# Experimental and Numerical Study to Improve Lateral Load Resistance of Masonry Stack

**A. K. Shukla, Saurav and P. R. Maiti**

**Abstract** Lateral load capacity of any structure plays a very important role to resist earthquake [1]. To understand the lateral load capacity of any low-rise masonry building, a 3D finite element model of unconfined brick masonry stack has been drawn here. The ANSYS modeling of plain brick masonry shows that masonry structure fails at the joint. Therefore, to impart ductility and strength in the stack, shear key of 4 mm diameter TMT bar of 1/8th, 1/6th, and 1/4th of longitudinal length of brick length is provided at every joint separately in different samples and performance of both confined and unconfined prism is tested against vertical and horizontal load [2]. The purpose of this study was to develop a better behavior of low-rise masonry building during earthquake. Numerical as well as experimental methods have been adapted to calculate the stress developed in masonry stack [3].

**Keywords** Masonry structure · Confined masonry · Unconfined masonry · FEM analysis of masonry structure

## 1 Introduction

Unconfined masonry was used in approx. all types of structure since the life begins [4]. The masonry structures were made by two basic materials: brick and stone. These structures were not reinforced and designed to support mainly gravity loads. These masonry structures were very good at resisting wind and earthquakes. Masonry building has shown very poor performance during strong earthquake, so it is very important to improve the lateral load resistance of masonry buildings [5]. So to achieve this objective, many researches have been performed in the past. The main

A. K. Shukla (✉) · P. R. Maiti
Indian Institute of Technology (IIT-BHU), Varanasi 221005, India
e-mail: akshukla.rs.civ16@iitbhu.ac.in

Saurav
Jaypee University of Information Technology, Solan, HP, India



S. Adhikari et al. (eds.), *Advances in Structural Engineering and Rehabilitation*, Lecture Notes in Civil Engineering 38,
https://doi.org/10.1007/978-981-13-7615-3_1

focus is on ensuring that these inertial forces caused by the ground vibrations reach the ground without causing major damage or complete collapse in the structures [6].

This research starts with analyzing the scaled unconfined model of four bricks on shake table in laboratory and then confined the same four brick model with varying diameter reinforced to strengthening the unconfined brick model to resist the lateral load [7]. And when the confined models were tested on shake table and compared the result with unconfined brick masonry, a significant lateral strength was observed.

## 2 Modeling of Structure

### *2.1 Choice of Elements*

The ANSYS software contains more than 100 different element types in its element library. Each element has a unique number and a prefix that identifies the element category, such as BEAM3, PLANE42, and SOLID45. ANSYS classifies the elements into 21 different groups, out of which our main concern is of structural group. SOLID45 is used for the 3D modeling of solid structures [8]. The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal $x$, $y$, and $z$ directions. The element has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities [9].

### *2.2 Material Properties*

For the brick element material properties which are assigned are modulus of elasticity (EX) and Poisson's ratio (PRXY) [10]. Values of EX and PRXY are taken according to Ali and page 1986 [5] and are tabulated below (Tables 1 and 2).

**Table 1** Material properties of bricks

| Properties | Mean |
|---|---|
| (a) Bricks | |
| Modulus of elasticity | 14,700 MPa |
| Poisson's ratio | 0.16 |
| Tensile strength | 1.20 MPa |

**Table 2** Material properties of mortar

| Properties | Mean |
|---|---|
| (a) Mortar | |
| Modulus of elasticity | 7400 MPa |
| Poisson's ratio | 0.21 |
| Tensile strength | 0.78 MPa |


**Fig. 1** Model of specimen M1

#### 2.2.1 Model Detail of Specimen

To model the masonry, rectangular blocks are used for bricks and also for mortar. Four numbers of bricks of standard size, i.e., 190 mm × 90 mm × 90 mm are used, and mortar of thickness 10 mm is placed in between them as shown in Figs. 1 and 2.

