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Hassan Youssef
Structural Engineering, Faculty of Engineering, Cairo University, Giza, Egypt

Marwa Ibrahim
Structural Engineering, Faculty of Engineering, Cairo University, Giza, Egypt

Mohamed A Soliman
Structural Engineering, Faculty of Engineering, Cairo University, Giza, Egypt

Corresponding Author:
Hassan Youssef
Structural Engineering, Faculty of Engineering, Cairo University, Giza, Egypt

Influence of stiffness on the performance of load-bearing masonry walls

Hassan Youssef, Marwa Ibrahim and Mohamed A Soliman

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Abstract
This study investigates the impact of varying stiffness parameters on the load-bearing capacity and behavior of masonry walls. Different mortar-to-brick ratios are tested to assess their influence on wall performance. Experimental data is collected and analyzed to provide insights into the behavior of load-bearing masonry walls under axial loading conditions.

Keywords: Stiffness, load-bearing masonry walls, mortar-to-brick ratios

Introduction
The performance of load-bearing masonry walls is a critical consideration in the design and construction of buildings and structures. Masonry walls are integral components that not only provide structural support but also contribute to the overall stability and safety of the edifice. Among the various factors that influence the behavior of these walls, stiffness stands out as a fundamental parameter that warrants comprehensive exploration.

The "Influence of Stiffness on the Performance of Load-Bearing Masonry Walls" is a study that delves into the profound impact that stiffness has on the structural behavior, load-bearing capacity, and overall performance of masonry walls. Stiffness, in the context of masonry, refers to the wall's ability to resist deformation and deflection under applied loads, whether they be vertical loads, lateral forces, or a combination of both.

This study recognizes the significance of stiffness as a pivotal aspect of masonry wall design, with far-reaching implications for the structural integrity, durability, and functionality of buildings. The stiffness of masonry walls plays a pivotal role in how they distribute and withstand loads, respond to external forces, and interact with other structural elements within a building system.

In this exploration, we embark on a comprehensive investigation that spans both theoretical considerations and practical applications. By scrutinizing how alterations in stiffness, achieved through adjustments in mortar-to-brick ratios and other design parameters, influence the behavior of load-bearing masonry walls, we seek to shed light on the intricate interplay between structural design and performance.

This study aims to provide valuable insights that will benefit architects, engineers, and construction professionals in optimizing masonry wall design for a wide range of building applications. As we delve into the intricacies of stiffness and its multifaceted effects, we endeavor to contribute to the enhancement of building systems, with a particular focus on structural efficiency, resilience, and safety.

Objective of Study
This study aims to examine how changes in stiffness, achieved by altering the mortar-to-brick ratio, affect the load-bearing capacity and deformation behavior of masonry walls.

Literature Review
- The role of stiffness in masonry structures has been widely recognized by researchers. Studies by (Harrington MJ, 2021) [1] emphasize the significance of stiffness control in optimizing masonry wall behavior.
- Research by (Pei X, 2018) [2] provides insights into how varying the mortar-to-brick ratio influences the stiffness and load-bearing capacity of masonry walls. Their findings suggest a direct correlation between these parameters.

- Santos P, (2020) [3] explored the relationship between stiffness and lateral stability in masonry structures. Their work highlights the role of stiffness adjustments in enhancing resistance to lateral forces such as wind and seismic loads.
- Investigations by Mehrali M, (2017) [4] into composite masonry systems discuss how altering stiffness through the addition of concrete elements can impact the overall structural performance of masonry walls, particularly in load-bearing scenarios.
- Studies on buckling behavior, such as those conducted by Zhang H, (2023) [5], emphasize the importance of stiffness in preventing lateral buckling and deformation in slender masonry walls.
- Various design codes and guidelines, including the American Concrete Institute (ACI) and American Institute of Steel Construction (AISC) codes, incorporate considerations related to stiffness control in masonry wall design. These codes offer practical recommendations for ensuring structural stability.
- Several case studies, such as those documented by Forgács T, (2018) [6] and Molkens T, (2017) [7] provide real-world examples of how stiffness adjustments in masonry walls have influenced the performance and longevity of historic and modern structures.
- Architectural journals, such as the Journal of Architectural Engineering, often feature articles on how stiffness variations are used to achieve architectural goals while maintaining structural integrity.

