PROSPECT OF CONSTRUCTING REINFORCED BRICK MASONRY (RBM) STRUCTURES IN BANGLADESH

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ABSTRACT

This paper presents a theoretical discussion on the subject of reinforced brick masonry (RBM) structures. It is intended as an overview of the types of available RBM and how they work. It discusses commonly applied terminology and models of mechanical behaviour that form a basis for understanding material performance without presenting mathematical details. Structure made with reinforced cement concrete (RCC) are not cheap and construction period of time is long. Moreover, they need extra shuttering cost. In addition, unreinforced brick masonry (URM) is weak in flexural and shearing resistance and hence they are very much vulnerable during an earthquake. They suffer severe damage under earthquake effects. On the other hand, RBM consist of both reinforcements and masonry. The two materials (masonry and reinforcement) complement each other, resulting in an excellent structural material. By reinforcing the masonry with steel reinforcements, the resistance to seismic loads and energy dissipation capacity can be improved significantly. The reinforcement provides additional tensile strength which can overcome the limitations in the use of URM. RBM shows the prospect of constructing low-to-mid rise masonry structures of residential buildings, hospitals and schools in the rural area of Bangladesh at a low cost and low construction period of time with adequate margin of safety.

Keywords: Bricks; reinforcement; earthquake; tensile; compressive strength; shearing resistance

INTRODUCTION

Brick masonry is one of the oldest forms of building construction, and reinforcement has been used to strengthen masonry since 1813. Reinforced brick masonry (RBM) is a construction system where steel reinforcement in the form of reinforcing bars or mesh is embedded in the mortar or placed in the holes and filled with concrete or grout. This masonry has greatly increased resistance to forces that produce tensile and shear stresses. The reinforcement provides additional tensile strength which can overcome the limitations in the use of unreinforced masonry (URM). This results an excellent structural material by complementing two materials such as masonry and reinforcement. By reinforcing the masonry with steel reinforcement, the resistance to seismic loads and energy dissipation capacity can be improved significantly (PWD, India 1996). Reinforced brick masonry contributes huge amount of shearing resistance and gives lateral stability against earthquake. A number of experimental works were carried out on RBM beams to study the flexural and web reinforcement ratio on the ductility, ultimate flexural, shear strength and mode of failures. According to several research works, design of RBM can be performed using the ultimate strength design method similar to that used for reinforced concrete beams (Khalaf et al., 1983 and Taly N, 2001). Mohamad et al. (2005) carried out experimental tests on masonry prisms subjected to compression.The failure mechanism of masonry depends on the difference of elastic modulus between brick unit and mortar. Oliveira et al. (2000) carried out the tests on prisms under cyclic loading and the stress-strain behaviour of the brick prisms showed a bilinear pre-peak behavior. Gumaste et al. (2007) studied the properties of brick masonry using table moulded bricks and wire-cut bricks from India with various types of mortars. It is also found that strength of URM is notably lower in comparison to that of RBM. Reinforced cement concrete can overcome this situation but they are not cheap and requires longer construction period. RC construction needs shuttering cost. On the other hand, URM is weak in flexural and shearing resistance and very much vulnerable during earthquake (Qazi et al., 2011). It is known that masonry structures have relatively low resistance to horizontal seismic forces and suffer severely during seismic forces (Priestley and Bridgeman, 1974). In earlier decades, masonry buildings mainly 4/5 storied were constructed as residential buildings, hospitals and schools. However, experience of past earthquakes has shown that a number of masonry structures are vulnerable to seismic actions and severe damage was observed (Dutta et al., 2013). Therefore, the main objective of this paper is to study the mechanical properties (compressive, tensile, flexure, shear, seismic performance, etc.) of RBM and discuss the feasibility of constructing RBM over URM in rural areas of Bangladesh.