### *2.3 Result and Discussion*

Postprocessing includes defining boundary condition and application of loads. For specimen M1, the one end of the brick masonry is fixed. The load is applied on the other end of the blocks. Pressure loads of 70 kN, 80 kN, and 90 kN are applied on the top face of the brick masonry. In addition to the vertical load, horizontal load is

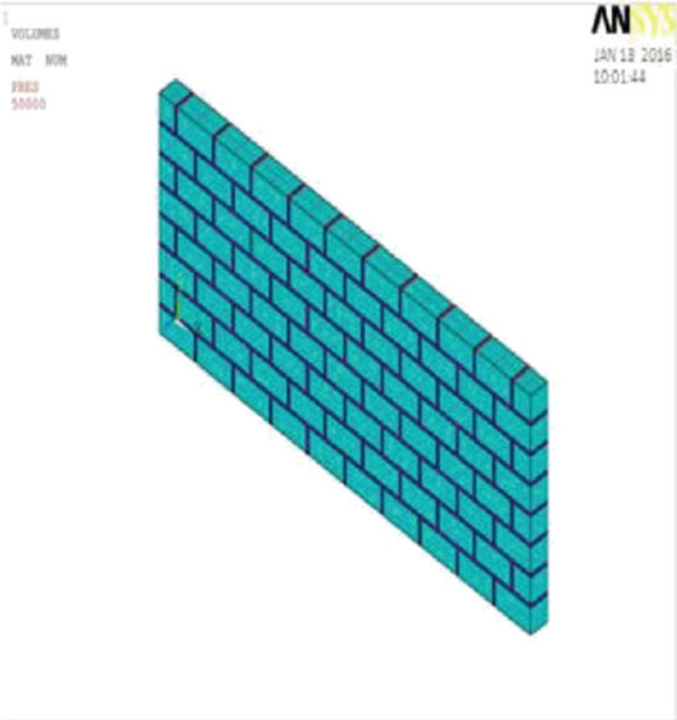


**Fig. 2** Model of specimen M2

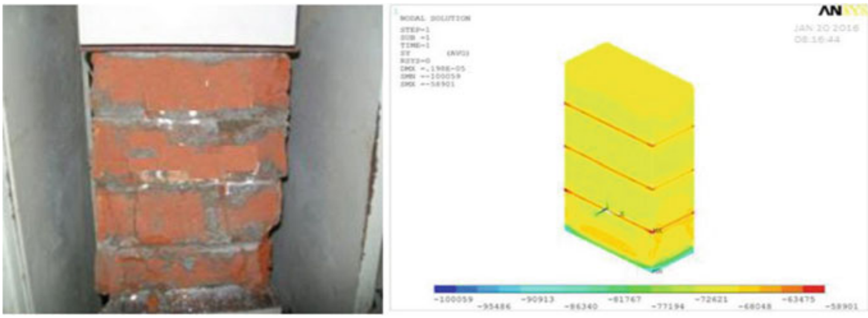

**Fig. 3** *X*-component of stress on UTM and ANSYS

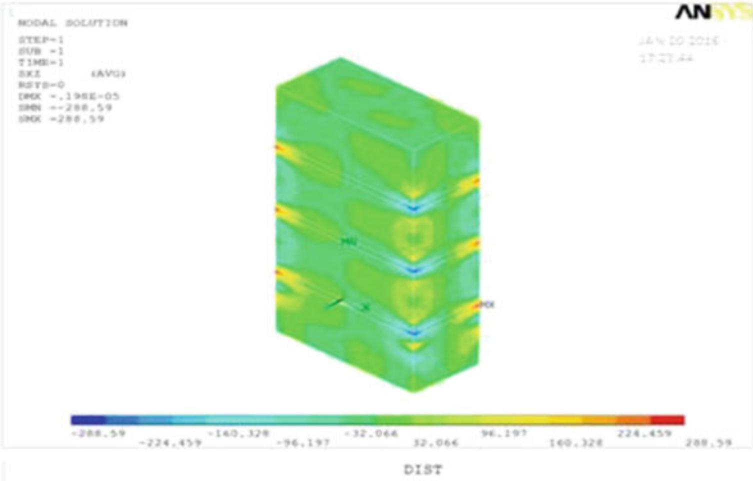


**Fig. 4** *XZ* shear stress

also applied to the specimen M1. Different stress contours are drawn, and graph has been plotted between different parameters. For specimen M2 in Fig. 2, one end is fixed to make it confined and vertical load is applied.