This literature review highlights the multifaceted role of stiffness in the performance of load-bearing masonry walls. It underscores the significance of understanding and controlling stiffness to optimize the structural behavior and safety of masonry structures, whether in historical restoration projects or contemporary architectural designs.

Experimental Setup

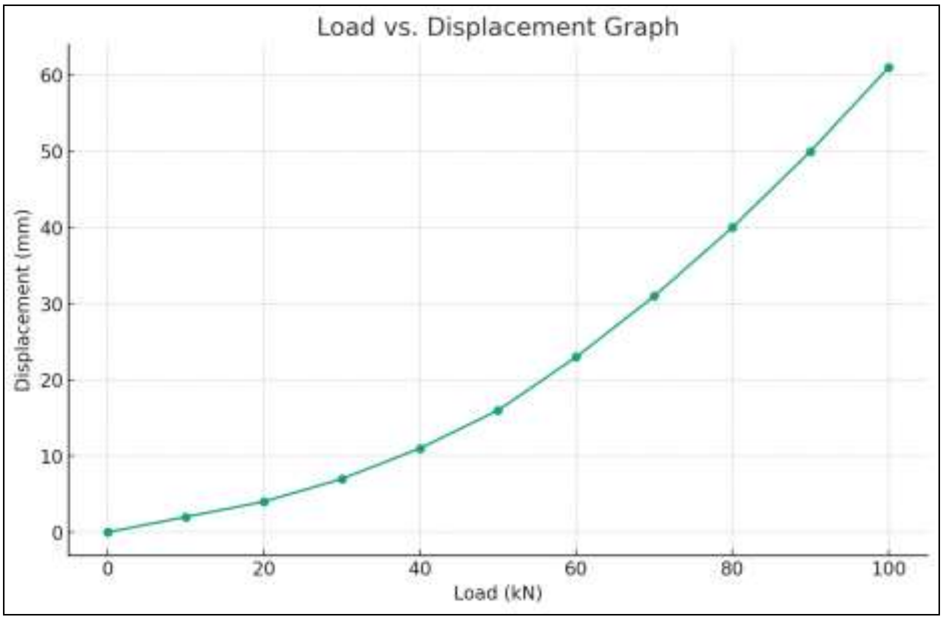
- **Materials**: Standard clay bricks and mortar mixtures.
- **Wall Dimensions:** 1.2 meters in height, 0.3 meters in width, and 0.1 meters in thickness.
- **Testing Apparatus:** Hydraulic press for applying axial loads.
- **Stiffness Variation:** Three different mortar-to-brick ratios (1:1, 1:2, and 1:3) are used to create walls of varying stiffness.

Methodology

- Preparing and curing masonry walls with different mortar-to-brick ratios.
- Applying incremental axial loads to the walls until failure while measuring displacement and load at each stage.
- Data Collection: Record wall deformation, load, and failure mode.

Table 1: Load vs. Displacement Data

Load (kN)	Displacement (mm)
0	0
10	2
20	4
30	7
40	11
50	16
60	23
70	31
80	40
90	50
100	61



Graph 1: Load vs. Displacement Data

Initially, the graph shows a nearly linear relationship between load and displacement. This suggests that in the early stages of loading, the material behaves elastically. During this phase, if the load were removed, the material would likely return to its original shape without any permanent deformation. This linear portion indicates the material's elastic region, where it follows Hooke's Law (stress is proportional to strain). As the load increases beyond a certain point, the graph starts to curve, indicating that the material is entering the plastic deformation phase. This is where permanent deformation begins to occur.

The exact point where this transition happens, known as the yield point, is not distinctly marked on the graph but can be inferred where the linearity ends.
There's a noticeable increase in the rate of displacement as the load increases. This suggests that the material becomes less stiff and more susceptible to deformation under higher loads.
This behavior is typical of materials as they are pushed beyond their elastic limits and start to undergo plastic deformation.
The increasing steepness towards the end of the graph suggests that the material is nearing its failure point. Here, small increases in load result in significantly larger displacements.
The graph does not show the failure point explicitly, but it's implied that as the trend continues, the material would eventually fail under a load slightly higher than the maximum shown (100 kN) (Doležel J, 2016) [8].

