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Effect of Vertical Reinforcement on the Behavior of Masonry Walls Subjected to in Plane Lateral Loading

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Abstract

Simple masonry has many a times behaved unsatisfactorily in earthquakes. It may fail under moderate earthquake and more importantly it fails suddenly (brittle failure), thus causing casualties. Since masonry is involved in large number of constructions, especially in rural areas where almost all the constructions are in masonry, research is continuously going on to improve the behavior of masonry under earthquakes (lateral loads). Introduction of reinforcement in the masonry walls ameliorates its behavior under lateral loads by improving the various parameters which may include collapse load (lateral), ductility, and stiffness. The reinforcement provided in masonry can be horizontal or vertical. In this project the effect of vertical reinforcement on the behavior of masonry under lateral loads will be studied. Wall Models of size 1.25mx1.25mx.1m were constructed, two models for each - simple unreinforced masonry and vertically reinforced masonry. The models were tested after 28 days. The results of this research paper showed that vertical reinforcement increases only the ductility of masonry walls without noticeably changing either stiffness or collapse load. Thus the brittle failure of masonry can be avoided by introducing vertical reinforcement.

Keywords: Lateral load, load capacity, ductility, stiffness, brittle failure.

Introduction

Masonry has been used since ancient times and is still a major construction material. The reasons are that masonry construction has low cost. It is easy to construct, easily available and provides good insulation. But unreinforced masonry has proven vulnerable during earthquakes and has been a cause of huge losses of life and property. During an earthquake, the ground surface moves in all directions. Damages to masonry are caused due to the lateral movements which are analogous to applying lateral loads[1`]. Conventional masonry constructions have proved vulnerable during earthquakes and the vulnerability is because of the following reasons: i. The material itself is highly brittle and its strength reduction due to load repetition is large. ii. Masonry constructions generally involve large weight because of thick walls. Consequently the inertia forces induced during earthquakes are large. iii. Higher stiffness of the material means lower period of vibration leading to larger response[2]. iv. Quality of construction is not consistent because of quality of the locally manufactured masonry units (brick), unskilled labour, etc., that leads to large variability in strength[3].

Research has continuously been going on for understanding and improving the behavior of masonry. The seismic behavior of simple masonry has been improved by incorporating reinforcement and confinement of the masonry respectively known as reinforced and confined masonry[4] respectively. In reinforced masonry, the reinforcement can be horizontal[5] or vertical. There are various codes which specify the amount of horizontal and vertical reinforcement. In this work a comparison between simple masonry walls and vertically reinforced walls will be done under lateral loads. The behavior of each masonry type will be studied which includes cracking pattern, failure type, maximum load capacity, ductility, and stiffness. This work will help in better understanding of the behavior of the two forms of masonry under earthquakes and the role of vertical reinforcement will be deduced. The comparison will tell us which is the better form of masonry (and in what aspect) that is to be adopted in the areas of high seismic risk, which will reduce the loss to life and property during earthquakes and also keeping in mind the costs of construction. Since Kashmir (where this work was done) lies in earthquake zone V[6]and is vulnerable to earthquakes and further most of the construction involves masonry as the main material, this work can be used to construct masonry buildings which will have better lateral behavior (earthquake resistance). It is a well-known fact that earthquakes don’t kill people, but unsafe buildings do. So we need to build safe, earthquake resistant structures.

Aim and Objectives: The aim of this study is to understand and compare the structural behavior of the two forms of masonry: simple masonry, confined masonry walls under in plane lateral loads and thus their suitability. The following objectives will be achieved to accomplish this aim: i. Compare the lateral load capacity of simple masonry and vertically reinforced masonry. ii. Compare the ductility (maximum deformation) of the above stated models of masonry. iii. Compare the initial stiffness of the stated three types of walls.

Research Methodology

The research methodology involved includes general description of models, characteristics of the materials used and finally model construction.

General: The investigations of this work were supported by experimental work which was conducted in two stages. In the first stage the tests were conducted on the constituent materials – sand, brick, mortar, steel, concrete. In the second stage four (4) wall specimens were constructed, two for each- i. Simple masonry, ii. Vertically reinforced masonry.

The comparison of simple and vertically reinforced masonry walls under lateral loads is done by constructing models of size 1.25mx1.25mx.1m. Two specimens were made for each type of masonry. The bricks were laid in stretcher courses. All the component materials were obtained from local suppliers of Hazratbal area of Srinagar, JandK India, and were tested before using them for wall construction.