## *2.4 Stress Computation*

*Stress computation for specimen M1 with vertical loading*

From Fig. 3, it can be seen that *X* component of stress is maximum at the middle points. It increases parabolically from ends toward the center. For middle bricks, this stress is more as compared to top and bottom bricks.

Figures 4 and 5 show that the maximum stress is at the joint of brick mortar in *XZ* direction.

It can be observed in Figs. 6 and 7 that shear stress increases with distance along *Y*-axis. At a distance of 90 mm, stress is approximately 1400 MPa but from 90 to 100 mm, i.e., at the level of mortar, it decreases abruptly to −1563 MPa. Maximum shear stress is also observed at 28 mm which is equal to 1693 MPa.

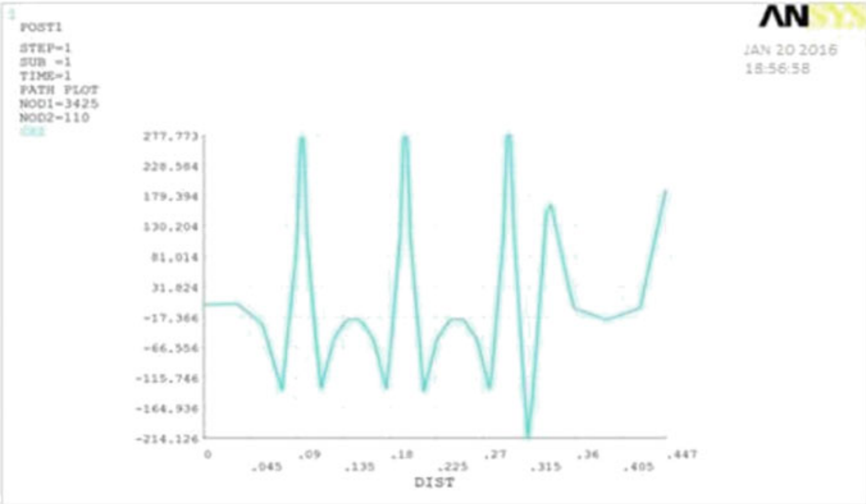


**Fig. 5** Variation of *XZ* shear stress *Y*-axis

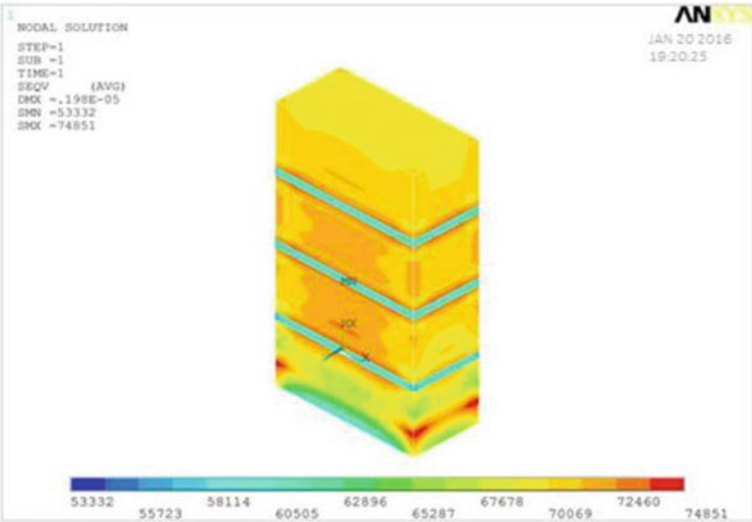


