CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY, ISLAMABAD

# Dynamic Analysis of Confined Brick Masonry Structure

by

Sami Ullah

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in the

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*I want to dedicate this achievement my parents, teachers and friends who always encourage and support me in every crucial time*

# CERTIFICATE OF APPROVAL

## Dynamic Analysis of Confined Brick Masonry Structure

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**Refereed Conference Article**

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# *Abstract*

Masonry is one of the old materials used for easy and economical construction. Masonry structures are still available as a historical heritage in the world. The brick masonry structure is not safe in terms of seismic loading as observed in the past earthquake. To ensure the safety of brick masonry structures reinforced concrete vertical and horizontal stiffeners are proposed to improve the lateral capacity of the brick masonry structure to resist the lateral forces of the earthquake. The confined brick masonry structures failed during the past earthquake due to insufficient lateral resistant members of reinforced concrete stiffeners. The confined brick masonry structure must be able to resist the earthquake forces to avoid human life losses and economical losses. For this purpose, analytical work is done on confined brick masonry structure of two stories ground floor, first floor and mumty by SAP2000 software using macro modeling for seismic zone 4 and soil profile type SD. A house is selected with vertical reinforced concrete stiffeners provided at a different location where needed and horizontal reinforced concrete stiffeners provided at a certain level to properly joint the vertical and horizontal stiffeners together. The model with vertical and horizontal reinforced concrete stiffeners of proposed sections was analyzed statically and designed as per codes. After linear static analysis, the model was analyzed by nonlinear time-history analysis with a total of 8 strong ground motions which included 4 near and 4 far-fault ground motions to investigate the seismic demand of the confined brick masonry structure. Pushover analysis was performed with stiffeners of SD, SC and SB for soil profile type SD and seismic zone 4. The confined brick masonry structure is checked for Far and near-fault strong ground motion by using the nonlinearity of material for precise effects of earthquake forces on the macro model of the structures. The deformation demand obtained from nonlinear time-history analysis with 4 near and 4 far-fault strong ground of the earthquake is less than the expected values. Therefore, the results show that the reinforced concrete stiffeners sections vertical stiffeners, as well as horizontal stiffeners proposed for seismic zone 4 and soil profile type SD, may be economized by using stiffeners of soil profile type SB.

**Keywords: Confined Brick Masonry Structure, Static Linear Analysis, Reinforced Concrete Stiffeners, Pushover Analysis and Nonlinear Time History Analysis.**

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# Abbreviations

| | |
|---|---|
| **BMS** | Brick Masonry Structure |
| **CBM** | Confined Brick Masonry |
| **CBMS** | Confined Brick Masonry Structure |
| **FEM** | Finite Element Method |
| **g** | Acceleration due to Gravity |
| **GPa** | Giga Pascal |
| **HS** | Horizontal Stiffeners |
| **Km** | Kilometer |
| **LD** | Limited Damages |
| **LWC** | Light Weight Cellular |
| **m** | Meter |
| **m/sec** | Meter per Second |
| **mm** | Millimeter |
| **MPa** | Mega Pascal |
| **Mw** | Magnitude of Earthquake |
| **NC** | Near Collapse |
| **PEER** | Pacific Earthquake Engineering Research Center |
| **PGA** | Peak Ground Acceleration |
| **RC** | Reinforced Concrete |
| **RMS** | Reinforced Masonry Structure |
| **SD** | Significant Damages |
| **SDOF** | Single Degree of Freedom |
| **Strike-Slip** | Strike-Slip |
| **UBMS** | Unconfined Brick Masonry Structure |

| | |
|---|---|
| **UM** | Unconfined Masonry |
| **URMS** | Unreinforced Masonry Structure |
| **VS** | Vertical Stiffeners |
| $\phi$ | 280 Grade of Reinforcement |
| # | 420 Grade of Reinforcement |

# Chapter 1

# Introduction

## 1.1 Background

Masonry is one of the oldest materials available for use in construction. Unreinforced masonry structures were constructed in the past which was unable to resist the lateral forces of the strong ground motion of the earthquakes. To improve the lateral load resisting capacity of the masonry structure confining method was proposed by French structural engineer Paul Cottancin. Therefore, the construction nowadays in the world most of CBMS consist of the brick masonry and confinement element of reinforced concrete vertical as well as horizontal stiffeners. The purpose of CBMS is to resist lateral loads like earthquake loads and enhance the ductility of the masonry structures. The CBMS failed in past earthquakes due to insufficient knowledge regarding the design and seismic behavior of the structures which causes a lot of damage to human lives as well as economic losses. The CBMS should be functional during and after the earthquake of strong ground motions to avoid human life and economic losses. The effect of the near and far fault ground motion on confined brick masonry structures is different and needs to be investigated.

In this study, a house is selected which included the ground floor, 1st floor and mumty with vertical reinforced concrete stiffeners provided at 19 different locations which consist of stiffeners at corners and junction as well as around the openings while the horizontal reinforced concrete stiffeners provided above the opening or either needed. The CBMS house is modeled with macro modeling in SAP2000 software and analyzed with static linear analysis as per UBC-1997 for seismic source types A, B, and C and design as per ACI-318. The CBMS are considered for seismic zone 4 and soil profile type SD which are the most seismically active regions. The reinforced concrete vertical and horizontal stiffeners are provided in the model same as provided in the proposed sections. The nonlinear material properties are determined and used for nonlinear analysis of the structure of nonlinear time-history analysis performed to determine the displacement demand of the macro model of confined brick masonry structures with different near and far-fault ground motions.

In the past masonry structures failed during earthquakes due to not being able to resist lateral loads of the strong ground motions of the earthquakes. The masonry structure is proposed to be confined with horizontal and vertical stiffeners of reinforced concrete to enhance the lateral force resistance and improve the ductility of the structure. As we know the near and far-fault have great effects on the performance of the CBMS especially near-fault ground motion which can badly damage the structure. From the literature review, it has been observed that no work is done yet on the near and far fault effect on the CBMS which needs to be studied in detail to ensure the safety of the CBMS during and after the earthquake of strong ground motions.

In this research work, static linear analysis and design have been done as per UBC-1997 and ACI-318 while the nonlinear time-history analysis is performed on the macro model of a CBMS to investigate the behavior of the structure under near and far-fault ground motion during earthquakes. This work helps us in determining the seismic demand of the CBMS under near and far-fault strong ground motions.

## 1.2 Research Motivation and Problem Statement

Earthquakes roots severe damage, such as the failure of buildings, roads, and bridges, which may cause losses of many people's lives. The unreinforced brick masonry structures suffered a lot in past during the strong ground motion of the earthquakes due to the insufficient capacity of masonry structures to resist lateral loads of the earthquakes. Because the UBMS construction work is based on transferring the vertical load of the structures to the foundation of the building. For improving the strength of the unreinforced brick masonry structure confining elements are used to enhance the lateral load resisting capacity of the brick masonry structures. For this purpose, vertical reinforced concrete confining elements are proposed at different locations of the building where necessary especially at the intersection or corner of the walls and around the openings of the structure, and horizontal reinforced concrete stiffeners above the openings of doors and windows or places where found necessary. The strength improvement of the masonry structures has been observed during the earthquakes where confined brick masonry structures perform better than unconfined masonry structures.

In past, many earthquakes occurred at different locations in the world which badly affect the area and causes a huge amount of economic and human losses. Few of these earthquakes were too effective such as the Indonesia Java earthquake which occurred in 2006 causes the death of 5,176 people and 40,000 people were injured [1]. Similarly one of the deadliest earthquakes occurred in Pakistan in 2005 which cause a lot of damage and human life losses which take a lot of time to recover[2]. Such sufferers can be avoided if specific behavior of structures during the strong ground motion of the earthquake is considered which can help in the proper design of the confined brick masonry structures. The research has aim to investigate the dynamic behavior of confined brick masonry structures (CBMS) under the strong ground motion of the earthquake. The confined brick masonry structures need to be functional during and after the earthquake as if they are damaged can suffer human life as well as cause economic losses. Thus, the problem statement is as follows.

“Confined brick masonry structures resist lateral forces during the severe earthquake, but the performance of CBMS against far and near-fault ground motions is not well known. This problem may be solved by the investigation of far and near-fault ground motion effects on confined brick masonry structures. Therefore, to investigate the near and far fault ground motion effects on the confined brick masonry structures to enhance the structure required parameters”.

The dynamic analysis of the confined brick masonry structure with the near and far-fault strong ground motion of the earthquakes was downloaded from the PEER database determining the seismic demand of the structure. This seismic demand obtained from a nonlinear time-history analysis of the confined brick masonry structure will help in the design of the reinforced concrete vertical and horizontal stiffeners locations and section detail of the confining elements. The proper design and efficient reinforced concrete (RC) confining stiffeners provision in brick masonry structures will help in reducing the economic losses as well as will save human lives during the strong ground motion of earthquakes in the future.

## 1.3 Overall Objective of the Research Program and Specific Aim of this MS Research

As masonry structures failure occurred in the world during the past earthquake which caused a lot of damages to human lives and economic losses. In Pakistan, the heaviest and deadliest earthquake occurred in 2005 in Kashmir Balakot which is known as the deadliest earthquake in Pakistan which causes a lot of damages and losses and completely paralyzed a village [3]. The Kashmir Balakot 2005 earthquake is one of the strongest earthquakes in Pakistan's history and can never be forgotten. To avoid the failure of the masonry structures reinforced concrete vertical and horizontal confined elements have been proposed for different seismic zones and soil profile types but zone 4 and soil profile type SD is one of the most seismic regions which need to be checked with nonlinear dynamic analysis to investigate the seismic demand of the structure. For this purpose confined brick masonry structures' behavior needs to be evaluated during the strong ground motion of the earthquakes. Therefore, the overall objective of the research program is

"To explore precise and accurate seismic behavior of confined brick masonry structures during ground motions to have safe housing units. The specific aim of this MS research work is to investigate the far and near-fault ground motion effects on confined brick masonry structures".

## 1.4 Scope of Work and Study Limitations

The unreinforced brick masonry structure failed in the past during the strong ground motions of the earthquakes as observed. These unreinforced brick masonry structures failed due to unable to resist the lateral load of the ground motions of the earthquakes. Reinforced concrete vertical and horizontal confining elements are proposed for these unreinforced brick masonry structures which analytical work is done on modeling software SAP2000. For modeling of the confined brick masonry structure, SAP2000 software was used to investigate the dynamic behavior of the structure during strong ground motions of the earthquakes. Confined brick masonry structures were analyzed by SAP2000 software for static linear and nonlinear time-history analysis with near and far-fault ground motions of the earthquakes as well as nonlinear pushover analysis through macro modeling. The models were analyzed as per code UBC-1997 and designed as per ACI-318 (2011) [4]. The first models analyzed static linearly to confirm the reinforcement of confinement reinforced concrete vertical and horizontal stiffeners (beams and columns) of the confined brick masonry structures as well as validate the sections of the stiffeners. Time-history nonlinear analysis is performed on confined brick masonry structures to determine the seismic displacement demand under considering near and far-fault ground motions of the earthquakes. Pushover analysis was performed on the macro model of a confined brick masonry structure to get the confining element response for seismic zone 4 and soil profile type SD with stiffeners of SD, SC and SB.

The Study limitations of the research include only numerical analysis of the confined brick masonry structure which was carried out in modeling software SAP2000. The confined brick masonry structures were analyzed for seismic zone 4 and soil profile type SD. First modeled the confined brick masonry structure in SAP2000 software through macro modeling technique as per the proposed plane and sections provided of reinforced concrete stiffeners. The model was then analyzed with linear static analysis as per UBC-1997 and designed as per ACI-318 to validate the reinforced concrete vertical and horizontal stiffeners. After that nonlinear time-history analysis was performed on model of confined brick masonry structures to check the seismic demand of the structures under near and far-fault ground motions of the earthquakes. Pushover analysis is performed for hinges response with stiffeners of soil profile types of SD, SC and SB.

In this study Confined brick masonry structures with reinforced concrete vertical and horizontal stiffeners are validated and the seismic demand of the structure investigates under near and far-fault ground motions of the earthquakes. Near and far-fault ground motions effects are considered for confined brick masonry structures and no experimental works are performed. The study of the research is limited to superstructure only and the base of the superstructure is hinged supported. The analytical work was performed in SAP2000 to investigate the behavior of CBMS and the stiffener's response of the structure. The analysis is performed for CBMS structure only and the findings (cost for example) are not compared with the framed structure as these two are different kinds of structures. Cost analysis is outside the scope of current work. The main emphasis is on the difference between static (Mehran Khan study) and dynamic (current study) behavior.

### 1.4.1 Rational Behind Variable Selection

There are many software is used for the modeling, analysis, and design of the structures such as SAP2000, ETABS and Staad-Pro, etc. SAP2000 was selected for the modeling and analysis of the confined brick masonry structures due to the use of easiness in modeling. The reason for performing time history nonlinear analysis is to remain the confined brick masonry structures functional during and after the earthquakes of strong ground motions because a lot of damage occurred to the structures in past earthquakes. The strong ground motion of near and far fault data was downloaded from the PEER database of the earthquakes as per PEER database guidelines and instructions. The static linear analysis was performed on the confined brick masonry structures to validate the reinforced concrete vertical and horizontal stiffeners used as confining elements for brick masonry structures. On the other hand, the nonlinear time-history analysis was performed under near and far-fault strong ground motions of the earthquakes as downloaded from the

PEER database to determine the seismic demand of the confined brick masonry structures. Pushover analysis was selected for seismic zone 4 and soil profile type SD to check the performance of the selected structure with stiffeners for soil types SD, SC and SB for the economization of stiffeners of the macro model of CBMS.

## 1.5 Research Novelty, Significance and Practical Implementation

It is observed from the literature review that mostly unreinforced brick masonry structures failed as compared to the confined brick masonry structures in past during the strong ground motions of the earthquakes. The failure of unreinforced brick masonry structures occurred during the strong ground motion of earthquakes in past due to insufficient lateral load resistant capacity of the structure. The unreinforced brick masonry structure failure during strong ground motion of earthquakes causes a lot of damage to human lives and economic losses. To avoid suffering from the earthquake's strong ground motion effects reinforced concrete vertical and horizontal stiffeners are supposed to confine the unreinforced masonry structure by French structural engineer Paul Cottancin. These reinforced concrete vertical and horizontal stiffeners are provided at specified locations in the structure like vertical reinforced concrete stiffeners are provided mostly at the corner of the walls and around the openings for doors and windows in the walls while horizontal reinforced concrete stiffeners are provided above the opening of the doors and windows in the walls. These reinforced concrete vertical and horizontal stiffeners effectively strengthen the brick masonry walls and enhanced the ductility as well as improve the lateral load resisting capacity of the brick masonry structures.

Therefore, the confined or reinforced brick masonry structures failure was also observed in a few earthquakes from the literature review like Chile but less than the unreinforced brick masonry structures. The reason for the failure of the confined brick masonry structures during the past earthquake was due to insufficient ductility of the structure to resist the drift that occurred due to the ground motions of the earthquakes. The significance of this study is to understand the behavior of

CBMS under far and near-fault ground motions lead to ensure the serviceability of the CBMS during and after the earthquakes as well as to achieve the economical design of CBMS. The nonlinear time-history analysis was performed on the confined brick masonry structures to validate the theoretical approach for possibilities of utilization of confined brick masonry structures for the actual field. The novelty of current research work assists in its contribution towards the damage performance level of CBMS under far and near-fault ground motions here by leading to achieve the economical design of the CBMS. This study helps in the validation of the reinforced concrete vertical and horizontal stiffeners sections for the confined brick masonry structures and determines the seismic demand of the structures under near and far-fault ground motions of the earthquakes downloaded from the PEER database as per PEER database guidelines and instruction. These strong ground motions include 4 near-faults ground motions and 4 far-faults ground motions so a total of 8 ground motions. Practicing designers should also consider the dynamic response of CBMS of this study as it provides a guide at the design stage for them.

## 1.6 Brief Methodology

In this study, a house is selected which includes the ground floor, 1st floor and mumty with dimensions on ground floor framing plane are 7.5 m and 12 m. The house selected with brick masonry walls thicknesses are 9 inches and reinforced concrete vertical and horizontal stiffeners are provided at different locations where suited necessarily. The house selected of confined brick masonry structure has a seismic zone 4 and the soil profile of SD is modeled in SAP2000 manually. The model of confined brick masonry structure consists of the ground floor, first floor, and mumty. Confined brick masonry structure with masonry wall modeled, where vertical and horizontal reinforced concrete stiffeners allocate in the location where needed. The reinforced concrete vertical stiffeners are allocated at corners of the walls of brick masonry and around the openings while horizontal reinforced concrete stiffeners are provided above the openings of doors and windows in the walls. The model analyzes with equivalent static force analysis as per UBC-1997 and design as per ACI-318.

