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Load-Carrying Capacity of Interlocking Mortarless Masonry Walls

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Abstract - Interlocking mortarless masonry is an innovative and sustainable construction system that offers numerous advantages, including reduced material usage, faster construction, and minimized environmental impact. However, the absence of standardized design codes and guidelines poses a significant challenge to its widespread adoption, particularly in structural applications. This study presents an analytical investigation of load-bearing interlocking mortarless masonry using a finite element (FE) program designed for analysis of interlocking mortarless masonry to evaluate its structural behaviour. A parametric study was conducted to examine the influence of slenderness and eccentricity on the system's load-carrying capacity. Based on the numerical results, a predictive equation was proposed to estimate the load capacity under varying conditions. The comparison between the FE analysis and the proposed equation demonstrated good agreement, with deviations ranging within an acceptable range (from -7% to 11.5%), particularly at lower slenderness values (H/t=8). The findings of this study contribute to the development of standardized design guidelines for interlocking masonry, facilitating its broader adoption as a sustainable construction system.

***Keywords*:** sustainable construction, affordable housing, load-bearing walls, interlocking block, mortarless masonry

1. Introduction

Several sustainable construction systems have been developed for housing to enhance energy efficiency, affordability, environmental impact reduction, and conserve earth resources. Zero-energy housing integrates passive and active design features to optimize energy performance and reduce carbon emissions [1]. Interlocking block masonry, a mortar-less system, minimizes material waste and promotes rapid construction [2]. Prefabricated housing reduces waste through efficient off-site production and is gaining attention for sustainable development [3]. Recycled concrete construction helps reduce waste and conserves natural resources by incorporating recycled concrete aggregates (RCA), which have been proven to maintain structural integrity while reducing environmental impact [4-6]. These systems contribute to the transition toward more sustainable housing solutions by optimizing materials, minimizing energy use, and reducing environmental footprints. The widespread adoption of sustainable construction is hindered by financial, regulatory, awareness, market, and technological barriers. Addressing these challenges requires stronger policy frameworks, financial incentives, industry training, and better public awareness campaigns [7,8].

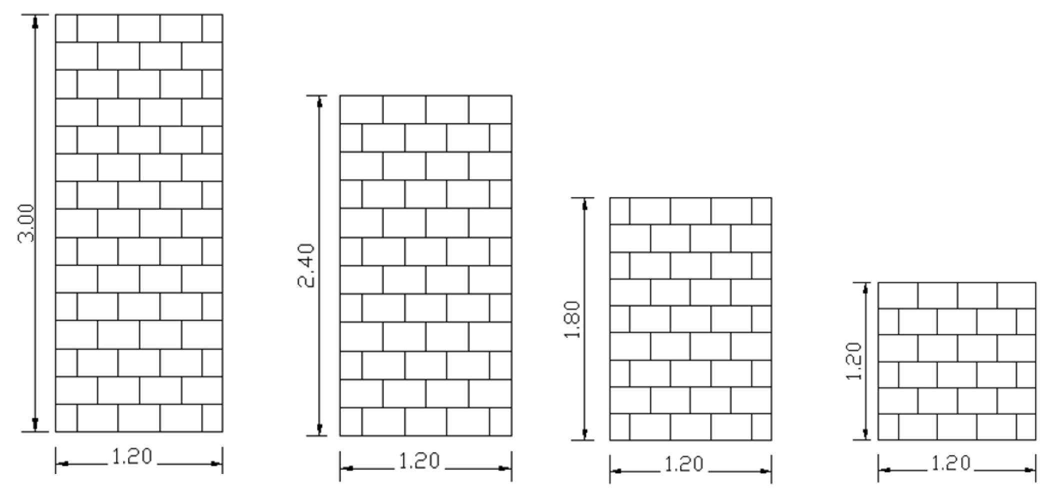
Interlocking mortar-less block masonry is gaining global recognition as a sustainable construction system due to its cost-effectiveness, reduced material consumption, and ease of assembly. Systems like Hydraform (Africa), Sparfil (South America), Meccano (Europe), and PUTRA blocks (Malaysia) have been developed to address local housing needs while reducing construction waste [9,10]. These systems eliminate the need for mortar, improving construction speed and reducing skilled labor dependency. However, challenges remain, including lack of standard design codes, limited structural validation, and resistance from conventional construction industries [11-13].