METHODOLOGY

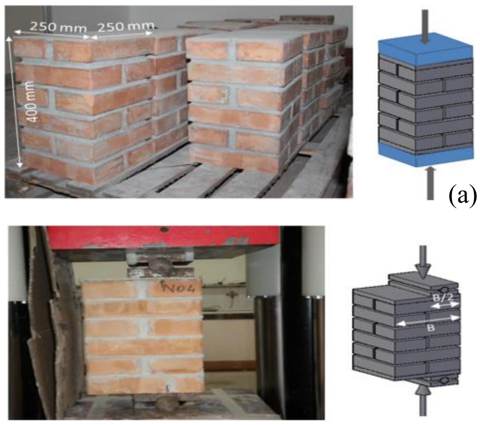
Based on the literature available, a comprehensive investigation has been carried out to assess the effects of compressive and tensile strengths, modulus of elasticity, shear, flexure and seismic performance of RBM. Finally, all such results will be compared to URM. Finally, some discussions to the feasibility of constructing RBM in rural areas of Bangladesh will be provided.

Mechanical strength tested by various researchers

Khan et al. (2012) conducted a research on compressive strength, diagonal tensile strength as well as modulus of elasticity, stress strain behavior of the unreinforced masonry prism having a size of length =16 inch, height = 16", thickness = 9" for compressive strength according to ASTM C1314–11a. Diagonal tensile strength was calculated from diagonal compression tests on masonry prisms (27" x 27"x 9"), as shown in Fig 1. The cement to sand ratio was 1:6. Campione et al. (2016) tested both concentric and eccentric loading conditions as shown in Fig 2. In order to accomplish these tests, universal testing machine (UTM) was used. The loading area had a width equal to b= 0.5B, with B the side of the square transverse cross section. The eccentricity was equal to B = 6.


(a) (b)

Fig.1: Strength test of brick prisms, a) Compressive strength b) Diagonal tension; Khan et al. (2012).



(a) (b)

Fig 2: Compressive strength test a) Concentric b) Eccentric; Campione et al. (2016)

Eccentric tests were carried out by loading the specimens on a reduced area with respect to the entire cross section, producing a disturbed region (D-region). Linear variable displacement transducers (LVDTs) were used to record the displacement of the prism. Table 1 shows the material properties of bricks and mortars that have been used by the researchers. Khan et al. (2012) obtained weak bond-between the bricks and mortar and, consequently, low diagonal tensile strength (7.3 psi) and compressive strength (438 psi). Freeda et al. (2013) found the compressive strength of unreinforced fly ash brick masonry was 34% more than the unreinforced clay brick masonry. The reinforced fly ash brick masonry was 20.7% more than the reinforced clay brick masonry. The introduction of wire mesh-in the clay brick masonry resulted in an increase of load carrying capacity by 25%. However, the main limitation of this study was the effects of moisture on the strength of brick masonry and the strength of eccentrically loaded brick work**.** Table 2 presents the summary of the results conducted by Campione et al. (2016), Freeda et al (2013), Khan et al. (2012), and Sakthivel et al. (2016). The peak loads and compressive strengths of URM and RBM under concentric and eccentric loads are provided. It is found from the results that rupture strain limit of URM is around 30 % lower than that of alternate steel grids (SG) of RBM and around 40% lower for every course of RBM as shown in Fig. 3.

Table 1: Mechanical properties of mortar and bricks

Sl no.	Description of the test	Value	Adopted from
1	Compressive strength of mortar, MPa	6.09	Khan et al. (2012)
2	Water absorption of bricks, %	23.0	Khan et al. (2012)
3	Elastic modulus of masonry, MPa	1230	Khan et al. (2012)
4	Specific weight of masonry material, Pcf	94	Khan et al. (2012)
5	Compressive strength of mortar, MPa	7.89	Campione et al. (2016)
6	Tensile strength of mortar, MPa	1.14	Campione et al. (2016)
7	Flexure strength of mortar, MPa	2.07	Campione et al. (2016)
8	Compressive strength of brick, MPa	7.83	Nayak and Dutta (2016)

