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An Investigation of Shallow Prestressed Masonry Brick Lintels with Varying Bed Joint Thickness Enhanced With Fibre-Reinforced Mortar

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Abstract - Masonry lintels are key to ensuring adequate load transfer over openings in masonry structures. Deficiencies in workmanship and the lack of adherence to construction standards pose a potential structural risk. This research investigates the effect of varying bed and head joint thicknesses, using Class II mortar, on the static load-bearing capacity of masonry lintels constructed from cement bricks in a stretcher bond pattern. Furthermore, it examines the impact of incorporating polypropylene macro-synthetic fibres into both bed and head joints on the performance of prestressed, shallow masonry lintels under in-plane vertical loading. The analysis specifically targets conditions in which arching action is absent due to an insufficient masonry height above the lintel required to develop a compressive arch. Twelve masonry single skin lintels (115mm wide) with bed joint and head joint thicknesses of 10 mm, 20 mm, and 30 mm, incorporating fibre volumes of 0%, 0.2%, 0.4%, and 0.6%, were tested to failure. Results show that increasing bed joint mortar thickness decreases the flexural capacity of lintels, with a 30 mm joint exhibiting a 24,68 % reduction compared to a 10 mm joint without fibre reinforcement. However, incorporating 0.4% polypropylene macro-fibres enhanced the load-bearing capacity by up to 100,57% in lintels with 10 mm thick joints. Results also noted that the incorporation of the fibres into the mortar matrix increased the compressive strength of the mortar. Failure modes included flexural, shear, and bond failures, highlighting the importance of joint integrity on the structural performance of lintels. The findings indicate that incorporating fibres into the mortar mix can help address construction deficiencies. The results also underline the necessity for enhanced quality control measures in lintel construction, which is especially critical for low-income housing projects in South Africa and developing countries where masonry construction is still the primary form of building.

***Keywords*:** Prestressed masonry lintels, Fibre Reinforced Mortar, Polypropylene macro-fibres; Low-income housing

1. Introduction

Masonry lintels are fundamental to structural and architectural integrity, transferring loads above openings such as doors and windows and resisting both flexural and compressive stresses (Hendry et al. [1]). Historically spanned by arches or beams, modern South African construction, especially in low- to middle-income housing, now favours prestressed concrete lintels for their affordability and ease of installation.

In composite masonry systems, the prestressed lintel provides tensile resistance at the soffit, while the overlying masonry offers compression, forming an integrated structural beam. Proper bonding and mortar application significantly improve flexural capacity. However, misconceptions persist among uncertified builders who believe the lintel alone carries the load, neglecting the contribution of surrounding masonry. Bed joint thickness is critical in this interaction. Research by Bohdan and Tomasz [2] and Akhaveissy [3] shows that increased joint thickness weakens confinement, bond quality, and deformation resistance. Zengin et al. [4] linked wall performance to material compatibility, joint dimensions, and bonding technique, while Monteagudo et al. [5] found that thicker joints diminish lateral confinement and structural capacity.

Standards prescribe 10 mm as the typical joint thickness. SANS [6], aligned with Eurocode EN 1996 [7], permits 6–15 mm, and SANS 2001-CM1 [8] confirms 10 mm as optimal. Thinner joints improve bond strength and stress distribution; thicker joints introduce stress concentrations, slippage, and early failure. This issue is especially critical in shallow walls—typically only four brick courses—where arching is absent, and the lintel behaves as a simple beam.

Concerns over South African construction quality are longstanding. Grieve [9] identified poor lintel practices, and the NHBRC [10] has reported widespread structural shortcomings in low-income housing. Figures 1(a) and (b) illustrate on-site deficiencies in joint thickness and bonding that compromise lintel performance.

(a)

(b)

Fig. 1: Typical lintel construction arrangements.

Although the NHBRC's Home Building Manual [10] and SANS 10400 [11] set minimum requirements, implementation on site remains inconsistent due to limited oversight, poor workmanship, and inadequate builder training. Mahachi [12], in developing a construction quality assessment tool, highlighted the urgent need for targeted interventions, particularly in the low-income housing sector. To address these challenges, this study investigates shallow prestressed masonry lintels, where limited wall height prevents arching action, by assessing the impact of mortar bed joint thickness and polypropylene macro-synthetic fibre inclusion on load-bearing performance, especially under site-modified mix conditions that compromise mortar integrity.