The absence of standardized design guides and formulas has contributed to the limited application of interlocking mortarless masonry within the construction industry. Addressing these gaps through research and standardization can enhance the widespread adoption of interlocking mortar-less masonry. This study presents an attempt to formulate a load-carrying capacity model for use in the structural design of load-bearing interlocking mortarless masonry. For the purpose of achieving the study goals, a Finite Element (FE) program designed for the analysis of interlocking mortarless masonry systems was utilized [14,15]. A parametric study, using the finite element program, was performed to evaluate the load-carrying capacity of walls with varying slenderness and eccentricities. Subsequently, regression analysis was applied to the obtained capacities to derive the load-carrying capacity formula.

2. Methodology

2.1. Parametric Study

The interlocking hollow concrete block units detailed in [14] were used to create the masonry wall models used as input data for the FE program, depicted in Fig. 1. The geometrical and mechanical properties of the blocks are thoroughly described in the cited study. Four slenderness ratios (the ratio of the wall panel height to the thickness, H/t) are considered in the study; 8, 12, 16 and 20. These ratios were selected to correspond to the typical range of slenderness ratios common in load-bearing walls in buildings. The transverse eccentricity (e/t) was varied from 0.0 to the value at which the resultant force acted at the centre of the block face-shell. The considered eccentricity ratios were 0.00, 0.12, 0.23, and 0.37.



H/t=20 H/t=16 H/t=12 H/t=8

Fig. 1: Wall Dimensions (all walls have a thickness of 0.15 m)

2.2. Finite Element Model

A comprehensive finite element model, utilizing a micro-modelling approach, was employed. Detailed descriptions of the model can be found in [14,15]. The FE model accounted for the nonlinear structural behaviour and failure modes of the materials and dry joints. Material and joint parameters used in the model were derived experimentally, with a full description of the experimental program and results reported in [16,17]. The model was extensively validated by comparing FE results with experimental data from block units, masonry prisms, and full-scale masonry walls. The model accurately simulated the structural response of the interlocking masonry system under axial and eccentric loading, effectively capturing the system's structural performance, including load-carrying capacity, deformations, and failure modes.

3. Analysis Results and Discussion

3.1. Wall Capacity Reduction Factor

The FE analysis results were normalized with respect to block unit strength, and capacity reduction factors were calculated. The analysis results are presented in Table 1. Wall capacity reduction, also referred to as wall efficiency, is defined as the ratio of the wall's compressive strength to the compressive strength of the masonry. As stipulated in various building codes, this factor accounts for the influence of slenderness and eccentricity on the wall's load-bearing capacity. Some codes define the compressive strength of masonry as the strength of small block assemblies, such as wallets or prisms (e.g., EN BS, ASTM). However, in this study, the compressive strength of masonry was taken as the unit block's compressive strength. This is because the FE program employed a micro-modelling approach, which relies primarily on the unit block's strength.

Regression analysis was performed to derive the optimal equation for wall capacity reduction (or wall efficiency). The FE analysis results for wall capacity reductions, presented in Table 1, served as the dependent variable. Normalized eccentricity (e/t) and normalized slenderness (H/t) were calculated using wall thickness (t) and wall panel height (H), respectively. These normalized values were then used as independent variables in the regression analysis.

To achieve a high correlation coefficient (R^2), an exponential equation was adopted for fitting the FE results. Trying different exponential equations forms showed that the best fit exponential equation form is:

$$\lambda_w = EXP\,[a + b\,(H/t)\,(e/t) + c\,(H/t) + d\,(e/t)] \tag{1}$$

Where

λ_w	wall capacity reduction factor
H	wall panel height
t	wall panel thickness
e	eccentricity of applied load
a, b, c and d	coefficients obtained from the regression analysis

The regression coefficients were obtained and Eq. 1 can be expressed as follows ($R^2 = 0.97$):

$$\lambda_w = EXP\,[-0.139 + 0.052\,(H/t)\,(e/t) - 0.047\,(H/t) - 2.096\,(e/t)] \tag{2}$$

The analytical results, detailed in Table 1 and Fig. 2, reveal that the differences between the FE program and the proposed equation exhibited the following ranges: -7% to 11.5% at a slenderness ratio of 8, -5.3% to 6.2% at 12, -1.4% to 1.6% at 16, and -2.5% to 9.5% at 20. Furthermore, it can be seen from Table 1 and Fig. 2 that the discrepancy between the FE program and the proposed equation was observed to be more pronounced at lower slenderness ratios. Conversely, the discrepancy was observed to be more pronounced at higher eccentricity ratios.