Table 2: Results of compressive strength adopted from various researchers

Series	e = 0 (Concentric)		e = b/6 (Eccentric)	
	Peak Load (KN)	Strength (MPa)	Peak Load (KN)	Adopted from
UM SG every course SG alternate course	759 1125 942	12.60 17.39 15.08	213 281 253	Campione et al. (2016)
URM RBM	- -	1.70 2.20	- -	Freeda et al (2013)
URM RBM	- -	3.00 4.20	- -	Khan et al. (2012)
URM RBM	8.56 22.48	- -	- -	Sakthivel et al. (2016)

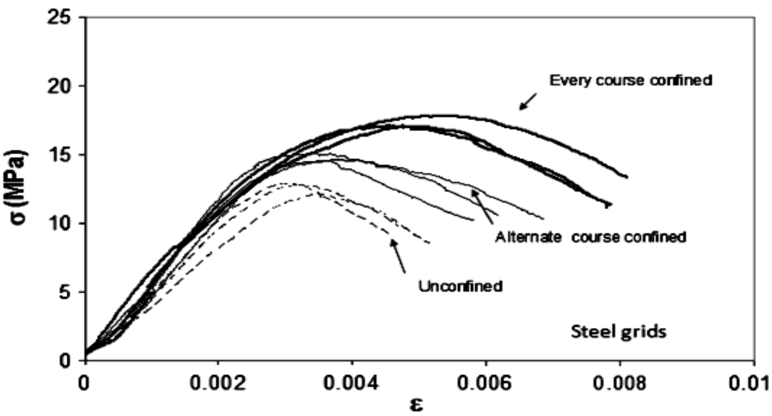


Fig 3: Stress-strain diagram of URM and RBM; Campione et al. (2016)

According to Sakthivel et al. (2016), RBM can be adapted where high compressive and diagonal tensile strength is required instead of RCC as shown in Fig. 4. During the diagonal compressive strength tests of URM and RBM, the result is found 8.56 kN and 22.487 kN, respectively in which capacity of RBM is 2.63 times higher than URM. Freeda et al. (2013) also conducted research on stress-strain behavior of URM and RBM with 10% and 20% replacement of fine aggregates with fly ash as shown in Fig 5. It is seen that rupture strain limit of unreinforced clay brick (CBP) is around 25% lower compared to reinforced clay brick (CBPR). Similar trend is observed for unreinforced clay brick with 10% and 20% replacement of fine aggregates with fly ash CBP10 and CBP20, respectively.

Fig 4: Uses of steel bar in masonry; Sakthivel et al. (2016).

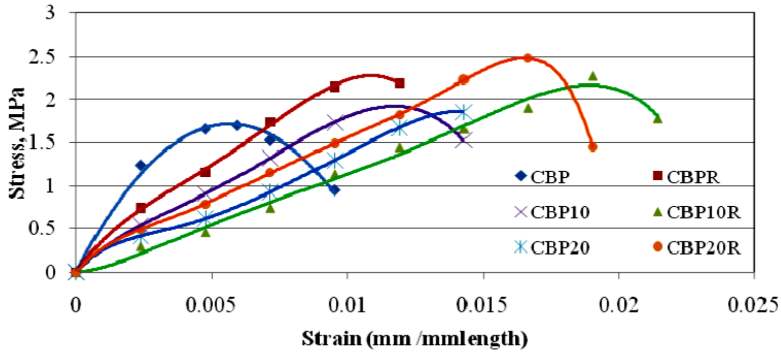
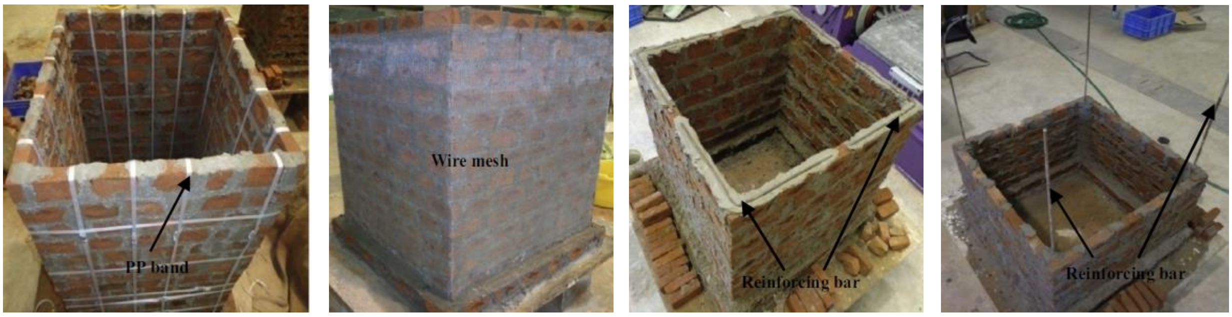