Characteristics of materials: To better understand the structural behavior of masonry wall it is important to have some knowledge of the properties of component materials. Masonry is a multi-component assembly; in the current study the wall specimens consisted of clay burnt bricks, cement mortar, concrete, and reinforcing steel.

The main purpose of testing the component materials was to characterize the materials, to facilitate the comparisons with other published results and design standards and to ensure that the quality of materials was being maintained. The materials were tested in the following sequence:

Brick: A brick is a block or a single unit of a kneaded clay-bearing soil, sand and lime, or concrete material, fire hardened or air dried, used in masonry construction. The bricks used in this study are clay burnt bricks. The size of bricks is 9"x4"x3". The average compressive strength of the bricks came out to be 82 Kg/cm^2 or 8.2 MPa. The strength classification by IS 3495: 1992 puts it in class B bricks. All the specifications regarding brick work as provided in IS 1077: 1992[7] and also those provided in IS 2212: 1991[8] were strictly followed.

Mortar: Mortar is a workable paste used to bind building blocks such as stones, bricks, and concrete masonry units together, fill and seal the irregular gaps between them, and sometimes add decorative colors or patterns in masonry walls. The mortar used in this research is cement-sand mortar. The cement-sand mortar consists of sand, cement and water. The cement-sand ratio used is 1:6. The cement used is OPC of grade 43. The average compressive strength of the mortar used at 28 days was found to be 3.8 MPa. The compressive strength of mortar is less than that of the brick which is a requirement laid by IS 4326[9] and IS 2250: 1981[10].

Concrete: The concrete is a composite material composed of water, coarse granular material (the fine and coarse aggregate or filler) embedded in a hard matrix of material (the cement or binder) that fills the space among the aggregate particles and glues them together. The ratio of cement-sand-coarse aggregate used is 1:2:4 (M15) as per nominal mix design. Sand used conformed to zone three. The size of coarse aggregate used is 20mm(60%) and 10mm(40%). Average compressive strength of concrete used in confining elements at 28 days was 16.2 MPa.

Steel: the steel grade used was Fe 415. Three test samples recorded an average tensile strength value of 440 Mpa.

Model Construction: The wall specimens were carefully built on the floor of Structural Laboratory at National Institute of Technology, Srinagar. The thickness of bond used is 10mm. Bricks were laid in stretcher courses. Also the mortar used in the brickwork is same conforming to the provisions in IS 1905 and IS 4326.

The size of the models was fixed to suit the experimental set up. For reinforced wall since the wall was only 100mm thick reinforcement was placed in concrete bands of size 75mmx100mm with toothing provided for proper bonding with masonry. One steel bar of diameter 8mm was provided vertical on each side of the wall at a distance of .25m from the end. Toothing was provided in the confining concrete to grip the wall. The models are shown in figure-1 (simple masonry) and figure-2 (vertically reinforced masonry). The models were properly cured for ten days after construction. The walls were loaded at 28 days from their construction. Load was applied with a hydraulic jack at one of the top corners shown in figure-3. The bottom of the wall was perfectly fixed. Deflections were constantly noted down for various loads with the help of a dial gauge as shown in figure-4. The top was allowed to move freely. To prevent the overtopping of the model during loading, vertical reactions were provided at the top of the model.

Figure-1
Simple masonry model

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Figure-2
Vertically reinforced model

Figure-3
Lateral load arrangement

Figure-4
Deflection measuring arrangement

Results and Discussion

The results have been presented in two parts- results of tests on simple masonry and results of tests on vertically reinforced masonry

Results of tests on simple masonry: The results of the experimentation on simple masonry models, model 1 and model 2, are presented in table1 and table-2, which give the various loads and corresponding (deflections of the top of the wall). The load at the beginning of cracks was also recorded. The crack pattern after loading is shown in figure-5. The load deflection curve for simple masonry model 1 and model 2 is shown in figure-6 and figure-7 respectively.

