***Seismic performance of* Masonry**

Structures using Abaqus

A thesis submitted in partial fulfillment of

the requirements for the degree of

Master of Science

In

Structural Engineering

Submitted By

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Military College Of Engineering (MCE)

NATIONAL UNIVERSITY OF SCIENCES & TECHNOLOGY (NUST)

SECTOR H-12, ISLAMABAD, PAKISTAN

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This is to certify that the
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To My Parents
And
My Brother
Hamza Jutt

ACKNOWLEDGEMENT

"And Allah is sufficient as a friend, and Allah is sufficient as a helper"
(4:45)

First and foremost, I would want to express my gratitude to Almighty Allah for providing me with the opportunity to complete my Masters at one of Pakistan's premier colleges. MCE's faculty is outstanding, and I couldn't have wished for a better curriculum. I am ecstatic to be a member of such a prestigious organization.

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Finally, I'd want to express my gratitude to Mrs. Tariq, my mother, and Mr. Muhammad Tariq, my father, for the sacrifices they made over the years to allow me to pursue my dreams and get to where I am now. They pushed me to pursue my aspirations in the other side of the country, despite the fact that I had never left Faisalabad alone, even for a day.

ABSTRACT

Brick masonry is the most prevalent method of construction in all of Pakistan and almost all of South East Asia. It is also employed extensively throughout the rest of the world. Pakistan is among the most earthquake prone areas of the world. It has been seen in recent years that brick masonry construction has experienced a number of failures in facing earthquake loadings.

Confined Masonry is a form of construction employed to improve the seismic resistance of masonry structures. Masonry structures are weak to resist the out of plane forces. Out of plane forces are generally applied through perpendicular walls carrying in plane loads. The presence of confinement at such points enhances the structure's performance. The confinement improves ductility and energy dissipation capabilities of the structures.

In this study, effect on performance of confined and unconfined structure due to irregularities, both in plan and elevation, will be studied. There are confinements provided in form of columns and beams. In order to study these effects, two 3-storey structures are analyzed on Abaqus. Both the structures are identical with the exception of one being confined. Each structure has eccentric walls as we move up the floors with openings provided for doors and windows.

The results obtained from the analysis emphasize on the importance of confinements. These results can then be used for academic purposes, as well as a basis for future research and design of confined masonry.

Chapter 1

1. Introduction

1.1.General

The use of bricks for construction has been dated as far back as 7500 BC. The bricks were found in the upper Tigris region and in southeast Anatolia near Diyarbakir. These bricks were made from shaped mud or clay bearing earth and are thought to have been dried in the sun. Other recorded use of bricks in construction has been recorded in the South Asian areas of Mehrgarh and Mohenjo-Daro and dates back to similar times of 7000BC. The next great advancement of bricks came in 3000BC where ceramic brick, bricks fired in an oven, were used for construction in early Indus Valley cities such as Kalibangan.

Masonry is a construction technique where individual units of similar properties are used to construct structures using a binding material known as mortar. These individual units can be bricks, stones, tiles or anything that may be useful and appropriate for use. Masonry is generally considered a durable method of construction however, the quality of mortar, the level of workmanship and the pattern of assembly of the individual units, can make a substantial difference in the properties of the finished product.

Masonry is used extensively throughout the world, the advent of newer techniques such as the making of arches allowed builders to construct huge spans with the help of masonry. Masonry finds use today extensively throughout the world. South Asian countries use masonry in huge amounts for construction purposes. The main reason behind this is that masonry offers a durable and relatively cheap means of construction as compared to wooden construction which is vulnerable to fire and damage from insects or even regular freeze and thawing cycles. Stone, brick and tile are highly resistant to damage from external elements which finds great use in a number of situations.

Brick masonry is the most used construction method in Pakistan with clay bricks fired in kilns beings the most used. In northern areas of Pakistan such as Murree and Swat, brick masonry is replaced with stone masonry due to the high moisture and precipitation in these regions. Bricks have a tendency to absorb moisture which is why these regions employ the use of non-porous stone masonry.

The reason for this is that brick masonry has a number of inherent advantages,

1. It is easy to construct and requires less skilled labor.
2. Increases the thermal mass of buildings.
3. It is noncombustible thus is safe from fire hazards.
4. Highly durable and strong as compared to wooden frame construction.
5. Has a high capacity to resist projectiles from strong winds.

Despite the numerous advantages that brick masonry has, it also suffers from a series of serious setbacks such as,

1. Extreme weather conditions can degrade masonry by frequent expansion and contraction
2. Masonry increases the self-weight of a building considerably and must be supplemented with a strong, usually artificial, foundation.
3. Does not allow for much mechanization thus the process is still dependent on labor
4. Masonry has high compressive strength but very low tensile strength.
5. Masonry is usually employed in the construction of walls where toppling also becomes an issue.

The property of masonry being weak in tensile strength is well known and often discussed in many studies. A number of efforts have been made to address the issue from using Fiber reinforced polymers, wooden posts in the middle of walls and addition of reinforcements to hollow brick walls. However all of these methods leave room for improvement.

During earthquakes, a simple 4 wall room faces seismic energy emanating from a particular direction. If the origin of these seismic energies is perpendicular to two walls yet parallel to the other two, a huge issue arises. The walls parallel to the origin point seem to fare well against the earthquake forces while the walls perpendicular to the earthquake have a tendency to topple.

Therefore, the primary Objective of this study is to compare and check the strength and dynamic response of brick masonry structures under Earthquake Motion using Abaqus.

1.2.Physical Properties of Masonry Structures

A masonry structure consists of layers of building blocks stacked together. Burnt bricks are the most commonly used building blocks used in regular masonry structures. Typical dimensions for bricks used in masonry work in Pakistan are:

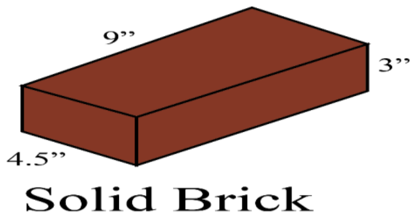


Figure 1 Brick Dimensions

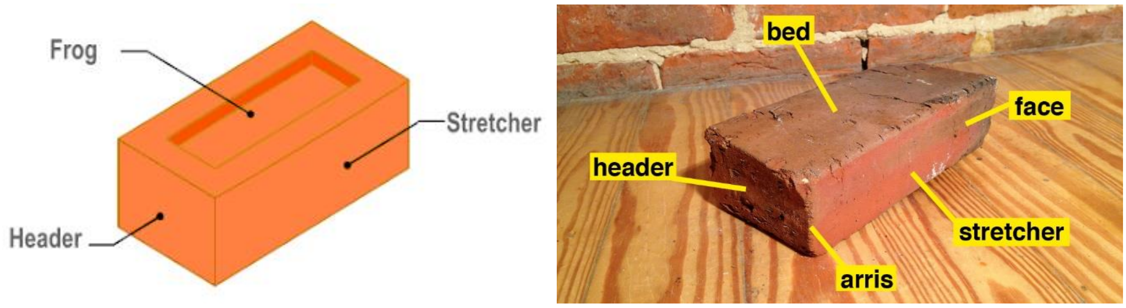


Figure 2 Brick Parts

Placement of the brick is also a key parameter in defining the type of masonry work undertaken. It can be placed in different arrangements to suit the need of the project. The configuration depends upon the strength that is required to be achieved. Each configuration leads to a different kind of bond with different strengths. Following image shows the different types of bonds used in masonry construction:

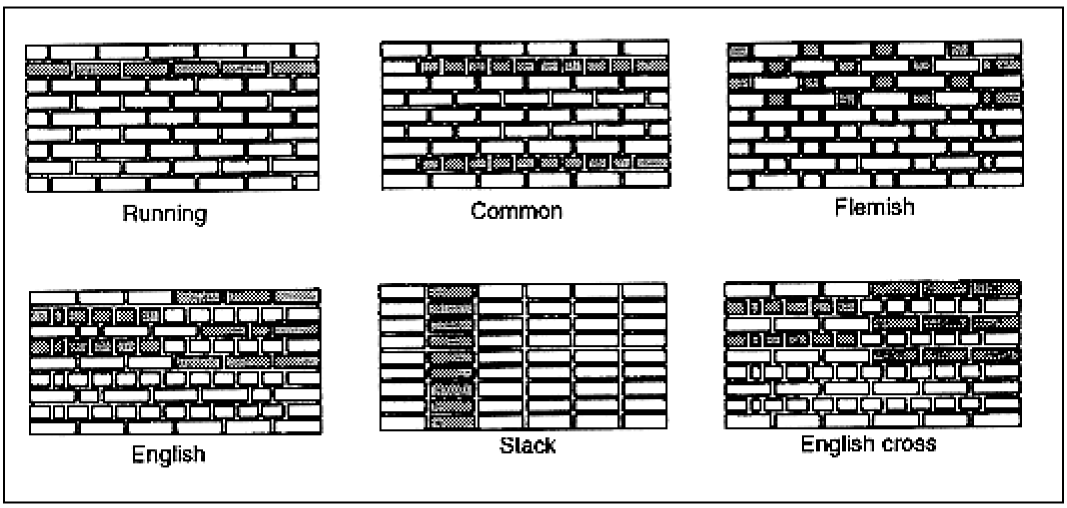


Figure 3 Brick Laying Types

In brick masonry, bricks are joined together by using different types of mortar. Each kind of mortar has its own properties and results in different strength and chemical resistance as compared to the others. Mortar consists of a binding material which gains strength by the addition of water and keeps the bricks (stones in case of stone masonry) together. Below are the few types of mortars that can be used in masonry:

1.2.1. Mud Mortar

It is one of the oldest types of mortars used for construction purposes. It consists of mud, which acts as a binding material alongside husk and saw dust to provide it with strength and stability. It is still used in places where other mortar types are not accessible and is preferred in case of temporary structures such as huts and temporary sheds on site.

1.2.2. Lime Mortar

It uses cement as a binding material and is used in places where lime is easily accessible. It has high plasticity as compared to other mortar types making its placement relatively easy. It can also be used to improve the aesthetic appeal of a structure with the addition of pigments in the mixture.

1.2.3. Cement Mortar

It is the most commonly used mortar in Pakistan. It uses cement as a binding material. Sand is added to the mixture to give it the required strength. It is preferred in case of brick masonry as it forms a stable bond with the bricks. It composition ranges from cement-sand ratio of 1:3 to 1:7.

The above discussion highlights two important physical components of a masonry structure i.e. building blocks and mortar. In our study, we shall be focusing on bricks as our building blocks and cement mortar as a binder to keep them together. The reason being that these are two most preferred components used in Pakistan for all of the masonry structures.

1.3. Way to go

Methods have been devised over time to improve their strength by adding more construction elements and preferable confining the masonry walls to minimize the damage. Confined Masonry is construction method which consists of the masonry walls supported by vertical confinements made up of reinforced concrete columns. Simple masonry can be distinguished from confined masonry simply on the basis of the provision of reinforced concrete columns at the ends. These columns help in supporting the vertical and lateral loads and distribute them to the base. Columns are provided at the wall connections and corners and also at the edges of the doors and the windows.

With every passing day, increase in population is giving rise to the need for new buildings, which is eventually forcing us to construct in critical area with serious seismic threat. Pakistan is a developing country with limited resources. Concrete is comparatively expensive and so brick masonry is still preferred. There are not enough resources available to ensure a cheap supply of concrete. Majority of the resident buildings are made of brick masonry. There is a need to compare the effects of seismic activity on different types of masonry structures to get the best alternative for construction purposes. Very few experimental studies have been done in the field and still there is no surety to whether well-confined masonry structures improve the seismic resistance of masonry structures as predicted.

In order to study the effects of columns on the strength of masonry structures, two different 3-storey models are studied. Both the models are similar to each other with respect to dimensions and floor configuration. They are also provided with a variation in the wall configuration at every floor. The structure is also provided with openings for doors and windows to replicate real life buildings. The only difference in both the models is that model 1 is a simple masonry structure while model 2 has confinements at the ends and wall junctions. Both the models will be analyzed using Abaqus. Following is the model aimed to be analyzed in the study:

Figure 4 Proposed Model

1.4.Problem statement

The use of brick masonry in structures today is to fulfill the need of a durable, strong and immovable structural aspect that allows the inhabitant to feel comfort and safety. Brick masonry fulfills this need but to the extent of normal loadings. It has been seen in recent years that brick masonry construction has experienced a number of failures in facing earthquake loadings. Therefore, the Objective of this study is to compare and check the strength and dynamic response of brick masonry structures under earthquake motion. commercially available software's do not capture these effects accurately. So there is a dire need to introduce a software where designers can work with confidence.

1.5.Objectives

- To model the response of masonry wall panel under application of cyclic load in ABAQUS and its validation under existing experimental results.
- To study the response of a three-story building, confined and unconfined, using ABAQUS under seismic loading.

Chapter 2

2. Literature Review

2.1.Case Study of full-scale Model

The effects of seismic loads on full scale masonry structures were studied in 2011 by a group of scientists based in the University of California. They studied a full scale model on a large outdoor shake table. The specimen was a 3 story building and was subject to a Maximum Considered Earthquake (MCE). Earthquake data used for this analysis was El Centro, 1979, Sylmar, Rinaldi and Chi Chi. The model also validates a few design concepts. Most of the design calculations do not incorporate the coupling moment produce by the floor planks. But it was observed here that the floors in fact were impressively stiff and resisted the coupling forces thus preventing the collapse of the walls. The middle wall was the first to slide while the other walls resisted for longer periods.

2.2. Case study of Confinements on Walls

MIHA TOMAZEVIC AND IZTOK KLEMENC concluded that the presence of confinements positively impacts the lateral strength of masonry structures in a study to illustrate the effects of confinements on seismic behaviour of masonry walls. They used a 1:5 scale to simulate structures, and the results were close to those expected theoretically. As a result, the interaction between brick walls and confinements occurs at the particle level and is unaffected by the structure's size. There should be no problem comparing the results to a full-scale model as long as all of the components are reduced in size uniformly. The inclusion of confinements also improved the structure's elastic (crack) limit, maximum resistance, and final state, allowing it to bear huge quantities of lateral loads and resulting in structural stability over a longer period.

Another study presented at the Euro Asia Civil Engineering Forum's 5th International Conference (EACEF-5) compared the strengths of a plain wall and a reinforced wall. To improve the ductility and flexural strength of brick masonry walls, they employed reinforcement steel. The study's findings are as follows:

Table 1 Wall Specifications

Wall specimen	Strengthening in vertical direction	Strengthening in horizontal direction
unreinforced	DTPV	DTPH
Steel reinforcement Φ 4,5 mm	DDPV-D4,5	DDPH-D4,5
Steel reinforcement Φ 6 mm	DDPV-D6	DDPH-D6
Steel reinforcement Φ 8 mm	DDPV-D8	DDPH-D8
Notations: - DTPV: wall without strengthening in vertical direction - DTPH: wall without strengthening in horizontal direction - DDPV-D4,5: wall with strengthening steel of 4.5 mm in vertical direction		

The results depict that the addition of reinforcement in common masonry can greatly help in improving the ductility manifolds thus allowing residents to escape before the structure fails. It also gives it greater strength allowing it to resist greater loads for a larger amount of time saving precious lives in the process.

A study was done in Japan to study the response of confinements. They concluded that the presence of confinements positively impacts the strength of masonry walls and helps them resist the loads in a better manner. It is because the confinements increase the overall strength of the wall and ductility while inducing shear stresses in the masonry walls when subjected to lateral loads.

2.3. Case Study of Earthquakes in Pakistan

Earthquakes are a result of the movement of tectonic plates lying under the surface of the Earth and their movement relative to each other. The outer shell of the Earth consists of basically seven tectonic plates, each named after the continents. These plates are in constant motion and whenever these collide or brush against each other, this results in an earthquake. The following picture depicts the location of Pakistan where two plates, Eurasian and Indian plates, join. This makes Pakistan an active region for earthquakes. During the past century Pakistan has faced dozens of earthquakes taking thousands of lives and resulting in irreparable damage to people's lives and their property. Two of the major earthquakes are:

- Quetta earthquake 1935, where the intensity of the earthquake was 7.7 and more than 30,000 people lost their lives.
- Kashmir earthquake 2005 resulted in more than 80,000 people losing their lives. Its intensity on the Richter scale was 7.6.

Pakistan's location makes it vulnerable to further such incidents in the future if no real measures are taken to counter the problem. Earthquake is a natural catastrophe and cannot be avoided. The only thing that we can control is the damage caused by it. And this can be done by constructing structures that are able to resist seismic activities or at least be able to give people enough time to escape to safe areas. The only way to achieve this goal is research and new methodologies to improve the whole set up. Following the Kashmir earthquake 2005, various studies were carried out to dig out the root causes of earthquake damage on buildings. One such study focused on the construction of seismic restrained buildings using the design and building code to minimize the effect of earthquake damage hinted at the deficiencies in the infrastructure. The study pointed out the fact that the construction codes in Pakistan lag far behind the Japanese in terms of quality and implementation. Japanese have taken the issue seriously and have devised building codes to counter the situation. They have ensured that the rules are followed. In Pakistan, we are lacking gravely in results regarding seismic activity. Extensive work is required to get to a conclusive phase where implementation can be started.

