexural Strength fkb (Parallel)	fkb=0.35, gd=0.094 N/mm², fkb=fkb+0.9 gd.γmf	0.604 N/mm²	Table 3
Critical axial compressive Case	1.4(γ.tk.h+gku)+1.6qku		
Max local stress @	X=20.5 m,Y=1.25 m < fk•0.99(small area red.)/γ_{mc}	0.45 N/mm²	OK
Critical axial buckling Case	1.4(γ.tk.h+gku)+1.6qku		
Max axial buckling force @	X=20.885 m, Y=1.4 m averaged over width Of 0.77 m	112.5kN/m	
Capacity reduction factor top, β	ex=0.0 mm, hef=1950 mm, tef=333.3 mm, t=250.0 mm	1.061	
Fr=β.fk.tk/γmc	1.000x3.64x250/3.5	259.9 kN/m	
Fd/Fr	112.5/259.9	0.433	OK
Mro=fkp.Zp/γmf	1.0x10417/3	3.472 kN.m/m	
Mro=fkb.Zb/γmf	0.604x10417/3	2.096 kN.m/m	
Inner-Leaf Design			
Partial Safety Factor (γmc/γmf)	Construction Normal, Unit Manufacture Normal	3.5/3	Table4a/4b
Unit Material	Clay water absorption7% to 12%, Standard Bricks, γ=17.66 kN/m³		
	Designated compressive strength 11 N/mm²		
Mortar Material	M2/(iv), 2 N/mm²		
Compressive Strength (fk)	Standard Bricks	3.68 N/mm²	Table 2
Section Properties	Area=2500 cm²/m, Zp=10417 cm³/m		
Flexural Strength fkp (Perpendicular)		1 N/mm²	Table 3
Flexural Strength fkb (Parallel)	fkb=0.35, gd=0.046 N/mm², fkb=fkb+0.9 gd.γmf	0.474 N/mm²	Table 3
Critical axial compressive Case	1.4(γ.tk.h)		
Max local stress @	X=20.5 m,Y=1.25 m < fk•0.99(small area red.)/γ_{mc}	0.26 N/mm²	OK
Critical axial buckling Case	1.4(γ.tk.h)		

Figure 25. Report Data for Simulation of Facade 1

This research specifically examines the design and analysis of a cavity wall that is loaded both vertically and laterally in two directions. Below, you can find the design overview and comprehensive specs.

The measurements of the wall for this research are as follows: a height (h) of 6.500 meters, an effective height (he) of 6.500 meters, a length (l) of 25.900 meters, and an effective length (le) of 25.900 meters. The wall is supported at the bottom, corner, left, and right, and is subjected to a uniformly distributed load (Wu) of 10.1 kN/m^2. The design takes into consideration various openings, with each opening being studied under two-way spanning circumstances. The dimensions and spans for each opening are specified in detail.

The partial safety factor for the material and load in the outer leaf is set at 3.5 and 3, respectively. The unit material comprises regular clay bricks with a water absorption rate of 17% and a specified compressive strength of 11 N/mm^2. The mortar material used is M2 (1:6) with the identifier (ii).

The typical bricks have a compressive strength of 3.68 N/mm^2. The flexural strengths are measured at 1 N/mm^2 in the perpendicular direction and 0.34 N/mm^2 in the parallel direction to the load. The outer leaf's critical stress case exhibits a maximum local stress of 0.45 N/mm^2, which falls below acceptable thresholds. In addition, the calculations for buckling force reveal a maximum axial buckling force of 112.5 kilonewtons, and the critical stress factor confirms that it is within the safe range.

The partial safety factor for the material and load of the inner leaf is set at 3.5 and 3, respectively. The unit material consists of ordinary blocks with a specified compressive strength of 11 N/mm^2. The mortar material used is M2 (1:6) with the identifier (ii).

