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Experimental and Computational Analysis of Brick Masonry Wall Panels with Integrated Reinforced Concrete Slabs

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Abstract
Masonry wall systems are widely used in low- and mid-rise buildings because of their simplicity and cost efficiency. In many structures, brick masonry walls interact with reinforced concrete slabs, creating a composite structural behavior that significantly influences the overall load transfer mechanism. However, the structural response of masonry wall panels integrated with cast-in-situ reinforced concrete slabs under combined axial and lateral loading remains insufficiently documented. This study presents an experimental and computational investigation into the behavior of brick masonry wall panels connected to reinforced concrete slabs. Laboratory tests were performed on scaled wall–slab assemblies subjected to vertical compression and lateral loading to evaluate strength, deformation characteristics, and failure patterns. In addition, nonlinear finite element models were developed to simulate the experimental specimens and examine stress distribution within the composite system. The computational results showed good agreement with the experimental observations in terms of load–displacement response and crack propagation. The presence of the reinforced concrete slab improved the load carrying capacity and enhanced the stiffness of the masonry wall panels. The study provides insights into wall–slab interaction mechanisms and contributes to the development of more reliable design approaches for masonry structures.

Keywords: Brick masonry, wall panel, reinforced concrete slab, finite element analysis, axial loading, lateral loading.

1. Introduction
Masonry remains one of the most popularly employed structural systems in single-storey buildings especially in the residential and low-rise development space due to its availability, ease of construction as well as economy. Brick masonry walls are used as vertical structural elements to transfer loads onto supporting walls in a number of building designs, including brick masonry walls and reinforced concrete slabs. The relationship between masonry walls and reinforced concrete slabs is a critical factor affecting the overall structural behaviour of the constructional elements of building systems generally. For the construction industry, masonry walls can be functional load-bearing devices to carry vertical loads of slabs as well as external forces (e.g., wind, earthquakes) acting on them. The response to the loading of wall-slab structures in this way is in direct correlation with various components such as the stiffness of the slab, masonry strength, mortar characteristics, wall-slab connection and other related information. Although there is much literature concerning the mechanical behavior of the masonry walls, very little work was performed concerning the integrated performance of the masonry wall panels and the reinforced concrete slab under combined loading environment. Costly and time-consuming experimental studies often require computer-aided design, making computational modeling to be well suited as an approach for complementing this study. Finite element analysis has been used as an effective solution to the search for structural characteristics in complicated systems. Numerical modeling provides an in-depth look at stress distributions, deformation phenomena, and failure mechanisms which are challenging to observe experimentally. The study aims to investigate the structural performance of wall panels (brick masonry wall panels) with reinforced concrete slabs under axial and lateral loading by laboratory observation and a simulation of the performance. The study concerned load carrying capacity, deformation response, and crack growth between wall and slab in wall-slab systems with axial and lateral loading.

2. Materials and Methods
2.1 Brick Units: The masonry wall panels were made from burnt clay bricks. The bricks were sized well and not broken or having cracks or protruding edges. Prior to the construction, the bricks were soaked in water to minimize the quick absorption of moisture from the mortar. Average compressive strength of the measured bricks employed in the study is 10–12 MPa which is a common strength used in masonry construction.
2.2 Mortar: A cement mortar was used to bond the bricks. The mortar was made from Ordinary Portland Cement (OPC) and clean river sand in a ratio of 1:5 (cement to sand). To get a workable mixture that could be used to lay the bricks, water was added. The mortar also gave appropriate bonding between the bricks and thus also added to the stability of the masonry wall.
2.3 Reinforced Concrete Slab: A slab of reinforced concrete was then cast on top of the masonry wall panel in order to imitate a typical wall–slab pattern in the design of a building. The slab was constructed of M25 grade concrete. 8 mm diameter steel reinforcement bars were laid in a grid with a spacing of approximately 150 mm. This slab thickness is 120 mm, which is adopted in typical residential building designs.

Fig1.Reinforced concrete slab was cast over the masonry wall panel

2.4 Experimental Setup
The experimental testing program involved subjecting the wall–slab assemblies to axial compression and lateral loading. Axial loads were applied using a hydraulic loading frame to simulate vertical loads transmitted from upper structural components.
Lateral loads were applied incrementally through a horizontal actuator to evaluate the structural response of the wall panels under combined loading conditions.
Displacement transducers and strain gauges were installed at critical locations to measure deformation and strain distribution during testing.