After static linear analysis, the confined brick masonry structures analyze by non-linear time-history analysis under the strong ground motion of near and far-fault downloaded from the PEER database as per PEER database guidelines and instructions. Total 8 ground motions were downloaded of which 4 included near-fault and 4 included far-fault. Nonlinear time-history analysis was performed on confined brick masonry structures to investigate the seismic demand of the structure under near and far-fault strong ground motions of the earthquakes. Nonlinear properties of the materials are used for nonlinear analysis of the confined brick masonry structures to obtain the most accurate result of the structure to practical behavior of the structures.

The model of confined brick masonry structures was analyzed for all seismic source types A, B, and C statically as per UBC-1997 and designed as per ACI-318 as well as analyzed by nonlinear time-history analysis with near and far-fault ground motions of the earthquakes. The pushover analysis is performed on the macro model of CBMS to investigate the stiffeners result for seismic zone 4 and soil profile type SD with stiffeners of seismic zone 4 and soil profile types SD, SC and SB. The results obtained from the analysis of the structures are then set in form of the tables and figures to be properly studied and compared.

## 1.7 Thesis Outline

In this thesis there are six chapters as summarized:

Chapter 1 consists of an introduction which includes the background of the research work, research motivation, problem statement, overall and specific objective of the work, research brief methodology, and outline of the thesis.

Chapter 2 consists of a Literature review which includes background, damages of brick masonry structures during past earthquakes, Seismicity of Pakistan, the performance of confined brick masonry structures during past earthquakes, numerical approach to the confined brick masonry structure, software used for the analysis of confined brick masonry structure and summary.

Chapter 3 consists of the methodology and selection of properties of the material for performing the analysis which gives complete details regarding the model and selection of cross-section of the reinforced concrete stiffeners as well as the location of the vertical and horizontal stiffeners.

Chapter 4 consists of the analysis of the confined brick masonry structures which include linear static analysis and nonlinear time-history analysis under near and far-fault strong ground motions of the earthquakes downloaded from the PEER database with 4 near and 4 far-fault strong ground motion.

Chapter 5 consists of results and discussion which include the result obtained from linear static analysis, nonlinear static/pushover analysis and nonlinear time history analysis as well as discussed these results in detail.

Chapter 6 consists of the future work and conclusion which includes the conclusion made from the analysis results.

# Chapter 2

# Literature Review

## 2.1 Background

Confined brick masonry structures are the most important structures nowadays in the world which are mostly constructed. These confined brick masonry structures should be able to resist the earthquake lateral loadings to avoid human and economic losses. As masonry structures are failed in the past during the strong ground motions of the earthquakes due to unable to resist the lateral forces of the earthquakes. The failure of the unreinforced brick masonry structures occurred during the past earthquake due to not reinforcing the structures with proper materials and techniques which were not able to resist the lateral forces of the earthquake. The UBMS were constructing while considering the vertical loads on the structure only because these structures only transferred the vertical load to the foundation of the structure. Therefore, a lot of human and economic losses caused by the earthquakes in past due to unreinforced brick masonry structures as observed from the literature review. The reinforcing elements are proposed for these unreinforced brick masonry structures to reinforce them. So, these brick masonry structures are reinforced with vertical and horizontal reinforced concrete stiffeners to improve the lateral loads resisting capacity of the brick masonry structures as well as enhanced the ductility of the structures. The confined brick masonry structures perform well as compared to unreinforced brick masonry structures as observed during the past earthquakes and reduce the losses caused by unreinforced or unconfined masonry structures in past during the strong ground motions of the earthquakes. These confined brick masonry structures are also failed but not as much as unreinforced brick masonry structures during the earthquakes in past. This happened because the insufficient knowledge about the location of the reinforced concrete stiffeners or provides an insufficient number of stiffeners. For the effectiveness of the reinforced concrete stiffeners research work is done to obtain the required strength of the structure to avoid the failure of the brick masonry structures in the future. For this purpose, the confined brick masonry structures should be properly designed and constructed to perform well during the strong ground motion of the earthquakes to reduce the losses of human lives and economic.

## 2.2 Damages of Brick Masonry Structures During Past Earthquakes

Masonry structures are widely used all over the world especially lower story houses and buildings up to three to five stories. Masonry is one of the oldest materials used for construction which is a solid element to ensure the safe transmission of stresses of the structure to the foundation of the structure [5]. The unreinforced brick masonry was mostly used and still used in many developing countries in which the walls are constructed orthogonal in-plane which acts as a load-bearing element of the structures [6]. The unreinforced masonry structures are still available as historical buildings which were constructed in past. These unreinforced masonry structures are renovated from time to time as they are our historical heritage buildings that can be useful for tourist purposes. In unreinforced brick masonry structures, the masonry walls transfers the structural loads to plinth beams and foundations. Unconfined Brick masonry structures include the foundation of the structure, brick masonry walls, floors, and roofs of the structure in which the loads from the roof or slabs are transferred to the foundation directly by a brick masonry wall. Most of the historical buildings in many cities of the world constructing from brick masonry material. These brick masonry structures should remain safe as many of them using as cultural heritage which can be conserved by future generations [7]. As the unreinforced brick masonry structures are mostly unable to resist the earthquake loading which in result cause the failure of the structures [8]. The failure of the unreinforced brick masonry structures occurred during the strong ground motion of the earthquake due to the brittleness of the masonry walls as they are unable to resist the lateral loadings [9].

The earthquake force is very dangerous to the unreinforced brick masonry construction as observed in the past earthquake of Kashmir in which more than 73,000 people lost their lives, injured were 80,000 and peoples who get homeless were approximately 3.5 million [10]. The Kashmir earthquake of Pakistan is known as the deadliest earthquake in Pakistan's history ever occurred which completely paralyzed the effective area and one village was completely collapsed during the earthquake. Brick masonry structures were destroyed in the Bam earthquake which occurred in December 2003, hit the historical city of Bam Iran with a magnitude of Mw = 6.5 causing the death of approximately forty-five thousand people which is huge losses [11]. The Pisco Peru earthquake occurred with a magnitude of Mw 7.9 in which most of the unconfined masonry structures were collapsed causing human and economic losses [12]. Central Java earthquake occurred with a magnitude of Mw 6.3 in May 2006 where 154,000 houses were destroyed while 260,000 were suffered from different types of nature [1]. Chile's earthquake that occurred in 1985 also causes a lot of damage to houses which include approximately 66,000 houses completed damaged while 127,000 were suffered from different kinds of damages [13]. From the literature review regarding the performance of unreinforced masonry structures, it has been found that these structures collapsed during the earthquakes due to unable to resist the lateral forces of the strong ground motions of the earthquakes.

The unreinforced brick masonry structures are brittle structures and unable to resist the lateral loads of the strong ground motions of the earthquakes. The houses of unreinforced brick masonry structures can be observed from Figure 2.1 which were damaged during the earthquake of September 7, 2017, in towns of Mexico with different types of typical damages. These structures' walls are brittle because additional structural elements are not provided in these walls which can help in reducing the brittleness of the walls [14]. The failure observed in the masonry structure after being hit by ground motions of the earthquake is in-plane and out-of-plane of the masonry wall. The In-Plane bending stresses are the stresses in which the elements of the structure are bending in its own plane while the Out-of-Plane bending stresses are the stresses in which the elements of the structure are bending out of its own plane [15]. The earthquake is one of the most disastrous natural hazards which can destroy the area hit by strong ground motions of the earthquakes as observed in the Kashmir Balakot earthquake in 2005 which completely collapsed a village. The rate of losses due to strong ground motions of the earthquake and floods is more than half of the losses caused by all other natural hazards as China suffered from few earthquakes and floods in recent years which caused a lot of damage in China [16]. In 2017 an earthquake of magnitude Mw 6.3 hit Lesvos island (Greece) which causes human fatalities and damaged masonry structures where the settlement of vrissa was the most affected area [17]. As the earthquake is most dangerous for the building, especially for unreinforced brick masonry structures as observed from the literature review. So, unreinforced brick masonry structures are unable to resist lateral forces of the ground motions of earthquakes.

(a) (b) (c)

Figure 2.1: Diagonal Tension Damage Patterns and Out-of-Plane Wall Collapses in Adobe and Plain Unreinforced Masonry in Housing Structures Located in (a) Pijijiapan,(b) Tonala and (c) Villa Flores Towns of Mexico [14].

## 2.3 Seismicity of Pakistan

Pakistan is located in seismically prone regions in the world which land is divided into different types of zone based on intensity levels and many disastrous earthquakes occurred in the past which causes a lot of damage to properties and causes human lives losses as well as economic losses [18]. Table 2.1 shows a few earthquakes which occurred from 1935 to 2019 in Pakistan such as Awaran District, Balochistan earthquake with magnitude Mw of 7.7, Gilgit Baltistan earthquakes with magnitudes Mw of 6.3, Dalbandin, Balochistan earthquake with a magnitude of 7.7, and Azad Kashmir, Balakot earthquake.

The one highest earthquake magnitude Mw of 8.1 ever occurred in Balochistan, Pakistan. The Azad Kashmir, Balakot earthquake is one of the deadliest earthquakes of Pakistan for which the most active tectonic belt of the Himalayan mountain region around Pakistan plays an important role [19]. As Indian and Eurasian plates divide Pakistan longitudinal way while the Indian, Eurasian, and Arabian plates formed a subduction zone in the southern part of Pakistan as well as the Himalayan pass through the Indian and Eurasian which make Pakistan a seismically active region [20].

Pakistan faced very bad situations in past due to the earthquakes of strong ground motions which badly affected the buildings, roads, canals, etc. Many earthquakes that occurred in Pakistan in the past few are listed in Table 2.1 in which earthquake with magnitude Mw 8.1 is the highest magnitude earthquake that occurred in Makran Coast, Balochistan on 11-28-1945 with a depth of 25 Km.

The Azad Kashmir, Balakot earthquakes have more effects on the region as compared to other earthquakes even the magnitude of the Azad Kashmir, Balakot earthquake is lower than especially Makran Coast, Balochistan earthquake which has the highest magnitude. The Azad Kashmir, Balakot earthquake is known as one the deadliest earthquake in Pakistan's history as one village was collapsed during the strong ground motions of the earthquakes, and a lot of damage to educational buildings, hospitals, and roads were occurred [2].

Table 2.1: Major Disastrous Earthquakes in Pakistan

| Date | Affected Area | $M_w$ | Depth (Km) |
|---|---|---|---|
| 12-25-2015 | Gilgit-Baltistan, Khyber Pakhtunkhwa | 6.3 | 212.5 |
| 9-24-2013 | Awaran District, Balochistan | 7.7 | 14.8 |
| 1-18-2011 | Dalbandin, Balochistan | 7.7 | 101 |
| 10/08/2005 | Azad Kashmir, Balakot | 7.6 | 15 |
| 2-27-1997 | Balochistan | 7 | 10 |
| 12-31-1983 | Gilgit-Baltistan | 7.2 | 214 |
| 11-28-1945 | Makran Coast, Balochistan | 8.1 | 25 |
| 5-31-1935 | Ali Jaan, Balochistan | 7.7 | - |

Pakistan is surrounded by the Indian; Eurasian, Himalayan, and Arabian plates, and the different cities of Pakistan are affected by the following faults.

1. The faults which are affected the Peshawar regions are Hazara Kashmir, syntax, Punjab fault, and Jhelum faults which are the most active fault contributing to the seismicity of Peshawar [18].

2. Karachi is one of the most populated city of Pakistan and have safe earthquake history in the past 175 years but Karachi is one of the seismic regions as compared to Los angles surrounded by the Nagar Parker fault, Ridge Axis fault, Jacobabad fault, and Gazabad fault [21].

3. The most historic earthquake occurred in past in Balochistan, Pakistan. The active fault for Balochistan is the Chaman fault in the northern region which is a very active fault and the Ornach Nal fault for the southern regions [22].

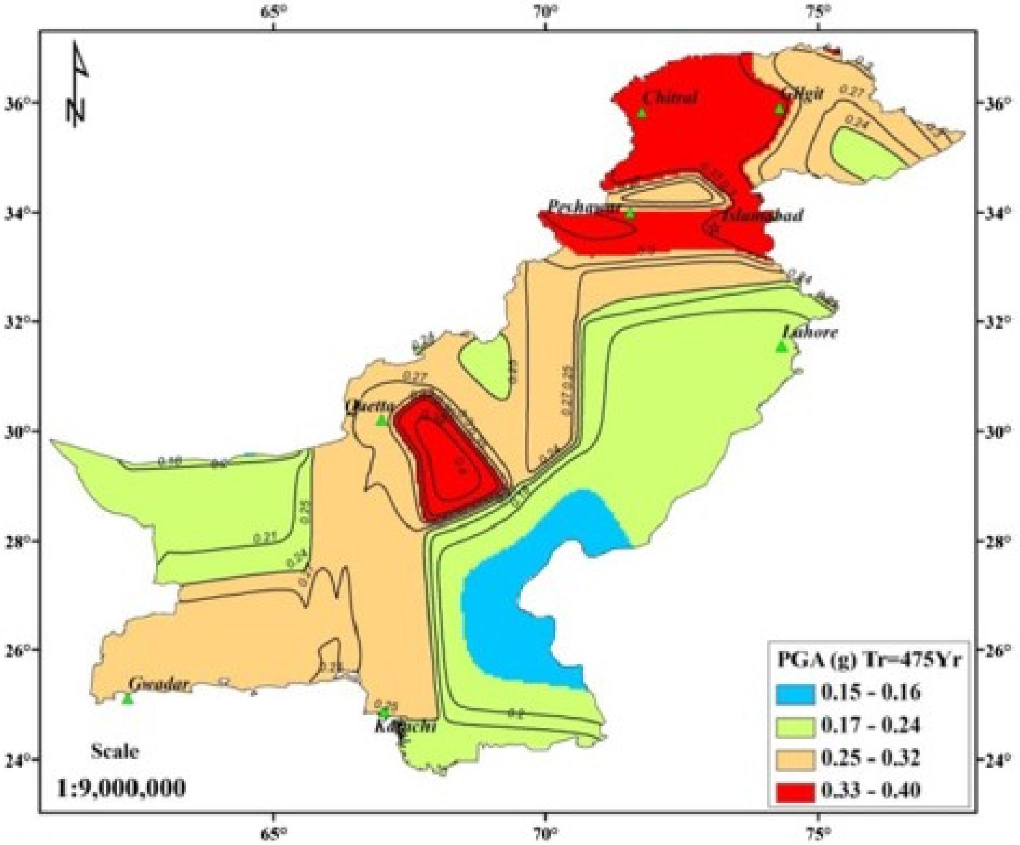


FIGURE 2.2: Seismic Probabilistic Hazard Map for Pakistan of PGA in "g" with Return Period of 475-Year [23]

Pakistan is located in the world's most seismically active region due to the tectonic plate settings like the Himalayan, Indian, and Eurasian plates which badly affect Pakistan [19]. The Himalayans were in a phase of very high seismicity level in between 1897 to 1952 as hit by 14 earthquakes with magnitude ranges up to 7.5 and a few were equal to and more than 8 which are a very high range of earthquakes. On the other hand, Pakistan had mostly nonengineered structures which are a clear threat to human life and property of the region caused a lot of damage to property and human lives during the strong ground motion of the earthquakes in past. In the strong ground motion of the past earthquake of Pakistan in 2005 especially badly affected regions of Kashmir, Balakot, and Muzaffarabad. **Figure 2.2** shows the seismic tectonic plates and range of the PGA in which the highest PGA value observed is 0.4g for Suleiman regions for a period of 475 years as can be seen from the figure. There are three major tectonic settings exist in which one is the southwestern coats (Makran subduction zone), the second one in the northwest of Pakistan which include the Hindu Kush and Pamir while in the northeast the

Himalayan and Karakorum regions, and the third one is the shallow crustal which include Chaman, Sulaiman, Kirthar and Himalayan regions [23]. The setting of the seismotectonic makes Pakistan a seismically more active region as the plate boundary of Eurasian and Indian in Pakistan divide it longitudinally as well as a subduction zone at the intersection of Arabian, Eurasian and Indian plates along the southern part of Pakistan [24].

Pakistan has a more seismic region that faces a lot of the earthquakes in past [25]. The earthquake that occurred in Pakistan was mostly with magnitudes Mw ranging from 4 to 4.9 while 13% of the earthquake that occurred had magnitudes ranging from 5 to 5.9 and only 15% of the earthquake had magnitudes ranging from 6 to 6.7 [19]. A very few earthquakes occurred with a larger magnitude of Mw 8 as well. It is also noted from the study that the earthquake that occurred with a magnitude greater than 4 and equal to 4 ($Mw \geq 4$) are mostly associated with surface and blind faults. Most earthquakes occurred with a focal depth of fewer than 50 km, the hinterland zone has a larger magnitude of earthquakes and some have a deeper level of seismicity with a focal depth of 50 to 200 km in the Hindukush range of Afghanistan. Pakistan suffers from a different range of earthquakes in past with a high level of magnitude because of the seismotectonic plate setting of Indian, Eurasian and Arabian in the region which makes it a more active region in the world [22]. An earthquake occurred in Balochistan, Pakistan in 2008 with a magnitude Mw of 6.4 known as one of the devastating earthquakes that occurred which causes huge losses to human lives and property of the people in the surrounding region. The region of Balochistan lying along the Quetta and Suleiman fold and thrust belt is considered in zone 4 which is a highly active seismic region and hit by many earthquakes of strong ground motions in past [26].