2.4. Case Study of Masonry Buildings

Another study carried thanks to Ponteficia Universidad Catolica, Peru studied the effects of seismic loads on masonry homes using the shake table analysis. They studied multiple models with different wall thickness, confinements and reinforcements. The Aim of the study was to find the best combination of the masonry, confinement and reinforcement to bear the severe earthquakes without collapsing. The models were designed by MIE University and UET Peshawar. A total of three tests were carried out and the test results obtained from the study are as follows:

Table 2 Study results (Confinements under seismic loading)

	First Test	Second Test	Third Test		
Structure	Brick	Confined Masonry	Confined Masonry with Rigid Roof Girder		
Wall Thickness	230mm	110mm (100mm)	105mm		
Added Reinforcement	No	No	No	Lintel Beam	Wire Mesh and Mortal Finishing
Input Max. Acce	1.7G	2G	2G	2.5G	2.5G
Input Max. Velo.	1m/s	1m/s	0.5m/s	0.5m/s	0.5m
Results	Collapse	Collapse	HeavyCracks	Cracks	No Damage

Another study carried out in India by Kushal J. Desai and his team studied the comparison between confined and unconfined masonry structures. They used mathematical models to prove their hypothesis and concluded that confinement does improve the seismic resistance of the masonry structures.

In the study by Simon PETROVČIČ and Vojko KILAR, they analyzed the mathematical response of seismic isolation to the behavior and strength response of unreinforced masonry structures. Their study was aimed at strength improvement of heritage buildings with respect to their seismic response. They concluded that the unreinforced masonry structures are rather weak against seismic forces and can collapse. Therefore, seismic isolation is required to protect the structure and help it withstand these loads over longer periods of time.

2.5. Findings Of Different Researchers About Seismic Behavior Of Masonry

The seismic behavior of unreinforced masonry has been improved by several studies. Steel has recently been used by researchers to enhance the lateral capacity, ductility, and energy dissipation of unreinforced brickwork. The use of fibre reinforced polymer sheets and laminates to enhance the seismic performance of unreinforced masonry is the subject of recent research. The findings of several researchers are presented in the following paragraphs.

1) Matsumura (1987) researched 57 concrete walls and 23 clay brick masonry walls, reporting on the behaviour of fully and partially reinforced masonry shear walls following trials. The influence of axial pre-compression, the quantity of horizontal reinforcement, and the failure mechanism of the walls were the key parameters he investigated. Different lengths, heights, and thicknesses of these walls were built and tested under in-plane lateral loading. The walls ranged in length from 0.4 m to 2.0 m, with heights ranging from 0.6 m to 1.8 m and thicknesses ranging from 100 mm to 190 mm. Rectangular mesh was used to offer horizontal and vertical reinforcements. He evaluated the walls using D10 horizontal bars with a vertical spacing of 400 mm and D29/D22

2) To assess the compressive behaviour of confined and unconfined brick wall panels, Bryan D. Ewing et al. (2004) conducted tests.Steel plates inserted into the bed mortar greatly improved the compressive strength of clay brick masonry by up to 40%, according to the researchers. The amount of confining steel has a direct relationship with the increase in ultimate compressive strength and strain. Confining plates may also help to mitigate the negative impacts of poor craftsmanship on the behaviour of clay brick masonry buildings. Higher volumetric steel ratios can be achieved using brick masonry restricted with steel plates, resulting in a significant improvement in strength. The findings of this study can be immediately applied to performance-based design processes for assessing the strength of masonry walls.

3) Yokel et al. (1975) compared the different failure theories of masonry walls by testing 32 un-reinforced single wythe brick masonry walls under diagonal compression. He divided the walls into four sections, each with three different types of masonry pieces and two different types of mortar (normal and high strength mortar). There were eight wall panels in each group. They found from their experiments that shear failure is caused by debonding at mortar joints and tensile splitting of masonry units. Joint debonding could induce failure in the event of modest gravity loads, whereas strong axial loads can cause tensile splitting of brick units. A key relationship between the principal biaxial strains governs the splitting failure of brick units at the middle of the walls.

4) Ferdous et al. [2] proposed a new wall system made up of pultruded glass fibre reinforced polymer composites. The span-to-depth ratio has a crucial influence in predicting failure modes and final capacities of double-H-plank and round-pile specimens, according to their findings. Porto et al. used low-diameter steel reinforcements and reinforced a wall horizontally to improve the masonry walls' in-plane behavior between the bricklayers [3]. The use of coils to integrate the wall, according to Gouveia and Lourenco's research, can increase the lateral strength and ductility of unreinforced masonry walls by up to 30% [4]. Based on trials, Nateghi and Alami investigated the effect of the wall's dimensions on the type of collapse. They showed that the failure mode and crack distribution in the wall depends directly on its dimensions [5]. Pujol et al.studied the effect of masonry materials in filling the space of the frame. For this purpose, a two-story bending frame structure in which its two openings were filled by masonry walls was tested on a seismic table [6]. According to their studies, these walls suffered a sharp drop in strength after structure yielding. Maheri et al. studied two masonry walls, one with vertical mortar and the other without vertical mortar. The results showed that the use of vertical mortar significantly increased the stiffness and in-plane strength of unreinforced walls [7]. To provide the data needed to improve the numerical models of unreinforced masonry walls, Beyer et al. studied the effect of boundary conditions on masonry walls' behavior [8–11]. The main failure observed in masonry walls is shear fractures, which are usually diagonal. This failure is very brittle and has little ductility. According to Sadeghi's research, increasing the axial load on the wall can increase its shear strength and decrease its displacement capacity.

5) Moslem Shahverdi et al.Presented a new way to enhance the performance of Masonry.He also compared the experimental results with Abaqus results by modeling wall panels in Abaqus and proved that the Abaqus results were near to Experimental Values.

2.6. Shaking Table

With the help of actuators, the shake table creates lateral stress. These actuators are placed on the side of the load that will be created. Actuators move the structure with oil-filled pistons. After the seismic forces have been generated, the displacement is detected by accelerometers and transducers mounted to the structure. Transducers may now produce data immediately on an excel sheet without the need for manual effort thanks to modern technologies. Most of the time, the structure to be tested is loaded until it fails. The structural behaviour can then be determined after establishing a link between acceleration and displacement.

Figure 5 Shaking table assembly for testing

2.7. Masonry wall panel under cyclic loading

The wall was analyzed under static cyclic lateral loading at 0.5 MPa pre-compression.The results after the test are as under:-

2.7.1. Hysteretic Behavior

Figure depicts the specimen's hysteretic loops. The hysteretic loops were not properly spread out, revealing the brittle behavior of unreinforced masonry. Only the stretchy branch stands out. The inelastic branch is almost non-existent, and there is a quick failure and stiffness decline following the peak stage. The specimen had suffered from diagonal cracking, which occurs when the material tries to move laterally. The specimen's yield strength and lateral displacement were 78 kN and 1.63 mm, respectively. The peak lateral load was 88.9 kN, with an ultimate lateral displacement of 3.31 mm at 20% deterioration. At the yield and ultimate stages, there was a very low drift ratio of 0.15 percent and 0.3 percent, respectively. The loops at the peak and ultimate stages are nearly overlapping, showing that inelastic behavior is not present.

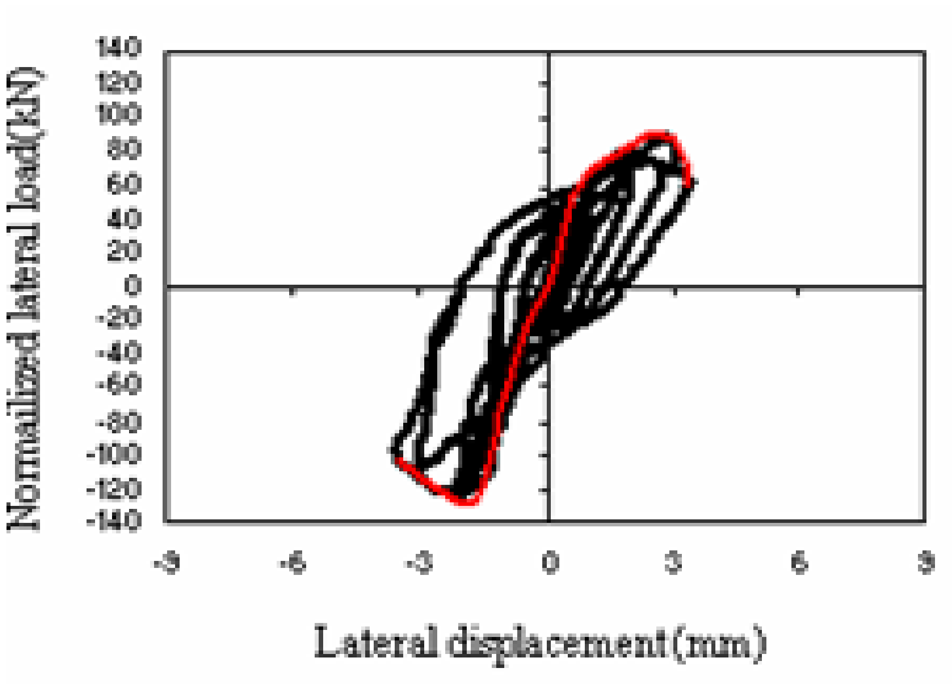


Figure 6 Hysteretic Loops Of Masonry wall panel

2.7.2. Ductility Factor and Stiffness

Due to the reduced ultimate lateral displacement, the ductility factor in the case of the specimen was fairly low. The lower the ductility factor, the more brittle the specimen will be. The specimen's ductility factor was found to be 2.03. The yield stage had a higher lateral displacement of 1.63 mm than the final stage, which had a lateral displacement of 3.31 mm. At the yielding and peak stages, stiffness values of 47.85 kN/mm and 30.76 kN/mm were measured. The stiffness values found at the final stage were 21.45 kN/mm.

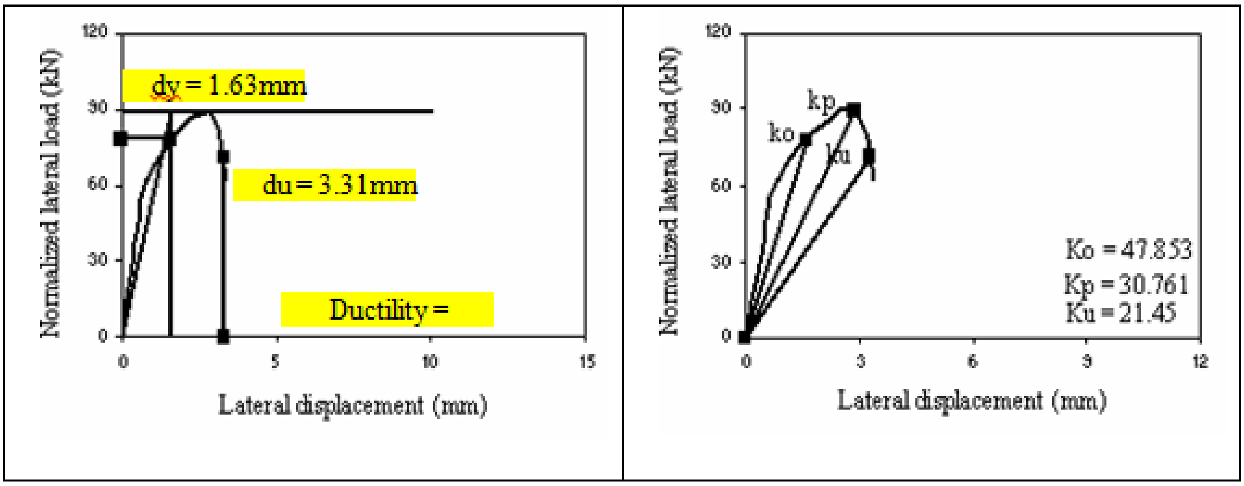


Figure 7 Ductility Factor and Stiffness

2.7.3. Failure Characteristics

With a lateral displacement of 2.86 mm, the specimen achieved a peak lateral strength of 88.9 kN. Brittle shear failure had occurred in the specimen. A first flexural crack occurred in the center of the specimen with a lateral displacement of 1.63 mm and a lateral load of 78 kN. The same crack extended from the center of the specimen to the bottom with a lateral load of 85.4 kN and a lateral displacement of 2.09mm.

More fissures propagated in both negative and positive directions as the cycle progressed. Soon after conceding, the final step began. The specimen's negative topside was quite unharmed. Cracks had spread to the lower, middle, and top parts of the specimen at ultimate lateral pressure. As the specimen was displaced from its origin, cracking predominantly dissipated the energy, and residual displacement was extremely high.

Vibrations caused by earthquakes generate additional loading. Shear stresses develop which cause damage to structural elements. Since masonry, which can be stressed relatively high in compression, is weak in resisting bending and shear, collapse is often the result.

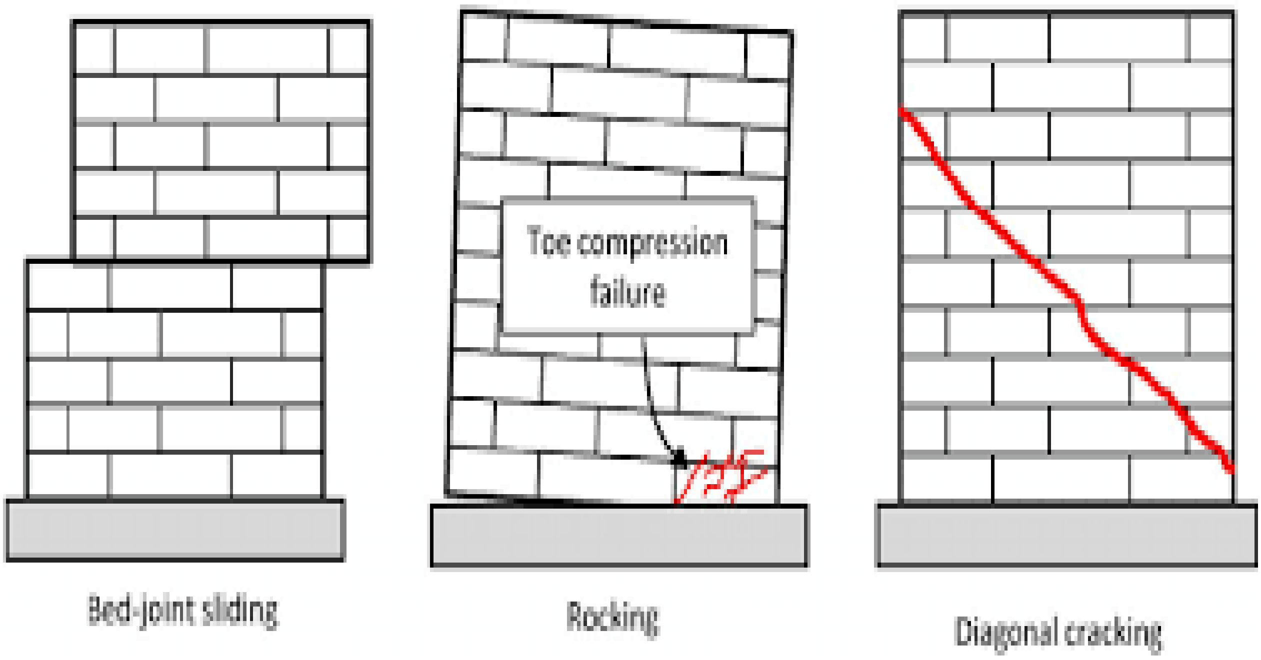


Figure 8 Failure Modes

(a) Specimen at the time of testing

(b) Diagonal cracks on both sides at wall back

(c) Undamaged negative topside

(d) Cracks passing through mortar positive side

(e)Diagonal cracks in middle & positive bottom

(f) Cracking at middle center of wall

(g) Diagonal cracking at negative side toe

(h) Diagonal cracking at positive backside toe

Figure 9 Pictorial view of failure of Masonry wall panel at different locations

The yielding began in the ninth cycle and peaked in the eleventh cycle. During the cyclic test, no toe/heel crushing was seen. The specimen failed by pure cracking mode, therefore there was no considerable upward movement of the base. The largest upward movement measured at the end of the test was only 0.35 mm. The lateral drift values were extremely high as compared to the ultimate lateral displacement. At the top of the specimen, the lateral drift was 1.795 mm on the positive side and 1.983 mm on the negative side.