Figure-5
Cracks in simple masonry wall after loading

Table-1
Load deflection values for simple masonry model 1

S. no	Load (tons)	Deflection (cm)
1.	0	0
2.	0.5	0.1
3.	1.0	0.15
4.	1.5	0.25
5.	2.0	0.4
6.	2.5	.7
7.	3.0	1.0
8.	3.5	1.5
9.	4.0	2.0
10.	4.5	3.5
11.	3.5	4.5
12.	2.0	5.5

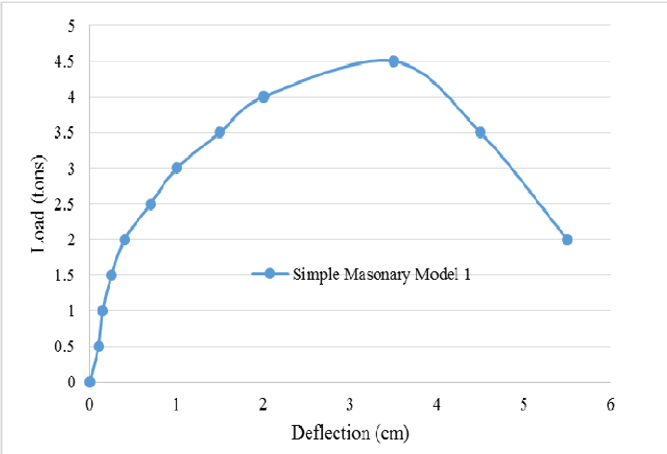

Figure-6
Load deflection curve for simple masonry model 1(Original figure required)

Table-2
load deflection values for simple masonry model 2

S. no	Load (tons)	Deflections(cm)
1.	0	0
2.	0.5	0.05
3.	1.0	0.17
4.	1.5	0.25
5.	2.0	0.4
6.	2.5	0.7
7.	3.0	1.1
8.	3.5	1.4
9.	4.0	2.0
10.	3.5	2.7
11.	3.0	3.5
12.	2.5	5

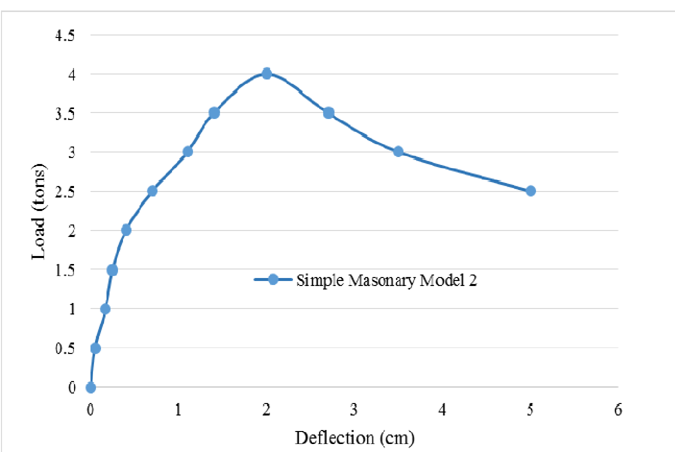

Figure-7
Load deflection curve for simple masonry model 2

Average values of the lateral load parameters for simple masonry wall models: i. The average collapse load was 4.25 ton (42.5KN). ii. The average maximum deflection recorded was 5.25 cm. iii. The average initial stiffness was 6.2 KN/mm.

Also both the models showed first crack at 2 tons (20 KN). The masonry showed brittle behavior collapsing almost immediately after reaching maximum lateral load capacity. The stiffness was initially high and the decreased very sharply.

Results of tests on vertically reinforced masonry: The results of the experimentation on vertically reinforced masonry models, model 1 and model 2, are presented in table-3 and table-4, which give the various loads and corresponding (deflections of the top of the wall). The load at the beginning of cracks was also recorded. The crack pattern in reinforced masonry at failure is shown in figure-8. The load deflection curve for vertically reinforced masonry model 1 and model 2 is shown in figure-9 and figure-10 respectively.

Figure-8
Cracks in vertically reinforced masonry

Table-3
load deflection values for vertically reinforced masonrymodel 1

S. no	Load(tons)	Deflection(cm)
1.	0	0
2.	0.5	0.05
3.	1	0.15
4.	1.5	0.2
5.	2	0.5
6.	2.5	0.7
7.	3	0.9
8.	3.5	1.3
9.	4	1.8
10.	3.5	2.5
11.	3	4.2
12.	2.5	6.0
13.	2	7.3