Fig 5: Stress-strain behavior of URM and RBM; Freeda et al. (2013).

Seismic behavior of masonry structures

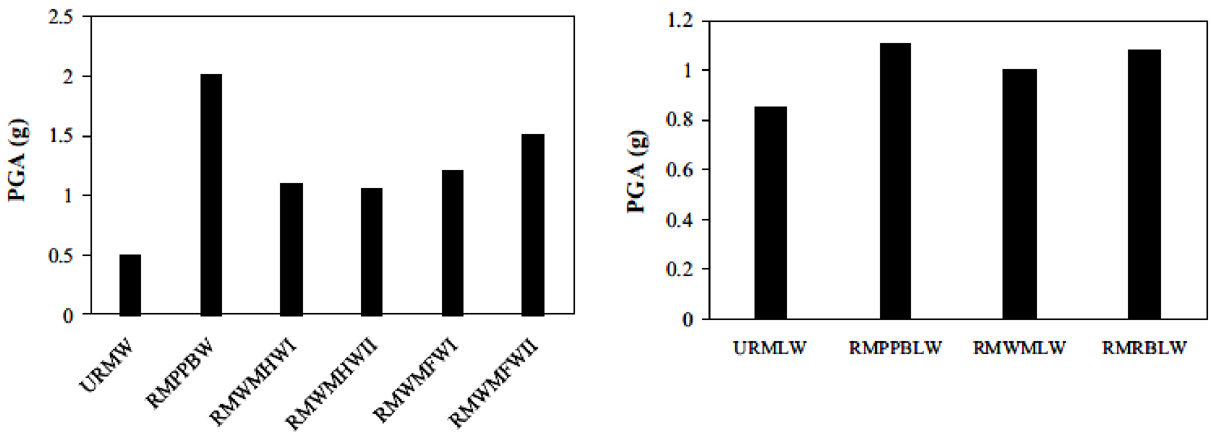
Horizontal shear failure, corner/junction failure and failure of out-of-plane walls initiated by junction failure are the most common type of failures in unreinforced masonry structures when subjected to seismic excitation. Corner/junction is identified as the weakest portion of such structures. It is needed to improve the integrity of the structures to behave as a single unit and to ensure proper interlocking between orthogonal walls to reduce the causalities during earthquake. Keeping in view of the above mentioned facts, Nayak and Dutta (2016) used 12 mm thick poly propylene (PP) bands, steel wire mesh and reinforcing bars to strengthen URM walls for achieving better seismic performance as shown in Fig 6. Use of PP band and wire mesh help to improve the integrity of the structures. Horizontal reinforcing bars ensure proper interlocking between orthogonal walls. The shake table with a 1m x 1m single axis horizontal electro dynamic shaker capable of shaking 1000 kg mass with peak ground acceleration of 1g is used in the experimental study. All experiments were carried out under the same ground excitation. Since, the real acceleration time history available corresponding to various real earthquakes may be biased by their spectral shape and frequency content, a ground excitation in the form of swept sine motion had been used in all the cases. Thus, PGA is used as a parameter for damage indicator in the study.



(a) (b) (c) (d)

Fig 6: Construction of reinforced four sided walls: (a) PP band provided in form of grid; (b) steel wire mesh all around; (c) horizontal re bar at the junction and (d) vertical re bar at the corner; Nayak and Dutta (2016).