As Pakistan is located on the Eurasian plates and Indian plates which are meeting in the northern parts and middle parts of the country. Pakistan has a different fault system or many faults exist in which most are in the northern part of the country. The significant faults in Pakistan are Kalabagh, Jhelum, Raikot, Chaman, Ghazaband, Ornach-Nal, Surghar, Hoshab, Sonne, Sulaiman range, Sistan Locked, Salt Range, Main Boundary, Main Mentel, Main Karakoram, Himalayan Frontal, Balakot-Bagh, Nagar Parkar, Allah Bund, Kutch Mainland, and Makran Coastal faults. In the above faults, the first eleven faults are Strike-Slip (SS) faults and the others are reverse (R) thrust faults while the Makran Coastal fault is normal [20].

Pakistan has different levels of earthquake from moderate to high level according to the available data in which the moderate level of earthquake has a magnitude Mw ranges 5.5-6.5 while having also a high level of the earthquake which have magnitude Mw greater than 6.5. **Figure 2.3** shows the epicenter distribution of the regions in Pakistan that have a magnitude greater than 6.5 which clearly shows that many earthquakes in the history of Pakistan have magnitude Mw $> 6.5$. There are many earthquakes in Pakistan of greater magnitude like the magnitude of 8 in Makran, the magnitude of 7.6 in Kashmir, 7.5 in Quetta, 8.2 in Debal, and 7.5 in Taxila as located in **Figure 2.3**. The most disastrous earthquake in Pakistan occurred in 2005 in Kashmir which completely paralyzed the region of Balakot and Kashmir which is also known as one of the deadliest earthquakes of Pakistan [27].

Pakistan suffered a lot in past due to the strong ground motion of the earthquakes of a high range of magnitude which cause damage to properties in the regions as well as losses of human lives. These earthquakes of strong ground motion happened due to the setting of the seismotectonic plate in Pakistan. Pakistan is divided into different provinces based on seismotectonic plates to clearly describe and discuss the seismicity of Pakistan. The Makran region in southern Iran and southern Pakistan region which divided into 1A zone as shallow seismicity and 1B zone where seismicity at depth of 60 to 80 km. The Murray Ridge province is composed of the northern Arabian Sea and Murray ridge and the other province is the coastal region southeast of Karachi. Few other provinces based on seismotectonic are the southern Kirthar range, northern Kirthar range, Quetta transverse zone, Sulaiman range, Chaman fault zone, Ornach-Nal fault zone, Gardez Kunar and Safed-Kab fault zone, the Pamir Karakorum region, the Hazara region, the salt range, the Himalayas and Indus Basin [28]. These divisions to provinces of Pakistan based on seismotectonic plates are done to easily study and discuss the seismicity of Pakistan. The seismicity of Pakistan is divided into three categories. The 1st one includes earthquakes of large dimensions in which some events occurred along the Chaman fault. The 2nd category is a relatively elongate and narrow zone of seismicity which includes the Quetta transverse zone, Sulaiman range, and the Himalayas. The 3rd one category of seismicity is of diffusion nature which includes the coastal range southeast of Karachi and the southern Kirthar range. Building Code of Pakistan (BCP) 2021 is built for a short and long period of acceleration with a return period of 2475 years but cannot be used due to the non-availability of site-specific acceleration being approved officially [24].

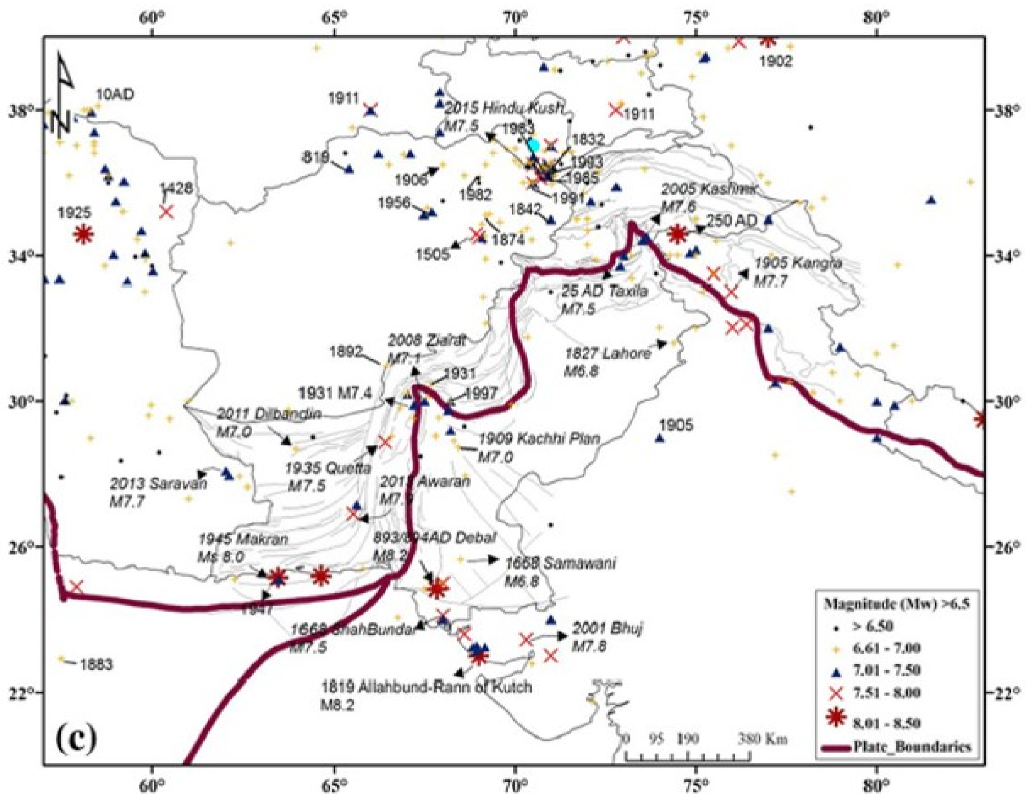


FIGURE 2.3: Earthquakes Magnitude Greater Than > 6.5 Epicenter Distribution in the Region [20]

## 2.4 Performance of Confined Brick Masonry Structure During Strong Ground Motion

Masonry is one of the oldest material used for construction of the buildings because of is abundantly available and provide an easy way of construction as well as economical. In the past masonry was one of the materials was using for construction from which still many buildings are available as historical heritage [29].

The unreinforced brick masonry structures (UBMS) failed during the past earthquake because not able to resist the earthquake lateral loads. As we know from the past earthquakes in the world mostly well-confined brick masonry structures performed well as compared to unreinforced brick masonry structures and confined brick masonry structures resist the lateral forces of strong ground motion of the earthquakes. The confined brick masonry structures (CBMS) perform well as compared to unconfined brick masonry structures (UBMS) in the Java, Indonesia earthquake caused save a lot of human lives and economic losses which can be higher if all the structures were unreinforced and unconfined brick masonry structures [1].

Mostly building of confined brick masonry structures (CBMS) newly constructed were safe in the Pisco Peru earthquake which caused heavy damage to unreinforced brick masonry structures (UBMS) leading to human lives losses and causing a lot of economic losses [12]. The Chile earthquake that occurred in 1985 caused little damage to reinforced brick masonry structures (RBMS) as compared to unconfined brick masonry structures (UBMS) because of the better design practices in the region to improve the buildings to resist the lateral forces of strong ground motions of the earthquakes [13], [30], [31]. As the Chile earthquake has a higher magnitude as compared to the java Indonesia earthquake while the damages rate in Java Indonesia is higher than in Chile due to well reinforced and proper design specifications were followed in Chile.

To improve the lateral resistance of the unconfined brick masonry structures (UBMS) the stiffener's method was proposed by French Structural Engineer Paul Cottancin at the end of the 20th century to confine the masonry structures known as confined brick masonry structures [32]. The confined brick masonry structures (CBMS) are the masonry structures with confining element reinforced concrete vertical and horizontal stiffeners provided at different locations to improve the lateral strength of the brick masonry panels as well as enhance the ductility of the structures [33]. In confined brick masonry structures the tie-columns do not act as a load-bearing member in the structure but avoid the disintegration of the structure and enhance its ductility of the structures. On the other, in designing the confinement members for confined brick masonry structures the reinforcement and sizes are selected based on experience and the number of stories of the building [34]. Turkey exposed to destructive strong ground motions of the earthquake that occurred in 2003 heavily damaged the buildings in Turkey which were mostly included structures with unconfined walls and structures designs with not consider ductile behavior as well as other deficiencies like poor concrete quality, short column, soft and weak stories, strong beam and weak columns were used [35].

As Chile faced many high magnitude strong ground motions of the earthquakes in past and the damage to buildings during these earthquakes was less as compared to expected. Similarly in earthquakes that occurred in February 2010 in Chile with a magnitude of Mw 8.8, no damages were observed in one to two-story confined brick masonry structures but three-story confined brick masonry structures were collapsed where three to four stories confined brick masonry structures were also exposed but a total of 1% damages occurred [36]. The most losses to human lives and economical occurred during the strong ground motions of the past earthquakes were due to the poor performance of the unreinforced masonry structures (UMS) instead of well-confined brick masonry structures (CBMS) which helps in saving human lives as well as economic losses [37]. So, the performance of BMS can be enhanced by proper confinement but their dynamic performance against far and near-fault were not being studied at the analysis/ design stage.

### 2.4.1 Effects of Confinement on Brick Masonry Structures

Confined brick masonry structures are some of the most commonly used structures in America, Europe, and Asia [34]. The confined brick masonry structures are constructed to provide a low-cost, low-rise building in the earthquake-prone region that can avoid damage to the structures and reduce human live losses as well as economic losses during the strong ground motions of the earthquakes [38]. In a confined brick masonry structure basically, the unreinforced brick masonry structure is confined by the provision of horizontal and vertical reinforced concrete (RC) beams and columns, which are also known as tie-columns and bond beams [39]. These columns and beams have enhanced the ductility of the structure and improved the lateral resistance of the structure to earthquake loadings of strong ground motions and hold the brick masonry walls to avoid disintegration of the walls during earthquake lateral forces [40]. The most commonly used technique is the construction of vertical and horizontal columns, which sizes are proposed for different seismic zones and soil profile types to efficiently and economically construct the confined masonry structures [41]. The effect of confining elements was checked on masonry structures and evaluated the properties of unreinforced forced masonry structures, which shows that confining of masonry structures gives an easy approach to enhancing the lateral load resisting properties of masonry structures [41]. In confined brick masonry structures (CBMS) cracks can occur in masonry walls due to stresses accumulating in masonry walls because of the reinforced concrete confining elements like slabs, beams, columns, roofs, and foundations excessive deflection, thermal expansion, and settlements [42].

The confined brick masonry structures (CBMS) are the structures in which the walls of the structures are confined by the confining elements at the edge and intersection of the walls, at the openings of doors and windows where the confining elements should be well connected at the floors levels for better performance of the structures [39]. The reinforced concrete vertical and horizontal confining elements in masonry structures not only improve the strength and ductility of the structures but also transform the failure behavior of the structures during ground motions of the earthquakes [43]. These reinforced concrete confining elements are very useful in construction which thickness are similar to the masonry wall thickness and improve the stiffness, ductility, lateral strength, displacement capacity, and drift and energy dissipation of the masonry structure (MS) during strong ground motions of the earthquakes [44]. For fast construction of the building, Mortarless interlocking masonry systems are introduced and tested with the provision of reinforced concrete stiffeners which shows improvement in the stiffeners of the structures and also avoids the failure of the structure [45]. The brick masonry panels are constructed with textile-reinforced concrete (TRC) and cast in place concrete which clearly shows that the textile-reinforced concrete (TRC) improves the stiffness, ultimate load, and little reduction in lateral deflection causing the strengthening of the masonry panels [29]. The confined brick masonry structures models tested for the earthquakes of different strong ground motions which indicate that the structures improve the strength and ductility of the structures and are very effective in avoiding the collapse of the structure during the strong ground motions of the earthquakes [46]. The confining element enhances the properties of brick masonry structure but does not provide detail regarding dynamic behavior under far and near-fault ground motions.

## 2.5 Numerical Approaches for Predict Confined Brick Masonry Structure Behavior

Confined brick masonry structure is the most important structure in the world nowadays but no work performed on CBMS regarding time-history analysis yet in detail. As confined brick masonry structures are the structures that provide safe living space to humans, which need to be safe during and after the hitting of the strong ground motion of the earthquake. Nonlinear static/pushover analysis and dynamic analysis were performed on masonry structures for three different cases which show that the pushover analysis is not matching totally with the experimental observation [47]. The unreinforced brick masonry structures using mostly where unreinforced brick masonry structures are economical as compared to reinforced brick masonry structures but unreinforced masonry structures are most vulnerable to earthquakes as compared to reinforced brick masonry structures in the seismic region especially when the result of analysis and experimental work compared [48].

Different approaches are used for the unreinforced and confined masonry structures. The three basic approaches of the finite element methods for the modeling of the masonry structures used are detailed micro-models, simplified micro models, and macro-numerical models where detailed micro-models consider the mortar and masonry unit as an individual element, simplified models considering mortar and masonry unit mechanical characteristic in the same elements, macro-models considering masonry is a continuum with anisotropic or isotropic properties [49]. As the confining of the masonry structures walls with reinforced concrete members increases the strength and stability of the wall as well as enhances the ductility of the walls against seismic lateral loading with or without opening. The non-linear behavior of confined masonry structures has been checked with nonlinear static analysis by using simplified models techniques to evaluate the structural behavior and it is found that the confined masonry walls of the structures act as load-bearing elements [50].

### 2.5.1 Finite Element Methods

The confined brick masonry structure is mostly used in the construction industry because of its efficient strength and economical as observed in past earthquakes as compared to unreinforced brick masonry construction. The finite element method is mostly used for confined brick masonry structures as studied in the literature review. The finite element method used in studying the strength, displacement, and pattern of cracks of confined and unconfined masonry elements was modeled with macro masonry properties [51]. In the micro modeling technique, the properties of up to brick-level are applied as well as joints and mortar properties are also applied; while in the macro modeling technique a whole brick masonry wall is taken as a single element and properties of bricks are applied [52]. The macro modeling technique is used for modeling CBMS due to the easy and fast modeling of the structure.

The finite element method (FEM) is used for masonry modeling to evaluate the properties of structural material for example strong or weak, large or short walls, etc. of the masonry building numerically and experimentally which helps in comparing the results obtained from the experimental and analytical work to get more accurate results [53]. A confined masonry (CM) building constructed with the lightweight cellular (LWC) panels and tested for seismic performance with numerical based on finite element methods which perform better for lateral loads with any significant damages and provide speedy construction for low rise medium building as well as economical [54]. Masonry structures used for a long time because of their economical and ease of construction. The confined masonry (CM) and unconfined masonry (UM) are modeled by the finite element macro modeling technique and analyzed to investigate the force-displacement curves and failure modes [49]. The finite element methods are used for the modeling of the structures because it's very useful in modeling and analyzing the structure in software.

The masonry structures used in the past need to be safe as these structures are historical buildings and many historic buildings are still exist. To keep safe these historical buildings and for new construction of masonry structures, a semi-random field finite element method (FEM) was used to investigate the maximum eccentric compressive load for masonry structures as masonry structures are resist vertically downward loads [55]. The confined brick masonry structures constructed with different dimensions of walls in length, the opening of doors and windows provided in few, few constructed solid walls and analyzed with different brick masonry properties in terms of strength and shapes which increase in ultimate load resistance and enhance the ductility of the walls by confining the masonry walls [43]. The macro-modeling approach was used for RC frames with infilled masonry to study the fiber plastic hinge of the structure [56]. As masonry is the old and most important material for the construction of the building and constructed many structures in the past which still exist as a heritage. For improving the properties of these old structure material properties a masonry shear is modeled and analyzed by the macro finite element method technique for improving the properties of the structures which show the properties of the existing structures can be enhanced [57]. So, FEM is used to study the behavior and properties of CBMS.

### 2.5.2 Softwares

There are different software used for the analysis of the structures in the world mostly like SAP2000, ETAB, Staad.pro and SAFE, etc. The software's used for the analysis and design of structures as per requirements but mostly software using nowadays ETAB and SAP2000 because of their good results and easiness in using for analysis and modeling. For the analysis of the nonlinear seismic performance of confined masonry walls, SAP2000 was used to evaluate the nonlinear seismic behavior of masonry walls [50]. The Staad.pro is also used for the modeling, analysis, and design of different types of structures which include masonry construction as well. N. Lingeshwaran and P. Poluraju used Staad.pro software for the analysis based on seismic performance of bed joint reinforced solid brick masonry walls in 2020 [58]. SAP2000 was used by Mehran khan in 2020 for the optimization of the reinforced concrete stiffeners for confined brick masonry structures to validate the vertical and horizontal reinforced concrete stiffeners as proposed by Majid Ali [41]. SAP2000 software is selected for this research to properly validate the reinforced concrete stiffeners statically as well as dynamically find out the seismic demand for the confined brick masonry structures for seismic zone 4 and soil profile type SD under near and far-fault strong ground motions of the earthquakes downloaded from PEER database as per PEER database guidelines and instruction. So, different software is used to study the behavior of CBMS and SAP2000 used due to the static analysis was already performed on it for CBMS and UBMS.

