Chapter 8

Conclusion and Future scope

8.1 General Discussion

Confined Brick Masonry (CBM) buildings have been widely adopted in earthquake-prone areas and are gaining global popularity. This is largely due to their superior seismic performance, affordability, and straightforward construction methods. Over the years, guidelines and design codes have been created in few countries to provide fundamental details on CBM and encourage its construction. However, the engineering behaviour of these buildings is not well understood due to variations in materials, insufficient research to comprehend the complex composite mechanisms, and a lack of development in the building sector. There exists significant research gaps, particularly in reliable analysis and design methods under gravity and seismic loads. This study aims to evaluate the behaviour of confined brick masonry walls through comprehensive numerical and analytical investigations. This chapter summarises the study's findings, outlines major conclusions, discusses limitations, and offers recommendations for future research.

8.2 Summary

This research investigates the seismic performance of confined brick masonry (CBM) walls through finite element modelling and parametric analysis. It focuses on the effects of various parameters, such as toothing schemes, confinement methods, and masonry properties, on the structural integrity of CBM walls under seismic loads.

The study examines aspects like wall thickness, opening sizes, and confinement schemes, analysing their influence on the ultimate strength, stiffness, and energy dissipation capacity of the walls. It also explores the impact of openings, representing 10% of the masonry area, and how different confinement techniques can mitigate the reduction in strength caused by these openings.

Toothing schemes are a critical element, with machine-made units generally providing superior strength and stiffness compared to hand-made ones. Additionally, the analysis of masonry properties reveals that walls constructed with higher compressive strength bricks show increased strength and ductility.

This research offers valuable insights and recommendations for optimising CBM wall design under seismic conditions through advanced modelling and a detailed understanding of the key factors affecting performance.

8.3 Conclusion

This comprehensive investigation into the seismic performance of CBM walls with various opening configurations, toothing schemes, and material parameters yields critical insights that can significantly inform and improve the design and construction of more resilient masonry structures. The key findings and their implications for structural engineering practice are summarised below:

1. Effect of opening size and area

The research reveals that the size and area of openings in CBM walls substantially influence their structural performance. Larger openings lead to a marked reduction in ultimate strength, stiffness, and energy dissipation capacity. This is primarily due to the diminished effectiveness of the diagonal compression strut mechanism, which is crucial for distributing and resisting applied loads. Additionally, larger openings introduce stress concentrations, especially at the corners, which act as initiation points for crack development and propagation. Conversely, when the opening area is kept below 10% of the masonry area, the load path remains largely undisturbed, preserving the wall's structural integrity. To mitigate the adverse effects of larger openings, it is recommended to incorporate confining elements around such openings, ensuring that the overall stability and strength of the CBM wall are maintained.

2. Shape and position of openings

The shape and position of openings play significant roles in the seismic performance of CBM walls. Rectangular openings with a height greater than their width are found to be more effective in resisting lateral forces compared to square openings or rectangular openings with a greater width. This is attributed to the enhanced load distribution characteristics of taller rectangular openings. Furthermore, the positioning of window and door openings relative to the loading point is crucial. Openings positioned farther from the loading point exhibit improved ultimate strength, as they allow for more efficient force distribution within the wall. However, placing door openings at the centre of the wall compromises stiffness due to their intersection with the loading diagonal, thereby affecting the wall's ability to effectively distribute and withstand applied loads.

3. Combination of window and door openings

The combination of window and door openings within a CBM wall presents unique challenges. While the ultimate strength remains consistent regardless of whether the window is placed on the left or right side of a central door, stiffness is observed to be higher for right-side window openings. However, having windows on both sides of a central door significantly reduces both ultimate strength and stiffness. These findings underscore the importance of strategic placement and combination of openings to optimize the structural performance of CBM walls.

4. Confinement strategies

Confinement around openings emerges as a critical factor in enhancing the seismic performance of CBM walls. While Confinement Scheme G demonstrates a notable 4.6% increase in ultimate strength compared to walls without openings, it may not be the most economically viable solution. More cost-effective alternatives, such as schemes A or E, offer substantial performance improvements while balancing economic feasibility. These confinement strategies effectively alleviate stress concentrations and mitigate the risk of localised failures near the corners of openings, thereby enhancing the overall structural integrity of CBM walls.

5. *Toothing schemes and wall thickness*

The study extensively explores the impact of different toothing schemes and wall thickness on seismic performance. Machine-made toothing schemes significantly outperform hand-made and no-tooth schemes, offering notable enhancements in ultimate strength, stiffness, and energy absorption. Variations in tooth size within machine-made schemes further influence seismic parameters, providing valuable insights for practical implementation. Additionally, increased wall thickness correlates with improved ultimate strength and stiffness, with machine-made units proving most effective in optimising these parameters. The investigation into vertical and horizontal projections of toothing highlights the importance of precise design considerations, with a 100-mm vertical projection outperforming a 200-mm projection in key seismic parameters.

6. *Material properties and mortar mix proportions*

In CBM structures, the choice of masonry materials and mortar mix proportions significantly impacts ultimate strength and seismic performance. Increasing the compressive strength of fly ash (FA) and clay bricks results in an expected rise in ultimate strength. However, clay bricks with a compressive strength of 3.8 exhibit lower seismic performance compared to FA bricks with a compressive strength of 3. This finding underscores the importance of selecting appropriate masonry types and optimising mortar mix proportions to achieve optimal seismic resistance in CBM walls.