The study conducted by Nayak and Dutta (2016) was extended to assess seismic behavior of unreinforced masonry (URM) wall as well as different types of reinforced masonry walls (RMW). For free standing walls, it was seen that URMW was destroyed at a very low (0.5 g) PGA as shown in Fig. 7(a). On the other hand, reinforced masonry PP band wall (RMPPBW) was destroyed at a very high (2.0 g) PGA compared to the URMW. Similar trend was found in case of reinforced masonry walls wrapped with wire mesh horizontal wall (RMWMHWI, II) and reinforced masonry walls wrapped with wire mesh full height wall (RMWMFWI,II). Unreinforced L shaped masonry walls (URMLW) was also failed (0.84 g) to relatively lower PGA compared to reinforced masonry PP band L shaped masonry walls (RMPPBLW), reinforced masonry L shaped walls wrapped with wire mesh (RMWMLW) and reinforced masonry walls horizontal L shaped reinforcing bar (RMRBLW) as shown in Fig. 7(b).



(a) (b)

Fig 7: Comparison of strength in terms of PGA for: (a) free standing walls; (b) L-shaped walls adopted from Nayak and Dutta (2016).

According to Sakthivel et al. (2016), RBM can be adapted for high seismic zone buildings as shown earlier in Fig 4. It is shown that shear stress was obtained 361.32 kN/m^2 and 137.54 kN/m^2 for RBM and URM, respectively which is 263% higher than ordinary brick masonry (URM). Thus, it can be concluded that the use of steel embedded brick is one of the best solutions against brittle fracture in brick wall systems in shear. Also, it withstands higher seismic forces compared to ordinary brick structures. Hence, it can prevent a large of masonry structures from collapses and damages during seismic activities.

Fractured surface

It is seen that URM failed both horizontal and vertical directions for compressive strength test. In case of seismic test, the condition was incendiary. On the other hand, reinforced masonry did not collapse fully. It is also said that a brittle failure is seen for URM. But for RBM only horizontal shear crack is seen and the failure mode is relatively ductile. Fig 8 shows different types of fractured patterns studied by Campione et al. (2016) and Nayak and Dutta (2016).

(a) concentric loading (b) concentric loading (c) URM (d) RBM with PP band

Fig 8: Fractured surface concentric (a) URM (b) RM with CFRP; adopted from Campione et al. (2016) (c) URM (d) RM with PP band; adopted from Nayak and Dutta (2016).

CONCLUSIONS

In this paper, a theoretical discussion on the subject of reinforced brick masonry (RBM) structure is presented. It is intended as an overview of the mechanical properties of unreinforced brick masonry (URM) as well as RBM of various techniques adopted from literature. The effects of the confinement produced by steel wire, vertical and L shaped reinforcements are also reviewed. The main conclusions that can be drawn from the present study are given below:

1) The compressive strength of RBM is significantly higher than that of URM. Strength of RBM can be obtained 263% higher than that of URM.
2) Tensile strength and modulus of elasticity of RBM are in higher capacities compared to those of URM.
3) Rupture strain limit of RBM is significantly higher compared to that of URM.
4) It is seen high modulus of toughness for seismic resistant structures of RBM can be achieved compared to a very low modulus of toughness of URM.
5) It is also seen that for a seismic test, URM failed at a low level of PGA which is a vulnerable condition during earthquakes.
6) Brittle failure pattern is shown for URM in a seismic excitation whereas a relatively ductile fracture is shown for RBM.

Finally, by reinforcing the masonry with steel reinforcement, FRP, wire mesh, the resistance to seismic loads and energy dissipation capacity can be improved significantly compared to URM. The reinforcing materials are also cheap, easily available and can be easily installed. Therefore, RBM shows the prospect of constructing mid-rise residential buildings, hospitals and schools in the rural area of Bangladesh at a lower cost and low construction period of time with adequate safety.

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