**Fig. 6** Von Misses stress along *Y*-axis

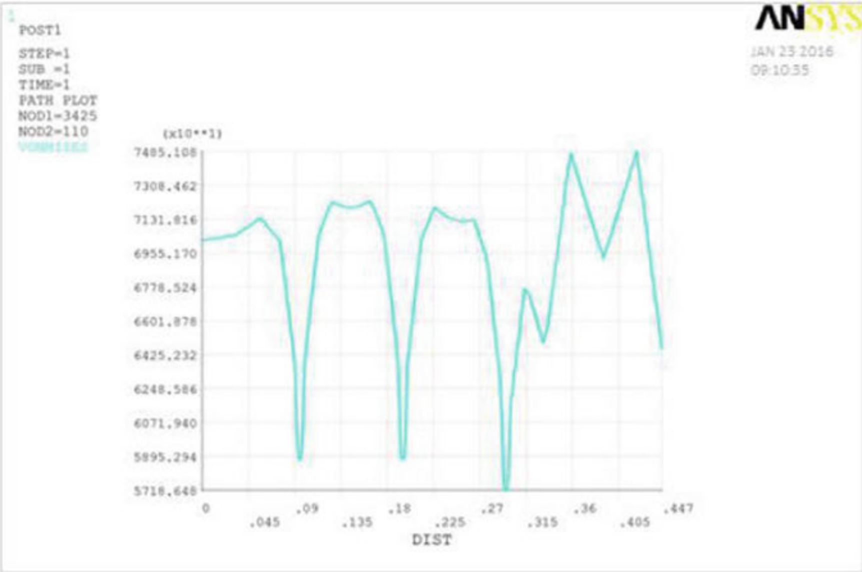


**Fig. 7** Variation of Von Misses stress along *Y*-axis

## 3 Experimental Investigation

For confinement of the masonry prism, TMT steel bars of 4 mm diameter were used. Between every course, shear keys of 26.25 mm = 1/8th, 35 mm = 1/6th, 52.5 mm = 1/4th of longitudinal length of brick length consecutively in different specimens were used as shown in Fig. 8a–c.

### *3.1 Compressive Strength*

For determination of compressive strength, bricks were taken out from curing tank and tested in UTM (Figs. 9 and 10). Tests were carried out at 7, 14, and 28 days of curing.

### *3.2 Testing of Masonry in Universal Testing Machine*

Different Stresses at Failure for Confined and Unconfined Masonry are tabulated below in Table 3.