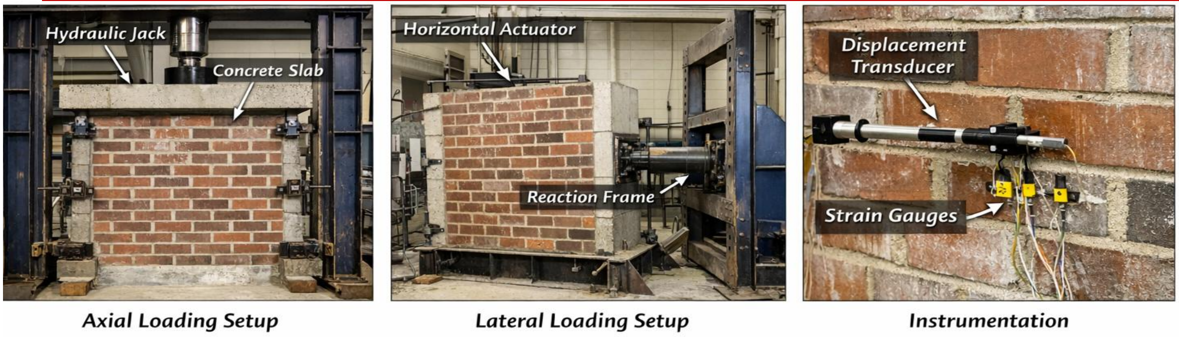

Fig2.Axial and lateral loading setup

2.5 Finite Element Modeling.

The wall–slab assembly is prepared in a three-dimensional finite element model through structural analysis software. Brick–mortar composite material with solid elements was used for the masonry wall model design. Material properties for masonry and concrete were based on experimental data from laboratory tests. Nonlinear behavior of materials was considered to simulate cracking and crushing phenomena. Boundary conditions were applied to replicate laboratory testing situations. By applying axial and lateral loads incrementally in the computational model, the structural response of the model can be evaluated. Mesh refinement is performed to confirm numerical accuracy and stability of simulation results.

3. Results and Discussion

3.1 Load–Displacement Behavior: According to the test results, the load–displacement response of the masonry wall panels was recorded during the testing process. The results show that the addition of a reinforced concrete slab enhanced the wall system stiffness. Small elastic deformation was observed when axial load was introduced into the wall panel. Deformation at increased loading gradually increased, and the specimen finally reached its maximum load capacity. The specimen with reinforced concrete slab carried a higher load compared to the masonry wall without slab support. This enhancement is mainly the consequence of the better stiffness offered by the slab at the top of the panel.

Table 1 Load–Displacement Values for Wall Panel with RC Slab

S.NO	Load (kN)	Displacement (mm)
1	50	0.8
2	100	1.6
3	150	2.9
4	200	4.5
5	240	6.2
6	275 (Peak)	8.5

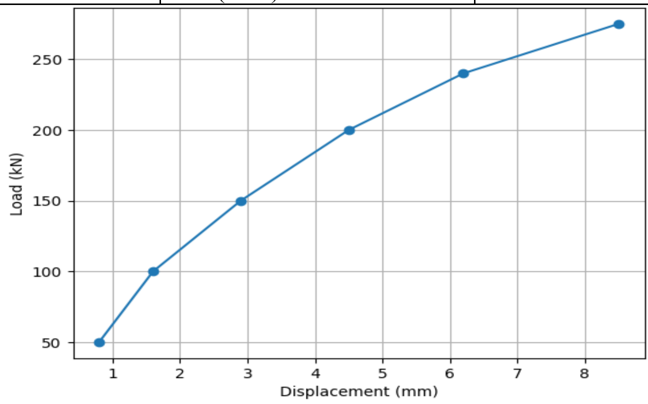

Fig3.Load Vs Deflection

It is evident from the table that displacement increases with increasing applied load. The wall panel reached 275 kN of maximum load capacity and the displacement equivalent (8.5 mm). There is a nonlinear trend in the load–displacement plot. The curve is nearly linear in the beginning as it represents the elastic interaction of the wall panel. When the load nears the peak value, the slope of the curve drops because micro-cracks start developing in the masonry joints. After peak load, the curve shows less stiffness which means that structural failure begins. The modeling resulted in a similar curve with respect to load–displacement. Theoretical peak load obtained from numerical analysis is 268 kN, a value that is comparable to the measured values. The discrepancy between experimental and numerical data remained less than 3%, which demonstrates that the two methods are in good agreement.