2.8. Different Theories of Failure

2.8.1. Brief Description of Theory of Plasticity

The majority of materials act within their elastic limits until they begin to yield, and then exhibit non-linear plastic behavior after that. Different plastic theories are used to model inelastic behavior. Plastic theories are divided into two categories: incremental plastic theory and deformation plastic theory. The mechanical strains are segmented into elastic and plastic components in the incremental type, whereas the stress is established using total mechanical strain in the deformation type. The incremental plastic theory, which is approximated using a yield surface, flow rule, and evolution rules, is the most widely used plastic theory.

2.8.2. Failure Criteria

Different yield criteria can be used to simulate the inelastic behaviour of various materials. The most often used failure criteria are Tresca, Von Mises, Rankine, and Mohr Coulomb.

2.9. Finite Element Models for Brittle Materials

Smeared and discrete crack models are commonly used in the finite element analysis of brittle materials, as explained below.

2.9.1. Smeared Crack Model

The smeared crack analogy can be used to represent tensile cracking in reinforced masonry since it does not require a significant number of degrees of freedom for modelling crack propagation and is also computationally efficient. The constitutive calculations are conducted individually at each integration point in this model, and cracks are incorporated in the calculations at each loading step. To account for induced crack along the orthogonal axes, the tensile cracks are modelled by modifying material parameters. This has a considerable impact on the stiffness matrix, resulting in stress redistribution inside the element. This stiffness matrix adjustment necessitates a lot of repetition within the stipulated load or displacement increment.

2.9.2. Model of a Discrete Crack

Discrete crack elements, also known as interface elements or joint elements, are used to explain the contact between different surfaces with known planes of weakness in discrete crack models. The discrete crack model approach has been used by several researchers, namely Page (1978), Dhanasekar (1985), and Shing et al (1993). Mortar joints, diagonal fissure, and masonry-frame contact can all be simulated with the separate pieces. To represent the inelastic behaviour of a discrete crack, decompose the pressure difference between contact objects into elastic and plastic components.

2.9.3. Difficulties in Predicting Softening Behaviour of Materials

The finite element model, according to Kozar and Bicanic (1999), cannot accurately forecast the softening regime of brickwork due to the lack of regularization of its material behavior. During the softening regime of the material, the weak point was employed to produce a single dependable physical path, which helped to avoid localization in zero volume and switching to the improper solution path. Rots (1988) investigated the fracture behavior of concrete and proposed a fracture energy concept for softening behavior of concrete in finite element modelling. In this model, he employed the fracture energy, concrete E-value, and the length of the components in the mesh. Because masonry has direction dependent material properties due to its orthotropic nature.

Chapter 3

3. Model Construction

3.1.Model Construction

3.1.1. Selection of Model:

Following were the parameters of concern while selecting the model for analysis:

- 3-storey Masonry Model
- Eccentricity in Plans
- Irregularities in Elevation
- Provision of openings for doors and windows
- Replicates the construction methods used in Pakistan

Multiple models used in previous research by renowned institutions were studied to narrow down the research. UET Peshawar has one of the finest equipment for shake table experiment in the country. Hence, multiple visits to their lab were made to study the past models and those being constructed at the moment. The objective was to narrow down the model selection process. Following are the few models that were studied. Some of them were already tested while others were in the construction phase:

Figure 10 UET, Peshawar Models

After a thorough research and multiple iterations, the following model was finalized. It fulfills all the requirements mentioned above and is in relation with the load and base requirements of shake table to be installed in MCE Structural Engineering Laboratory. The surface area of the model when resized will be 9ft x 9ft (including 1ft clear space on each side for the base slab) and its estimated weight will be within 12 tons. 2 such models will be constructed with one being confined and the other being unconfined.

Figure 11 Proposed model

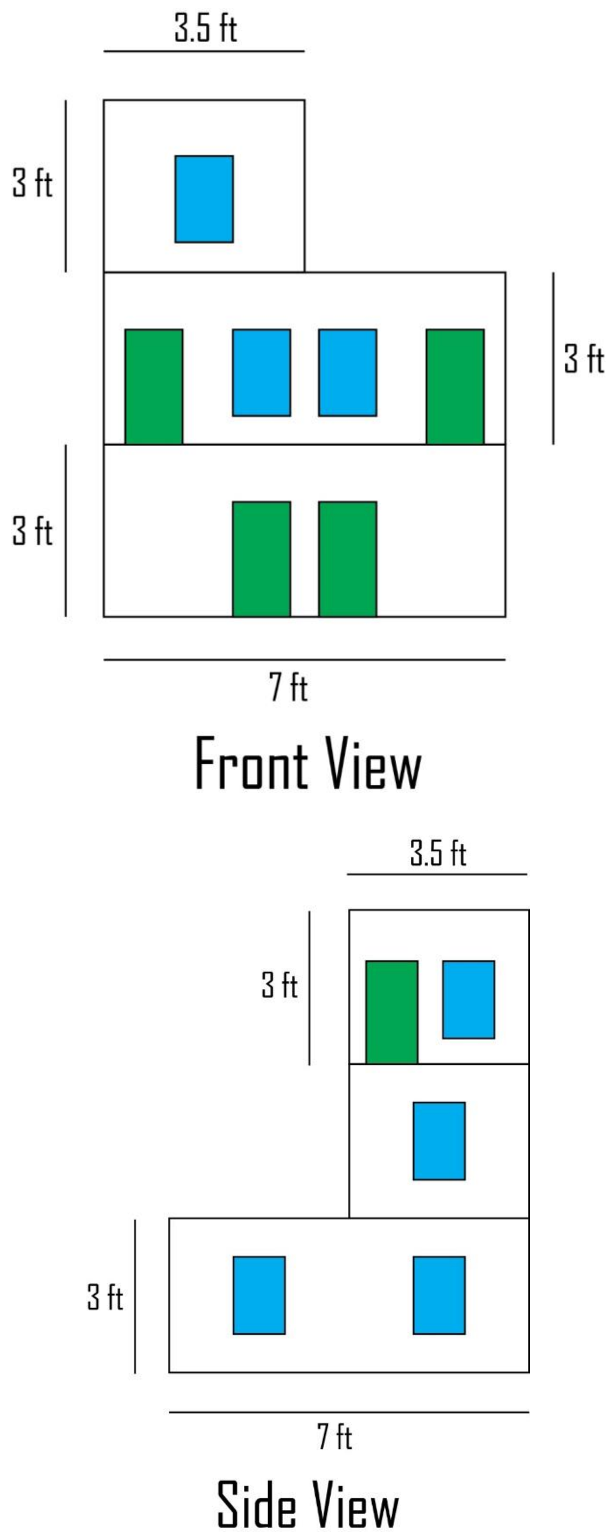


Figure 12 Elevations and Section views

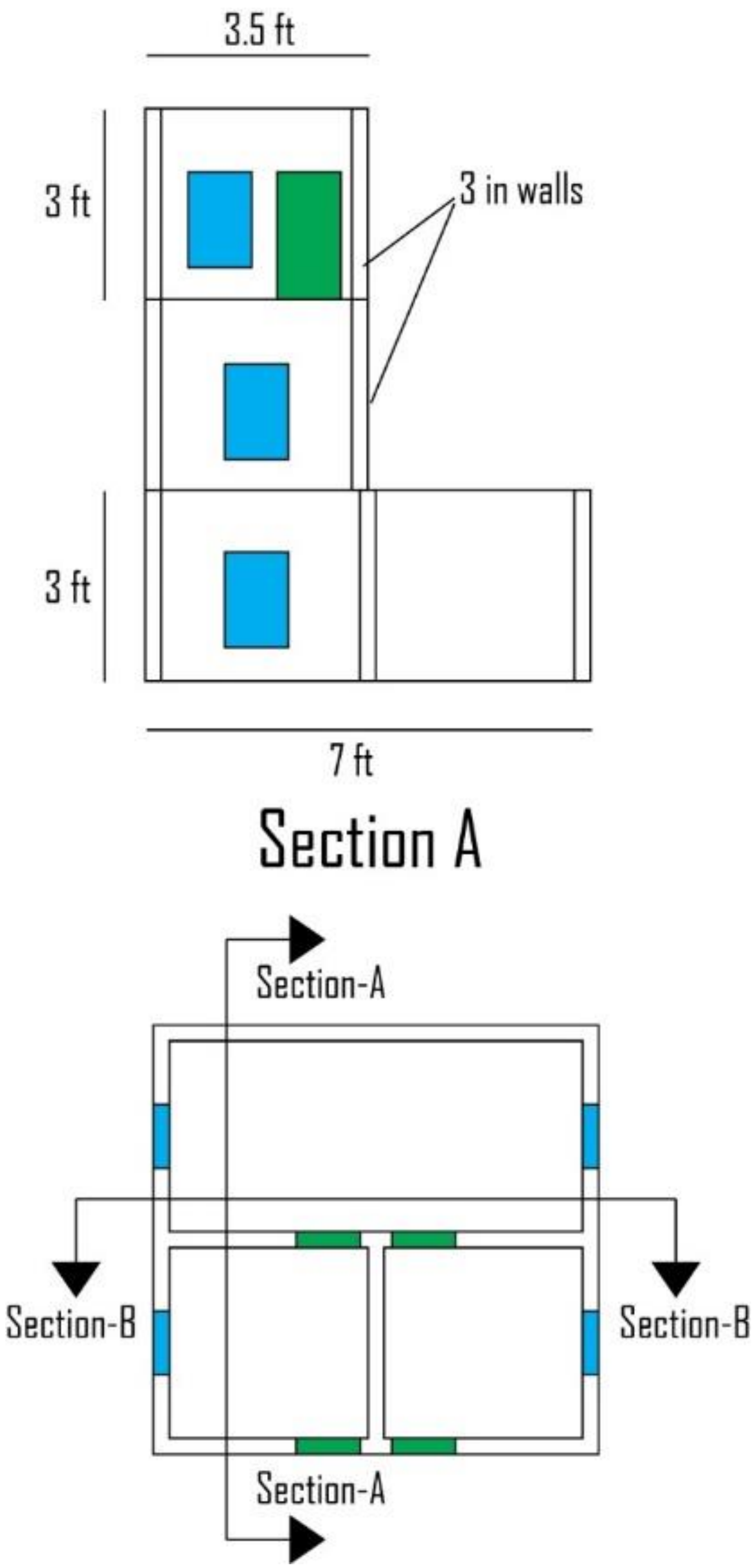
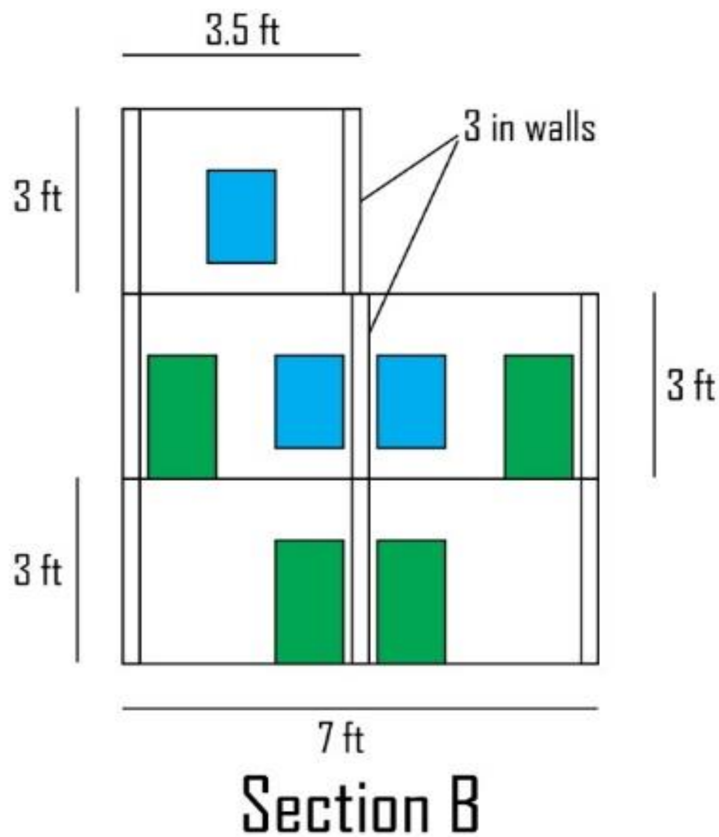


Figure 13 Elevations and section views



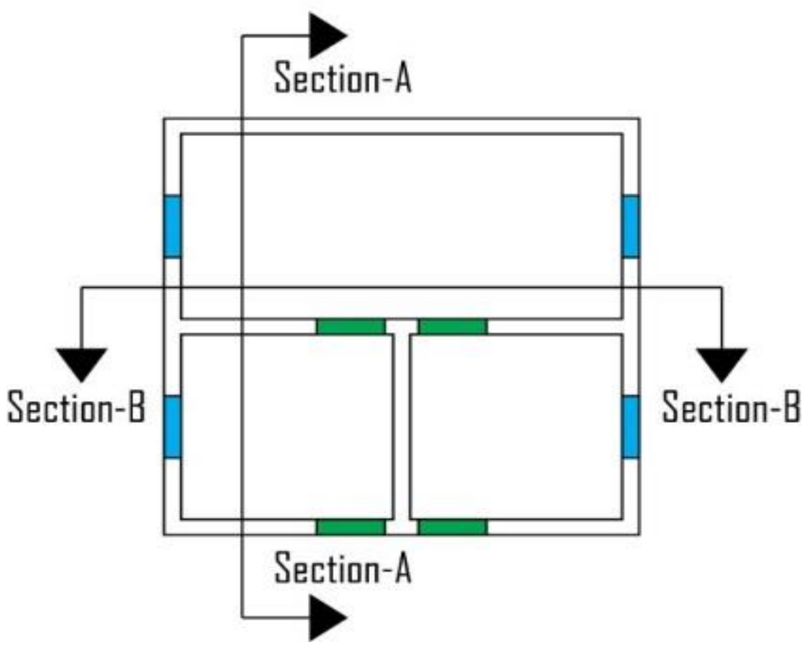


Figure 14 Elevations and Section views

3.1.2. Cost Estimation:

After finalizing the design of the model, the first step was to estimate the cost of undertaking the project. The whole structure was analyzed to calculate the quantity of materials required for the construction of model. Prices of all the raw materials were inquired from the field and a preliminary cost estimation was done.

3.1.3. Procurement of Materials:

To begin the construction process, material was procured from different places. Following are the key items procured:

- **Bricks**: One of the key elements for masonry construction are the bricks. The size of the brick used in the construction of the model is as below:

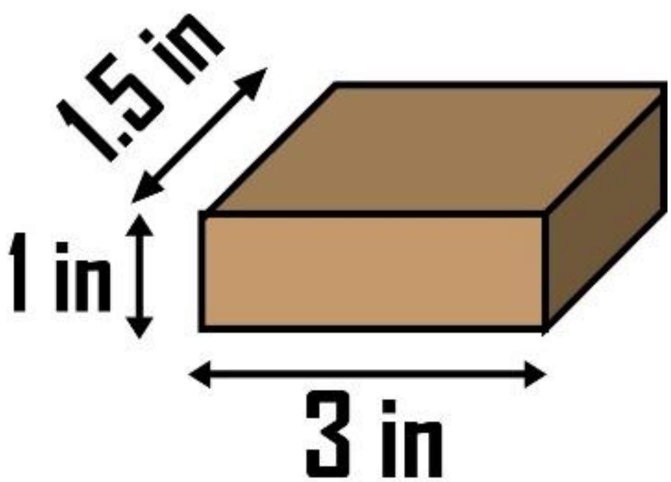


Figure 15 Small Scaled Bricks

It is difficult and expensive to make small size bricks in regular furnace as it will not be able to withstand the heat and will burn. The alternative to this was to use brick tiles and to cut them into smaller bricks for construction purposes.

Following is the manner in which the tile was cut down to make the required size bricks. The extra length is to incorporate any kind of damage. These tiles were bought from Nowshera and transported to Bara Banda for cutting in a marble factory. Each tile produced 12 bricks.

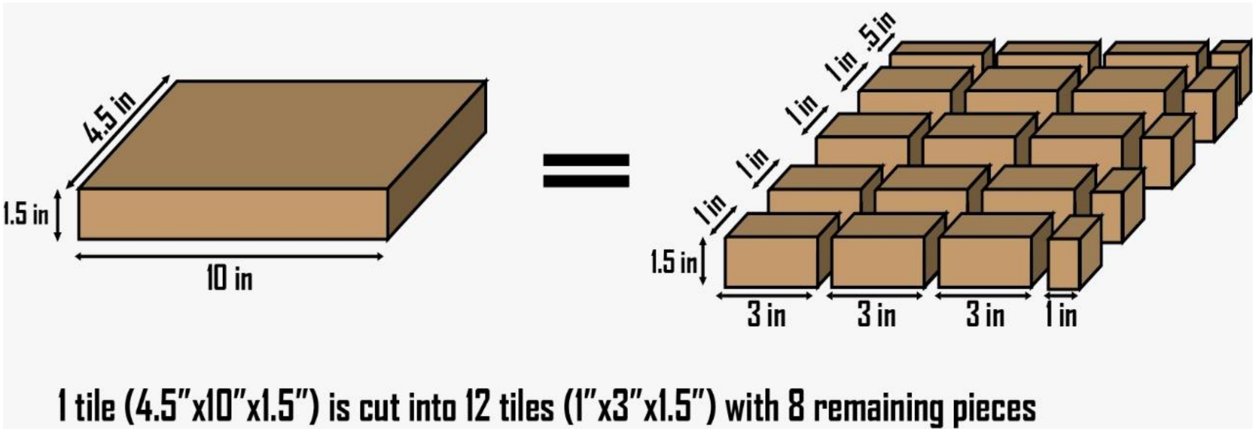


Figure 16 Tile cut into Bricks

After cutting, these were then transported to Structural Engineering Lab, MCE.