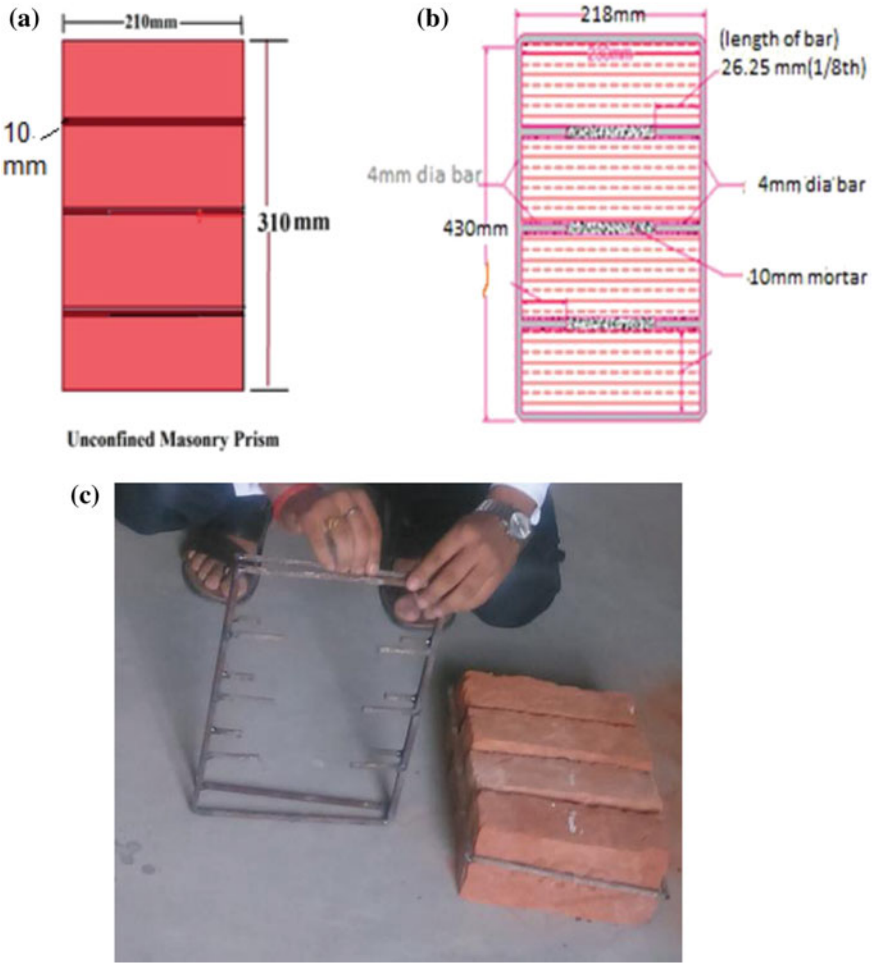


**Fig. 8** **a** and **b** Schematic view of masonry prism. **c** Pictorial view of reinforcement used

**Table 3** Compressive strengths at failure

| Compressive stress at failure | | | | |
|---|---|---|---|---|
| Prism type | | Strength in MPa of stack after | | |
| | | 7 Days | 14 Days | 28 Days |
| Unconfined brick masonry | | 4.32 | 6.02 | 6.66 |
| Confined brick masonry | Shear key length 26.25 mm | 5.80 | 9.19 | 10.33 |
| | Shear key length 35.00 mm | 6.47 | 9.19 | 10.33 |
| | Shear key length 52.50 mm | 7.61 | 10.42 | 12.14 |

**Fig. 9** Unconfined masonry failure

**Fig. 10** Confined masonry failure

**Fig. 11** Experiments performed on shake table

For understanding the behavior of masonry prism against lateral loading, i.e., in earthquake or in wind load, shaker table test with varying frequency was performed. The unconfined brick masonry samples were put on the shaker table platform and fixed with the help of clamp (Fig. 11). After fixing unconfined masonry tightly on the platform, a frequency of 5 Hz and amplitude of 10 mm was set and the motor was run on this frequency for at least 120 s.

### *3.3 Testing of Structure Under Horizontal Load: Shake Table Results*

All the samples including confined and unconfined masonry are tested under the horizontal load using the unidirectional shake table with varying frequency and amplitude as shown in Fig. 11. The result is tabulated in Table 4.

## 4 Results and Discussion

When brick was tested under universal testing machine (UTM), the average strength of brick was found to be 9.21 N/mm$^2$ and strength of cement sand mortar was found to be 14.57 N/mm$^2$ at 28 days of curing.

So material was found according to weak brick strong mortar theory.

Test conclusion of unconfined and confined brick masonry tested under universal testing machine and under shake table test is summarized below in Table 5.

**Table 4** Shake table test results

| Stability analysis | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| S. No. | Frequency of shake table (Hz) | Amplitude (mm) | 'g' value | Unconfined brick masonry | | Confined | | Confined | | Confined | |
| | | | | | | Brick masonry (shear key = 26.25 mm) | | Brick masonry (shear key = 35 mm) | | Brick masonry (shear key = 52.5 mm) | |
| | | | | Stability | Time (in s) | Stability | Time (in s) | Stability | Time (in s) | Stability | Time |
| 1 | 0.3 | 2.5 | 2 | Stable | 120 | Stable | 120 | Stable | 120 | Stable | 120 |
| 2 | 0.4 | 5.0 | 2 | Stable | 120 | Stable | 120 | Stable | 120 | Stable | 120 |
| 3 | 0.5 | 7.5 | 2 | Collapse | 26 | Stable | 120 | Stable | 120 | Stable | 120 |
| 4 | 0.6 | 10 | 2 | | | Cracking seems at joints after 80th s | | Very small cracking pattern observed at joint after 360 s | | Stable | 360 |