Figure-9
Load deflection curve for vertically reinforced masonry model 1

Table-4
load deflection values for vertically reinforced masonry model 2

S. no	Load(tons)	Deflection(cm)
1.	0	0
2.	0.5	0.11
3.	1.0	0.18
4.	1.5	0.3
5.	2.0	0.5
6.	2.5	0.7
7.	3.0	1.0
8.	3.5	1.4
9.	4.0	1.6
10.	4.75	2.2
11.	3.5	3
12.	3.0	5
13.	2.5	6.5
14.	2.0	8

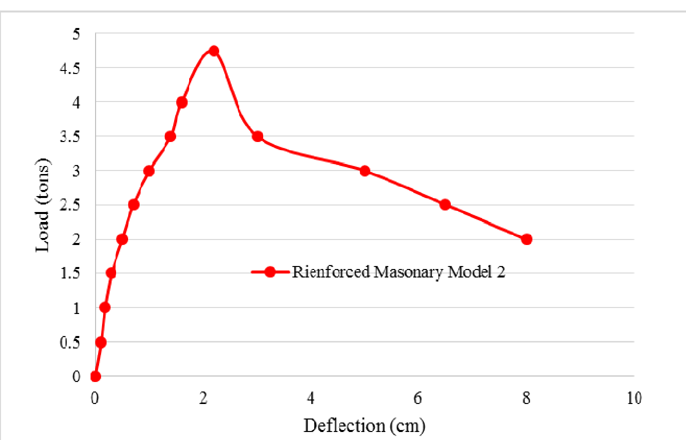

Figure-10
Load deflection curve for vertically reinforced masonry model 2

Average values for vertically reinforced models
The average collapse load was 4.37 ton (43.7KN)
The average maximum deflection was 7.65 cm

The average initial stiffness was 6.2 KN/mm. Also both the models showed first crack at 2.2 tons (22 KN). The masonry showed some ductility after reaching maximum lateral load capacity. The stiffness was initially high and the decreased very sharply.

All the models failed in shear. The cracks were diagonal, extending from one corner where the load was applied to the diagonally opposite corner. The pattern of cracks was same in brick masonry and vertically reinforced masonry. Vertically reinforced masonry behaved in a similar way as simple masonry with respect to the parameters studied i.e, lateral strength and stiffness. However, the failure of reinforced masonry was ductile as compared to the failure in simple masonry. Since ductility will allow sufficient time for evacuation from a building we deduce that vertically reinforced masonry is very much suitable for earthquake prone areas. Further from the above results it is clear that vertical reinforcement does not increase the lateral load capacity nor does it affect initial stiffness the results of the experimentation are compared in figure-11.

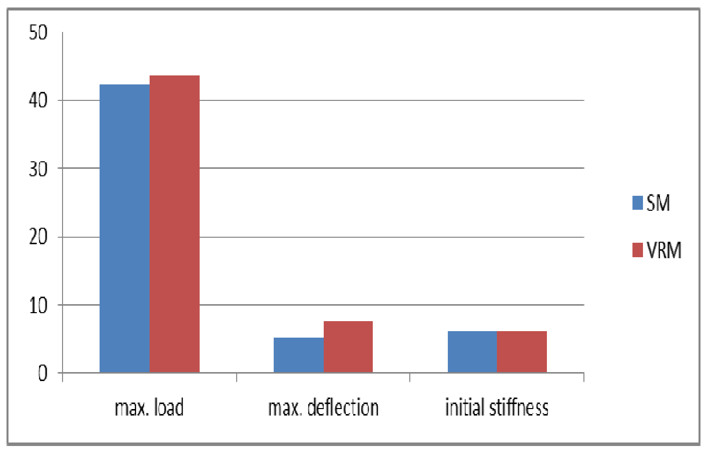

Figure-11
Comparison of various lateral load parameters between simple masonry (SM) and vertically reinforced masonry (VRM)

Conclusion

i. Vertical reinforcement did not noticeably affect the lateral load capacity of the masonry wall. ii. 2. Vertical reinforcement did not change the stiffness of masonry wall. iii. Vertical reinforcement enhanced the ductility of masonry walls by about 46 %. iv. Failure of simple masonry was brittle and should be avoided in constructions. v. For models with high vertical load failure occurs due to shear in which the cracks are diagonal.

Recommendations: i. Unreinforced masonry should be completely avoided in constructions as it fails in a brittle manner. ii. Vertical reinforcement bars should be embedded in masonry walls at proper distances. iii. Vertical reinforcement bars should also be provided at places in the building prone to cracks such as around doors, corners etc.

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