Figure 17 Bricks

- **Other materials**: Rest of the material used in the project were easily available in the market and were bought from Risalpur and Nowshera. Another concern was the small sized steel reinforcement. Normal bar size available in the market is #3 bar and above, but the slabs and confinements required #2 bars. These were bought from Peshawar road, near Nowshera.

3.1.4. Testing of Materials:

3.1.4.1 Brick Testing

Testing of the bricks was done by *using construction of prism* method. In this method two prisms, one using full size bricks and the other one using scaled bricks was made. Prisms were built using the units that are actually going to be used in the construction. These are built in air-tight bags and flat base. Their purpose is to find the strength of the units at any desired time. Brick units were stacked in stretcher position with one layer over the other. The construction process resembled the one being aimed at, while actually laying of bricks in masonry construction. Each prism had 2 units in length and 4 units in height. Following is the geometry of the prisms:

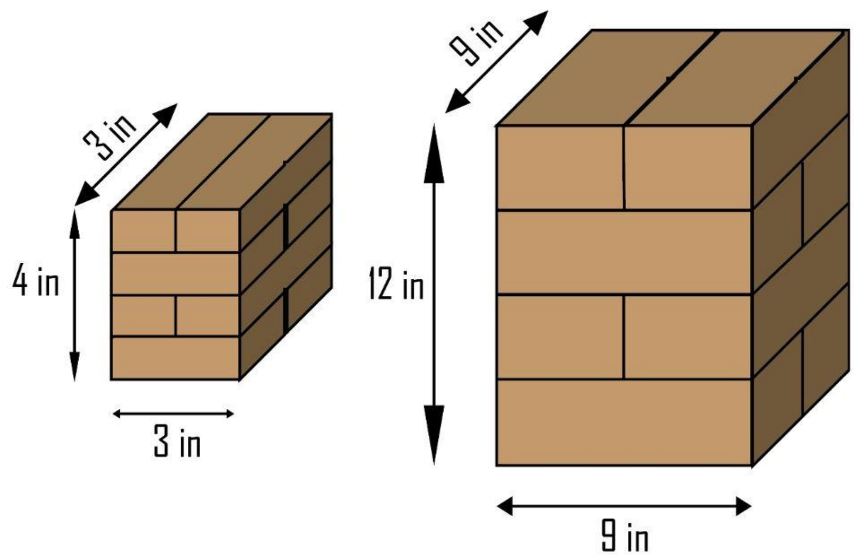


Figure 18 Prisms Proposed Models

These prism were then sealed in air-tight bags for the next 14 days and were only opened for curing every 24 hours. The prisms built are as below:

Figure 19 Prism made

These models were transported to the testing machine using a strap to avoid any damage during the handling process. These models were then subjected to uniform compressive load using metal plate placed on the top and the results are as follows:

Table 3 Prism made

Type	Surface area (in2)	Load (until visible damage) (pounds)	Compressive Strength (psi)
Small-Scale Prism	9	11013	1220
Full-Scale Prism	36	43450	1206.9

The results prove that resizing the bricks in no ways affects it compressive strength. The difference observed here can be accounted to human errors and slight variation in the type of conditions.

3.1.5. Model Construction

Model construction was done in the MCE Structural Engineering Lab with the aid of skilled personnel. All the necessary precautions were taken to prevent any damage to any individual or the model as a whole.

3.1.5.1. Unconfined Masonry Structure

3.1.5.1.1. Base Slab:

a) Size of slab: Base slab has a size of 9ft x 9ft. its thickness is 11inches. The size of the structure to be placed above is 7ft x 7ft. Additional 1ft is provided on each side for handling and provision of hooks.

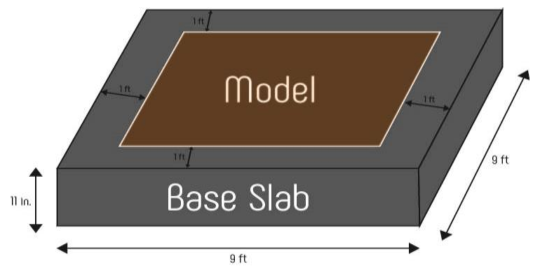


Figure 20 Base Slab area w.r.t Model

b) Design of Base Slab:

The first step in the slab construction was its design. It must be able to resist all the structural loads with no bending at all. Slab is to act as the foundation. Corners of the slab will be provided with hooks so that it can be lifted by crane later to be place on the shake table. To prevent any shear on the corners, it is heavily reinforced with beams on the borders and corner reinforcements provided at the top and bottom. Slab is also provided with double mesh reinforcement and a beam running in the center. Following figure only shows the main reinforcements used in base slab. Apart from these, there are 9inches wide beams running on all the edges and in one direction in the center to account for the bending moment and negate its effect on the performance of the structure.

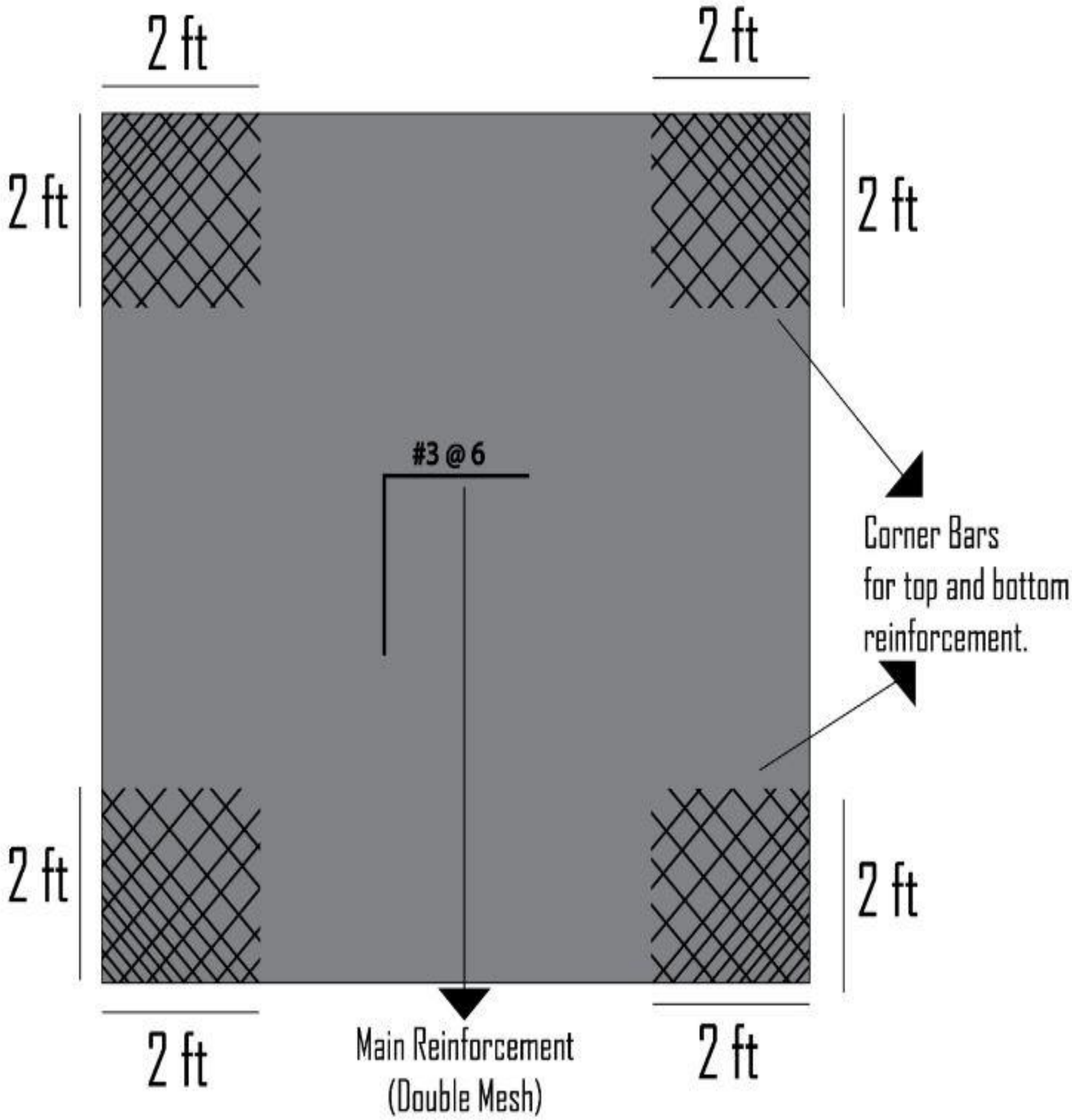


Figure 21 Base Slab Reinforcement Detailing

c) Steel fixing: Once the slab is designed, the next step is steel binding. Professional workers were hired for the job. Their job was to fix the steel as stated in the design before the pouring process began.

Figure 22 Steel Fixing

d) Shuttering Pipe Fixing: Pipes were added to provide holes in the slab so that it can be mounted onto the shake table for testing purposes. Pipes were placed in the steel cage by fastening them to the steel bars and were restrained at the base by pouring lean concrete. Following is the configuration of pipes' spacing with the diameter of holes being 35cm:

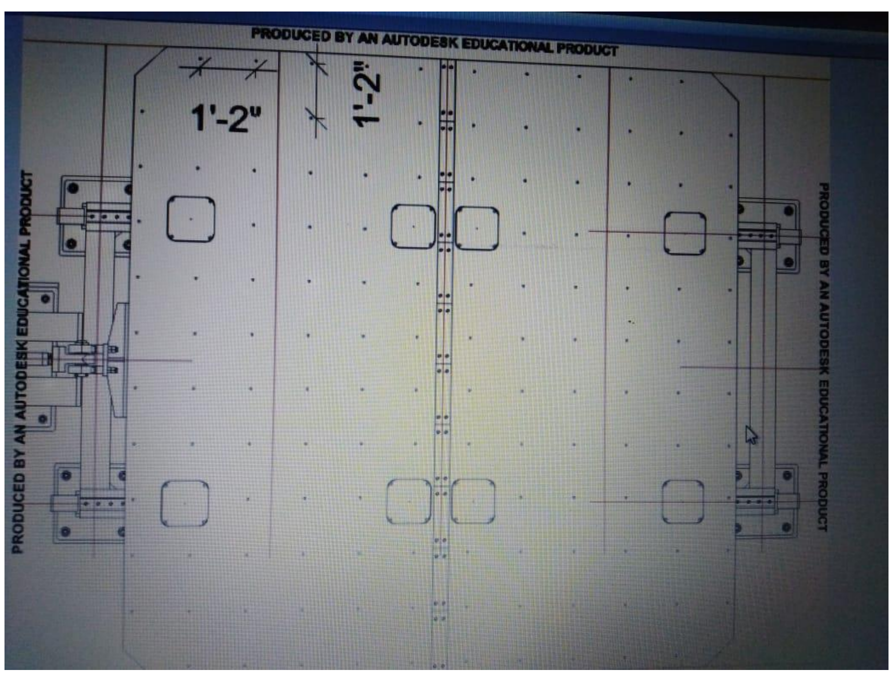


Figure 23 Hole-Spacing Sheet

Shuttering was done using wooden barriers on all four sides of slab. Base of the slab was covered with plastic sheet to separate it from the floor.

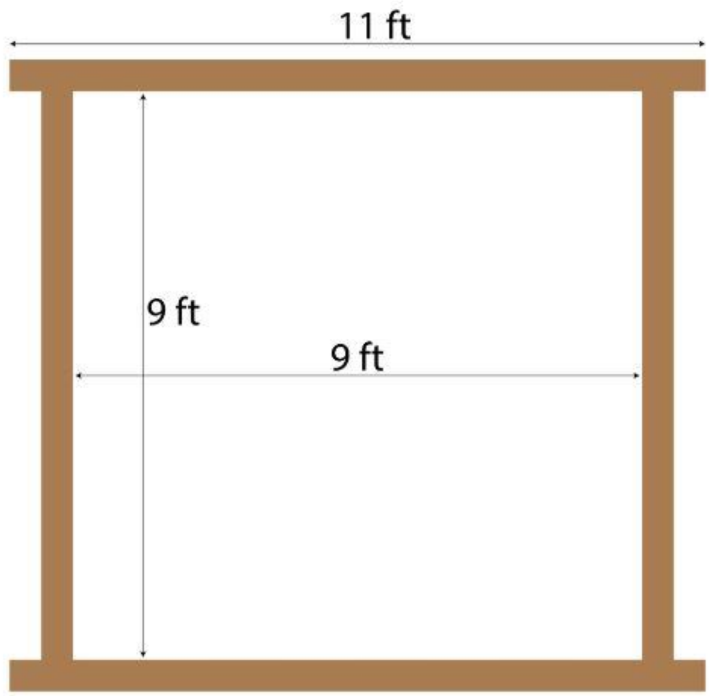


Figure 24 Shuttering Dimensions

e) Concreting and Curing of Slab: Concrete with a mix ratio of 1:1.5:3 was used for the slab. Concrete was made inside a mixer and was poured and levelled manually. Rodding was done in the concrete to make sure that the concrete mix was well compacted and filled all the parts. Special attention was given on the corners where heavy reinforcement made it difficult to place the concrete mixture with ease. At the end of the pouring process, the surface was levelled. Special care was taken to ensure that the pipes fastened for holes were not disturbed. Shuttering was removed the next day. Curing of the slab was done for a week before moving to the brick laying phase.

3.1.5.1.2. Story 1:

a) Walls Construction: The next step in the process is the brick laying. It is where the actual construction of the model begins. Bricks are laid in alternate layers of header and stretcher with the help of professional masons. Openings were left for doors and windows. Top of the openings was covered by a layer of lintels to avoid any collapse. Height of the walls is 3 ft. this story has one larger room in the back and two smaller ones in the front.

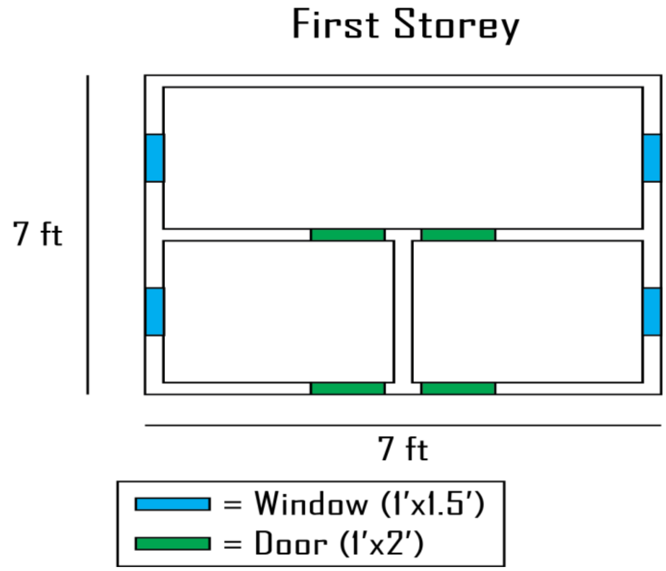


Figure 25 Story 1 Plan

Figure 26 Model in Construction Phase

b) Roof Slab: Roof slab has also been reduced in size just like the rest of the model. Its thickness is 2 inches and is provided with #2 bars of main steel, distribution steel and negative steel on the edges. Following image shows the detailing of the roof slab:

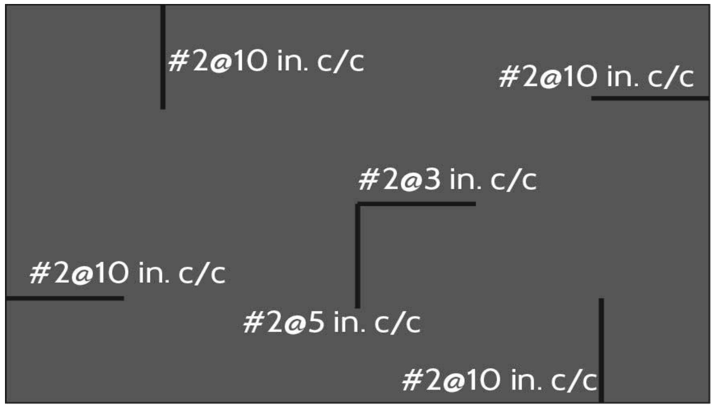


Figure 27 Reinforcement Detailing Roof Slab#1

Roof slab shuttering was done using wooden planks and it was cast using mechanical mixer. Shuttering was removed the next day and curing was done for the next week to ensure that it achieves maximum strength. Small size crush was used in the mixture due to little spacing between the bars. Compaction was done using rodding technique.