**Table 5** Result of UTM and shake table

| S. No. | Sample (after 28 days) | Failure load KN | Stability on shake table | | |
|---|---|---|---|---|---|
| | | | Frequency (Hz) | Amplitude (mm) | Remarks |
| 1 | Unconfined masonry prism | 137 | 15 | 35 | Total Collapse at 26th s |
| 2 | Confined with shear key 26.25 mm | 217 | 20 | 50 | Cracking at 80th s |
| 3 | Confined with shear key 35.00 mm | 230 | 20 | 50 | Very small cracking at 360th s |
| 4 | Confined with shear key 52.50 mm | 255 | 20 | 50 | Stable after 360 s |

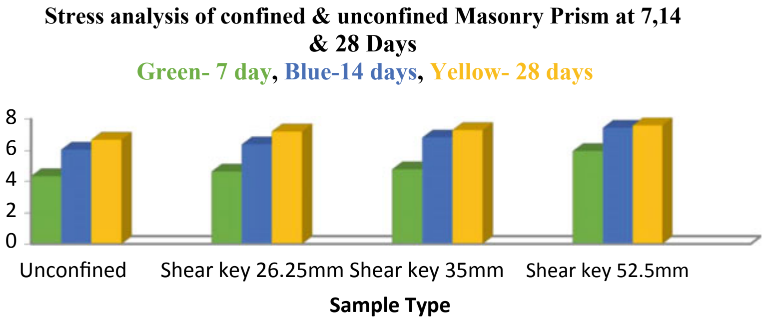


**Chart 1** Stress analysis

## 5 Conclusion

After analyzing Chart 1 of performance of confined and unconfined brick masonry, it is concluded that the stress capacity of unconfined brick masonry at 28 days of curing was found to be 6.6 $N/mm^2$ while after confinement, stress capacity increased to 12.14 $N/mm^2$ for shear key length 52.5(1/4th of sample length) mm, i.e., the compressive load capacity of confined brick masonry was approximately doubled of unconfined brick masonry structure at 28 days. But if we look the shake table result, then we found that this stack does not show any crack even after the application of vibration for 360 s.

From the experimental study, it can be concluded that the brick stack with shear key length 1/6th of longitudinal length will be an economical solution for confinement.

## References


1. Page AW, Brooks DS (1985) Load bearing masonry—review. In: Proceedings of the 7th international brick masonry conference, pp 81–99
2. Drysdale RG, Wong HE (1985) Interpretation of the compressive strength of masonry prisms. In: Proceedings of the 7th international brick masonry conference
3. Suter GT, Naguib EMF (1987) Effect of brick stiyness orrhorrapy on the lateral stress in stuck-bonded brick masonry prisms. In: Proceedings, fourth North American masonry conference, paper 18
4. Khoo CL, Hendry AW (1973) A failure criterion for brick work in axial compression. In: Proceedings of the 3rd international brick masonry conference
5. Ali S, Page AW (1988) Finite element model for masonry subjected to concentrated loads. J Struct Div ASCE 114(8):1761–1784
6. Rots JG (1991) Computer simulation of masonry structure: continuum and discontinuum models. In: Proceedings of the international symposium on computer methods in structural masonry Swansea, UK, April 1991, pp 93–103
7. Stockl S, Bienvirth H, Kupfer H (1994) The influence of test method on the results of compression tests on mortar. In: Proceedings of the 10th IBMAC, University of Calgary, pp 1397–1406
8. Brooks JJ, Abu Baker BH (1998) The modulus of elasticity of masonry. Br Mason Soc J 12(2)
9. Yoshimura K et al (2004) Experimental study for developing higher seismic performance of brick masonry walls. In: Proceedings of the 13th World conference on earthquake engineering, Vancouver, Canada, Paper No. 1597
10. Mohammed MS (2009) Finite element analysis masonry walls of unreinforced masonry