## 2.6 Contribution of this Study

The novelty of the research work shows the contribution of the study towards the near and far fault effects on confined brick masonry structures and significant performance damage levels of the structure. As confined brick masonry structures need to be functional during and after the earthquake which is a serious concern to reduce human lives losses and economic losses. The nonlinear analysis method used for the analysis of the macro model of confined brick masonry structures validates the theoretical approach to utilize the structure as per the actual field. This study may control or reduce the failure of the confined brick masonry structures to reduce human lives losses and economic losses. The confined brick masonry structure was analyzed with nonlinear time-history analysis with the near and far-fault ground motion of the earthquake for seismic zone 4 and soil profile type SD to determine the seismic demand for the seismic source type of structure A, B, and C.

## 2.7 Summary

The literature review shows that the damages to the unreinforced brick masonry structures during the strong ground motions of the past earthquake occurred due to unable to resist the lateral forces of the earthquakes. The disastrous earthquake located in the world damaged badly the structures and cause a lot of damage to human lives as well as collapsed structures. To reduce the human live losses and economical losses unreinforced brick masonry structures are confined with reinforced concrete vertical and horizontal stiffeners to improve the lateral resistance of the masonry structures. The performance of the confined brick masonry structure depends on the soil condition as different soil has different effects on the behavior of the structures from soft soil to hard rock. Similarly, the confined brick masonry structure's behavior is different with the fault distance as for near and far-fault which act differently on the structure.

# Chapter 3

# Research Methodology

## 3.1 Background

The confined brick masonry structure is widely used in the world, especially in Asia. The structure used mostly consists of brick masonry walls with reinforced concrete vertical and horizontal members which are known as vertical and horizontal stiffeners. These stiffeners confined the masonry structures to help in improving the ductility and lateral load resisting capacity. The confined brick masonry structures uses mostly up to two-story buildings (Ground floor and first floor) including mumty at top. The reinforced concrete vertical stiffeners are provided at the corner and intersections of the walls as well as around the openings of doors and windows while the horizontal reinforced concrete stiffeners are provided above the openings level and floor levels. The selection of the location of vertical stiffeners are divided into three types including locations at junctions and around corners, locations around doors and large windows openings and locations around small windows openings but it's depending on the experience and requirements of the structure. The section of the vertical and horizontal reinforced concrete stiffeners is selected based on zone and soil profile type as proposed the sections for different zones and soil profile types. As earthquakes effects are different on structures in a different zone and soil profile types. Similarly, the reinforcement concrete Grade used for the section is also different as per the section shown in figures for different soil profile types and seismic zones. The confined brick masonry structure is modeled in SAP2000 software with selected reinforced concrete (RC) section properties of vertical and horizontal stiffeners.

The location of the vertical reinforced concrete stiffeners was selected basically on three different categories. The 1st selects the critical location which is mostly at the junction and around the corner of the building or walls, 2nd positions of the vertical RC stiffeners around the doors and large windows openings while the 3rd one taking as the less important location which is around the small windows openings. These locations are the location that efficiently contributes to improving the masonry structure properties like stability, strength, and ductility, especially in the case of lateral earthquake loading. As we know that during the strong ground motions of the earthquakes unreinforced brick masonry structures failed because they were unable to resist the lateral loadings of the earthquakes. Many earthquakes occurred in Pakistan with a high magnitude up to 8 which including Balochistan, Gilgit, and Kashmir earthquakes of strong ground motions which badly affect Pakistan. In 2005 Kashmir Balakot earthquake occurred which is known as the deadliest earthquake in the history of Pakistan because this earthquake was paralyzed Pakistan and one village was completely collapsed which cause a lot of human lives losses and economic losses. For reducing the losses due to strong ground motions of the earthquakes the provision of the stiffeners in masonry structures was proposed by French structural engineer Paul Cottancin. As this reinforced concrete vertical and horizontal stiffeners are working as confining members which improve the strength of the masonry walls and enhanced the ductility of the walls of the masonry structure. The confining elements in the confined brick masonry structures do not act as load-bearing structures but only hold the masonry walls to avoid disintegration of the structures during the strong ground motions of the earthquakes where masonry walls act as a load-bearing of structure.

## 3.2 Proposed Vertical and Horizontal Stiffeners

The confined brick masonry structure consists of the vertical and horizontal reinforced concrete stiffeners at the corner or intersection of the masonry walls and around the openings of the doors and windows. The reinforced concrete vertical stiffeners used for confining the brick masonry structures are provided to avoid the disintegration of the masonry walls during the lateral forces of the strong ground motions of the earthquakes. As we know from the literature reviews that these reinforced concrete vertical stiffeners improve the lateral strength of the brick masonry structures as well as enhanced the ductility of the brick masonry structures. The horizontal reinforced concrete stiffeners are provided above the openings of doors and windows as well as at floors levels. For better performance of the confined brick masonry structures, the tie-columns and tie-beams should be properly connected so that well confined the brick masonry of the walls of the structure to enhance the properties of the confined brick masonry structures related to strong ground motions of the earthquakes. For confining the brick masonry structures reinforced concrete vertical and horizontal stiffeners proposed by Mehran Khan and Majid Ali with sections are selected as per the different zone and soil profile types can be seen in Figure 3.1 and Figure 3.2. These reinforced concrete vertical and horizontal stiffeners sections are selected as per experienced and requirements. For reinforced concrete, vertical and horizontal stiffeners designing proper calculation are not available as these stiffeners do not work as load-bearing members in the structures as the brick masonry walls work as load-bearing members to transfer loads of the buildings to foundations. The confined brick masonry structures consist of foundations, brick masonry walls, vertical reinforced concrete stiffeners, horizontal reinforced concrete stiffeners, floors, and roof reinforced concrete slabs.

The proposed vertical reinforced concrete (RC) stiffeners su mmary is shown in **Figure 3.1** for different soil profile types and seismic zones with I=1 and T $\leq$ 0.7s. From **Figure 3.1** it can be seen that only two kinds of concrete used of compressive strengths (15MPa and 20MPa) two types of reinforcement grades (280 and 420 as represented by symbol $\phi$ and # with diameter of the bar) two sizes of concrete sections (115 mm $\times$ 115 mm and 230 mm $\times$ 230 mm) are proposed from different soil profile type and seismic zones to meet the particular of seismic demands. As the seismic demand changes mostly the diameter of the reinforcement changes in vertical stiffeners. For cross-section 115 mm $\times$ 115 mm the longitudinal reinforcement proposed are 1-$\phi$6, 1-$\phi$10, 1-$\phi$13, 1-#10, 1-#13 while for cross-section 230 mm ×230 mm the reinforcement used are 4-$\phi$6, 4-$\phi$10, 4-$\phi$13 and 4#10. The increment variable proposed in transverse reinforcement for concrete cross-section 230 mm × 230 mm with grade 280 of longitudinal reinforcement are $\phi$6-115 mm/230 mm, $\phi$6-100 mm/200 mm, $\phi$6-90 mm/180 mm while with Grade 420 of longitudinal reinforcement is $\phi$10-115 mm/230 mm. The cross-section selected of vertical stiffeners for this research work of seismic zone 4 and soil profile type SD is 230 mm × 230 mm with longitudinal reinforcement 4-$\phi$13 and ties $\phi$6-90 mm/180 mm as can be seen from **Figure 3.1**. These reinforced concrete vertical stiffeners are provided at the corners of walls and intersections of the brick masonry walls as well as around the doors and windows opening of the buildings. The selection of the locations of the reinforced concrete vertical stiffeners are based on the most critical locations (locations of stiffeners at junctions and corners of the masonry walls), 2nd most important locations (locations of the stiffeners around doors and large window openings) and 3rd important locations (locations of the stiffeners around small window openings) depending upon the requirements and numbers of the stories of the buildings.

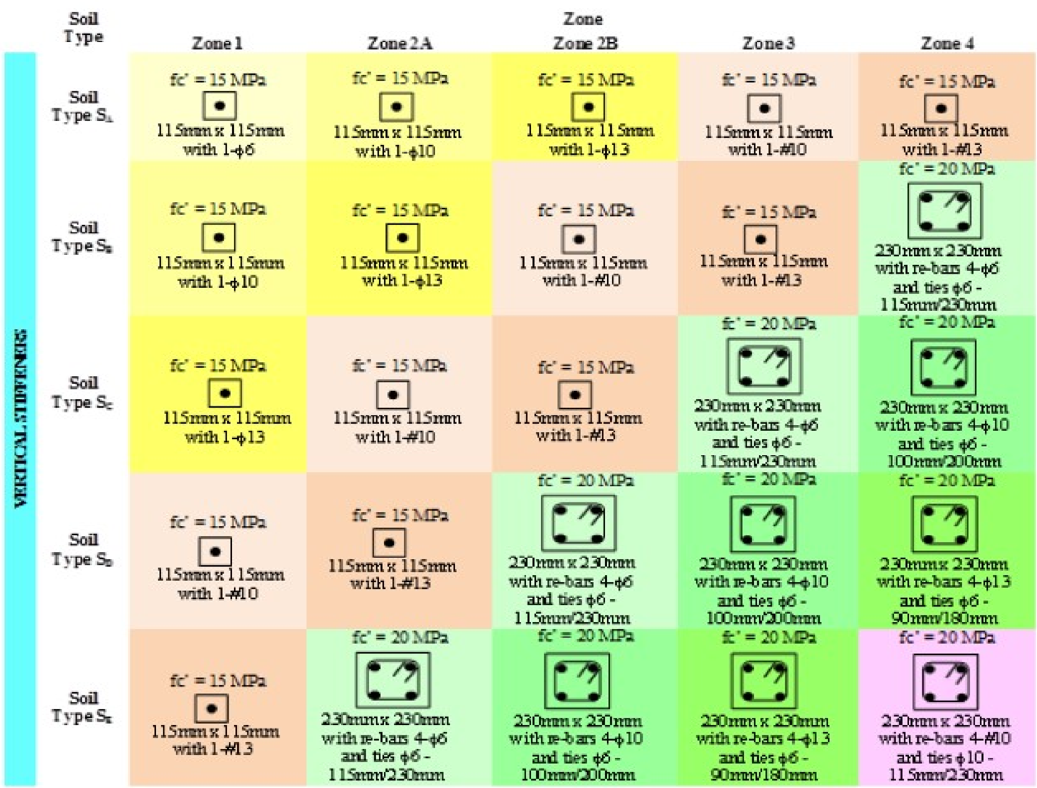


FIGURE 3.1: Cross-section Details of Reinforced Concrete Vertical Stiffeners for Different Seismic Zones and Soil Profile Types with I = 1 and T $\leq$ 0.7 Seconds

The reinforced concrete vertical stiffeners are shown in **Figure 3.1** used for brick masonry structures to confine the structures and hold the masonry walls to avoid disintegrations of the walls during the lateral strong ground motions of the earthquakes. Similarly, the horizontal reinforced concrete stiffeners proposed for different seismic zones and soil profile types are summarized in **Figure 3.2** with I =1 and T $\leq$ 0.7 seconds. These reinforced concrete horizontal stiffeners are supposed to provide above the doors and windows opening and floors levels in brick masonry structures. Similarly for horizontal reinforced concrete stiffeners two types of concrete of compressive strengths 15Mpa and 20Mpa are proposed as can be seen in **Figure 3.2**. The reinforcement proposed for horizontal reinforced concrete stiffeners of grades 280 and 420 with symbols respectively is $\phi$ and # with a diameter of the bar. The cross-sections selected for the horizontal stiffener are (230 mm $\times$ 75 mm) and (230 mm $\times$ 150 mm) for different seismic zones and soil profile types. From Figure 3.2 it can be observed that with increasing seismic demand the variable changing is reinforcement bar diameter and number of reinforcement bars. The selected increment in longitudinal reinforcement for horizontal stiffeners is 2-$\phi$6, 2-$\phi$10, 2-$\phi$13, 2-#10, 2-#13 for 230 mm $\times$ 75 mm of stiffeners cross-section while 230 mm $\times$ 150 mm cross-sections are 4-$\phi$6, 4-$\phi$10, 4-$\phi$13, and 4-#10. Similarly selected variable increment for transverse rebar's for horizontal reinforced concrete stiffeners of cross-sections 230 mm $\times$ 75 mm are $\phi$6-200 mm, $\phi$6-150 mm, $\phi$6-100 mm, $\phi$10-200 mm, $\phi$10-150 mm while for cross-section 230 mm $\times$ 150 mm are $\phi$6-200 mm, $\phi$6-150 mm, $\phi$6-100 mm and $\phi$10-200 mm. The selected cross-section of horizontal reinforced concrete stiffener for seismic zone 4 and soil profile type SD is 230 mm $\times$ 150 mm with I = 1 and T $\leq$ 0.7 seconds as from the proposed horizontal stiffeners shown in **Figure 3.2**.

The reinforced concrete stiffeners are vertical as well as horizontal used in confined brick masonry structures as shown in **Figure 3.1** and **Figure 3.2** as proposed for different seismic zone and soil profile types. Pakistan is divided into five different types of seismic zones (Zone 1, Zone 2, Zone 2B, Zone 3, and Zone 4) as shown in the **Figure 3.1** and **Figure 3.2** and five soil profile types (SA, SB, SC, SD, and SE) as shown in Figures. The confined brick masonry structures used in this research study consist of the reinforced concrete vertical and horizontal stiffeners from seismic zone 4 and soil profile type SD as selected from the **Figure 3.1** of vertical reinforced concrete stiffeners and **Figure 3.2** of horizontal reinforced concrete stiffeners. The sections details of the reinforced concrete vertical and horizontal stiffeners for confined brick masonry structures can be obtained from **Figure 3.1** and **Figure 3.2**.

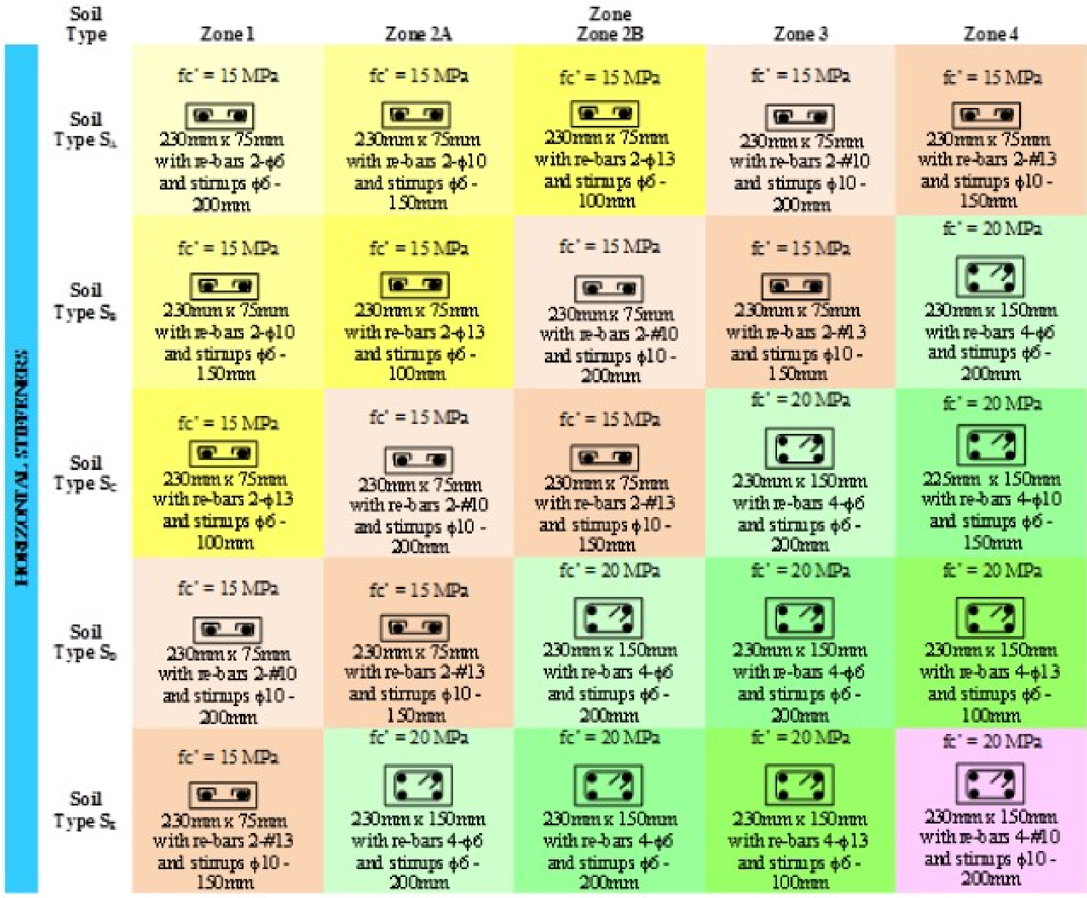


FIGURE 3.2: Cross-section Detail of Reinforced Concrete Horizontal Stiffeners for Different Seismic Zones and Soil Profile Types with I = 1 and T $\leq$ 0.7 Seconds

These reinforced concrete members used for confining the brick masonry structures have different names given by researchers known as vertical and horizontal stiffeners, tie-beams, and tie-columns. From **Figure 3.1** and **Figure 3.2**, we can see that the reinforced concrete vertical stiffeners have the same thickness as the masonry walls thickness of the structure while the horizontal reinforced concrete stiffeners have the same width as the masonry walls but the depth/thickness of the horizontal stiffeners are smaller than vertical reinforced concrete stiffeners. These reinforced concrete vertical and horizontal stiffeners are proposed for the confined brick masonry structures of low rise two stories structures consisting of the ground floor, first floor, and mumty. As we know that nowadays confined brick masonry structures are used mostly in Pakistan as compared to unreinforced brick masonry structures because of the damages to these structures during the past earthquakes and more study is required to study the behavior of the confined brick masonry structures during the earthquakes which can help in reducing the human lives losses and economical losses in future.