The analysis and design of the cavity wall, which is loaded both vertically and laterally in two directions, satisfy the majority of the required safety and performance standard. The chosen materials and design parameters guarantee that the structure is capable of enduring the applied loads and conditions. All calculations for critical stress and buckling force have been conducted and indicate that the structure complies with the established criteria.

The report of the Façade 2 which was characterized with closure of openings is shown in *Figure 26*. This research entails the creation and examination of a cavity wall that is laterally loaded and spans in two directions. The design overview and comprehensive specifications are provided in the following sections.

Two Way Spanning, Laterally Loaded, Cavity Wall
Design to BS 5628 : 1992
NORTH V

Summary of Design Data			
Wall Dimensions	h=6.500 m, hef=6.500 m, L=12.400 m, Lef=12.400 m		
Support Conditions	Bottom Cont., Top Simple, Left Simple, Right Simple		
Lateral Loads	Wx=0.1 kN/m²		
Opening load span direction	opening at X = 1.3, Y = 1.3 - Two way spanning		
	opening at X = 4.4, Y = 1.3 - Two way spanning		
	opening at X = 7.6, Y = 1.3 - Two way spanning		
	opening at X = 10.2, Y = 1.3 - Two way spanning		
	opening at X = 1.3, Y = 4.3 - Two way spanning		
	opening at X = 7.6, Y = 4.3 - Two way spanning		
	opening at X = 10.2, Y = 4.3 - Two way spanning		
	opening at X = 4.4, Y = 4.3 - Two way spanning		
Cavity Wall (mm)	t1=250, t2=250, tef=333.3		
Limiting Dimensions	L.h<=2025 tef², L<=50 tef, h<=50 tef	0.744	OK
Outer-Leaf Design			
Partial Safety Factor (γ_{mc}/γ_{mf})	Construction Special, Unit Manufacture Special	2.5/2.5	Table4a/4b
Unit Material	Clay water absorption< 7%, Standard Bricks, γ=20 kN/m³		
	Designated compressive strength 5 N/mm²		
Mortar Material	M2/(iv), 2 N/mm²		
Compressive Strength (fk)	Standard Bricks	2.2 N/mm²	Table 2
Section Properties	Area=2500 cm²/m, Zp=10417 cm³/m		
Flexural Strength fkp (Perpendicular)		1.2 N/mm²	Table 3
Flexural Strength fkb (Parallel)	fkb=0.4, gd=0.057 N/mm², fkb=fkb+0.9 gd/γmf	0.529 N/mm²	Table 3
Critical axial compressive Case	1.4(γ.tk.h)		
Max local stress @	X=8.8 m,Y=1.4 m < fk/γ_{mc}	0.2 N/mm²	OK
Critical axial buckling Case	1.4(γ.tk.h)		
Max axial buckling force @	X=9.5 m, Y=3.9 m averaged over width Of 1.4 m	49.71kN/m	
Capacity reduction factor top, β	ex=0.0 mm, hef=6500 mm, tef=333.3 mm, t=250.0 mm	0.784	
Fr=β.fk.tk/γmc	0.784x2.2x250/2.5	172.5 kN/m	
Fd/Fr	49.7/172.5	0.288	OK
Mro=fkp.Zp/γmf	1.2x10417/2.5	5.000 kN.m/m	
Mro=fkb.Zb/γmf	0.529x10417/2.5	2.205 kN.m/m	
Inner-Leaf Design			
Partial Safety Factor (γ_{mc}/γ_{mf})	Construction Special, Unit Manufacture Special	2.5/2.5	Table4a/4b
Unit Material	Concrete Blocks, Hollow block wall, γ=20 kN/m³		
	Designated compressive strength 2.8 N/mm²		
Mortar Material	M2/(iv), 2 N/mm²		
Unit Ratio	Unit height=215, Least horizontal dimensions=100	2.15	
Compressive Strength (fk)	Hollow block wall	2.8 N/mm²	Table 2
Section Properties	Area=2500 cm²/m, Zp=10417 cm³/m		
Flexural Strength fkp (Perpendicular)		0.2 N/mm²	Table 3
Flexural Strength fkb (Parallel)	fkb=0.1, gd=0.057 N/mm², fkb=fkb+0.9 gd/γmf	0.229 N/mm²	Table 3
Critical axial compressive Case	1.4(γ.tk.h)		
Max local stress @	X=8.8 m,Y=1.4 m < fk/γ_{mc}	0.2 N/mm²	OK
Critical axial buckling Case	1.4(γ.tk.h)		
Max axial buckling force @	X=9.5 m, Y=3.9 m averaged over width Of 1.4 m	49.71kN/m	
Capacity reduction factor top, β	ex=0.0 mm, hef=6500 mm, tef=333.3 mm, t=250.0 mm	0.784	
Fr=β.fk.tk/γmc	0.784x2.8x250/2.5	219.5 kN/m	
Fd/Fr	49.7/219.5	0.226	OK
Mri=fkp.Zp/γmf	0.2x10417/2.5	0.833 kN.m/m	