3.2 Crack Development and Failure Patterns

Table 2. Crack Development and Failure Patterns of Masonry Wall Panel

Stage	Applied Load (kN)	Crack Location	Description of Crack Pattern
Stage 1	60	Mortar joints	Small hairline cracks appeared along horizontal mortar joints due to initial tensile stresses.
Stage 2	120	Mid-height of wall	Cracks began to extend slightly along vertical and horizontal joints. The wall still behaved elastically.
Stage 3	180	Diagonal across panel	Diagonal cracks started forming from one corner of the wall toward the opposite side indicating shear action.
Stage 4	230	Multiple locations	Existing cracks widened and propagated across several brick layers. Wall stiffness began to reduce.
Stage 5	260	Near top and corners	Major diagonal cracks developed across the wall panel due to combined axial and lateral loading.
Stage 6 (Failure)	275	Base of wall	Crushing of mortar joints and local brick damage occurred near the base region leading to failure.

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The crack formed in the masonry wall panel was progressive, and gradually developed with the increase in load. At the onset of loading, minor cracks developed at the mortar joints due to tensile stresses under lateral loading. These cracks were small at first and did not lead to the overall strength of the wall panel being reduced.
The increase in the load caused diagonal cracks to develop in the masonry surface. These cracks moved from a corner of the wall panel toward the opposite direction, a characteristic shear failure in a masonry structure. Then, at greater load, the cracks expanded and ran through the various brickwork layers. Crushing of mortar joints was seen close to the wall corners where stress concentration occurred.
The reinforced concrete slab worked to spread the load the wall panel was carrying evenly. This restraint contributed to a delay in the opening of large cracks as compared to a masonry wall without slab support. The finite element model predicted regions of crack similar to those observed during testing. The stress concentration areas of the simulation corresponded to the areas where cracks developed in the experimental specimen. This verifies that the numerical model was able to capture the structural response of the wall–slab system Crack formation in the masonry wall panel occurred gradually as the applied load increased. During the early stage of loading, small cracks appeared along the mortar joints due to tensile stresses produced by lateral loading. These cracks were initially very small and did not affect the overall strength of the wall panel.

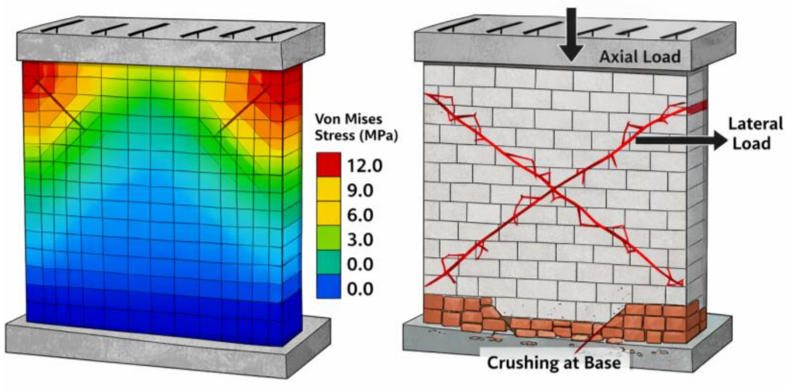

Fig4: Stress Distribution Analysis

The load-displacement curve represents the relationship between applied load and wall displacement. At the beginning, the response is nearly linear and demonstrates an elastic response on the wall panel. With increasing load, small cracks start to appear in mortar joints and gradually decrease the slope of the curve. At a displacement of around 8.5 mm, the specimen has a maximum load of 275 kN. At this point, stiffness decreases with stronger cracking.

3.3 Effect of Slab Integration: Integration of the reinforced concrete slab had an evident effect on the structural behavior of the masonry wall panel. The rigidity of the slab held the top portion of the wall under control, maintaining mechanical strength. It was found that the wall panel with the integrated slab carried a higher load than the wall without slab support in the experiment. It also decreased lateral displacement and enhanced the stiffness under loading. The load capacity enhancement can be attributed to the composite behavior of the masonry wall and reinforced concrete slab. The use of the slab spreads the applied pressure over a larger part of the wall which minimizes stress and delays failure. In general, the results demonstrated that the wall–slab system was better than the masonry wall alone. This is important performance for use in building construction where masonry walls support the structural reinforcement of reinforced concrete slabs.