A combination has been made of the vertical and horizontal reinforced concrete stiffeners for different seismic zones and soil profile types based on proposed vertical and horizontal stiffeners as shown in Figure 3.1 and Figure 3.2. The combination of the vertical and horizontal reinforced concrete stiffeners for different seismic zones and soil profile types can be seen from Figure 3.3 below for confined brick masonry structures. In Figure 3.3 in the bracket, the 1st one shows the seismic zone and the 2nd shows the soil profile type. From the combination of the reinforced concrete stiffeners made can be seen that for seismic zone 1 and soil profile type SA as well as for seismic zone 4 and soil profile type SE not match with any other zones while for seismic zone 1 soil profile type SB and seismic zone 2A soil profile type SA are similar. Similarly for (1, SC), (2A, SB), and (2B, SA) sections are the same for vertical and horizontal reinforced concrete stiffeners. The reinforced concrete vertical and horizontal stiffeners sections can also be seen for other seismic zones and soil profile types as well from Figure 3.3 below.

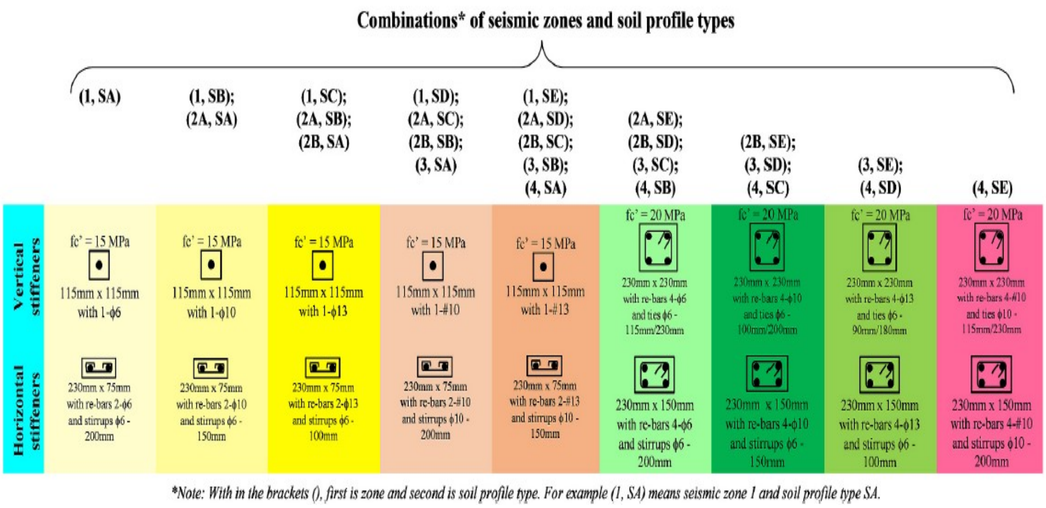


FIGURE 3.3: Combination of Proposed Vertical and Horizontal Reinforced Concrete Stiffeners for Different Seismic Zone and Soil Profile Types

## 3.3 Finite Element Modeling of Confined Brick Masonry Structure (CBMS)

In this study a house selected of confined brick masonry structure for seismic zone 4 and soil profile type SD to be analyzed with static linear analysis and nonlinear time-history analysis with near and for-fault strong ground motions downloaded from PEER database as per PEER database guidelines and instructions. The confined brick masonry structure is the structure in which reinforced concrete confining elements are provided at corners, intersections of the walls, and around openings of the doors and windows. The superstructure of the house is modeled in SAP2000 software. The architectural plan of the ground floor is shown in **Figure 3.4**. There are three colors used for indication of the vertical reinforced concrete stiffeners locations based on the requirements. The red color shows the locations of the stiffeners at corners and junctions. The cyan color shows stiffeners around doors and large window openings. The green color shows the locations of the stiffeners around small window openings as can be seen in **Figure 3.4**.

The elastic modulus used for this research study is 1.5 GPA and poison ratio 0.15 respectively. There are three types of ground floor plans one with 25 numbers of locations, 19 numbers of locations, and 12 numbers of locations. The house selected for this research with 19 numbers of vertical reinforced concrete stiffeners. The thickness of all the walls selected is 230 mm where the length of the longitudinal wall is 12 m while the transverse wall length is 7.5 m long. All the properties of concrete and reinforcement of the vertical and horizontal reinforced concrete stiffeners are used as shown in F**igures 3.1** and **3.2**.

The confined brick masonry structure plans are shown in **Figure 3.4** with the different numbers of locations (25, 19, and 12). The house of confined brick masonry structure selected for this research study is with 19 numbers locations to avoid under-designed and over-designed of structures so we selected the middle one option for getting economic structure and to achieve the required strength of the structure. As the confined brick masonry structure house selected has plot dimensions of 7.5 m × 12 m which consists of three rooms one bathroom and a car porch. The dimensions of the rooms and bathrooms of the confined brick masonry structures selected for the analysis of static linear and nonlinear time-history analysis are shown in **Figure 3.4**. The reinforced concrete vertical and horizontal stiffeners should be properly bonded to improve effectively the lateral strength of the confined brick masonry structures to resist the strong ground motions of the earthquakes as well as enhanced the ductility of the structure. The confined brick masonry structure shown in **Figure 3.4** architectural plan consists of 19 numbers of vertical RC stiffeners as per the proposed section at junctions and corners of the walls, around the doors and large window openings, horizontal reinforced concrete stiffeners above the openings of doors and windows, at floors levels as well as roofs slab of the structures. Therefore the architectural plan is shown in Figure 3.4 modeled in software SAP2000 as per the given information regarding the masonry structure with section details for seismic zone 4 and soil profile type SD as well as checked for seismic source type A, B, and C. The macro-models of the CBMS are analyzed for linear static analysis and design after that nonlinear time-history analysis will be done with 4 near-fault and 4 far-fault strong ground motions of the past earthquakes downloaded from the PEER database.

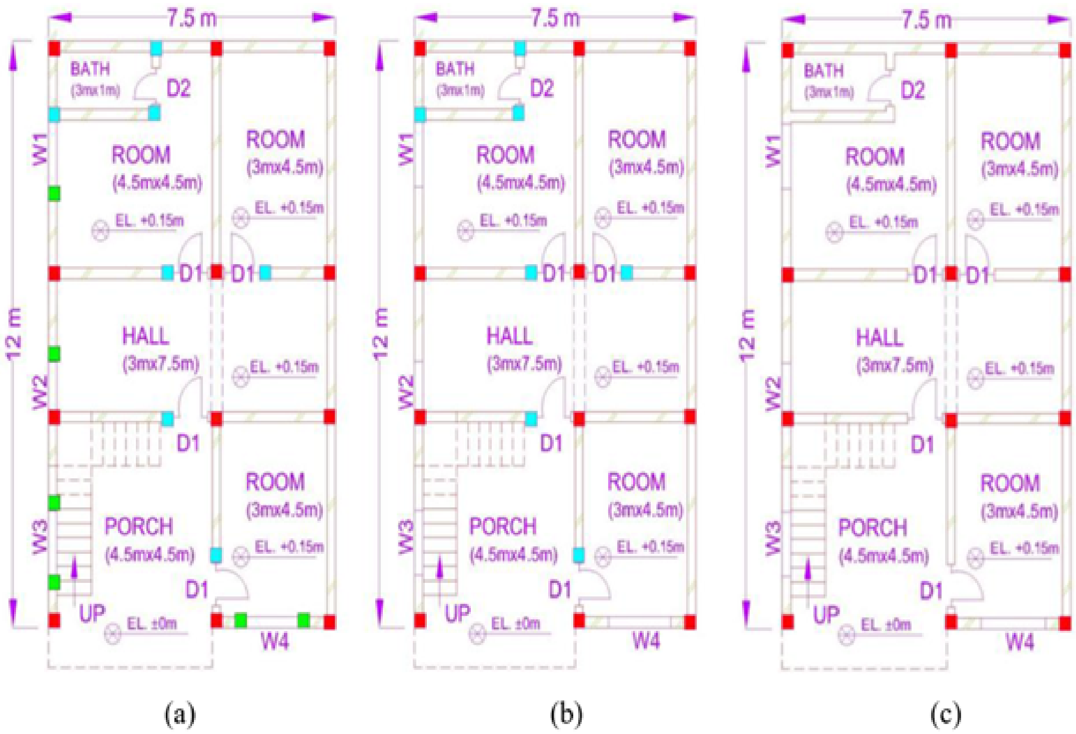


FIGURE 3.4: Proposed Vertical Reinforced Concrete Stiffeners for Considered Ground Floor (a) at 25 Locations (b) at 19 Locations (c) at 12 Locations

### 3.3.1 Description of Confined Brick Masonry Structure

The confined brick masonry structure selected to be modeled in SAP2000 software consist of 7.5 m width and 12 m length which include a total of three rooms with one master bedroom with attached bathroom, hall, and porch at the ground floor framing plan shown in **Figure 3.4**. The house plan suggested for modeling and analysis of the research work modeled with macro-modeling properties for static linear and dynamic nonlinear time-history analysis under near and far-fault ground motions of the earthquake. The proposed house plan suggested different numbers of vertical reinforced concrete stiffeners locations based on experience. These vertical stiffeners locations consist of three types of locations as shown in **Figure 3.4**. Based on the importance of the provision of the stiffeners the house plan suggested a total of 25 locations, 19 locations, and 12 locations while using the house with 19 numbers locations of the vertical reinforced concrete stiffeners because of the considering of effectiveness of the stiffeners on the confined brick masonry structure and get economic structure. The house of a confined brick masonry structure is selected for modeling and analysis work has a wall thickness of 230 mm all over the building. The house plan is shown in **Figure 3.4** consisting of the ground floor, 1st floor, and mumty at the top of the house while reinforced concrete vertical and horizontal stiffeners are provided at 19 locations.

The confined brick masonry house selected for the research study was considered for seismic zone 4 and soil profile type SD. The house walls consist of brick masonry construction with vertical reinforced concrete stiffeners at 19 different locations as can be seen in **Figure 3.4(b)**. The vertical reinforced concrete stiffeners section is used as per details given in **Figure 3.1** for seismic zone 4 and soil profile type SD. The horizontal reinforced concrete stiffeners are used above the openings of doors, windows, and floor levels with the cross-section as mentioned in **Figure 3.2** for seismic zone 4 and soil profile type SD. The vertical reinforced concrete stiffeners use cross-section as shown in **Figure 3.1** according to seismic zone 4 and soil profile type SD. The concrete and reinforced properties used for vertical and horizontal stiffeners of a confined brick masonry structure can be seen from **Table 3.1** which is used as per proposed values in **Figures 3.1** and 3.2 for vertical and horizontal stiffeners according to seismic zone 4 and soil profile type SD. The vertical and horizontal reinforced concrete sections details selected for confined brick masonry structure are given in **Table 3.1** below. The sections details used in software for the materials with properties consist of compressive/yield stress, ultimate stress, modulus of elasticity, modulus of rigidity, and poison ratio. The column/vertical stiffeners and beam/horizontal stiffeners are used for confined brick masonry structures have compressive stress of 20 MPa, ultimate stress of 17 MPa, modulus of elasticity of 21 GPa, modulus of rigidity of 9 GPa, and Poison ratio of 0.15 while the reinforcement of grade 280 has properties of compressive stress 280 MPa, ultimate stress 500 MPa, Modulus of elasticity 200 GPa, modulus of rigidity 87 GPa and poison ratio 0.15. The modifiers values were selected for RC vertical and horizontal stiffeners of the CBMS as modifiers of columns and beams. Therefore, the modifiers used for vertical stiffeners are 0.70 and for horizontal stiffeners is 0.35 as per the provision of the code considered in the analysis and design. The above house ground floor plan was modeled and analyzed as with provided proposed reinforced concrete vertical and horizontal stiffeners which consist of 1st floor and mumty as well at the top of the building. The house will be analyzed with linear static analysis and will check for dynamic nonlinear time-history analysis under near and far-fault ground motions of the earthquakes.

Table 3.1: Concrete and Reinforcement Properties

| **Material Type** | **Compressive/ Yield Stress (MPa)** | **Ultimate Stress (MPa)** | **Modulus of Elasticity (GPA)** | **Modulus of Rigidity (GPA)** | **Poisson Ratio (-)** |
|---|---|---|---|---|---|
| Beam Concrete | 20 | 17 | 21 | 9 | 0.15 |
| Column Concrete | 20 | 17 | 21 | 9 | 0.15 |
| Grade 280 steel | 280 | 500 | 200 | 87 | 0.15 |

### 3.3.2 Modelling

Modeling of the confined brick masonry structure is done by finite element software SAP2000. The confined brick masonry structure is modeled which consists of three rooms, one hall, a bathroom, and a car porch with plot area dimensions of 7.5 m×12 m. The confined element consists of reinforced concrete vertical and horizontal stiffeners as can be seen from **Figure 3.1** and **Figure 3.2** for seismic zone 4 and soil profile type SD. The vertical reinforced concrete stiffeners are provided at 19 numbers of locations at corners of the walls and intersection of the walls as well as around the openings of the doors and windows as can be seen in **Figure 3.4(b)**. The models are prepared for seismic zone 4 and soil profile type SD with different source types A, B, and C. Considering zone 4 and seismic soil profile type SD, the values of Ca are 0.528, 0.44 and 0.44 for seismic sources A, B and C, respectively. Considering zone 4 and seismic soil profile type SD, the values of Cv are 1.024, 0.64 and 0.64 for seismic sources A, B and C, respectively.

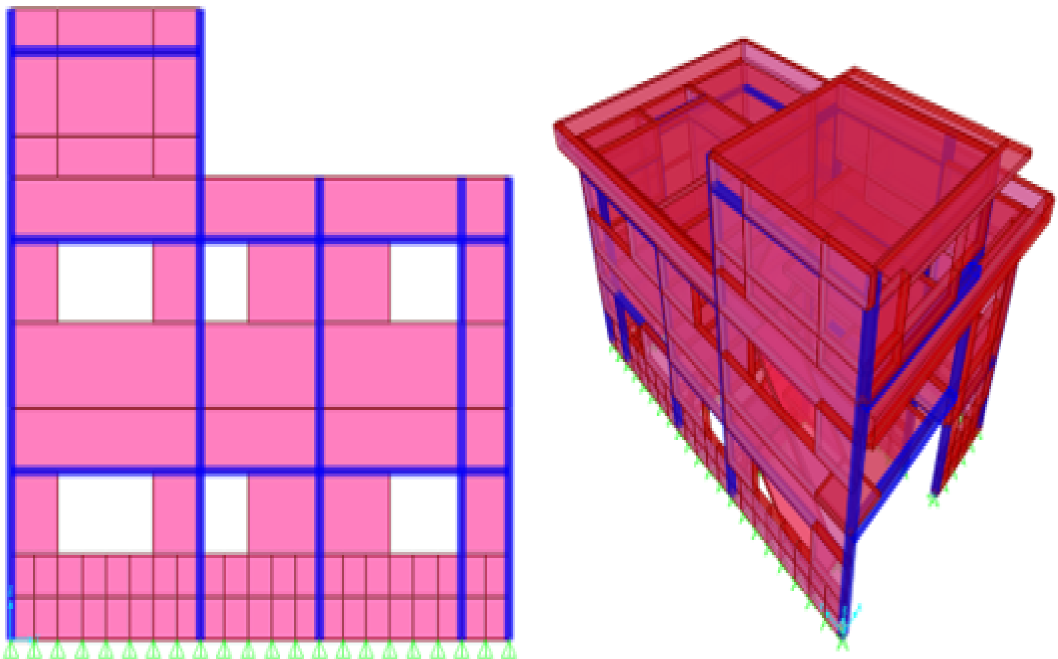

FIGURE 3.5: 2D and 3D View of the Confined Brick Masonry Structure Model

First of all, the models for sources A, B, and C were analyzed with equivalent static linear analysis as per UBC-1997 and designed as per the ACI-318 code with seismic zone 4 and soil profile type SD. After that nonlinear time-history analysis was performed to determine the seismic demand of the confined brick masonry structure. Furthermore, near and far-fault ground motion data was downloaded from the PEER database according to PEER database guidelines. Total 8 strong ground motion data were downloaded of which 4 for near-fault and 4 for far-fault. The data then matched with the required seismic area. For nonlinear time-history analysis, the effects of near and far-fault are considered.