2. Literature Review

Recent studies reveal structural deficiencies in South African masonry construction linked to poor workmanship. Khuzwayo et al. [13] attributed this to weak technical enforcement, which fosters unethical practices and reduced performance. Shrivastava [14] emphasised that unit type, mortar strength, bond quality, and workmanship critically shape masonry behaviour. Vermeltfoort et al. [15] highlighted the sensitivity of the brick–mortar interface to site execution and quality control, which directly affects load capacity. BS EN 1996 [16] underscores the link between mortar compressive strength and flexural performance. Govardhan et al. [17] and Hendry et al. [1] further noted that even slight increases in bed joint thickness significantly reduce compressive strength

2.1 Mortar Joint Thickness and Structural Integrity

Mortar joints function as both mechanical and adhesive connectors in masonry, significantly influencing structural strength and stiffness. Multiple studies have analysed the impact of joint thickness on performance. Govardhan et al. [17] recorded a 47% drop in compressive strength from a 1 mm increase in bed joint thickness. Thamboo et al. [18] found that thicker joints compromise confinement, leading to lateral displacement and microcracking. Francis et al. [19] linked thick joints to stress concentrations, reduced bond efficiency, and greater shear failure risk. Yadav and Pal [20] confirmed joint thickness influences failure modes in masonry prisms. Zengin et al. [4] noted that excessive thickness disrupts load paths and stiffness, causing early cracking, particularly in shallow walls where lintels bear full flexural loads in the absence of arching

2.2 Fibre-Reinforced Mortar (FRM) and Masonry Enhancement

Fibre-Reinforced Mortars (FRM) enhance tensile strength, ductility, and durability in cementitious systems, although most research centres on cement-based matrices. Cajamarca-Zúñiga et al. [21] observed that PET fibres at 0.5% and 1% improved tangential adhesive strength by 37% and 60%, respectively, while 1.5% reduced it by 22.86%. Almeida et al. [22] showed that PAN fibres significantly improve toughness and flexural capacity at higher volumes. Coir fibres at 0.5% increased flexural strength by 10–22% and compressive strength by 16–19%, while also reducing shrinkage (Syamala et al. [23]). Illampas et al. [24] reported that alkali-resistant glass textiles enhance shear and deformation resistance. Abousnina et al. [25] found that macro polypropylene fibres raised compressive and tensile strength by 19.4% and 41.9%, respectively. Erdogmus [26] noted that 0.5% synthetic fibres improve Type N mortar flexural response, and Erler and Jäger [27] concluded that textile reinforcement in bed joints can double flexural strength in masonry walls.

2.3 Bond Strength and Composite Action in Lintel Systems

For prestressed lintels to act compositely with masonry above, effective bonding and interlock are vital. Hardy [28] identified bond failure as a primary limit state when joint uniformity is lacking. Efficient stress transfer between the tensile lintel and compressive masonry relies on compacted, thin joints and roughened contact surfaces. Without arching action, lintels behave as simple beams, with failures driven by flexure and bond deterioration (Hendry et al. [1]; Malpas [29]). In such cases, joint thickness and mortar cohesion significantly influence crack development and load capacity

2.4 Construction Practice and Regulatory Context in South Africa

Although South African codes prescribe a 10 mm bed joint for Class II mortars, site inspections frequently reveal deviations due to insufficient training and oversight (Khuzwayo et al. [13]; NHBRC [10]. While SANS 2001-CM1 [30] and SANS 10400 [11] address lintel design, they offer limited guidance on how joint thickness and workmanship variability impact prestressed lintels. This study addresses that gap by evaluating the load-bearing performance of lintels with 10 mm, 20 mm, and 30 mm joints using Class II mortar, under conditions representative of low-income housing. It also assesses the structural impact of polypropylene macro-synthetic fibres at 0.25%, 0.4%, and 0.6% dosages, intended to counter issues such as over-watering, poor mixing, and uneven mortar application

3. Scope and Significance

This study focuses on typical low-income housing configurations where arching action is absent due to shallow masonry height, specifically when the masonry height-to-span ratio falls below 0.6. Hendry et al. [1] noted that effective arching generally requires a ratio between 0.6 and 1.0. The research addresses the following objectives:

- Structural Risk Mitigation: Assess the influence of mortar joint thickness and fibre reinforcement on structural behaviour to promote safer design practices.
- Performance Assessment: Quantify how deviations from SANS-prescribed joint thickness affect lintel flexural and compressive strength.
- Regulatory Advancement: Generate empirical data to support updates to SANS [30], SANS 10400 [11], and the NHBRC Manual [10].
- Public Safety: Support the Housing Consumer Protection Measures Act [32] by reinforcing structural quality in the built environment

4. Experimental Methodology

This study assessed the structural performance of twelve prestressed masonry lintels embedded in single-leaf wall panels built with 7 MPa cement stock bricks in stretcher bond. To replicate typical South African site conditions, a Class II mortar mixed in 35-litre controlled batches was applied under uncontrolled bricklaying conditions to simulate on-site practices. Despite workability variation, joint thicknesses were consistently maintained using gauges. Bed joint thicknesses were set at 10 mm, 20 mm, and 30 mm to evaluate their influence on lintel performance. Mortar followed a 1:6 cement-to-sand volume ratio using 42.5N cement (EN 197 [34]) and sand meeting SANS 1090 [33] specifications (Grading Modulus: 1.29), with no lime or chemical admixtures added to the mix.

Each panel included a prestressed lintel (2100 mm × 115 mm × 75 mm) reinforced with two 4 mm diameter strands stressed to 1700 MPa per SANS 1504 [35], representative of common low- to middle-income housing construction in South Africa. For additional tensile capacity and crack control, 2.8 mm diameter galvanised brick force (SANS 10244 [36]) was placed in each brick course, aligning with SANS 10400 [31]. Polypropylene macro-synthetic fibres (EN 14651 [37]) were added to Class II mortar at 0%, 0.2%, 0.4%, and 0.6% dosages by volume, reflecting documented fibre performance ranges where 0.2% improves strength (Dawood et al. [38]) and ~0.5% enhances flexural response (Erdogmus [26]), supporting the fibre selection for crack control and flexural enhancement. Table 1 presents the specific joint configurations tested across all specimens

Table 1: Wall Sample combinations, detailing the joint thickness and the percentage of macro fibres incorporated into the mortar mix design

	WALL SAMPLE / SPECIMEN No											
	A1	B1	C1	A2	B2	C2	A3	B3	C3	A4	B4	C4
JOINT THICKNESS (mm)	10	20	30	10	20	30	10	20	30	10	20	30
FIBRE % IN MIX	0%	0%	0%	0.20%	0.20%	0.20%	0.40%	0.40%	0.40%	0.60%	0.60%	0.60%

Test specimen construction was completed over two consecutive days under ambient temperatures of 14°C to 28°C. During construction, mortar cubes (150 mm × 150 mm × 150 mm) were cast and tested for compressive strength after 28 days of ambient curing, in accordance with SANS 5863 [39]. To ensure quality, twelve bricks were randomly selected and tested to confirm compliance with the 7 MPa compressive strength requirement. Structural testing was performed using a hydraulic actuator in a two-point loading configuration to replicate service conditions, with load applied at 0.5 kN/s until failure. Mid-span deflections were measured using dial gauges and Linear Variable Differential Transformers (LVDTs). Crack initiation, propagation, and failure modes—including flexural, shear, and bond failures—were closely observed.

5. Results and Discussion

Based on the result obtained, the optimal performance was achieved with 10 mm mortar joints and 0.4% polypropylene fibres, doubling the load capacity of unreinforced lintels while improving ductility and crack control. Thicker joints (20–30 mm) reduced strength by up to 25%, exhibiting shear/bond failures. Fibres enhanced mortar compressive strength (5.07 MPa at 0.4% vs. 2.8 MPa unreinforced), but excessive dosage (0.6%) caused clumping and strength loss. The combination of 10 mm-thick joint and 0.4% fibre content delivered optimal structural resilience for masonry lintels, as demonstrated by the following results:

5.1 Flexural Performance

5.1.1 Ultimate Load Capacity

Structural testing results revealed the combined impact of mortar joint thickness and fibre dosage on the ultimate load capacity of prestressed masonry lintels. As shown in Figure 2, fibre inclusion improved capacity across all joint configurations, with peak gains at 0.4% fibre volume. Lintels with 10 mm joints consistently outperformed those with 20 mm and 30 mm joints. The 10 mm joint with 0.4% fibre achieved a peak load of 31.77 kN - a 100.57% increase over its unreinforced counterpart. In contrast, 30 mm joints showed a notable decline; the unreinforced sample reached only 11.93 kN, approximately 24.7% lower than the 10 mm equivalent.