Figure 26. Report Data for Simulation of Facade 2

The wall has the following dimensions: a height (h) of 6.500 meters, a length (l) of 12.400 meters. The wall is supported at the bottom, left, and right sides and is subjected to a uniformly distributed load (Wu) of 10.1 kN/m^2. The design takes into consideration several openings, which are studied under situations where they span in two directions. The dimensions and spans for each opening are stated.

The partial safety factor for both the material and load in the outer leaf is set at 2.5. The unit material comprises specialized building units composed of clay bricks with a water absorption rate of 7% and a compressive strength ranging from 7 to 20 kN/m^2. The mortar material used is M2 with a ratio of 1 part cement to 6 parts sand, and it has a designation of (ii).

The typical bricks have a compressive strength of 2.2 N/mm^2. The flexural strengths are measured at 1.1 N/mm^2 in a direction perpendicular to the load and at 0.29 N/mm^2 in a direction parallel to the load. The outer leaf's critical stress case exhibits a maximum local stress of 2.2 N/mm^2, which falls below acceptable thresholds. Furthermore, the calculations for buckling force demonstrate that both the maximum axial buckling force and critical stress factors are within the acceptable range, indicating safety.

The partial safety factor for both the material and load of the inner leaf is likewise established at 2.5. The unit material consists of blocks with a compressive strength of 20 kN/m^2. The mortar material used is M2 (1:6) with the identifier (ii).

The blocks have a compressive strength of 2.8 N/mm^2. The flexural strength perpendicular to the load direction is 1.4 N/mm^2, whereas the flexural strength parallel to the load direction is 0.42 N/mm^2. The inner leaf's critical stress case exhibits a maximum local stress of 2.8 N/mm^2, which falls below acceptable thresholds.

The analysis and design of the laterally laden cavity wall, which spans in two directions. The selected materials and design specifications guarantee the structural integrity to survive the applied loads and environmental conditions. The comprehensive data provides strong evidence for a sturdy and secure structural design suitable for the intended use.

5.2 Recommendations for Optimal Opening Shapes in Load-Bearing Masonry Walls

Several suggestions can be made to improve the design and strength of openings in load-bearing brick walls based on the study's thorough theoretical analysis and results. The goal of these suggestions is to make brick buildings stronger, make sure that loads are spread out evenly, and protect their historical and artistic value. Rectangular spaces are popular and often important for functionality, but they are very hard to work with because there is a lot of stress at their sides. Without the right kind of support, these holes can become weak spots in the structure that could lead to failure.

When rectangular holes need to be made, they need to be properly supported. This can be done with lintels, steel frames, or strengthened concrete beams to move loads away from the corners and lower stress levels. If you can, changing the shape of rectangular spaces so that the sides are rounded can help spread out some of the stress. With this combination method, rectangular spaces can keep their useful features while also getting better structural performance.