The confined brick masonry structure modeled in SAP2000 software for the analytical study can be seen in Figure 3.5. The model consists of the superstructure including masonry walls, vertical and horizontal reinforced concrete stiffeners, openings of doors and windows as well as floor and roof slabs as can be seen. The vertical reinforced concrete stiffeners were provided at 19 6numbers of locations including critical locations at the corner of the walls and 2nd most important locations around the openings of doors and windows. The horizontal reinforced concrete stiffeners are provided at floors levels and above the openings of doors and windows. The model of the confined brick masonry structure includes the ground floor, 1st floor, and mumty at the top as can be seen from Figure 3.5. The model of the confined brick masonry structure is analyzed with static linear analysis as per UBC-1997 and design as per ACI-318.

After the linear static analysis and design nonlinear time-history analysis was performed for investigating the seismic demand of the confined brick masonry structure under near-fault and far-fault strong ground motions of the earthquakes. The near-fault and far-fault strong ground motions records of the earthquake were downloaded from the PEER database with very care by following the instructions and guidelines of the PEER database. These analyses will help in ensuring the safety of the confined brick masonry structure in seismic-prone regions. Advanced FE tools like OpenSees, Abaqus etc. can predict precise and accurate behaviors; but still, many researchers used SAP2000 in predicting the building behavior reasonably to a large extent [59]. The SAP2000 software has been used for design and modeling purposes because it takes less time for analysis. In addition, the modeling was already done for CBMS and UBMS in SAP2000 for the previous study by Mehran Khan [41].

### 3.3.3 Parameters Analyzed

Nowadays advanced Softwares are available for modeling and analysis of the structures in the world. Researchers work on different Software to check the effects of these Software on the structures behavior and compare the result. The finite element method used for modeling provides the detail of the structure response as it is well approached by considering the material and geometry nonlinearity of the structure. Different damages states of the confined brick masonry structures have like limited damage, significant damages, and near collapse. The pushover analysis is performed to investigate the response of the stiffeners of soil profile types SD, SC and SB of the selected structure. The nonlinear time-history analysis is performed under considering the near and far-fault effects and seismic demand of the confined brick masonry structures determined. The near and far-fault strong ground motion of earthquakes data was downloaded from the PEER database as per PEER database guidelines for nonlinear time history analysis. The models were analyzed for each seismic source A, B, and C for seismic zone 4 and soil profile type SD as well as designed. Similarly, seismic demands are determined for each seismic source types A, B, and C with a total of 8 strong ground motions which include 4 near-fault and 4 far-fault strong ground motions of the earthquakes.

## 3.4 Summary

In this chapter the confined brick masonry structure properties like geometry, vertical stiffener's location and cross-section of the reinforced concrete vertical and horizontal stiffeners and materials properties like reinforcement and concrete properties used in the modeling and analysis of the structures are explained. Finite element modeling of confined brick masonry structure explained as well as described the confined brick masonry structure in detail. Explain the procedure of the equivalent static analysis which is performed according to UBC-1997 and designed the reinforced concrete vertical and horizontal stiffeners as per ACI-318. Also, describe the modeling of confined brick masonry structures as well as the parameters which are analyzed like static analysis and nonlinear time-history analysis of the structure with near and far-fault strong ground motions of the earthquakes. The confined brick masonry structure modeled for analysis consist of 19 numbers of locations for vertical reinforced concrete stiffeners which are provided at corners and intersections of the walls as well as around the openings of doors and windows of the walls.

# Chapter 4

# Data Analysis and Discussion

## 4.1 Background

The CBMS is selected for the macro-modeling and analysis which consists of the ground floor, first floor, and mumty on the 2nd floor of the house. SAP2000 software is used for the macro-modeling and analysis of the confined brick masonry structure. The confined brick masonry structure consists of the reinforced concrete vertical and horizontal stiffeners where reinforced concrete vertical stiffeners are provided at 19 numbers of locations. The reinforced concrete vertical stiffeners are located at corners of the walls, intersections of the walls, and around the openings of doors and windows. The horizontal reinforced concrete stiffeners are located above the openings and at floors levels of the confined brick masonry structure.

The sections for the reinforced concrete vertical and horizontal stiffeners are selected as per the proposed section for seismic zone 4 and soil profile type SD. After modeling the confined brick masonry structure in SAP2000 software make three models with seismic source types A, B, and C to analyze for the research study. The reinforced concrete vertical and horizontal stiffeners are well connected to properly hold the masonry walls so enhancing the strength and ductility of the masonry walls.

The static linear analysis of the confined brick masonry structure is done as per UBC-1997 code and designed the stiffeners are as per ACI-318 code for seismic zone

4 and soil profile type SD. Strong ground motions of the earthquakes data were downloaded from the PEER database for considering the near and far-fault effects on structures. The nonlinear time-history analysis is performed to determine the seismic demand for the structure. A similar procedure was followed for all seismic source types A, B, and C to analyze with linear static analysis and nonlinear time history analysis with 4 near-fault and 4 far-fault strong ground motions of the earthquakes. These analyses will help to determine the seismic demand and validate the stiffeners.

## 4.2 Equivalent Static Analysis

The confined brick masonry structure is model in SAP2000 software for seismic zone 4 and soil profile type SD. The confined brick masonry structure was modeled for all three seismic source types A, B, and C. The macro-models have vertical RC stiffeners at 19 numbers of locations which are provided at corners of the buildings, intersections of the brick masonry walls, and around the openings of the doors and windows. The horizontal reinforced concrete stiffeners are provided in the models of the confined brick masonry structure above the openings of doors and windows as well as at the floor levels of the buildings. For properly confining the brick masonry walls of the confined brick masonry structures the reinforced concrete vertical and horizontal stiffeners should be properly connected.

The reinforced concrete stiffeners improve the strength of the brick masonry structure as well as enhanced the ductility of the structure. The models are analyzed in SAP2000 by the equivalent static procedure according to UBC-1997 for seismic zone 4 and soil profile type SD as well as designed as per code ACI-318. The reinforcement and cross-section of reinforced concrete stiffeners vertical as well as horizontal validated for seismic zone 4 and soil profile SD as per UBC-1997 of equivalent static procedure are given below in **Table: 4.1**.

Note 1: $\phi$ denoted the grade 280 of reinforcement.

Note 2: 4-$\phi$13 means the number of rebars is 4 with a diameter of rebar 13 mm.

Table 4.1: Cross-Section Details of Vertical and Horizontal Stiffeners and Reinforcement

| **Member Type** | **Size** | **Main Reinforcement** | **Stirrups** |
|---|---|---|---|
| Vertical Stiffeners | 230 mm×230 mm | 4-$\phi$13 | $\phi$6-90 mm/180 mm |
| Horizontal Stiffeners | 230 mm×150 mm | 4-$\phi$13 | $\phi$6-100 mm |

As in this analysis, the confined brick masonry structure models are analyzed by equivalent static force procedure according to UBC-1997 codes for the seismic zone 4 and soil profile type SD. After the equivalent static analysis, the horizontal and vertical reinforced concrete stiffeners were designed as per the ACI-318 code from which the reinforcement is validated as shown in **Table 4.1** for the cross-section of the stiffeners. In this research work, a model is prepared of confined brick masonry structure for seismic zone 4 and soil profile type SD which is further divided into 3 models according to seismic sources A, B, and C. After that all the models are analyzed with static linear analysis as per UBC-1997 and design as per ACI-318. The reinforced concrete vertical stiffeners section used 230 mm×230 mm with main or longitudinal reinforcement is 4-$\phi$13 and the stirrups are provided $\phi$6-90 mm/180 mm of c/c spacing. The horizontal reinforced concrete stiffeners of size 230 mm×150 mm with longitudinal reinforcement of 4-$\phi$13 and the stirrups of $\phi$6-100 mm c/c spacing are used. These reinforced concrete sections of vertical and horizontal stiffeners validate through linear static analysis as per UBC-1997 code. These sections are validated for seismic zone 4 and soil profile type SD for seismic source types A, B, and C of the confined brick masonry structure.

The design cross-section horizontal and vertical reinforced concrete stiffeners as per ACI-318 code based on equivalent static procedure validated are shown in **Table 4.1**. The cross-section used of vertical and horizontal reinforced concrete stiffeners is 230 mm × 230 mm and 230 mm × 150 mm respectively. The main reinforcement for vertical and horizontal reinforced concrete stiffeners are the same which 4-$\phi$13 means 4 numbers of bars used with a diameter of 13 mm. The transverse or ties/stirrups used for the stiffeners are different. For vertical reinforced concrete stiffeners, the transverse reinforcement is $\phi$6-90 mm/180 mm mean 6 mm diameter of the bar used with a spacing of 90 mm c/c in the first and last quarter and 180 mm c/c in center portion of reinforced concrete vertical stiffeners while for horizontal reinforced concrete stiffeners the transverse reinforcement is $\phi$6-100 mm mean 6 mm diameter of the bar used with 100 mm of c/c spacing. The vertical reinforced concrete section is provided at 19 numbers of locations as can be seen in the ground floor framing plan at corners of the buildings, at intersections of the walls, and around the openings of doors and windows of the confined brick masonry structures. The horizontal reinforced concrete stiffeners are provided above the openings of doors and windows and at floor levels of the confined brick masonry structure with section detail as given in Table 4.1.

## 4.3 Damage Limit States

The confined brick masonry structures are the structures that provide shelter to humans for living safely and these structures should withstand before and after the strong ground motions of the earthquakes. In the past masonry structures failed due to being unable to resist the strong ground motions of the earthquakes which caused a lot of losses to human lives and economic losses as can be seen from the literature review and past earthquakes data. The structure failed due to insufficient design guidelines to follow for the high seismic regions to avoid the failure of the structures. The confining elements are proposed to improve the lateral strength of the masonry structures and enhanced the ductility of the structures to avoid the collapse of the confined brick masonry structures. For avoiding the collapse of the confined brick masonry structures the structure should be confined enough to give ductile behavior so that the structure should stay with limited damages levels to save human lives as well as avoid economic losses. The confined brick masonry structure failure is defined in different damages levels which are known as damages performance levels of the confined brick masonry structure as can be seen from **Figure 4.1**. Damage limit states define the performance level of the structure which indicate the different stage of possible damages that occurred to the structure. The performance levels of the damage limit as specified in Eurocode 8 and available in several guidelines are near collapse (NC), significant damages (SD), and limited damages (LD).

According to Eurocode 8, the near-collapse (NC) is the damage level of the structure which has left with low residual stiffness and strength. The vertical element of the structure will be able to withstand the vertical loads but the structures will not be able to resist the moderate level of earthquake forces. Near collapse (NC) is the ultimate damage level capacity of the structure which have elastic and inelastic part of deformation. The structure has permanent drift and is feasible to nearly collapse. The significant damage (SD) level of the structure is the level that has permanent drift and repairing will be uneconomical. The structure will have moderate stiffness and strength and vertical elements will be able to withstand the vertical loads. According to Eurocode 8 part 3, the significant damages (SD) have the drift capacity of equal to 75% of the near-collapse (NC) of the structure. The limited damages (LD) states are the level of the structure in which the structure is lightly damaged. The structure prevented from significant yielding and retaining their strength and stiffness to withhold the vertical loads. At the limited damage (LD) level the structure does not need repairing and has negligible drift. The limited damage (LD) level is the yield point drift of the graph as shown in **Figure 4.1** which is the deformation capacity graph of confined brick masonry structure as per Eurocode 8.

## 4.4 Dynamic Characteristics

The confined brick masonry structures with reinforced concrete vertical and horizontal stiffeners provided are modeled in SAP2000 software for seismic zone 4 and soil profile type SD. The reinforced concrete vertical stiffeners are located at 19 numbers of locations at corners and around the openings of the doors and windows. The horizontal reinforced concrete stiffeners are provided above the openings of doors and windows as well as at floor levels of the confined brick masonry structures. The models of the confined brick masonry structures are analyzed with finite element procedure in SAP2000 software for seismic zone 4 and soil profile type SD and the result of the first 9 modes of vibrations are presented. The result of the linear modal is presented in Table 4.2 in terms of the time period and mass participating ratios. The mass participating ratio for the first and second modes is 55.5% and 8.66% along the x-direction while for the y-direction the values of mass participation ratios for the first and second modes are 2.93% and 70.89%. **Table 4.2** shows the governing moment modes for the different directions. The governing moment for x-direction is 1st mode, for y-direction is the 2nd mode while for z-direction the 8th mode is governing. The time period for the first and second modes is 0.24 seconds and 0.17 seconds as given in **Table 4.2**. This table data helps in defining the governing moments for the structures with a higher percentage which can be seen from **Table 4.2** for each direction X, Y, and Z-axis.

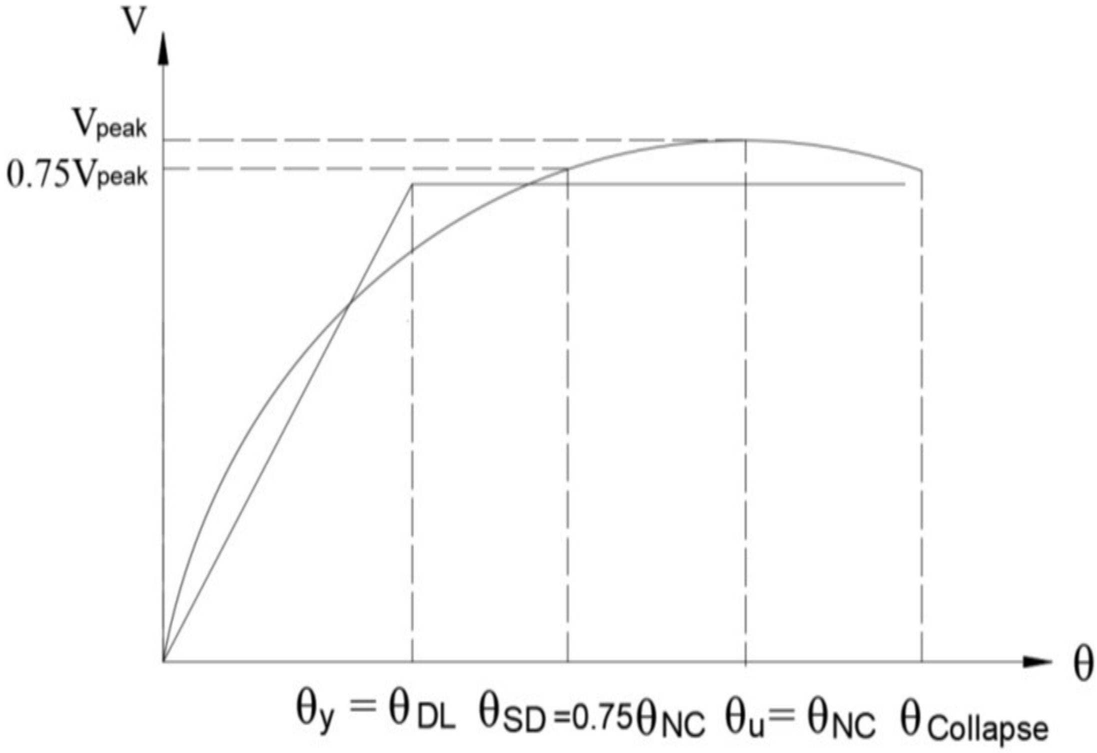


FIGURE 4.1: Limit State Rotations and Bilinear Force-Deformation Relationship of the Confined Brick Masonry Structure as Per Eurocode 8

**Figure: 4.1** shows the limit state rotations and bilinear force-deformation relationship of the confined brick masonry structure which defines the different limits of the structure including yield point and ultimate point. From **Figure 4.1** the yield point and ultimate point can be observed where the yield point represented the damages limited (DL) level and the ultimate point represented the near-collapse

(NC) while significant damages (SD) is taken 75% of near collapse as can be observed from the figure. The damages limited state of the structure is defined as the level of performance of the structures which have negligible drift and have damages which are not required any repairing measurement. Significant damages (SD) defined the level of performance of the structure in which repairing of the structure will be uneconomical. Near collapse (NC) level of performance is the damages level of the structure which does not collapse but will not be possible to repair. Therefore the confined brick masonry structure will be better to withstand in limited damages performance level to save human lives losses and economic losses.