Implications of the present study on Structural Engineering Practice

This research provides valuable practical insights for the construction industry, particularly in seismic-prone regions. The findings advocate for the integration of strategically designed confinement schemes, optimal toothing configurations, and careful consideration of opening sizes, shapes, and positions to enhance the seismic resilience of CBM walls. Implementing these recommendations can significantly improve the durability and safety of masonry structures, ultimately reducing damage and ensuring better protection of life and property during earthquakes. This study serves as a comprehensive guide for engineers and builders, offering clear guidelines for designing more resilient and robust CBM buildings that can effectively withstand seismic forces.

8.4 Significant contributions

The findings of this study offer practical recommendations to improve the seismic performance of Confined Brick Masonry (CBM) structures and serve as a precursor to future research directions. Limiting openings to less than 10% of the masonry area, or reinforcing larger openings with effective confinement strategies, ensures the preservation of load paths and structural integrity. Cost-effective confinement schemes, such as Scheme A or E, strike a balance between performance and economic feasibility, while the use of high-strength materials, such as fly ash bricks, coupled with optimised mortar mixes, enhances durability and seismic resistance.

The implementation of machine-made toothing schemes has demonstrated superior performance in terms of strength, stiffness, and energy dissipation, making them an essential design consideration. Additionally, increasing wall thickness further amplifies these benefits, contributing to better overall resilience. The strategic placement of openings, such as taller rectangular shapes positioned away from central load paths, facilitates efficient load distribution and reduces stress concentrations, particularly at critical points.

These practical insights lay the foundation for designing CBM structures that achieve a robust balance between safety, functionality, and cost-effectiveness. They form a vital basis for advancing resilient masonry practices, ensuring better protection of life and property in earthquake-prone regions. This seamless integration of design improvements provides a stepping stone for the future research avenues outlined in the following section.

8.5 Future scope of work

Based on the findings of this comprehensive investigation into the seismic performance of confined brick masonry (CBM) walls, several avenues for future research and development are identified. These future studies can further refine our understanding and contribute to the advancement of resilient masonry construction practices.

1. Advanced confinement strategies

Future research could explore the development and testing of innovative confinement strategies beyond those studied. This includes:

- Experimenting with new materials and techniques for confinement, such as fiber-reinforced polymers (FRPs) or other composite materials, to enhance the seismic performance of CBM walls while maintaining cost-effectiveness.
- Investigating the long-term durability and performance of various confinement schemes under different environmental conditions and loading scenarios.

2. Optimisation of opening designs

Further studies could focus on optimising the design of openings in CBM walls to maximize structural performance:

- Conducting detailed parametric studies to explore the effects of varying opening shapes, sizes, and positions on wall performance under seismic loads.
- Developing design guidelines and predictive models for the optimal placement and sizing of openings to balance aesthetic, functional, and structural requirements.

3. Enhanced toothing configurations

Building upon the promising results of machine-made toothing schemes, future work could include:

- Investigating the effects of different tooth shapes, sizes, and arrangements on the seismic performance of CBM walls, particularly in combination with various wall thicknesses and confinement strategies.

- Studying the potential benefits of integrating machine-made toothing with advanced construction techniques such as 3D printing or modular construction.

4. Material Innovations

Exploring the use of novel materials in CBM construction can lead to significant improvements in seismic resilience:

- Evaluating the performance of new masonry materials, such as high-strength concrete blocks, lightweight aggregates, or eco-friendly alternatives, in combination with optimised mortar mixes.
- Investigating the impact of different mortar compositions, including the use of additives and admixtures, on the overall performance of CBM walls.

5. Performance-Based Design Approaches

Adopting performance-based design principles can enhance the resilience of CBM structures:

- Developing and validating performance-based design frameworks that incorporate the findings from this study to ensure that CBM walls meet specific seismic performance criteria.
- Conducting full-scale experimental testing and numerical simulations to validate and refine these performance-based design approaches.

6. Cyclic In-Plane Loading Analysis

A promising avenue for future research is extending this analysis to a cyclic in-plane loading scenario. Unlike monotonic pushover analysis, cyclic analysis can capture the progressive deterioration of structural capacity under repeated loading, providing a more comprehensive understanding of the hysteretic behaviour, energy dissipation, and stiffness degradation of confined brick masonry (CBM) walls. This would enable a more accurate assessment of their seismic resilience by simulating the effects of cyclic loading, which better represents real earthquake conditions.

7. Real-World Implementation and Case Studies

Conducting real-world case studies and pilot projects can provide valuable insights into the practical application of the research findings:

- Implementing the recommended design and construction practices in new CBM buildings and monitoring their performance over time.
- Documenting and analysing the outcomes of these projects to refine and improve the guidelines and recommendations for future constructions.

By pursuing these future research directions, the construction industry can continue to enhance the seismic resilience of masonry structures, ensuring better protection of life and property in seismic-prone regions. These efforts will contribute to the development of more robust, durable, and sustainable building practices, ultimately advancing the field of structural engineering.