The trend across fibre dosages supports this: 0.2% fibres yielded modest improvements in crack control and ductility, with optimal performance at 0.4%. At 0.6%, load capacity declined, likely due to fibre clumping and reduced workability, which negatively affected matrix cohesion and bond strength.

These findings confirm that polypropylene fibres enhance ductility and post-cracking behaviour, especially in thinner joints. However, excessive fibre content reduces effectiveness. The best overall performance was obtained with a 10 mm joint and 0.4% fibre, offering a practical balance between structural strength, constructability, and consistency under realistic site conditions.

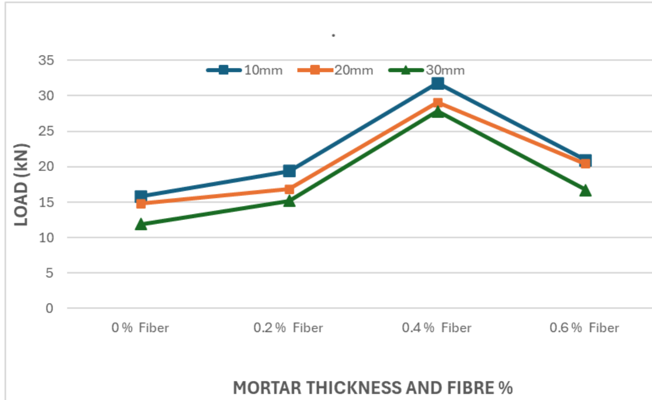
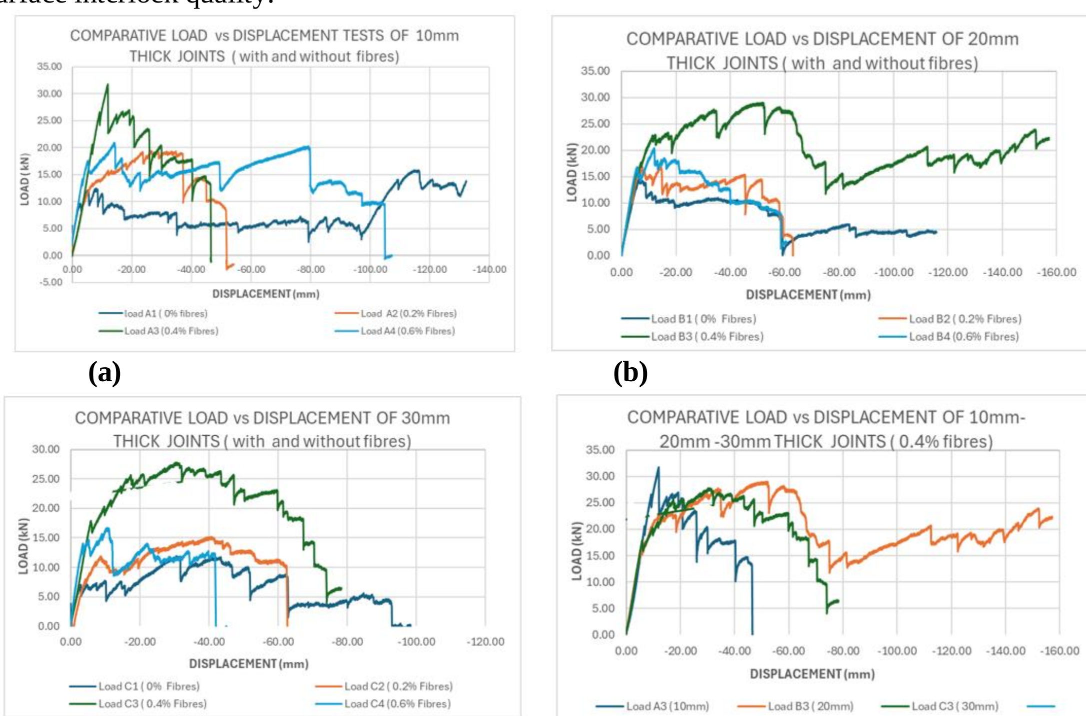


Fig. 2: Comparative lintel load carrying bearing capacity

5.1.2 Flexural Behaviour and Failure Modes

The flexural load-displacement responses presented in figures 3a–d reveal the influence of mortar joint thickness and fibre content on the load-bearing performance of prestressed masonry lintels. Joints of 10 mm (figure 3a) showed the highest stiffness and peak load, particularly at 0.4% fibre dosage. Load A3 (0.4%) exhibited a defined stiffness ascent and ductile post-peak behaviour, indicating effective bond interaction and stress redistribution. These findings align with prior studies confirming that fibre reinforcement enhances strength and ductility.