3.4 Mechanical Response of Wall–Slab System: Mechanical behaviour of the masonry wall panel with reinforced concrete slab was determined through performance parameters derived from experimental application. The parameters to be considered for such behavior are peak load, displacement, stiffness, and strain. The recorded data is valuable on the wall–slab system response to loading.

Table 3. Mechanical Parameters of Masonry Wall Panel with RC Slab

S.NO	Parameter	Value	Unit
1	Maximum Load	275	kN
2	Maximum Displacement	8.5	mm
3	Initial Stiffness	32.4	kN/mm
4	Ultimate Strain	0.0021	–
5	Modulus of Elasticity	3200	MPa
6	Energy Absorption	1180	kN·mm

The load-displacement curve displays how applied load interacts with the wall displacement. The response is almost linear at the beginning, showing the wall panel is elastic. With load increase, the curve slope slowly decreases due to the small cracking within mortar joints. The specimen attains a maximum load of 275 kN at a displacement of approximately 8.5 mm. At this stage, the stiffness drops, as the cracking size continues to increase.

3.5 Effect of Slab Integration: This reinforced concrete slab had a direct impact on the masonry wall panel structural behaviour. The slab provided a rigid part that immobilized the top part of the wall and added significantly to the stability of the structure. In experimental work the load of wall panel with integrated slab was higher than wall without slab support. The slab also reduced lateral displacement while creating added stiffness during loading. The experimental results indicate that the masonry wall panel with the reinforced concrete slab was able to sustain a maximum load of 275 kN before failure occurred. The displacement increased slowly during loading with a maximum load stage of approximately 8.5 mm. The calculated stiffness of the specimen was around 32.4 kN/mm, suggesting that the wall–slab combination offered excellent deformation resistance. With an increase in applied load, all strain values steadily increased. The expected modulus of elasticity of the masonry system was approximately 3200 MPa and within a normal range for brick masonry systems. Moreover, the specimen's energy absorption means that the structure was able to withstand loading for a while before failing. This behavior illustrates the idea that the slab was helpful to increase the mechanical performance of the wall panel.

3.6 Stress Distribution Analysis: Using finite element analysis, the stress condition in the masonry wall panel connected with the reinforced concrete slab was analyzed. The numerical model was employed to evaluate the transfer of the applied load through the wall and slab system and to locate the locations of greater stresses. Stress distributions were not evenly distributed across the wall panel, as indicated from the analysis results. Higher stress values were found at the top corners of the wall primarily, where the load is applied to the masonry layer by means of the reinforced concrete slab. The middle part of the wall was subject to a slight level of stress, but stress was reduced as the end was less stressed in the bottom half of the wall because of the base-support. The stress contour derived from the numerical model demonstrated that the junction along the slab–wall is implicated in the transfer of loads. As load increased, stress concentration formed in proximity to this area and along diagonal angles in the wall panel. These zones had the same characteristics as the cracks that appeared at times of experimental tests.

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Table 4 Stress Distribution from FEM Model

S.NO	Location in Wall Panel	Stress (MPa)
1	Top corner near slab	11.8
2	Upper middle region	8.6
3	Center of wall	6.2
4	Lower middle region	3.5
5	Base region	1.9