## 4.5 Strength and Deformation Capacity of Confined Brick Masonry Structure

The strength and deformation capacity are the most important properties of any structure. The unreinforced and unconfined brick masonry structures were failed during the strong ground motions of the earthquakes because the structures had insufficient lateral strength to resist the strong ground motions of the earthquakes and collapsed due to the brittle behavior of the structures. The vertical and horizontal reinforced concrete stiffeners are provided in brick masonry structures as confining elements for masonry walls. The confining elements in confined brick masonry structures increased the lateral strength of the masonry structure as well as enhanced the ductility of the masonry structure.

The curve shown in **Figure 4.1** shows different damages performance levels of the confined brick masonry structures where yield limit is taken as limited damages (LD) performance level, while the ultimate point is taken as near collapse (NC) damages performance level while 75% of the near-collapse damages performance level is taken is significant damages (SD) performance level of the confined brick masonry structures. The limited damages performance level is the level at which the house can be directly occupied after being hit by strong ground motions of the earthquakes and no need of repairing while the significant damages (SD) will have uneconomical repairing of the structures. The confined brick masonry structure will be better to designed up to limited damages (LD) performance levels only which can avoid the human lives losses and economical losses due to the strong ground motions of the earthquakes.

TABLE 4.2: Modal Mass Participation Ratio for First 9 Modes Vibration of the Design Template of A, B and C

| **Mode** | **Period (sec)** | **M$_x$ (%)** | **M$_y$ (%)** | **M$_z$ (%)** |
|---|---|---|---|---|
| **1** | 0.24 | 55.5 | 2.93 | 0.00 |
| **2** | 0.17 | 8.66 | 70.89 | 0.00 |
| **3** | 0.14 | 19.6 | 7.83 | 0.01 |
| **4** | 0.099 | 2.39 | 0.00 | 0.06 |
| **5** | 0.097 | 0.05 | 0.00 | 0.00 |
| **6** | 0.095 | 1.13 | 0.08 | 0.13 |
| **7** | 0.091 | 2.05 | 0.12 | 1.65 |
| **8** | 0.089 | 0.09 | 3.58 | 6.94 |
| **9** | 0.087 | 0.00 | 0.02 | 2.88 |

The confined brick masonry structures with ground floor, first floor, and mumty at 2nd floor modeled and analyzed with equivalent static linear analysis in SAP2000 software as per UBC-1997 code for seismic zone 4 and soil profile SD. The model of the confined brick masonry structure was designed and has a modal mass participation ratio for the first 9 modes of vibration of the design template of seismic source types A, B, and C as can be seen in **Table 4.2**. For 1st mode of vibration period is 0.24 seconds with moment at x-direction 55.5%, at y-axis 2.93% and at z-axis 0.00% similarly for 2nd mode vibration of 0.17 second period with moment at x-axis 8.66%, at y-axis 70.89% and at z-axis is 0.00%. The mass participation ratio is shown for the first 9 modes of vibration only which can be seen in **Table 4.2**. The target displacement for the confined brick masonry structure can be calculated from the formulas given in equation number 4.1 below.

$$\Delta t = C_O C_1 C_2 C_3 S_a (T_e 2/4\pi^2) g \tag{4.1}$$

Where,

$\Delta$t: target displacement.

$C_o$: the modification factor to relate spectral displacement and likely roof displacement.

$C_1$: modification factor of the maximum inelastic displacement.

$C_2$: the modification factor to represent the effects of hysteresis shape.

$C_3$: modification factor of consideration P-delta effect.

$S_a$: the response spectrum acceleration in the direction under consideration of g.

$T_e$: effective fundamental time period.

g: the acceleration due to gravity or gravitational acceleration.

As equation 4.1 is used for calculating the target displacement of the confined brick masonry structure which needs to be compared with the seismic demand of the structure. The target displacement for the CBMS calculated from taking 50% the value of the target displacement for caculated from equation 4.1. The target displacement of the structure is basically the displacement by which a building can deform. The confined brick masonry structure model will be analyzed with a nonlinear time-history analysis of 4 near-fault and 4 far-fault strong ground motions of the earthquakes to determine the seismic demand of the confined brick masonry structure. The near-fault and far-fault strong ground motions of the earthquakes can be seen in **Table 4.3** which consists of a total of 8 strong ground motions of the earthquakes with 4 near-fault ground motions and 4 far-fault ground motions of the earthquakes.

These strong motions of the earthquakes were downloaded from the PEER database as per PEER database guidelines which will be used in the analysis of the nonlinear time-history analysis of the confined brick masonry structures to determine the seismic demand of the structure. These strong ground motions data downloaded from the PEER database are matched with the required region of the confined brick masonry structure seismic zone 4 and soil profile type SD through a software known as seismomatch or seismograph which give the results can be seen in **Figure 4.3** of the graph of the acceleration of the original and matched earthquake in horizontal directions. In pushover analysis, the performance of the building is checked against target displacement obtained from equation (4.1). FEMA-273, NEHRP guidelines are used to estimate the target displacement from equation (4.1). It may be noted that the target displacement as per FEMA-273 is 63.5 mm for the RCC structure. For CBMS, it is taken as 50% of this value, which is 31.75 mm. The actual displacement obtained through macro modeling (dynamic analysis) is 22.9 mm. This is less than 31.75 mm, which seems fine. As per the procedure, there are no further checks for displacement in pushover analysis. Against this target displacement, hinges status is shown in **Figure 4.2**.

The **Figure 4.2** shows the results of hinges for seismic zone 4 and soil profile type SD of the CBMS with stiffeners sections used of soil profile type SD, SC and SB obtained from pushover analysis. The plastic hinges are 15.3%, 17.9% and 19.8% for stiffeners of SD, SC and SB, respectively, to total hinges. Pushover analysis has been performed for seismic source type A with seismic zone 4 and soil profile type SD while using stiffeners of soil profile types SD, SC and SB. As we move to stiffeners of lower soil profile types of the confined brick masonry structure the plastic hinges are increasing. From the result, it is obtained that we can use stiffeners of soil profile type SB instead of SD for seismic zone 4 and soil profile type SD to achieve the economical design of the structure. The stiffeners below soil profile type SB can cause the failure of the structures during the strong ground motions of the earthquakes.

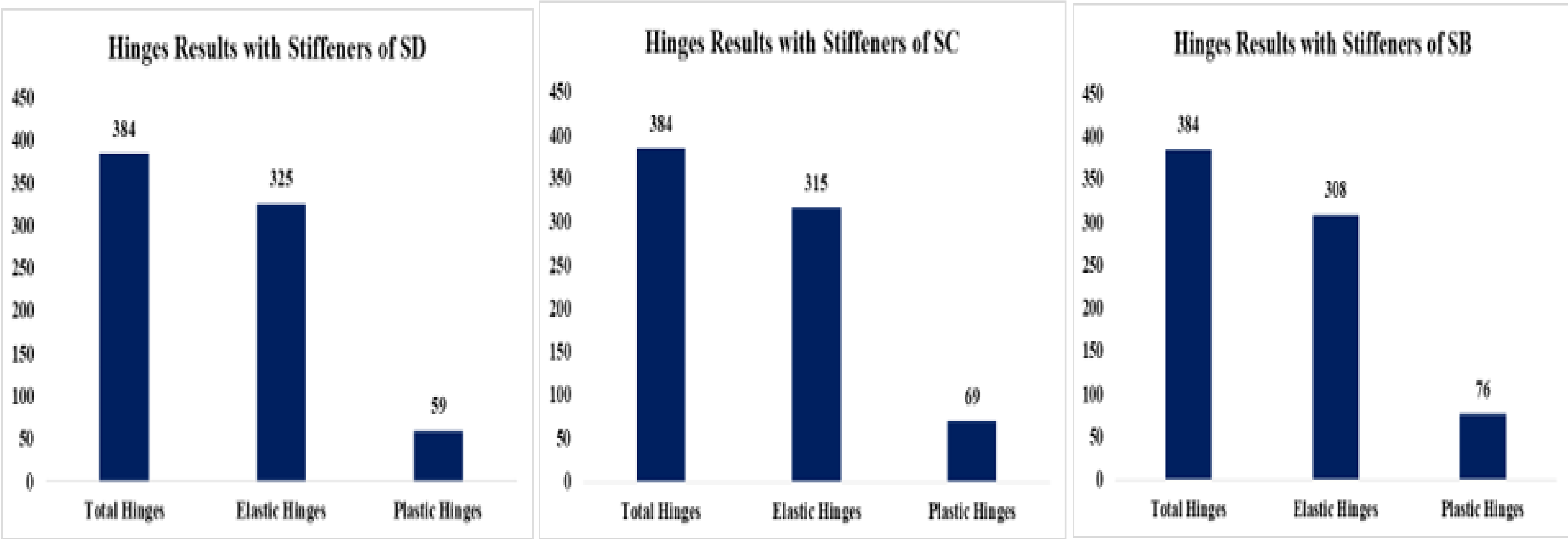


FIGURE 4.2: Hinges Results of Seismic Zone 4 and Soil Profile Type SD with Stiffeners of Soil Profile Types SD, SC and SB of CBMS

The near-fault and far-fault are the two most important factors in performing a nonlinear time-history analysis of the confined brick masonry structures. The total number of ground motions downloaded is 8 with 4 selected for near-fault and the rest 4 selected for far-fault. The data was downloaded from Pacific Earthquake Engineering Research (PEER) database and followed the guidelines of the database. The data was selected from the PEER database of NGW-WEST2 very carefully while following the PEER database guidelines and requirements. The data include the strong ground motions of the earthquakes with magnitude Mw of 6.19 to 7.9 with 4 selected for near-fault while 4 selected for far-fault as the near-fault selected based on the closest distance of less than 10 km [60].

## 4.6 Ground Motion Data and Estimation of Seismic Demand

The downloaded data of the strong ground motions of the earthquakes from the PEER database can be seen in **Table 4.3** with PEER records number, locations of the earthquakes, year, magnitude, closest distance, velocity, peak ground accelerations, and durations of the earthquakes with 4 near-fault and 4 far-fault strong ground motions of the earthquakes. The confined brick masonry structure's seismic performance is one of the most important factors to be known to achieve the field behavior of the structure before execution in designing of the structures. For this purpose, strong ground motions of the earthquakes of near-fault and far-fault strong ground motions of earthquakes data need to apply on confined brick masonry structures to achieve the seismic demand of the structure as well as investigate the behavior of the structure under near-fault and far-fault ground motions.

TABLE 4.3: Far and Near-Fault Ground Motion Records

| **Sr. No** | **PEER Record No** | **Location** | **Year** | **Mw** | **Closest Distance (Km)** | **Vs30 (m/sec)** | **PGA (g)** | **Duration (sec)** |
|---|---|---|---|---|---|---|---|---|
| Near | | | | | | | | |
| 1 | 2114 | Denali, Alaska | 2002 | 7.9 | 2.74 | 329.4 | 0.238 | 92.09 |
| 2 | 1605 | Duzce, Turkey | 1999 | 7.14 | 6.58 | 281.86 | 0.346 | 25.88 |
| 3 | 159 | Imperial Valley-06 | 1979 | 6.53 | 0.65 | 242.05 | 0.472 | 28.44 |
| 4 | 1141 | Dinar, Turkey | 1995 | 6.4 | 3.36 | 219.75 | 0.141 | 27.96 |
| Far | | | | | | | | |
| 5 | 1639 | Manjil, Iran | 1990 | 7.37 | 171.7 | 302.64 | 0.027 | 17.58 |
| 6 | 280 | Trinidad | 1980 | 7.2 | 76.26 | 311.75 | 0.028 | 19.68 |
| 7 | 426 | Taiwan Smart 1(25) | 1983 | 6.5 | 93.67 | 308.39 | 0.014 | 17.48 |
| 8 | 449 | Morgan Hill | 1984 | 6.19 | 39.08 | 288.62 | 0.045 | 28.36 |

Note: ClstD = Closest distance from the recording site to the rupture fault area and Vs30 = Shear-wave velocity in the top 30 meters at the recording sites.

The strong ground motion record downloaded from the PEER database as per PEER database guidelines can be seen in **Table 4.3** which includes the record ID, Location of the earthquake, Closest distance of the earthquake fault, the magnitude of the earthquake, year of the occurrence, velocity of the ground motions, peak ground acceleration, and duration of the earthquakes. There is a total of 8 strong ground motions records of the earthquakes in which including 4 near-fault and 4 far-fault. These strong ground motions record of the earthquakes were downloaded from the PEER database for use in nonlinear time-history analysis of the confined brick masonry structure. The analysis work was carried out for seismic zone 4 and soil profile type SD for seismic source types of A, B, and C. The near-fault ground motions data includes the Denali Alaska with record number 2114, Duzce Turkey with record number 1605, Imperial Valley-06 with record number 159, and Dinar Turkey with record number 1141 while far-fault ground motions data including Manjil Iran with record number 1639, Trinidad with record number 280, Taiwan Smart 1(25) with record number 426, and Morgan Hill with record number 449 as shown in Table 4.3. These strong ground motion records were downloaded from the PEER database to investigate the seismic demand of the confined brick masonry structure by nonlinear time-history analysis considering the near-fault and far-fault strong ground motions of the earthquakes.

The original ground records downloaded from the PEER database as shown above in **Table 4.3** are matched with the required seismic zone 4 and soil profile type SD as shown in **Figure 4.3** consist of the acceleration of original and matched earthquakes in the horizontal direction. The matching of the original strong ground motion records of the earthquakes with required seismic zone 4 and soil profile type SD was done with seismomatch software. There is a total of 8 matching graphs which include 4 near-fault and 4 far-fault strong ground motions of the earthquakes. **Figure 4.3** shows the original record with orange color and matched record showing with blue color for all graphs of the matching and original data. This matched record of the near-fault and far-fault used for the analysis of nonlinear time-history analysis of the confined brick masonry structures to investigate the seismic demand under near-fault and far-fault strong ground motion record of the earthquakes.

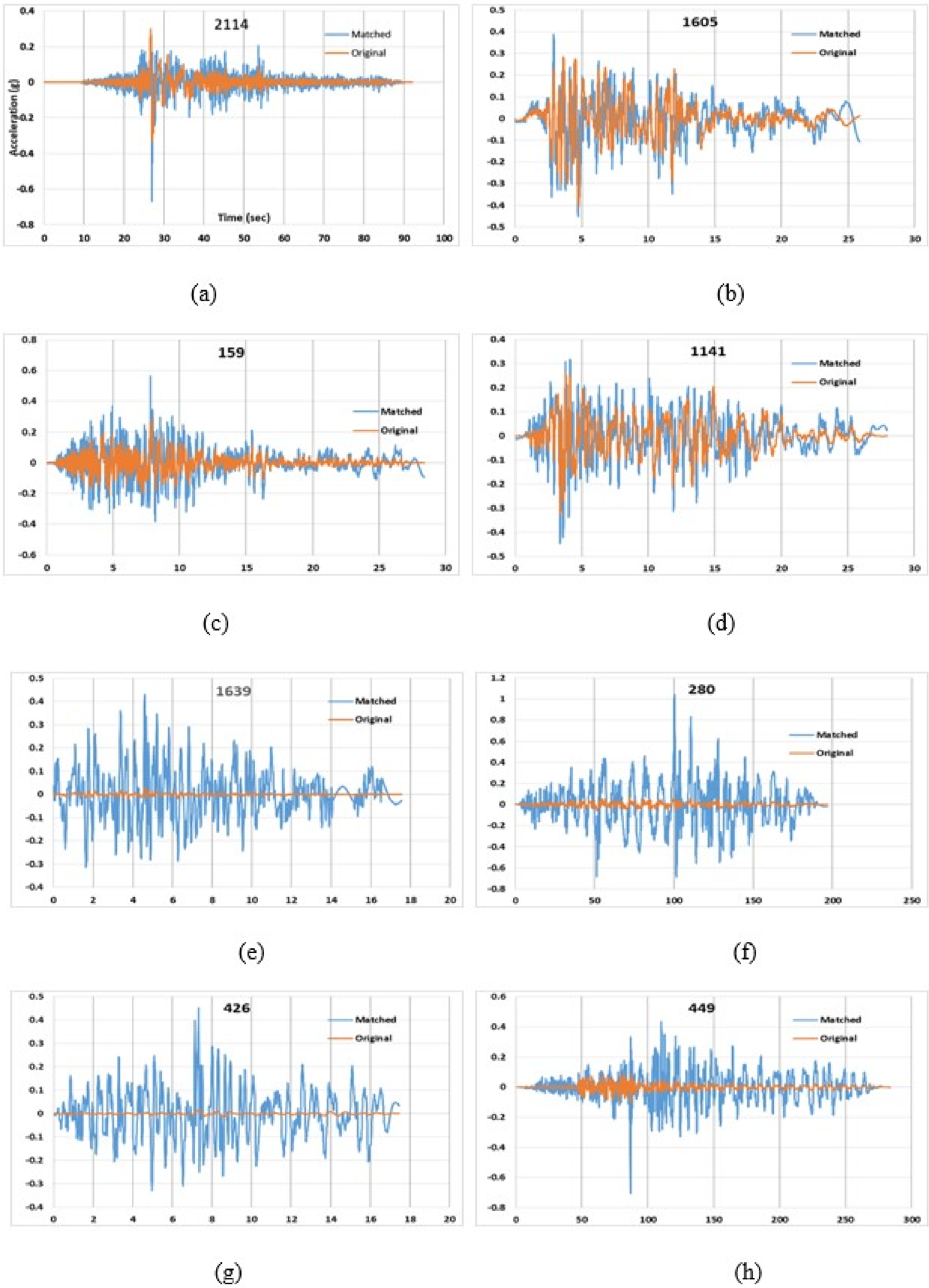


FIGURE 4.3: Acceleration of the Original and Matched Earthquakes in Horizontal Direction, (a) Denali, Alaska Earthquake, (b) Duzce, Turkey Earthquake, (c) Imperial Valley-06 Earthquake, (d) Dinar, Turkey Earthquake, (e) Manjil, Iran Earthquake, (f) Trinidad Earthquake, (g) Taiwan Smart 1(25) Earthquake, and (h) Morgan Hill Earthquake