3.1.5.1.3. Story 2:

a) Walls Construction: Similar method was followed for placement of bricks. The only difference here was the reduction in size of built up area. Story 2 covers half the space as compared to story. Story consists of two small rooms in the back half of the plan. The following plan shows the area covered by story 2:

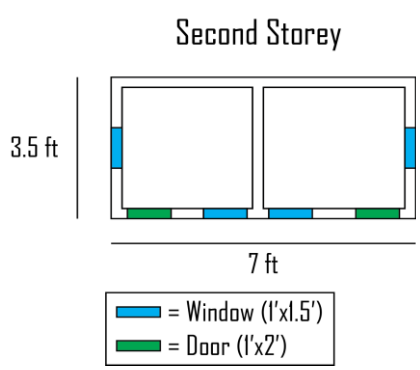


Figure 28 Story 2 Plan

b) Roof Slab: Same mix ratio was used for the construction of this slab. Aggregates and cement-water ratio were all similar. The only difference here was the roof slab steel detailing.

Figure 29 Reinforcement Detailing Roof Slab#2

3.1.5.4. Story 3:

a) Walls Construction: Construction of walls was tricky at this stage as the work could not be done from ground level as the structure had achieved an overall height of 7 ft. (including the base slab thickness). Therefore, wooden planks supported by rods were used as a platform to aid the construction process. This story only has one room at the back of the structure.

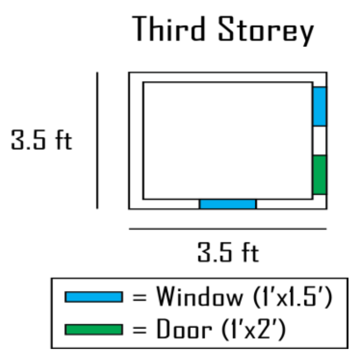


Figure 30 Story 3 Plan

Unconfined Masonary Structure Model

Figure 31 Unconfined Masonary Structure Model

3.1.5.2. Confined Masonry Structure:

Construction of the confined masonry structure follows the same procedure as the unconfined masonry structures, with one exception and that is the provision of beams and columns at walls joints. Both the beam and columns have a cross-section of 9in. x 9in. and are cast monolithically with the roof slab. The steel used in columns is #2 bars and concrete mix also consists of similar material as the slab.

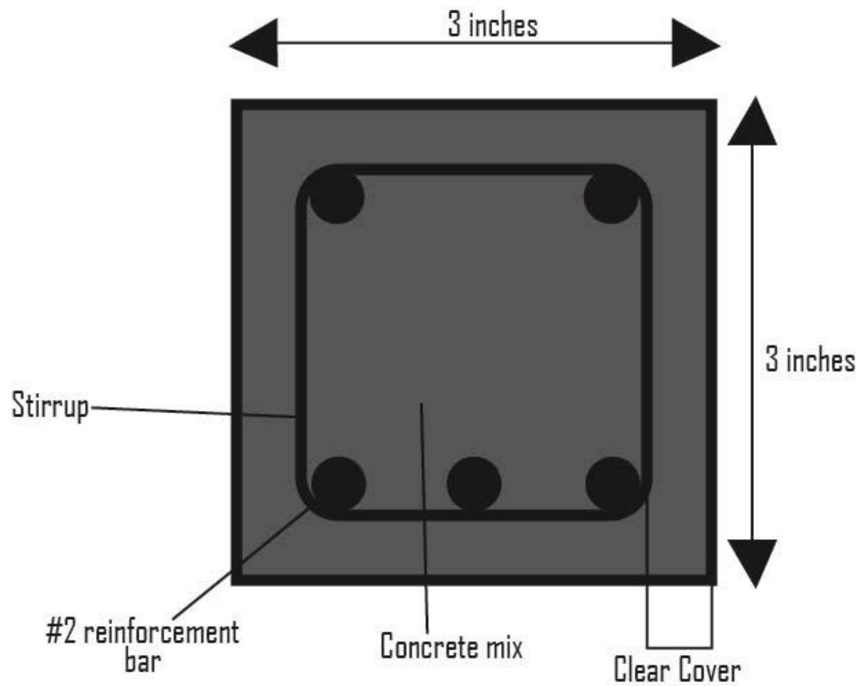


Figure 32 Beam and Column X-Section

Confined Masonary Structure

Figure 33 Confined Masonry Structure

Chapter 4

4. Modeling

4.1. Earthquake Modelling of Structures

Our study's modelling requirements necessitate a detailed comprehension of the various parts of a powerful structural model's analysis. The study in our example is primarily concerned with developing a modelling method for the stresses and structural systems involved in an earthquake.

Due to the potentially destructive nature of earthquakes, seismic loading systems are a particularly essential design concern in many civil engineering constructions. In real-world constructions, the inelastic response of the structure must be considered for a cost-effective design. As a result, a variety of constraints place severe limitations on the various materials available for model testing.

Table 4 Summary of Scale Factors for Earthquake Response of Structures

			Scale Factors		
(1)	(2)	Dimension (3)	True Replica Model (4)	Artificial Mass Simulation (5)	Gravity Forces Neglected Prototype Material (6)
Loading	Force, Q	F	$S_E S_l^2$	$S_E S_l^2$	S_l^2
	Pressure, q	FL^{-2}	S_E	S_E	1
	Acceleration, a	LT^{-2}	1	1	S_l^{-1}
	Gravitational acceleration, g	LT^{-2}	1	1	Neglected
	Velocity, v	LT^{-1}	$S_l^{1/2}$	$S_l^{1/2}$	1
	Time, t	T	$S_l^{1/2}$	$S_l^{1/2}$	S_l
Geometry	Linear dimension, l	L	S_l	S_l	S_l
	Displacement, δ	L	S_l	S_l	S_l
	Frequency, ω	T^{-1}	$S_l^{-1/2}$	$S_l^{-1/2}$	S_l^{-1}
Material properties	Modulus, E	FL^{-2}	S_E	S_E	1
	Stress, σ	FL^{-2}	S_E	S_E	1
	Strain, ε	—	1	1	1
	Poisson's ratio, ν	—	1	1	1
	Mass density, ρ	$FL^{-4}T^2$	S_E/S_l	[a]	1
	Energy, EN	FL	$S_E S_l^3$	$S_E S_l^3$	S_l^3

[a] $(g\rho l/E)_m = (g\rho l/E)_p$.

A final type of scaling system in which gravity stresses are neglected in structural behavior and during which the same materials are used in both model and prototype to enable test to failure

(G. Harris & M. Sabnis, 1999).

4.2. Earthquake Modelling of loads

While searching for similar methods of structural models for their seismic response, one very important model is that of the three-story, two-bay frame model (Chowdhury and White, 1977).

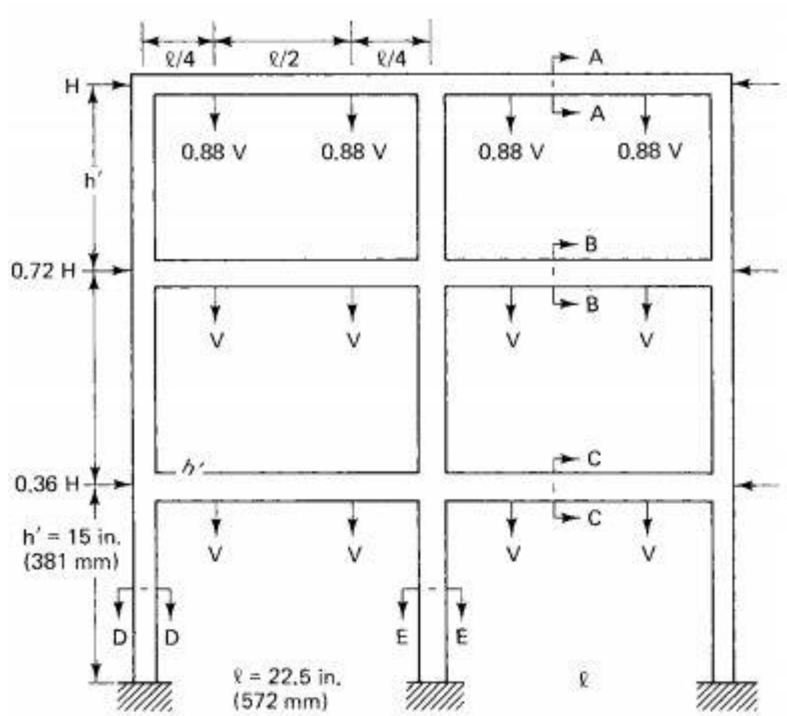


Figure 34 Two bay Frame Model

The hefty base beam was bolted to the shake table testing surface to secure the frame's bases. The frame was tested in the horizontal plane since the testing bench made it simple to supply the required out-of-plane constraint. The table also served as an excellent attachment surface for the experiment's numerous gauges and loading devices. At quarter points of each of the six beams, gravity loads were applied using six gravity load simulation equipment. The beams and table were fixed and fastened with these mechanisms.

4.3.Abaqus Modelling

In this Chapter, we'll look at how to model brick constructions on Abaqus using the same blueprint. The results from this section can be compared to the results from the shake table experiment. The main layout of Abaqus is seen here.

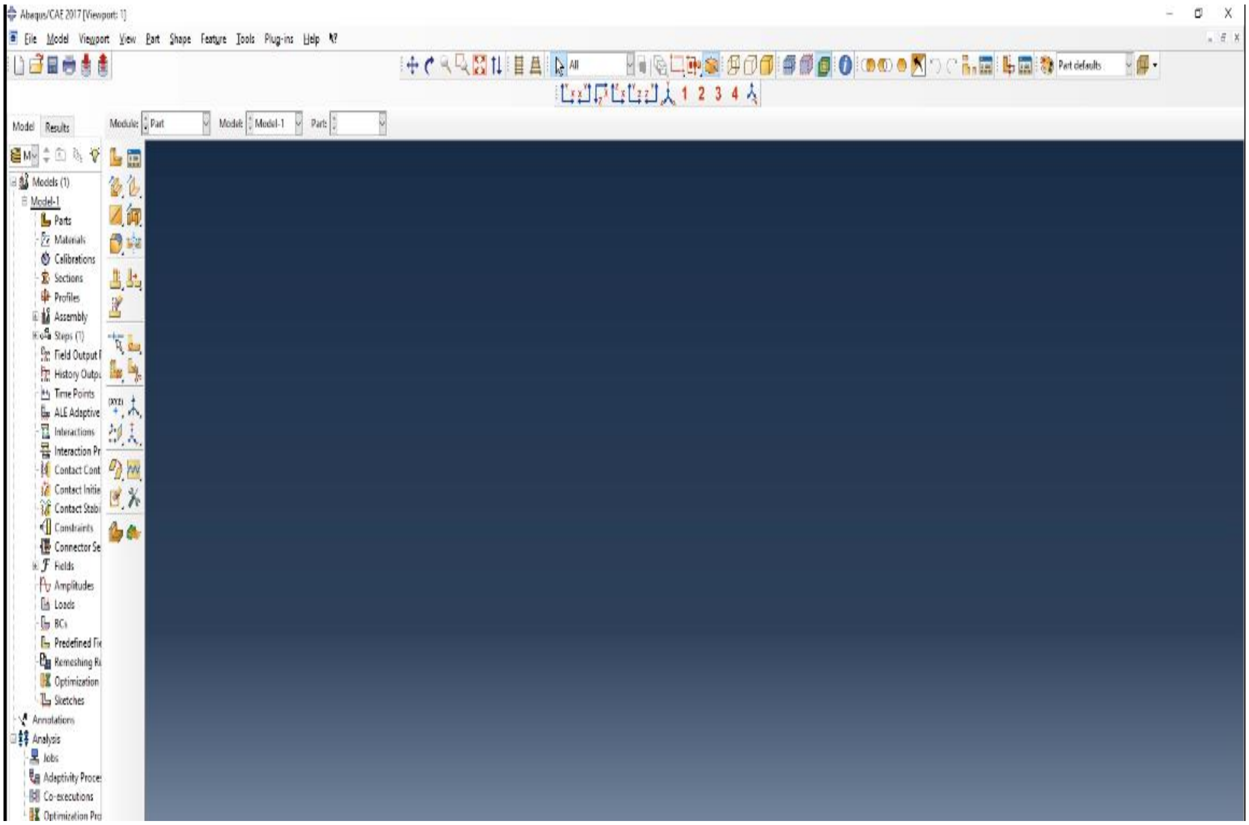


Figure 35 Layout Plan of Abaqus

4.3.1. Modeling of Masonry Structures In Abaqus

This Chapter will explain the modeling of unconfined masonry structure on Abaqus. We have modeled a full-scale unconfined masonry model. Following are the steps we followed in the process:

Step 1 : Part

We use the Part module to create each of the parts. We can create parts that are native to ABAQUS/CAE, or We can import parts created by other applications either as a geometric representation or as a finite element mesh.

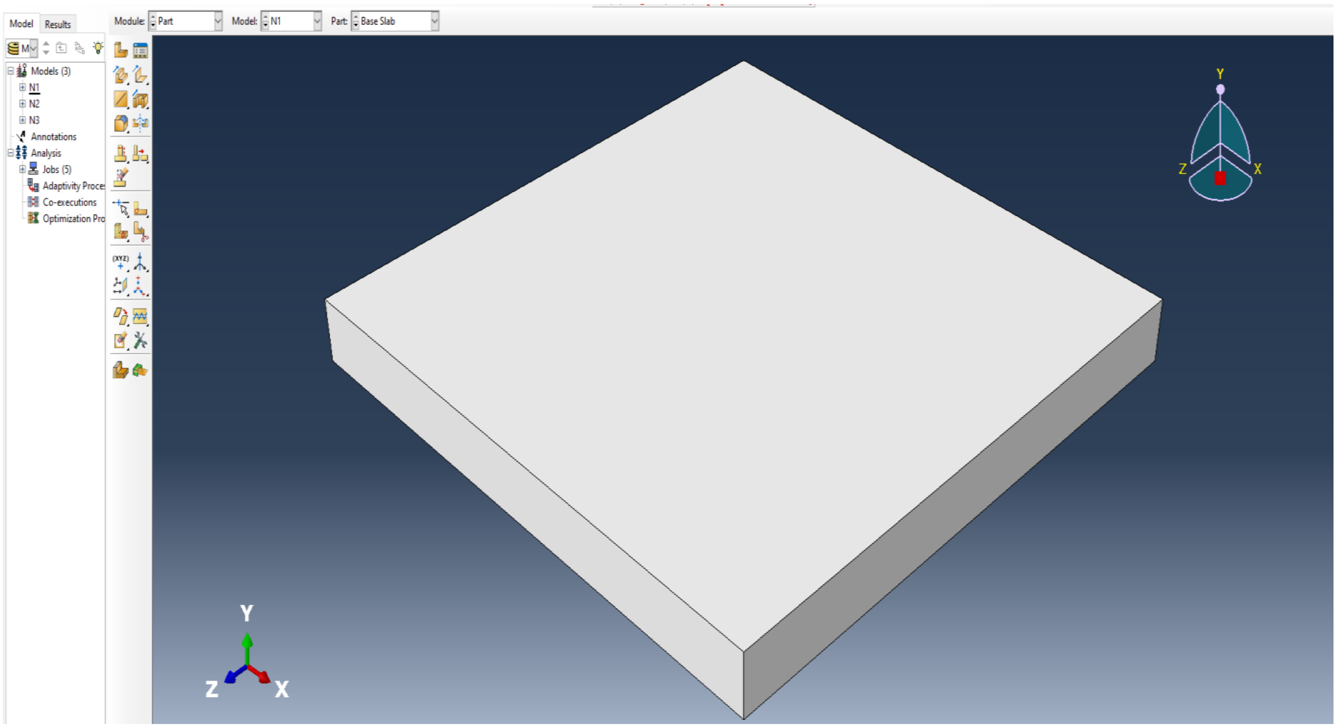


Figure 36 Brick Part Modelling in Abaqus

Step 2 : Property

We use the Property module to create a material and define its properties.