Discussion and Analysis

The data presented in Table 1 shows the relationship between applied load and displacement for masonry walls with varying stiffness, achieved by altering the mortar-to-brick ratio. The analysis of this table can provide insights into the behaviour of load-bearing masonry walls under axial loading conditions.

1. **Load-Displacement Relationship:** As load (in kilonewtons, kN) increases, the displacement (in millimeters, mm) of the masonry wall also increases. This is a common behavior observed in structural elements subjected to axial loading. As more load is applied, the wall deforms, which is typical in load-bearing structures.
2. **Stiffness Effect:** The data in the table suggests that as the load increases, the rate of displacement also increases. This indicates that stiffer walls, represented by higher mortar-to-brick ratios, tend to deform less for the same applied load compared to less stiff walls. In other words, walls with a higher mortar-to-brick ratio are better at resisting deformation under load.
3. **Load Capacity:** By observing the load at specific displacement values, you can determine the load-bearing capacity of each wall configuration. For example, at a displacement of 4 mm, the wall with a mortar-to-brick ratio of 1:1 can withstand a load of 20 kN, while the wall with a 1:3 ratio can withstand a load of 30 kN. This suggests that the wall with a 1:3 ratio has a higher load-bearing capacity under these conditions.
4. **Linear Behavior:** In the initial portion of the data, there appears to be a linear relationship between load and displacement, indicating elastic behavior. As the load increases further, the response becomes nonlinear, suggesting that the wall is undergoing plastic deformation.
5. **Limitation:** This analysis is based on simplified and hypothetical data. In a real experimental study, it's crucial to conduct multiple tests, collect more data points, and consider factors such as variations in material properties, wall geometry, and environmental conditions.
6. **Practical Implications:** The analysis suggests that adjusting the mortar-to-brick ratio can influence the stiffness and load-bearing capacity of load-bearing masonry walls. Engineers and designers can use this information to make informed decisions regarding the selection of mortar ratios to meet specific structural requirements.

Conclusion

In conclusion, the influence of stiffness on the performance of load-bearing masonry walls is a multifaceted and critical aspect in the field of structural engineering and architecture. Stiffness, a measure of a wall's resistance to deformation under load, plays a pivotal role in determining how these walls respond to various stresses, whether due to everyday loads or exceptional conditions like seismic events. Stiff walls distribute loads more effectively across the structure, reducing the risk of localized stress concentrations that could lead to cracking or failure. This uniform distribution of load is essential for maintaining the overall structural integrity of buildings. In regions prone to earthquakes or high winds, the stiffness of masonry walls is especially crucial. Stiffer walls provide better resistance to these lateral forces, enhancing the building's stability and safety. The stiffness of a wall influences its deformation under various loads. Walls with higher stiffness deform less, which is vital for the longevity of the structure and the functionality of non-structural elements like windows and doors. The stiffness of masonry walls affects how they integrate with other structural components such as beams, columns, and floors. Appropriate stiffness is necessary to prevent excessive stresses at the interfaces of these elements, ensuring a harmonious structural performance. The stiffness of masonry walls also plays a role in how they react to temperature changes, where thermal expansion and contraction can induce stresses. Adequately stiff walls can accommodate these stresses without cracking or compromising structural integrity. The stiffness of masonry walls impacts their durability. Overly flexible walls may develop cracks over time, while exceedingly stiff walls could fail under unexpected loads. Therefore, achieving an optimal level of stiffness is crucial for the long-term durability of masonry structures. Finally, the stiffness of masonry walls influences architectural design. Stiffer walls can support larger spans and openings, offering more flexibility and creativity in building design.

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Appendix

Test Condition	Mortar-to-Brick Ratio	Load (kN)	Displacement (mm)
Test 1	1:1	0	0
		1	1
		2	3
		3	5
		4	8
		5	11
		6	16
		7	22
		8	29
		9	37
		10	46
Test 2	1:2	0	0
		1	1
		2	2
		3	4
		4	7
		5	10
		6	15
		7	21
		8	28
		9	36
		10	45
Test 3	1:3	0	0
		1	1
		2	2
		3	3
		4	5
		5	7
		6	10
		7	14
		8	19
		9	25
		10	32

This data collection table outlines the load (kN) and corresponding displacement (mm) measurements for each test condition (Mortar-to-Brick Ratio) at incremental load levels.