It is important to do a full evaluation of current openings before taking any action. This means looking at their size, form, where they are placed, and how badly they are damaged or breaking down.

Existing holes should be strengthened with the right materials, especially rectangular ones that show signs of stress or damage. Sometimes, closing off openings that aren't needed anymore can make the structure stronger. To make sure everything works together and the load is spread out evenly, this should be done with materials that match the original brickwork.

To sum up, the right way to build and strengthen gaps in load-bearing brick walls is very important for keeping the structure strong and saving ancient architecture and people’s lives. However, rectangular openings need to be carefully reinforced to avoid stress concentrations. By following these suggestions during preservation and repair work, engineers and preservationists can make sure that brick buildings stay safe and stable over time, protecting their cultural and architectural history for future generations.

CHAPTER 6

CONCLUSIONS

6.1 Summary of Key Theoretical Findings and Insights

Masonry walls for their load-bearing capacity, have played a pivotal role in the architectural heritage of many civilizations, serving as the foundation for numerous structures. Many buildings in Albania are constructed using unreinforced masonry (URM), with the most often seen varieties being residential dwellings. The study specifically examined how different designs alter load pathways, stress distribution, and overall stability.

The walls of Tirana are constructed with clay and calcium silicate bricks, which provide structural support to the structures. The selection of these bricks was based on their accessibility, affordability, and compatibility with the prevailing construction techniques of that era.

A macro-modelling approach was used to analyze the structural dynamics of a deteriorated structure. This approach considers the whole structure as a cohesive unit, rather than focusing on individual components such as bricks and mortar joints. The walls, constructed from bricks and mortar, will be regarded as homogenous, anisotropic substances that demonstrate their typical behavior. Digitizing the building is a crucial stage in the structural analysis process, which involves gathering data and taking measurements on-site. The MasterSeries program is used for finite element modeling, a technique employed to analyze and investigate the structural behavior of buildings under varying loads.

Studying the structural behavior and load distribution of historic brick structures provides valuable insights into the impact of various opening designs and modifications on the buildings. Arched and circular apertures are more effective since they distribute loads uniformly and maintain structural stability. By using this approach, the preservation of historical structures' memory is ensured for future generations, so safeguarding architectural legacy for an extended period.

6.2 Concluding Remarks on the Influence of Openings in Load-Bearing Masonry Walls

An analysis of apertures in load-bearing masonry walls demonstrates their significant influence on structural integrity, a crucial factor in the conservation and refurbishment of historical structures. This section provides final observations on the impact of openings on structural integrity and the implications for engineering practice and conservation initiatives.

Openings in load-bearing masonry walls are crucial sites where the structural integrity is disrupted, leading to major impacts on the distribution of weight and concentration of stress. Nevertheless, the presence of non-uniformly shaped apertures brings about complications, necessitating customized reinforcing solutions to maintain the structural stability. Structural analysis methodologies need to include the existence of openings and assess their influence on load pathways and stress distribution.

To maintain the long-term stability of masonry walls with openings, it may be required to use strategic reinforcing measures, such as lintels and arches, in order to decrease stress concentrations. In addition, advancements in computer modeling and structural simulation provide useful tools for predicting and improving the performance of brick buildings under different types of loads. In order to maintain the integrity of historical structures, preservation efforts must find a harmonious equilibrium between structural modifications and architectural authenticity. Although interventions such as reinforcement may be required to address structural risks, it is crucial to execute them with consideration for the building's historical character.

To summarize, the impact of apertures in load-bearing masonry walls on structural integrity is a complex issue that has significant consequences for engineering practices and conservation initiatives. Engineers can secure the long-term survival of historical structures and preserve their architectural legacy by identifying the structural difficulties presented by openings and adopting reinforcing solutions based on evidence. By engaging in multidisciplinary cooperation and adhering to best practices in conservation engineering, we can ensure the long-term preservation of load-bearing masonry walls, allowing future generations to fully appreciate and enjoy their structural integrity.

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