3.2. Load-carrying capacity

To obtain the load carrying capacity of an interlocking mortarless block wall, multiply the capacity reduction factor proposed in Eq. 2 by the compressive strength of individual block and the wall bedding area. The load-carrying capacity (nominal load, P_n) of an interlocking mortarless block wall can be determined using Eq. 2, where the capacity reduction factor is multiplied by the compressive strength of the individual blocks and the wall's bedding area as follows.

$$P_n = f_b A_w \lambda_w \tag{3}$$

Where

f_b	compressive strength of block unit
A_w	bedding area of the wall

Table 1: Finite element analysis and proposed equation results

Slenderness ratio H/t	Eccentricity ratio e/t	Capacity Reduction Factor		Discrepancy %
		FE Program	Proposed Equation	
8	0	0.576	0.598	4
	0.12	0.500	0.492	-1.7
	0.23	0.434	0.404	-7
	0.37	0.289	0.323	11.5
12	0	0.501	0.496	-1
	0.12	0.436	0.418	-4.2
	0.23	0.371	0.352	-5.3
	0.37	0.272	0.289	6.2
16	0	0.405	0.412	1.6
	0.12	0.360	0.355	-1.4
	0.23	0.308	0.306	-0.6
	0.37	0.261	0.258	-0.9
20	0	0.336	0.341	1.7
	0.12	0.309	0.301	-2.5
	0.23	0.243	0.266	9.4
	0.37	0.237	0.231	-2.5

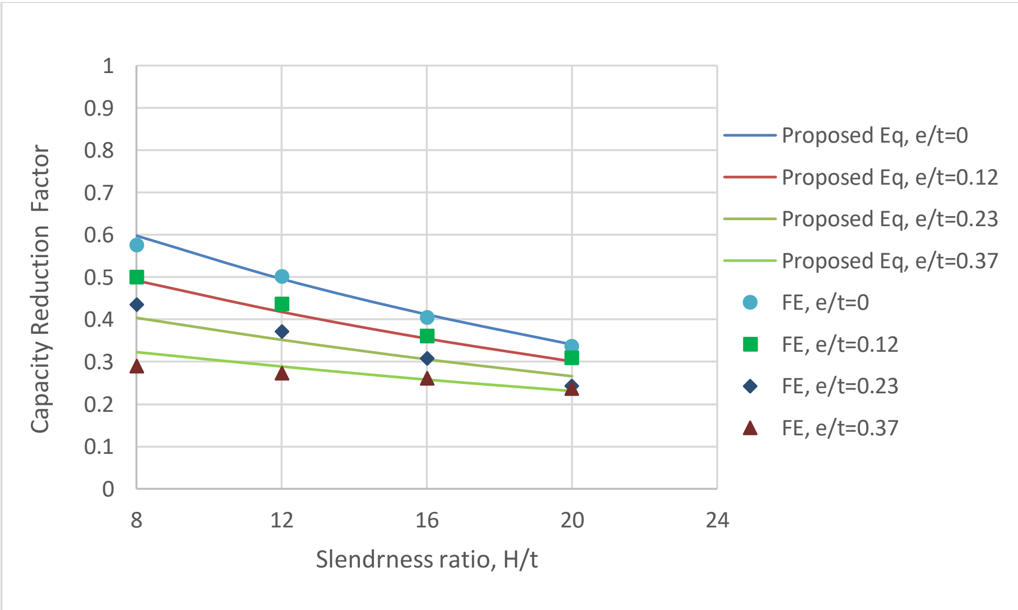


Fig. 2: Relation between wall paned capacity reduction and slenderness under axial and eccentric loads

4. Conclusion

An analytical study was conducted using a finite element (FE) program designed for the analysis of load-bearing interlocking mortarless masonry. A load- carrying capacity equation for the interlocking mortarless masonry load-bearing walls under axial and eccentric load was proposed. The proposed equation is applicable for hollow concrete block walls with slenderness ratios ranging from 8 to 20 and eccentricity ratios up to 0.37. The observed deviation between the FE analysis results and the proposed equation ranged from -7% to 11.5%, particularly at lower slenderness values (H/t=8).

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