In the 20 mm joints (figure 3b), fibre inclusion, especially at 0.4%, contributed to performance; however, post-peak behaviour showed signs of reduced confinement and increased crack localization compared to 10 mm joints. At 30 mm joint thickness (figure 3c), all specimens demonstrated reduced peak load. Even Load C3 (0.4%) performed well below its 10 mm counterpart, supporting Govardhan et al. [17] in observing that increased joint thickness diminishes shear transfer and bond efficiency. A comparison across 0.4% fibre content (figure 3d) confirmed an inverse relationship between joint thickness and performance—thicker joints resulted in earlier stiffness loss and failure, likely due to fibre clumping and weak interface bonding. While polypropylene fibres improved flexural behaviour overall, their benefit was diminished in overly thick joints. The main failure mechanisms were flexural cracking at mid-span, diagonal shear cracks in 30 mm joints, and bond failure at the brick–mortar interface. These were influenced by joint thickness, mortar cohesion, and surface interlock quality.



(c) (d)

Fig. 3: Reflects the load vs Displacement for the various fibre dosage combinations

Crack propagation was primarily vertical from tensile bending, with horizontal cracks more frequent in thicker joints due to weaker bonding, and some cracks initiating at the lintel–brick interface, highlighting the role of surface roughness.

Overall, the observations noted in figures 4(a) and (b) confirm that thinner mortar joints and appropriate fibre reinforcement not only enhance load-bearing performance but also mitigate sudden failure by promoting ductile behaviour and improving crack distribution along the joint interfaces.

(a)

(b)

Fig. 4: Typical crack propagation arrangements along the masonry wall Lintel

5.2 Mortar Compressive Strength

Compressive strengths of the mortar mixes, shown in figure 5, highlight improved performance at 0.4% fibre content. Tests on 150 mm mortar cubes showed that fibre-free mixes averaged just 2.8 MPa, below the Class II target of 7 MPa as per SANS 2001-CM1 [30]. This shortfall likely reflects on-site mixing adjustments, such as excess water for workability, which reduce the water-cement ratio.

Polypropylene fibres enhanced compressive strength, with 0.4% content achieving a peak of 5.07 MPa, attributed to improved microcrack control and stress redistribution. However, contents above 0.4% led to reduced strengths, likely due to fibre clumping and inadequate dispersion within the mortar matrix.

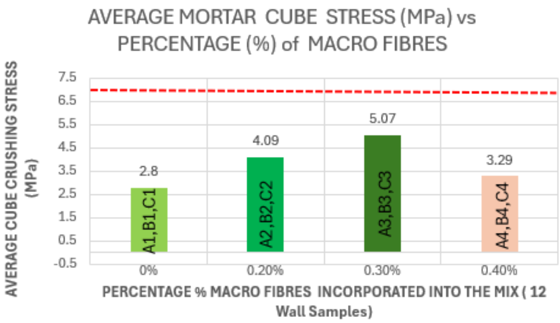


Fig. 5: Average mortar cube stress with respect to percentage of incorporated fibre in the mix

6. Conclusion and Recommendations

This study evaluated how varying mortar bed joint thickness and polypropylene macro-fibre inclusion influence the structural performance of prestressed masonry lintels under typical on-site practices. Findings confirmed that uncontrolled site mixing, particularly water addition to improve workability, reduces the water-cement ratio and compromises mortar strength. Lintels constructed with 10 mm joints, in line with SANS 2001-CM1 [30], exhibited superior performance in terms of load capacity, stiffness, and crack control. A 0.4% fibre dosage further enhanced strength, achieving over 100% capacity improvement versus unreinforced samples. Conversely, lintels with 20 mm and 30 mm joints showed reduced performance, marked by early onset of shear, bond, and delamination failures posing a potential safety concern. Identified failure modes included mid-span flexural cracking, diagonal shear, and bond separation, more severe with increased joint thickness.

This research reinforces the importance of joint thickness and workmanship in shallow masonry lintel construction, particularly where arching action is absent or quality control is limited. The inclusion of fibres macro fibres (0.4%) can enhance the structural capacity of lintels, mitigating potential safety concerns associated with bad workmanship and non-adherence to code requirements.

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