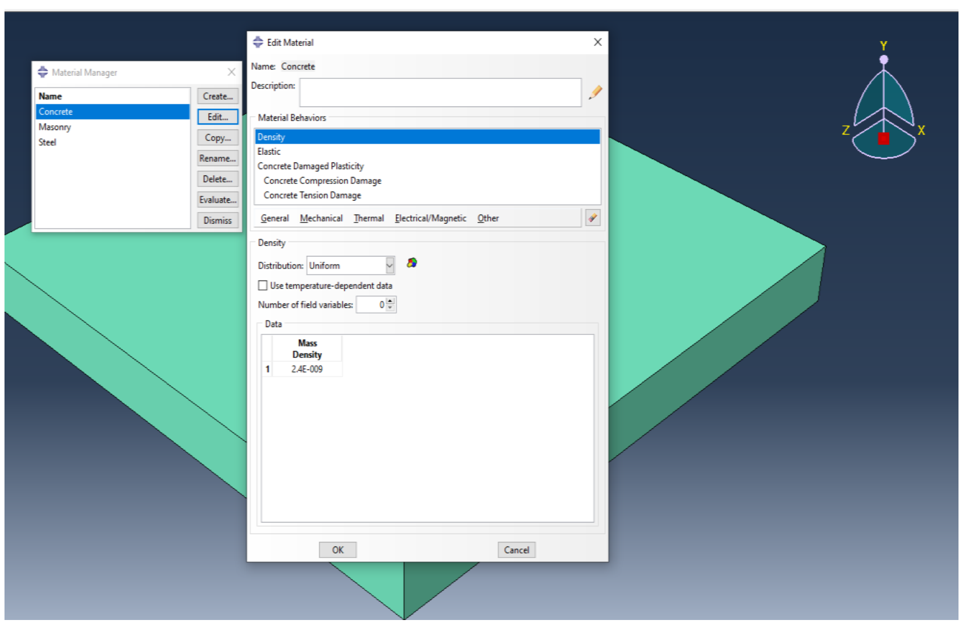


Figure 37 Properties of Model In Abaqus

Step 3: Assembly

Each part that We create is oriented in its own coordinate system and is independent of the other parts in the model. We use the Assembly module to define the geometry of the finished model, called the assembly, by creating instances of a part and then positioning the instances relative to each other in a global coordinate system. Although a model may contain many parts, it contains only one assembly.

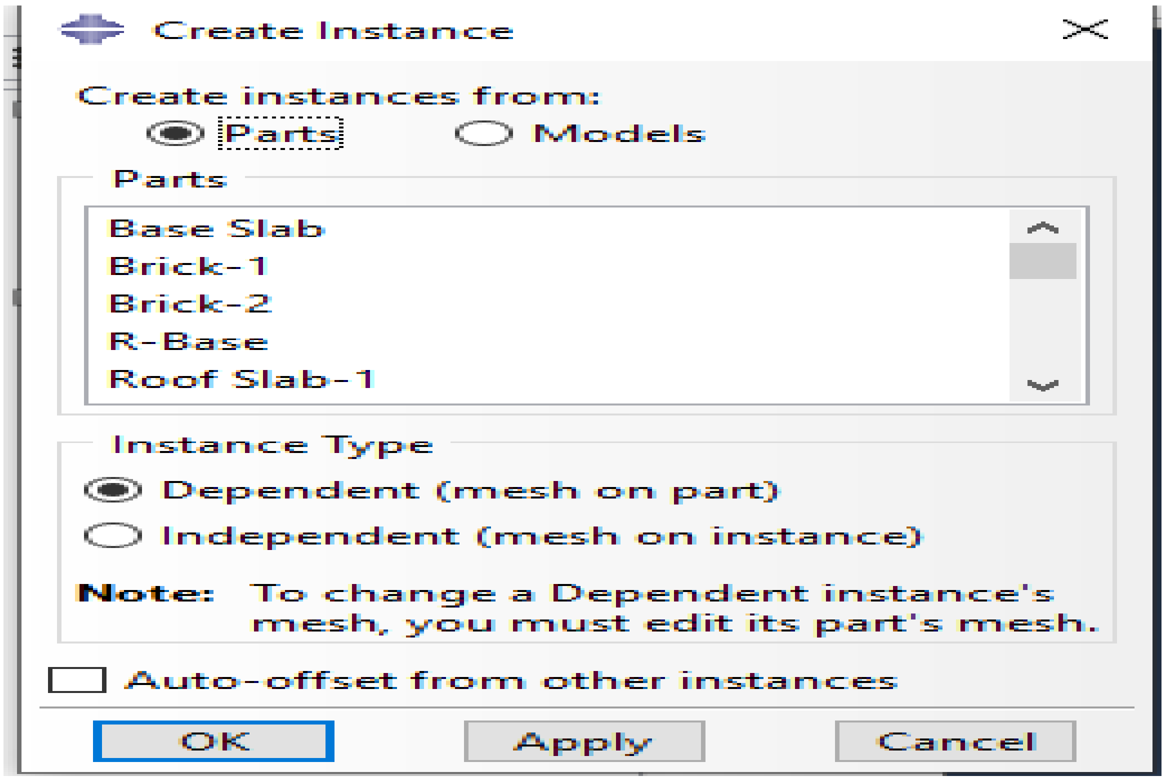


Figure 38 Assembly Module

Step 4 : Step

Now that We have created our part, We can move to the Step module to define Our analysis steps.

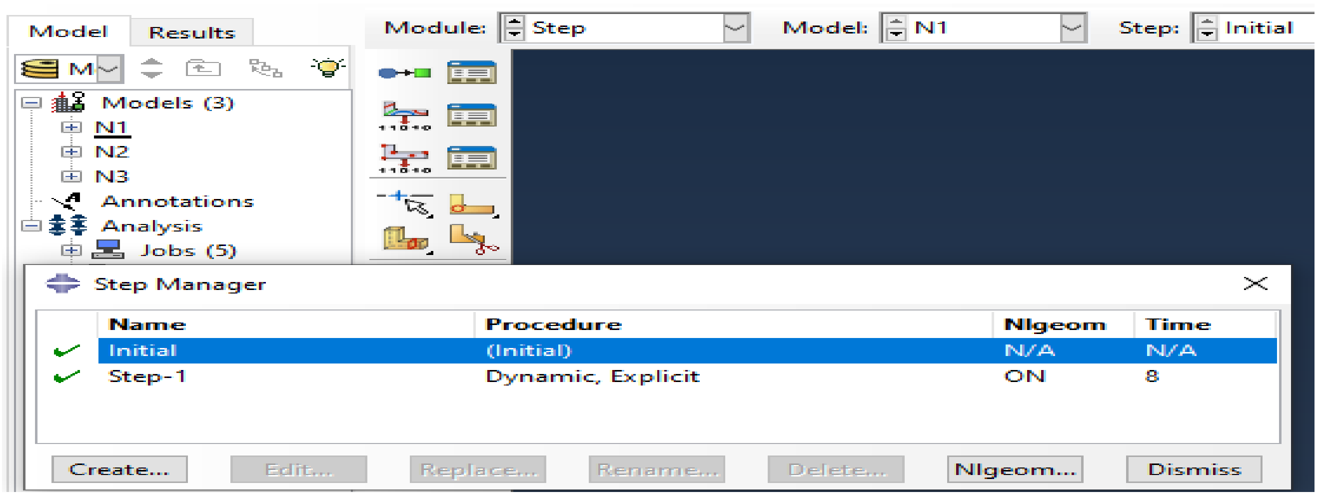


Figure 39 Analysis Steps in Abaqus

Step 5 : Interaction

In this Step We apply Interaction between concrete, bricks and steel.

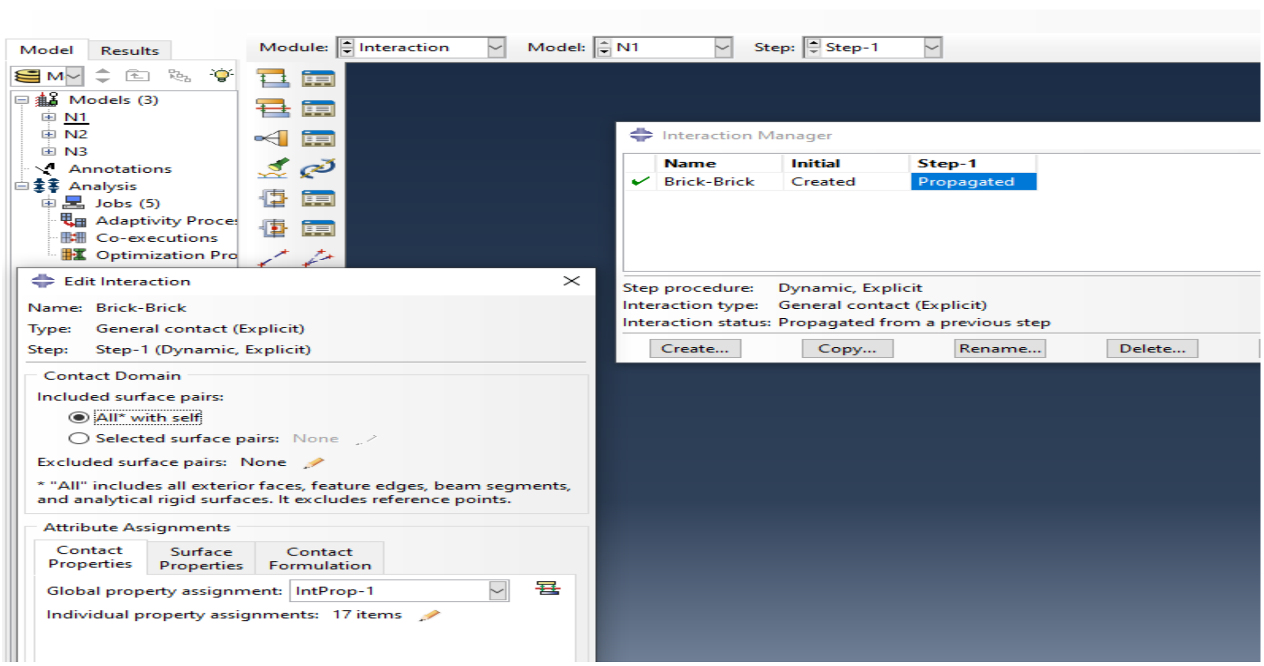


Fig 36 Interaction Module

Step 6: Load

The load is applied during the general, static step We created using the Step module.

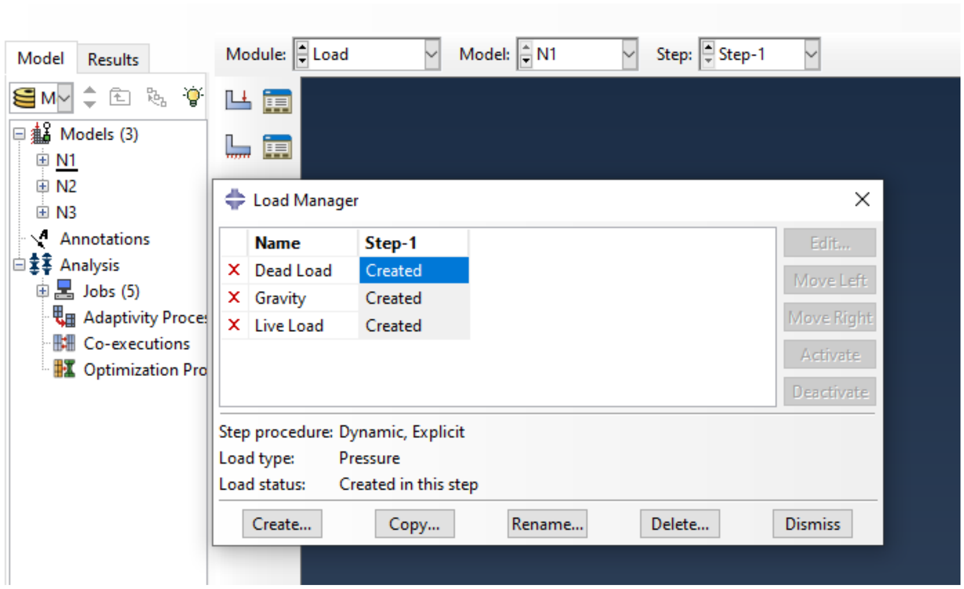


Figure 40 Load Module

4.3.2. Numerical Modeling

The masonry wall can be modeled either microscopically or macroscopically. In general, there are three modeling methods for masonry walls, two of them are microscopic, and the last one is macroscopic. In the detailed micro-model, all the details of the masonry units, mortar, and interaction between them must be completely modeled. A simplified micro-modeling approach can be a suitable alternative. In this method, the masonry units are expanded by adding the mortar thickness, and the mortar is simulated by the cohesive interaction between the expanded masonry units. In the third approach, known as the macro-model, the wall's behavior is considered an integrated, homogeneous, and brittle material. The macroscopic model's main advantage over microscopic models is that running analyze time is much less than the other models. This method cannot effectively predict the spread of crack, but it is acceptable for studying overall wall behaviors such as static base shear.

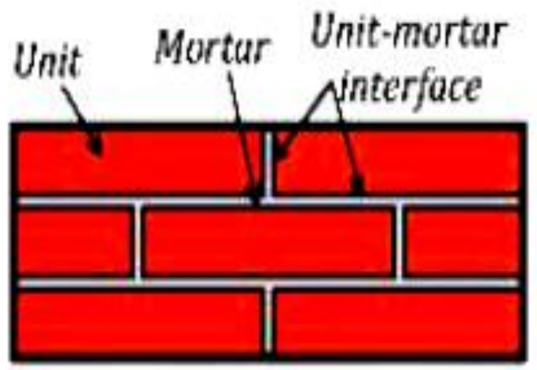


Figure 41 Interaction Btw Brick and Mortar

4.3.3 Material Model

In the current study, the macro-model approach has been used. In this approach, masonry material's behaviors are simplified so that this material is assumed to be isotropic and homogeneous. In the plasticity part, the dilatancy is controlled by the parameter called dilation angle. Agnihotri et al. proposed that the value of 30 is appropriate for dilation angle.

Table 5 Material properties for Masonry wall panel

Properties	Masonry	Concrete	Steel
Elastic Modulus Ex (MPa)	5100	30000	200000
Poison's Ratio	0.2	0.3	0.3
Density (Kg/m^3)	2200	2400	7890

Table 6 Plastic Properties for Masonry

Dilation angle	30°
Flow potential eccentricity	0.1
The ratio of initial equibiaxial compressive yield stress to initial uniaxial compressive yield stress	1.16
The ratio of second stress invariant	0.67
Viscosity parameter	0.001

4.3.4. Boundary Conditions

The foundation of the wall is connected to the ground through a steel beam. The stiffness of this steel beam can be considered rigid compared to the stiffness of the wall. Therefore, in numerical modeling, the masonry wall foundation is considered rigid. Hence, instead of modeling the foundation, the degree of freedom at the wall bottom is fixed in three directions. Vertical and horizontal loads are applied to the sample by a steel beam drilled on top of the masonry wall. This steel beam's stiffness is very high compared to the wall's stiffness, so vertical and horizontal loads can be considered uniformly on the wall's upper surface. Therefore, instead of modeling steel beams, a rigid body and coupling to the reference point were used to reduce the degree of freedom in the numerical model.

4.3.5. Loading History

Loading History was applied in Abaqus as shown:

Figure 42 Loading history (masonry wall panel)

4.3.6. Material Strengths(Confined and Un-confined Structures)

- **Concrete Columns**

2500 psi.

12’ *12’

- **Concrete Beams**

2500 psi

18’ *12’

- **Concrete Slab**

6’ thick

2500 psi

- **Masonry Used**

f_{cu} =1500psi (Compressive Strength)

9’ thick

4.3.7. Failure Criteria

- The Drucker-Prager plasticity model is being used to simulate the compressive non-linear behavior of masonry.
- Compressive failure of masonry can be captured.