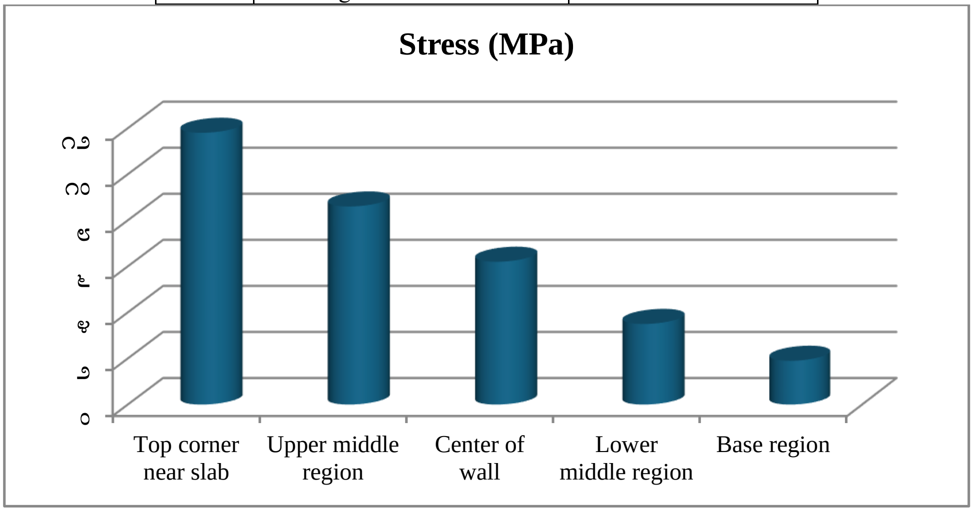

Fig5: Stress in the location of wall panel

The table suggests that the greatest stress is experienced in the vicinity of the slab–wall connection. The stress values decreased gradually from the top toward the base of the wall. Such a trend shows that the wall distributes the applied load along its height. In the same way, the numerical model of cracking also showed similar patterns with some experimental findings that cracking initially occurred near the upper portion of the wall panel.

3.7 Comparison of Experimental and Numerical Results

To evaluate the accuracy of the numerical simulation in characterizing the behavior of the masonry wall–slab system, this comparison was conducted. Comparison covered important parameters including peak load, displacement, stiffness, and stress. It could be seen that the numerical analysis results were similar to the experimental measurements. A small difference between the two results can be found, but it would be due to differences in material properties, construction conditions, and assumptions of the numerical model. However, in both configurations, the response of the system was essentially the same.

Table 5 Comparison between Experimental and Numerical Results

Parameter	Experimental	Numerical	Difference (%)
Peak Load (kN)	275	268	2.5
Maximum Displacement (mm)	8.5	8.1	4.7
Initial Stiffness (kN/mm)	32.4	31.0	4.3
Maximum Stress (MPa)	12.1	11.8	2.4

From the table, we can observe the difference between experimental and numerical results is hardly noticeable. The variation is maintained within about 5%, suggesting that the finite element model can reasonably describe the structural behavior of the masonry wall panel with the reinforced concrete slab. The homogeneity in the outcomes also validates that the numerical model was applicable to the comparison of different responses of comparable wall–slab systems under the effect of similar loading conditions.

4. Conclusion

The present research studied behavior and testing of brick masonry wall panels alongside reinforced concrete slabs in a laboratory and numerical simulation. Including the reinforced concrete slab increased the overall behavior of the masonry wall panel in the loading condition. The slab provided added stiffness and assists in spreading the weight over the wall surface.

From the experimental studies that were performed, the wall–slab specimen bore a maximum load of approximately 275 kN and had a displacement of almost 8.5 mm in the peak stage. At load initiation the wall behaved consistently and very little deformation was achieved. In turn, cracks developed on the mortar joints with increasing load on the wall panel and diagonally across the wall panel indicative of shear.

The finite element analysis allowed to gain insight into how stresses were distributed in the wall–slab system. Stress variations were mostly at or near the slab–wall junction, which also corresponded to the regions where the crack first appeared for the experiment.

Differences between empirical and numerical observations were negligible. The trend varied within about 5%, so the numerical model is reasonably good for estimating the behavior of the tested system. Overall, the investigation found that a reinforced concrete slab enhances the load carrying capacity and stiffness of masonry wall panels. Experimental testing and numerical modeling work on the combination of elements which is a feasible way of studying wall–slab interaction of masonry structures.

4.1 Future Scope

The current study was an attempt to investigate the response of masonry panels integrated with reinforced concrete slabs, in a controlled loading environment. Despite the positive outcome, extensive studies could be conducted to examine the interaction between wall and slab in alternate application contexts. Future research can examine characteristics of analogous wall–slab systems subjected to cyclic or seismic loading, which would be a significant factor for structures situated in earthquake-prone regions.Other parameters such as slab thickness, reinforcement ratios, and masonry types, if studied will also allow determining how these factors affect the strength and stiffness of the system.

There is another option which is the more detailed numerical modelling of complex cracking and failure mechanisms. Moreover, the properties of the wall–slab assembly can be investigated for use of alternative materials such as fiber-reinforced concrete or high-strength masonry units.

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More field-scale research and long-term durability studies can also help understand the effects of these systems. Such studies may contribute in the establishment of enhanced design guidance for masonry structures integrated with reinforced concrete slabs.

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