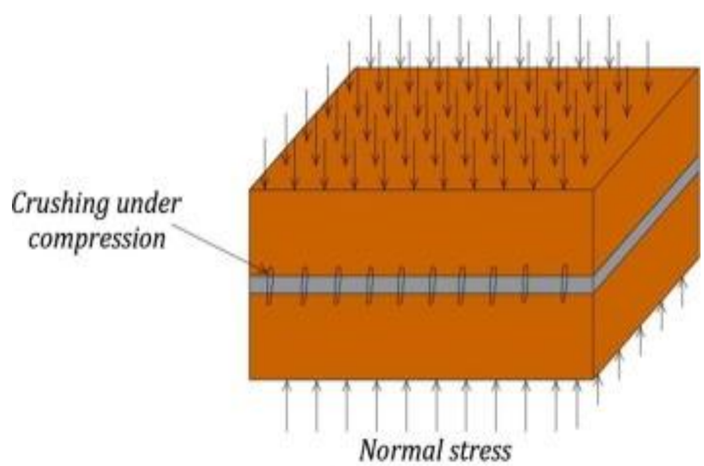


Figure 43 Drucker – Prager Failure Criteria

Unconfined Masonry Structure

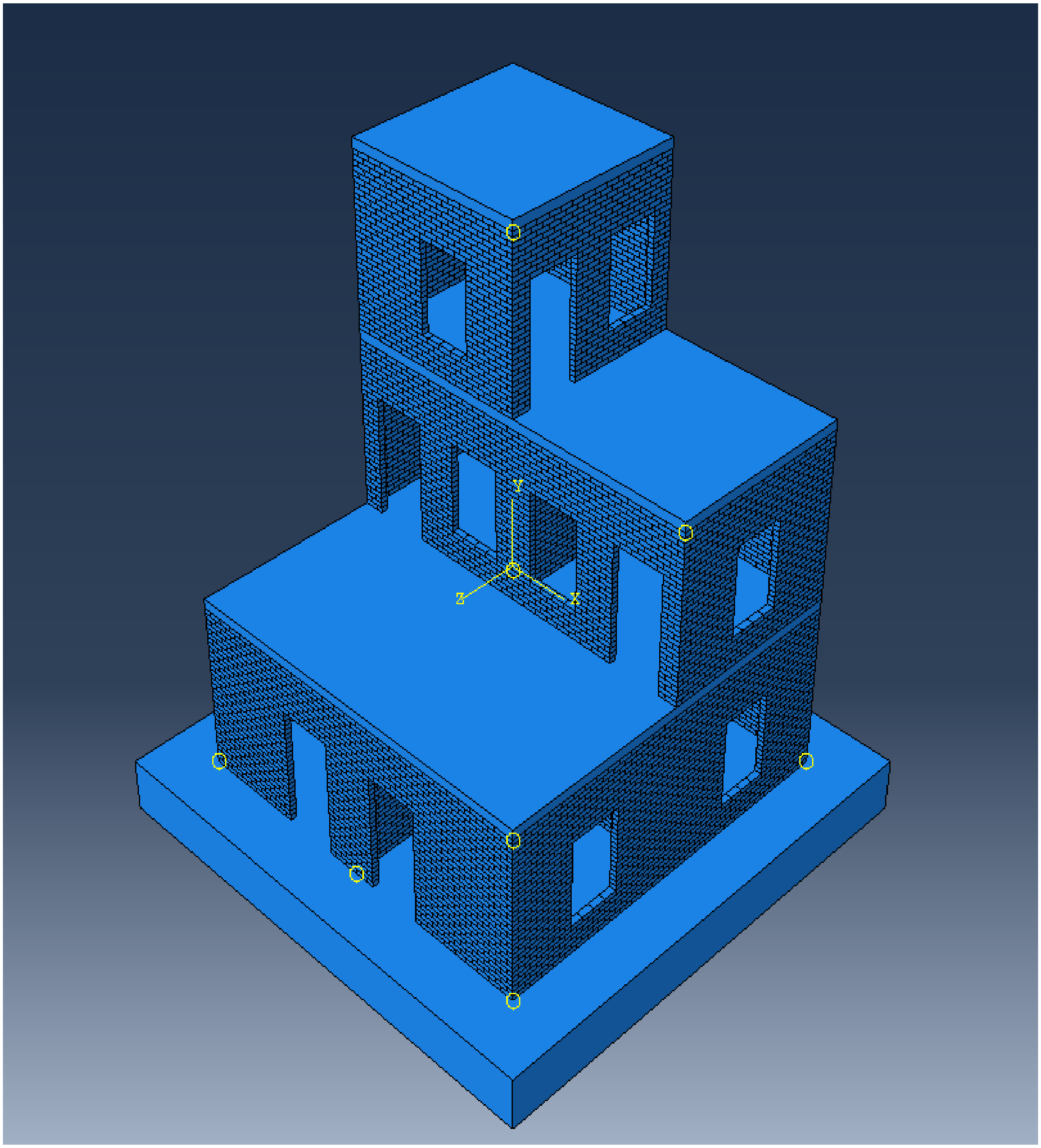


Figure 44 Abaqus Model of Unconfined Masonry Structure

Confined Masonry Structure

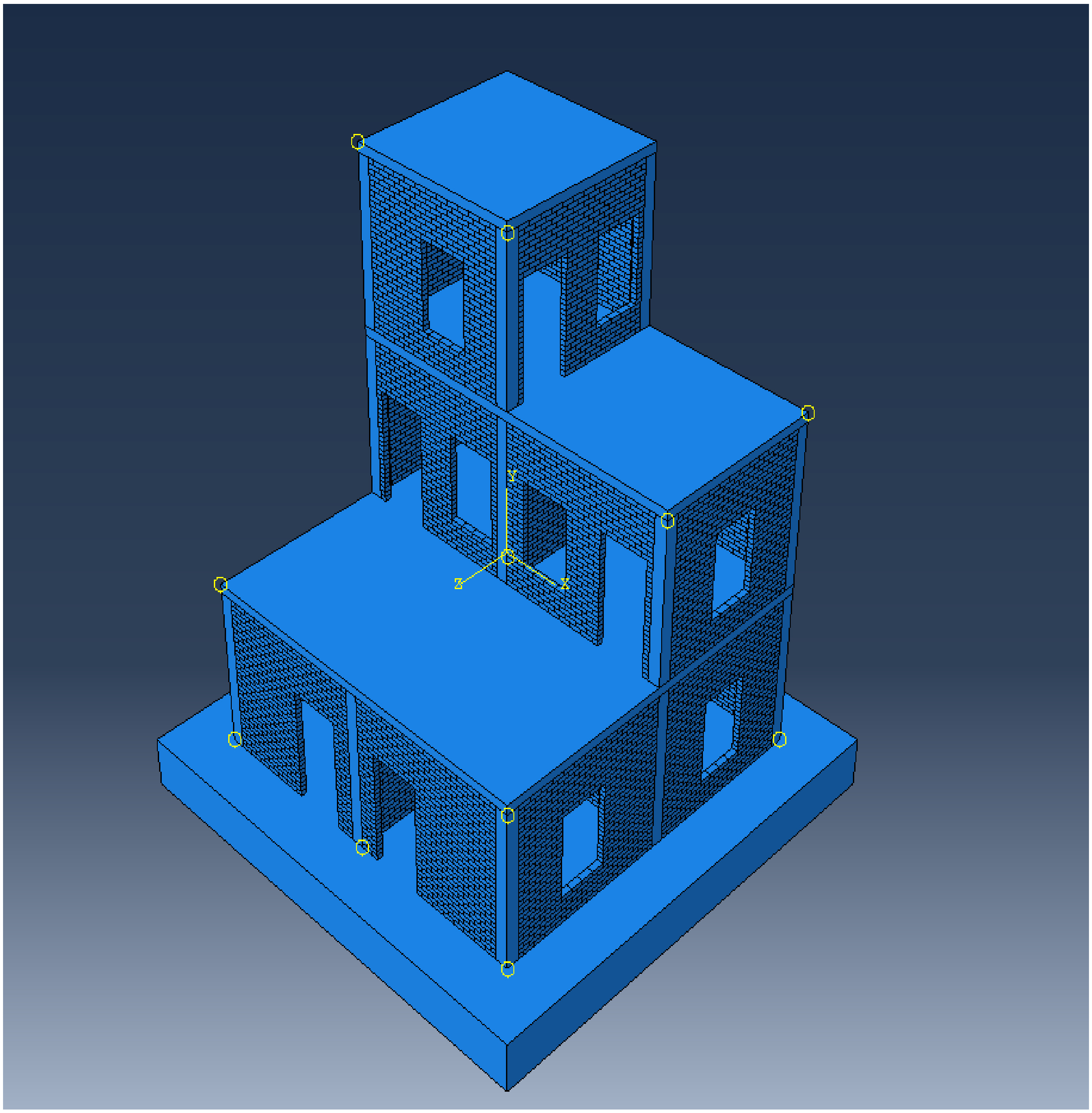


Figure 45 Abaqus Model of Confined Masonry Structure

4.4. Masonry Wall Panel

- L*H = 1200*1600 mm
- Mortar = 10mm

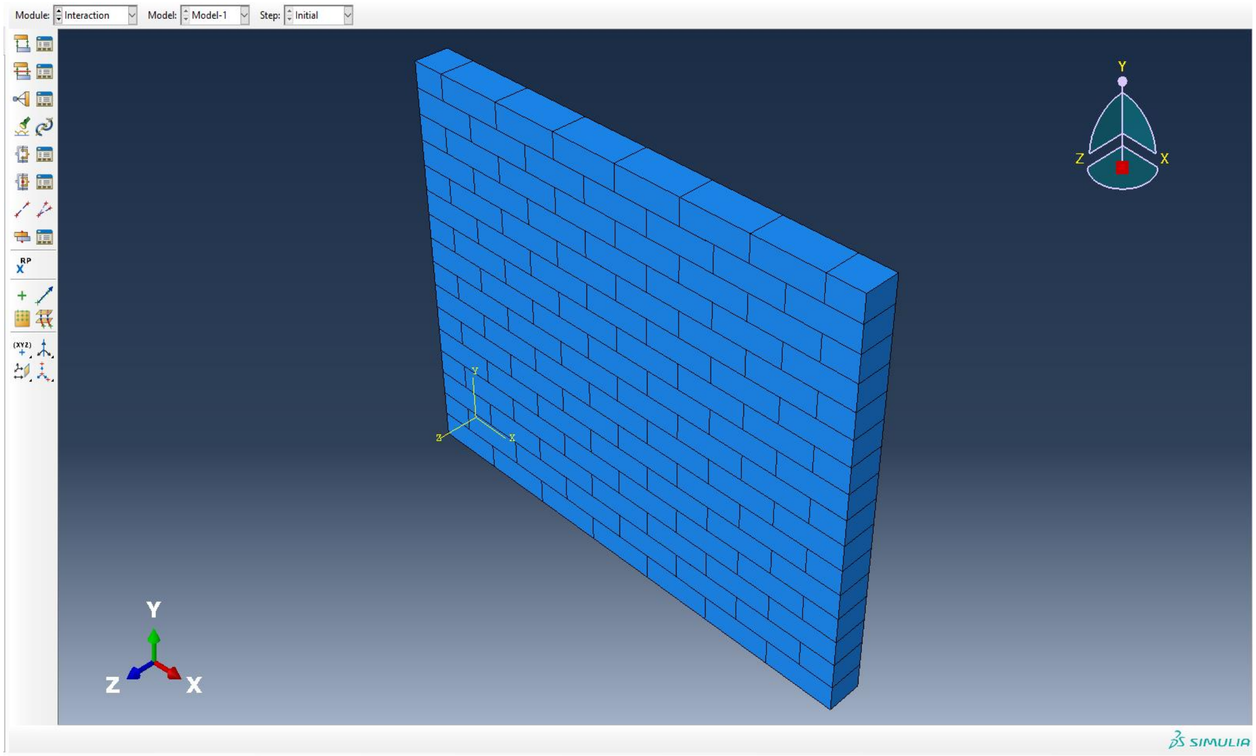


Figure 46 Abaqus model of Masonry wall panel

Chapter 5

5. Analysis And Discussion

5.1. Validation of Masonry Wall Panel

a.Hysteretic Behavior

Figure depicts the specimen's hysteretic loops in which Black represents Experimental results while color represents analytical results. The hysteretic loops were not properly spread out, revealing the brittle behavior of unreinforced masonry.

Only the stretchy branch stands out. Due to lower lateral resistance and lateral displacements at the yielding, peak, and final stages, ductility, and energy dissipation were greatly reduced.

- The yield strength and displacement of the specimen are 54.57 kN and 1.39 mm.
- The ultimate Strength is 93.298KN and Displacement is 5.01mm.
- The peak lateral load is 110.378 kN and displacement is 4.01 mm

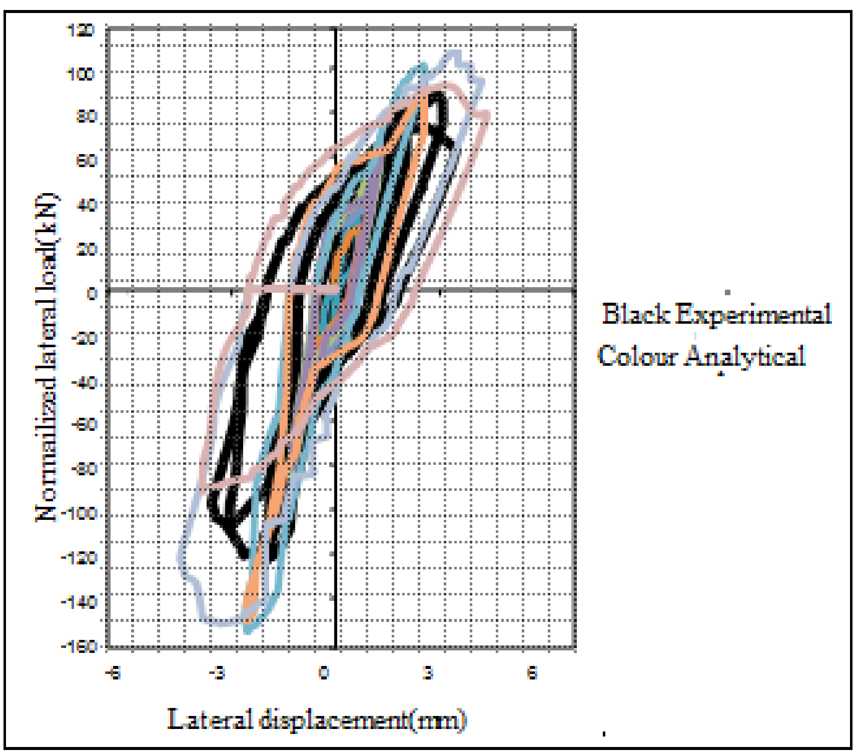


Figure 47 Figure 47 Hysteretic Loop of Masonry wall panel

b.Ductility

The ductility factor in case of masonry wall panel was quite less due to lower ultimate lateral displacement. The lower ductility factor primarily indicates brittle behaviour of the specimen. The ductility factor is 3.06 in case of analytical results represented by Blue line.

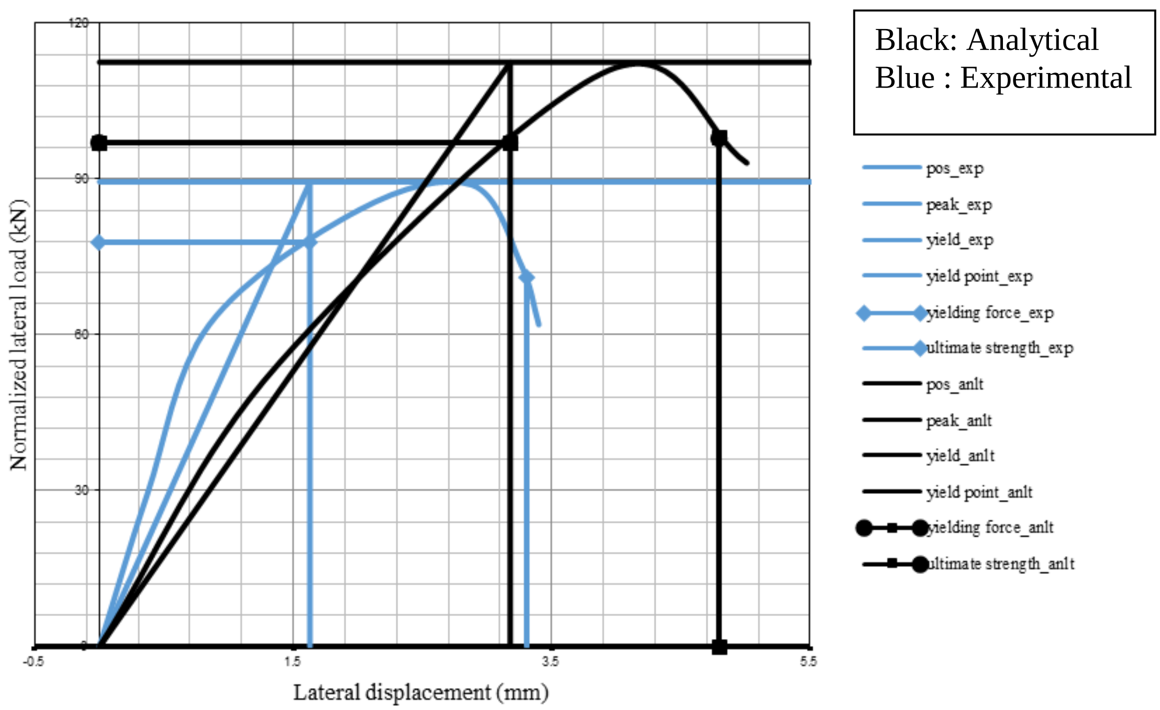


Figure 48 Ductility Factor

5.2.Comparison of Confined And Un- confined Masonry structures

Deformed Shape:

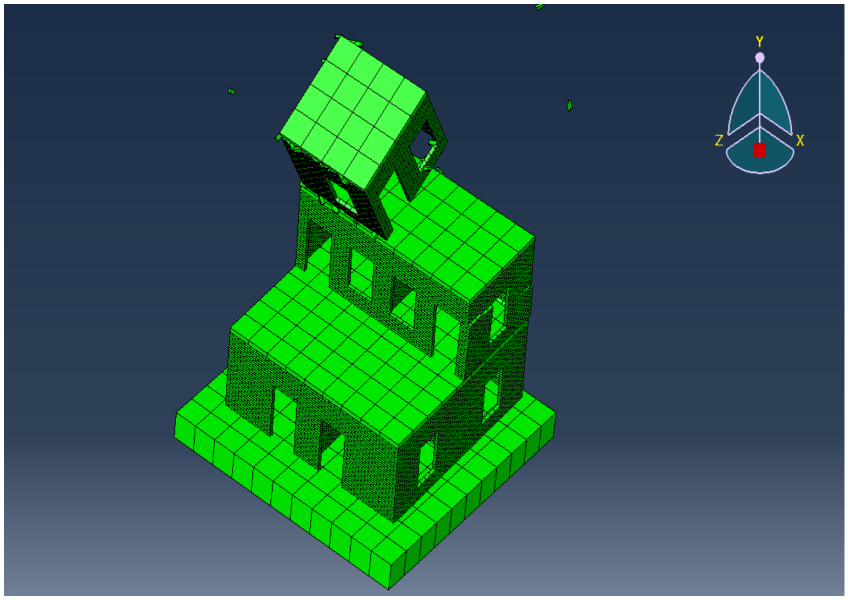


Figure 49 Unconfined Masonry Structure

Deformed Shape:

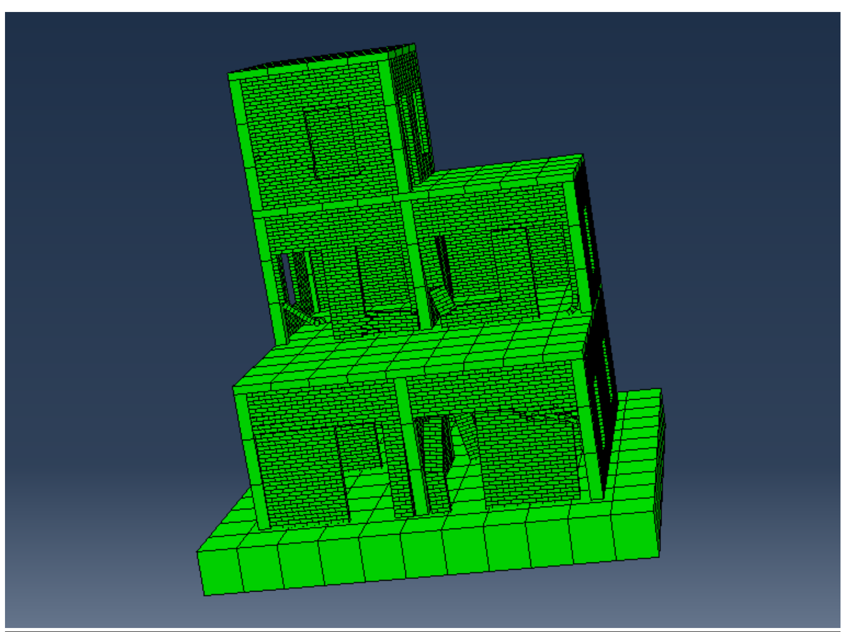


Figure 50 Confined Masonry Structure

5.3. Displacements Comparison

From our analysis on Abaqus, we conclude that the most critical condition for the structure will be when it is subjected to time- history accelerations of a real earthquake data. This data directory of earthquake is related with the mass source to create a force in the structure which will then affect its strength and a response curve is obtained. The data input is in relation with the gravitational acceleration.

Absolute Lateral (Story MAX) Time History Displacements for Confined and Unconfined Masonry in X-Direction:

Table 7 Time History Displacement X-Direction

Story Name	Confined Masonry Displacement (mm)	Unconfined Masonry Displacement) (mm)
Story 1	0.59	1.09
Story 2	1.38	2.25
Story 3	1.016	2.2

D

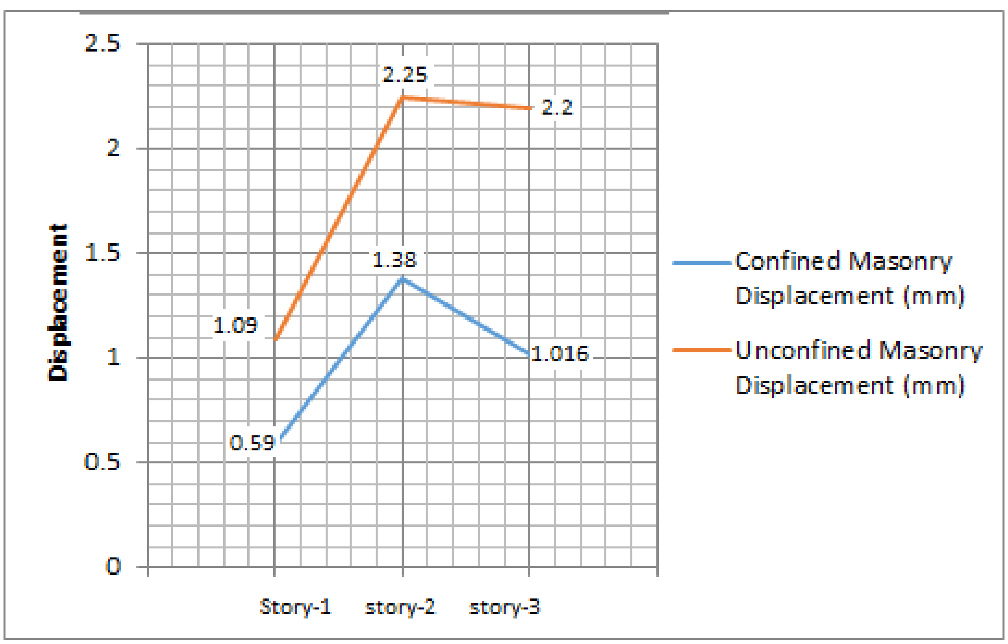


Figure 51 Time History X-Direction Displacement

The above graphs show the difference between maximum X-direction displacement in confined and unconfined masonry. Confinement has improved the structural stiffness resulting in lesser displacements.

- Absolute Lateral Displacements for Unconfined and Confined Masonry in Y-Direction:

Table 8 Time History Displacement Y-Direction

Story Name	Confined Masonry Displacement (mm)	Unconfined Masonry Displacement (mm)
Story 1	4.8	10.9
Story 2	10.4	13.2
Story 3	12.7	17.5

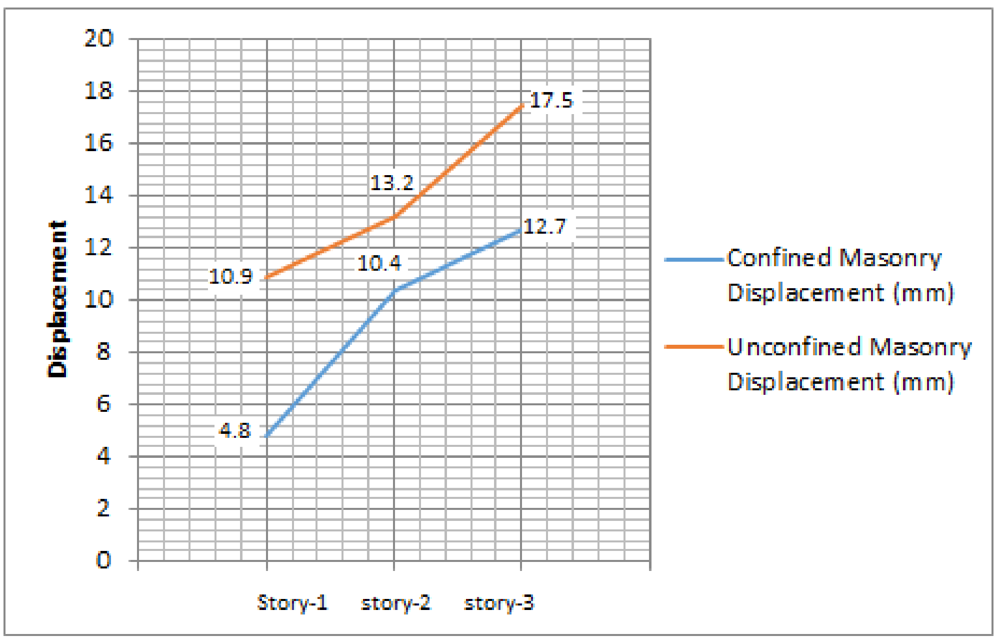


Figure 52 Time History Y-Direction Displacement

Y-Direction displacements also depict the same trend with confined masonry having lesser story displacement as compared to unconfined masonry. The reason being an improved stiffness and better structural performance.

Nodes

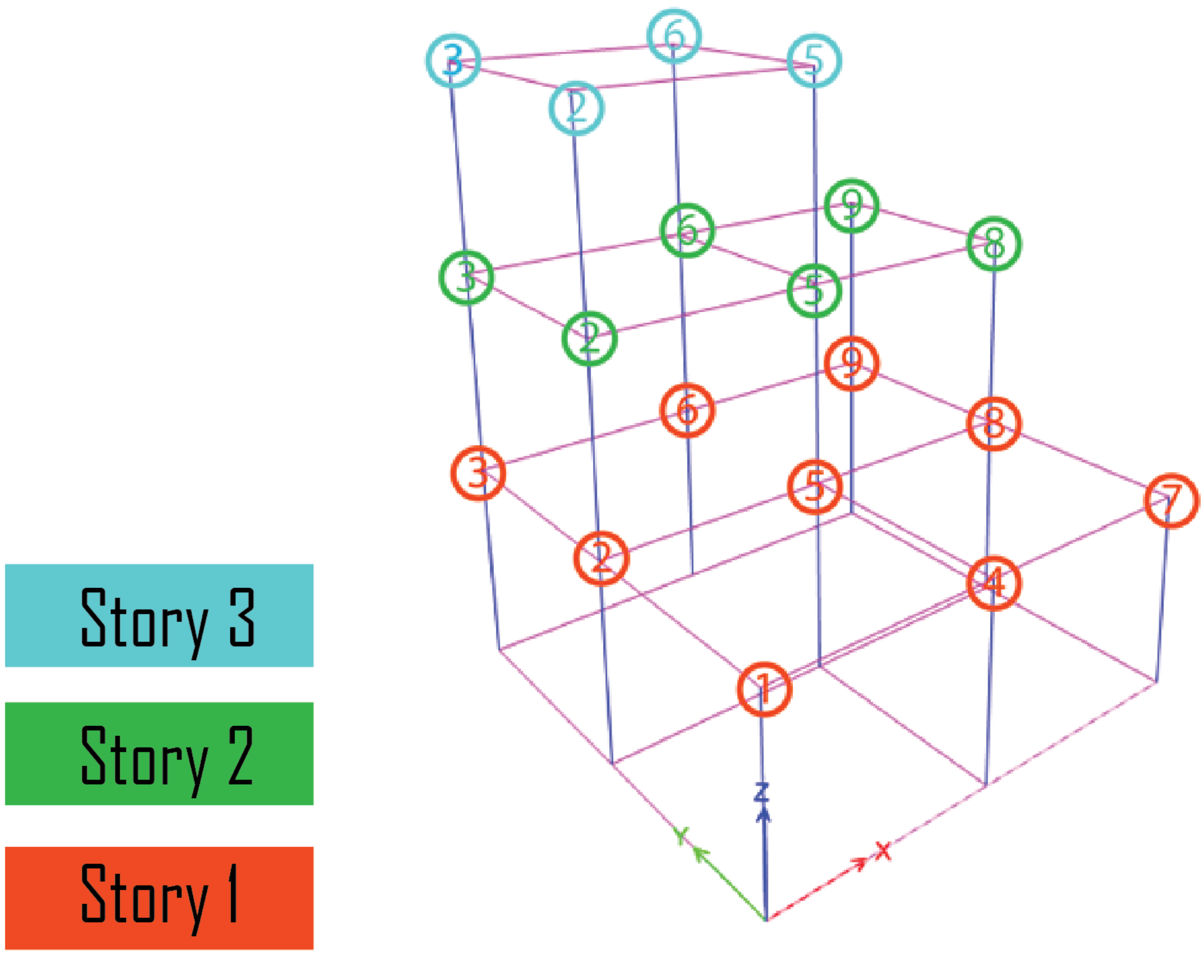


Figure 53 Nodes labeled

The following is the maximum time history displacements observed at the nodes defined above:

Table 9 Maximum Time History Displacements

Confined Masonry

Story	Label	UX	UY	UZ
		mm	mm	mm
Story3	2	0.119	0.8382	0.1078
Story3	3	0.05	0.87	0.0544
Story3	5	0.10	0.508	0.0508
Story3	6	0.0508	0.8636	0.1066
Story	Label	UX	UY	UZ
		mm	mm	mm
Story2	2	0.05334	0.3048	0.0556
Story2	3	0.04572	0.3066	0.0456
Story2	5	0.0566	0.2945	0.0544
Story2	6	0.0566	0.2433	0.06544
Story2	8	0.0508	0.3322	0.0345
Story2	9	0.0736	0.2877	.0533
Story	Label	UX	UY	UZ
		mm	mm	mm
Story1	1	0.000887	0.007904	0.000802
Story1	2	0.000955	0.00867	0.002654
Story1	3	0.000631	0.0095	0.001149
Story1	4	0.00076	0.007404	0.001392
Story1	5	0.000894	0.008277	0.001698
Story1	6	0.000741	0.009339	0.000413
Story1	7	0.000681	0.006532	0.001193
Story1	8	0.000768	0.006598	0.001569
Story1	9	0.000889	0.006784	4.00E-05

Unconfined Masonry

Story	Label	UX	UY	UZ
		mm	mm	mm
Story3	2	1.9	0.051227	0.508
Story3	3	0.2133	0.050983	0.2014
Story3	5	0.236	0.051727	0.2377
Story3	6	0.2265	0.052281	0.0236
Story	Label	UX	UY	UZ
		mm	mm	mm
Story2	2	0.2363	0.877	0.009519
Story2	3	0.127	.94	0.00566
Story2	5	0.2455	0.602	0.007333
Story2	6	0.227	0.706	0.001628
Story2	8	0.2534	0.223	0.0042
Story2	9	0.32	0.32	0.000196
Story	Label	UX	UY	UZ
		mm	mm	mm
Story1	1	0.001524	0.0065	0.000811
Story1	2	0.001117	0.00698	0.00304
Story1	3	0.000977	0.007633	0.002935
Story1	4	0.001414	0.006126	0.001425
Story1	5	0.00143	0.006832	0.003284
Story1	6	0.001036	0.007632	0.00114
Story1	7	0.001525	0.005817	0.001203
Story1	8	0.001263	0.005827	0.001707
Story1	9	0.001182	0.005979	0.000116

Chapter 6

6. Conclusions and Recommendations

6.1. Conclusions

The seismic resistance of Masonry buildings is too weak to bear a severe earthquake. They are unable to resist any kind of out of plane loads due to the poor ductility, stiffness and load transferring ability of the walls. Most of the medium scale constructions in Pakistan are made of brick masonry. Pakistan lies on a fault line and so calls for improvement in structural resistance with respect to seismic loading. In the wake of Kashmir earthquake of 2005, the dangers of seismic damages have been rekindled. To improve the performance of structures, one suggestion is to provide beams and columns as confinements. To test this theory, two 3-story structure with eccentric floor plans and openings was modeled on Abaqus. One structure was with confinements and the other one was without any confinements. Structure was then subjected to earthquake according to the provisions provided in UBC 97. The results were obtained in form of displacements.

1) It is noted that with the provision of 9in. x 9in. confinements, there is a considerable improvement in the strength, ductility, and stiffness of the structure. It is able to resist the seismic loads without being subjected to permanent deformations. The comparison was made between the two structures based upon the loading type and the axis of deformations. Maximum story displacements were the focus of the study.

2) It is noted that in most of the cases, story displacements increase as we move up the story due to lesser restraints. The different between confined and unconfined masonry in higher stories is greater as compared to story 1 in X-direction. Therefore, it is concluded that confinements help in providing better restraints to the structure which are otherwise unavailable in simple masonry structure.

6.2. Recommendations

Based upon the results obtained from the study and those highlighted in the literature review, the provision of confinements does improve the strength of masonry structures. But still there are certain aspects that need to be studied to further optimize their structural behavior.

Following are the few variables that need to be studied for more in-depth analysis of the performance of masonry structures:

1) To learn the effect of confined on increased story height of building.
2) Effects of opening sizes and placements on the strength of masonry buildings.
3) Optimization of confined masonry to replace RCC frame structures for low-rise buildings.
4) Effect of confinement sizes on the strength increase in masonry buildings.
5) Effects of bracing and unbracing of confinements on the performance of masonry structures.
6) Behavior of masonry structures for different size of bricks.

With all the scope of the study explained and all the objectives met, it is proposed that the provision of confinements in masonry structures improves its seismic strength and must be provided where lateral loads are a problem.

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