For matching the original record of the near-fault and far-fault of the strong ground motion of the earthquakes with the required seismic zone and soil profile type by seismomatch/seismograph software by following the instruction and guidelines of the seismomatch/seismograph software with very care. The matching graph of the original and matched data of near-fault and far-fault are shown below in **Figure 4.3**. The graph in **Figure 4.3** shows the original acceleration and matched for seismic zone 4 and soil profile type SD. The original acceleration is consisting of near and far-fault strong ground motions of the earthquakes. In **Figure 4.3** acceleration values shown in the y-direction and time shown in the x-direction. The acceleration downloaded for near-fault are consists of Denali Alaska, Duzce Turkey, Imperial Valley-06, and Dinar turkey while the far fault included the ground motion are Manjil Iran, Trinidad, Taiwan Smart 1(25), and Morgan Hill. The acceleration matched with required seismic zone 4 and soil profile type SD as per code of UBC-1997. This procedure of matching accelerations is done by seismomatch software for seismic zone 4 and soil profile type SD by using the procedure of matching accelerations. From **Figure 4.3** it can be seen that the original and matched acceleration are not much different because the far-fault records are compared with the near-fault records. The matched acceleration values can be seen in **Figure 4.3** which for Denali Alaska earthquake is 0.669 g, for Duzce Turkey earthquake is 0.452 g, for Imperial Valley-06 earthquake is 0.564 g, for Dinar Turkey earthquake is 0.446 g, for Manjil Iran earthquake is 0.429 g, for Trinidad earthquake is 1.033 g, Taiwan Smart 1(25) earthquake is 0.454 g and for Morgan, Hill earthquake is 0.704 g, respectively. The g represented the acceleration due to gravity and the original acceleration values of the respective earthquake records are given in **Table 4.3**.

## 4.7 Time History Analysis and Performance Evaluation

Time-history nonlinear analysis of the confined brick masonry structures is performed for seismic zone 4 and soil profile type SD. The near and far-fault ground motions are considered for performing the nonlinear time-history analysis of the confined brick masonry structures. The near and far-fault ground motions are downloaded from Pacific Earthquake Engineering Research (PEER) database as per the guidelines of the PEER database provided. A total of 8 numbers ground motions are selected which included 4 for near-fault and 4 for far fault ground motions records. These ground motion records of the PEER database then matched with the required seismic zone 4 and soil from type SD of the confined brick masonry structure which can be seen in **Figure 4.3** of the original and matched acceleration graphs. The matched values were then used for the time-history analysis of the CBMS macro-models in SAP2000 software. After completion of the nonlinear time-history analysis, the seismic demand is obtained from the nonlinear time-history analysis of the structure. The seismic demand is the demand of the structure to be displaced during the ground motion of an earthquake [61].

The damages performance level of the confined brick masonry structures is also evaluated under consideration of near-fault and far-fault effects on the performance level of the confined brick masonry structures. The damages level of the confined brick masonry structures are damages limited (DL) performance level, significant damages (SD) performance level, and near collapse (NC) damages performance level as per Eurocode 8. **Table 4.4** shows the effects of the near and far-fault strong ground motions of the earthquakes on confined brick masonry structures in x-direction and y-direction for seismic source types A, B, and C.

The result of the nonlinear time-history analysis of the confined brick masonry structure can be seen in **Table 4.4** for seismic zone 4 and soil profile type SD with different seismic source types A, B, and C. From the results, it can be seen that the maximum seismic demand determined by nonlinear time-history analysis for x-direction is 22.9 mm and for y-direction 9.9 mm. The seismic demand in the x-direction of the confined brick masonry structures is higher than the seismic demand along the y-direction because of the geometry of the structure. The difference in seismic demand of the confined brick masonry structure is due to the geometry of the structure as we know that the longitudinal length is along the y-direction and the shorter side of the structure along the x-direction.

Table 4.4: Near-Fault and Far-Fault Strong Ground Motions of Earthquake's Effects on Confined Brick Masonry Structures

| **S. No** | **PEER Record No** | **Seismic Demand (mm)** | | | | | | **Target Displacement** |
|---|---|---|---|---|---|---|---|---|
| | | **Seismic Source A** | | **Seismic Source B** | | **Seismic Source C** | | **(mm)** |
| **Near Fault** | | X-Axis | Y-Axis | X-Axis | Y-Axis | X-Axis | Y-Axis | 31.75 |
| **1** | 2114 | 22.3 | 7.2 | 22.3 | 7.2 | 22.3 | 7.2 | |
| **2** | 1605 | 22.2 | 8.5 | 22.2 | 8.5 | 22.2 | 8.5 | |
| **3** | 159 | 22.3 | 8.8 | 22.3 | 8.8 | 22.3 | 8.8 | |
| **4** | 1141 | 22.1 | 8.7 | 22.1 | 8.7 | 22.1 | 8.7 | |
| **Far Fault** | | | | | | | | |
| **5** | 1639 | 22.9 | 9.2 | 22.9 | 9.2 | 22.9 | 9.2 | |
| **6** | 280 | 21.9 | 7 | 21.9 | 7 | 21.9 | 7 | |
| **7** | 426 | 22.6 | 8.4 | 22.6 | 8.4 | 22.6 | 8.4 | |
| **8** | 449 | 22.3 | 9.9 | 22.3 | 9.9 | 22.3 | 9.9 | |
| **Average** | | 22.32 | 8.46 | 22.32 | 8.46 | 22.32 | 8.46 | 31.75 |

The seismic demand is less than the expected displacement of the structural displacement as calculated by FEMA-273, NEHRP guidelines in terms of target displacement which is used as an input for performing pushover analysis. The equivalent static analysis procedure is conservative and less detailed as compared to dynamic analysis. The output of equivalent static analysis (previous study) is used for dynamic analysis, due to which the seismic demand is less than the target displacement. The average seismic demand determined of the confined brick masonry structure along the x-direction is 22.32 mm and in the y-direction is 8.46 mm as can be seen in **Table 4.4**. A comparison has been made for seismic demand of the confined brick masonry structure under near-fault and far-fault which is shown in **Table 4.5**.

TABLE 4.5: Comparison of Near-Fault and Far-Fault Seismic Demands

| **S. No** | **Near-Fault** | | | **Far-Fault** | | |
|---|---|---|---|---|---|---|
| | **Record No** | **X-Axis (mm)** | **Y-Axis (mm)** | **Record No** | **X-Axis (mm)** | **Y-Axis (mm)** |
| 1 | 2114 | 22.3 | 7.2 | 1639 | 22.9 | 9.2 |
| 2 | 1605 | 22.2 | 8.5 | 280 | 21.9 | 7 |
| 3 | 159 | 22.3 | 8.8 | 4426 | 22.6 | 8.4 |
| 4 | 1141 | 22.1 | 8.7 | 449 | 22.3 | 9.9 |
| Average | | 22.22 | 8.3 | | 22.42 | 8.62 |

As the confined brick masonry structure macro-models were analyzed with nonlinear time-history analysis under near-fault and far-fault ground motion records were downloaded from the PEER database to investigate the seismic demand of the structure. From **Table 4.5** it can be seen that the maximum seismic demand of the confined brick masonry structure under near-fault is 22.3 mm in the x-direction and 8.8 mm in the y-direction while under the far-fault the seismic demand is 22.9 mm along the x-direction and 9.9 mm along the y-direction. The average seismic demand of the confined brick masonry structure under near-fault is 22.22 mm along the x-direction and 8.3 mm along the y-direction while under far-fault 22.42 mm along the x-direction and 8.62 mm along the y-direction as can be seen from **Table 4.5**. There is a slight difference between the seismic demand of the confined brick masonry structure under near-fault and far-fault because of the different effects of the near-fault and far-fault of the earthquakes.

## 4.8 Summary

This chapter consists of the results and analysis and briefly explains the analysis procedure, as well as the result, get from the analysis of the confined brick masonry structures. First of all, done the equivalent static analysis of the confined brick masonry structures as per UBC-1997 and designed the horizontal and vertical reinforced concrete stiffeners of the confined brick masonry structures as per ACI-318-08. The dynamic characteristics of the confined brick masonry structure are explained using for the analysis and taking help in determining the dynamic characteristics of the structures. The model mass participation ratio for the first 9 modes of vibration for the design template of A, B, and C are described in the **Table 4.2** which shows the governing moment for the directions x, y, and z. The earthquake strong ground motion records were downloaded from the PEER database for near and far-fault and matched with the required seismic zone 4 and soil profile type SD of the confined brick masonry structure. A typical pushover curve is briefly explained and nonlinear time-history analysis is performed and the effects of the near and far-fault ground motions are considered for the macro-models of CBMS.

# Chapter 5

# Discussion

## 5.1 Background

In this chapter, the different performance levels of the confined brick masonry structures are discussed like limited damages (LD) performance level, significant damages (SD) performance level, and near collapse (NC) damages performance level. The comparison of the current study is done with the previous study regarding the confined brick masonry structures according to different aspects. Also discussed the near and far-fault ground motion effects on the confined brick masonry structures in detail. Guidelines regarding different aspects of the confined brick masonry structures for the practical designer are discussed for designing the confined brick masonry structures horizontal as well as vertical reinforced concrete stiffeners.

## 5.2 Comparison of the Current Study with Previous Study

The unreinforced brick masonry structures failed during the past earthquake as mentioned in the literature review that damages occurred to the structures from low to high levels [2], [3], [10], [13], [62], [63]. These unreinforced masonry structures failed during the past earthquakes due to unable to resist the lateral forces of the strong ground motions of the earthquakes. On the other hand, the confined brick masonry structures failed during the past strong ground motions of the earthquake due to non-availability of the sufficient design guidelines for RC vertical and horizontal stiffeners of the structures as well as unexperienced work performed.

The damages that occurred during the different earthquakes depend upon the intensity of the earthquake, location of regions, and type of construction mostly. The types of construction are one of the most important factors in the damage of the structures as can be concluded from the literature review that the magnitude of the Chile earthquake was more than the Java, Indonesia earthquake but the damages rate occurred low in Chile as compared to Java, Indonesia because of the good structure construction in Chile. So, from the literature review, it has been observed that the damages to unreinforced or unconfined brick masonry structures were more than as compared to reinforced or confined brick masonry structures. The reason for more damages to unconfined brick masonry structures was the permanent drift in the structure because the unconfined brick masonry was not able to resist the lateral loads of the earthquakes. As in past, only static analysis work was done on CBMS while this study considered the dynamic analysis of the structure to achieve more accurate behavior of the structure under near and far-fault ground motions of the earthquakes. To achieve the economical design pushover analysis was performed for RC vertical and horizontal stiffener's response of the structure. For achieving a more accurate response of the structure nonlinear time-history analysis was performed of the CBMS under the near and far-fault ground motion of the earthquake which was not done before that.

In the previous study most work was done on static analysis of the structure. The effects of the near-fault and far-fault of the earthquak ground motions on confined brick masonry structures are not much different. The comparison of the seismic demand of near-faults and far-fault strong ground motions of the earthquakes of the confined brick masonry structures is made as can be seen in **Table 4.5** where the seismic demand of the confined brick masonry structures is little higher in the case of far-fault strong ground motions as compared to near-fault strong ground motions of the earthquakes. In the case of equivalent static analysis, the vertical and horizontal stiffeners (230 mm×230 mm with 4-$\phi$13 main reinforcement and $\phi$6-90 mm/180 mm transverse reinforcement and 230 mm×150 mm with 4-$\phi$13 main reinforcement and $\phi$6-100 mm transverse reinforcement, respectively) are for seismic zone 4 and soil profile type SD. But after dynamic analysis, the stiffeners of two steps down in soil profile type SB i.e. for the same seismic zone (230 mm×230 mm with 4-$\phi$6 main reinforcement and $\phi$6-115 mm/230 mm transverse reinforcement and 230 mm×150 mm with 4-$\phi$6 main reinforcement and $\phi$6-200 mm transverse reinforcement) comes out to be fine for soil profile type SD and zone 4.

## 5.3 Guidelines Practical Designers

The designing of the confined brick masonry structures is most important to do with much care as these structures not only resist the vertical loads but also resist the lateral loads of the strong ground motion of the earthquake. The locations of the vertical RC stiffeners should be selected with very care. The vertical RC should be provided at each corner of the confined brick masonry structures and provide around the opening of the structure. The location of horizontal reinforced concrete stiffeners will be better above the opening. It will be better if the horizontal reinforced concrete stiffener is used throughout the building as it will connect with the vertical reinforced concrete stiffeners to strengthen the confined brick masonry structures. The location of the necessary stiffeners and the number of vertical reinforced concrete stiffeners to be used for the brick masonry structure can be seen in **Figure 3.4** above which show the location of the vertical reinforced concrete stiffeners.

Basically, three types of the number of locations are suggested consists of critical locations or most important locations, moderate locations, and rare locations. These locations of the vertical reinforced concrete stiffeners shown in **Figure 3.4** above will help in the selection of the location of the vertical reinforced concrete stiffeners for confined brick masonry structures. The vertical and horizontal reinforced concrete stiffeners cross-section can be used in **Figure 3.1** for vertical reinforced concrete stiffeners and **Figure 3.2** for horizontal reinforced concrete stiffeners. The performance level of the confined brick masonry structures is analyzed by nonlinear time-history analysis with a total of 8 ground motions records of the earthquakes which include 4 near-faults and 4 far-faults strong ground motions of the earthquakes. The performance level of the confined brick masonry structure is defined in three categories which are limited damages (LD) performance level, significant damages (SD) performance level, and near collapse (NC) damages performance level as the values shown in **Table 4.5**. The limited damages performance level of the confined brick masonry structure is the level at which the structure drift is negligible and the damages measurements are not required. The significant damages performance level of the confined brick masonry structures is defined as the level of the structure at which the structure's vertical elements strength and stiffness are enough to withhold the structure load vertically but the repairing of the damage will be uneconomical. Near collapse performance level of the confined brick masonry structures is the level at which the structures stand vertically have permanent drift but not collapse and the structure will not resist any further earthquake ground motions. Therefore, for designing the confined brick masonry structures the performance of the limited damage level is always considered.

The damages performance level should always keep smaller or equal to the limited damages (LD) performance level of the structures to avoid future expenses after hitting the structure by the strong ground motion of the earthquake. The above guidelines provided will help the practical designer in designing the confined brick masonry structures, selecting the vertical reinforced concrete stiffeners for brick masonry structures, and will also help in designing and constructing the structure which will be enough to resist the lateral loads of strong ground motions of the earthquake to avoid human lives losses as well as economic losses. As we can see from **Table 4.4** that the average seismic demand of the confined brick masonry structure with proposed vertical and horizontal reinforced concrete stiffeners is 22.32 mm in X-direction and 8.46 mm in Y-direction which is much less than the target displacement of the structure of 31.75 mm as calculated from **equation 4.1**.

Table 5.1: Performance Evaluation of the Considered CBMS as Per Eurocode 8

| **Performance Evaluation** | **Horizontal Stiffeners** | **Vertical Stiffeners** |
|---|---|---|
| Satisfaction LD/SD/NC | 230 mm×150 mm LD | 230 mm×230 mm LD |

Note: LD=Limited Damage, SD=Significant Damage, and NC=Near Collapse.

In **Table 5.1** the performance level of the confined brick masonry structure reinforced concrete vertical and horizontal stiffeners are decided based on the seismic demand and target displacement of the structure. As the seismic demand of the confined brick masonry structure is investigated by nonlinear time-history analysis considering the near-fault and far-fault ground motions effect. The seismic demand is compared with the target displacement based on which the reinforced concrete stiffeners of the confined brick masonry structure lay in the limited damages performance level.

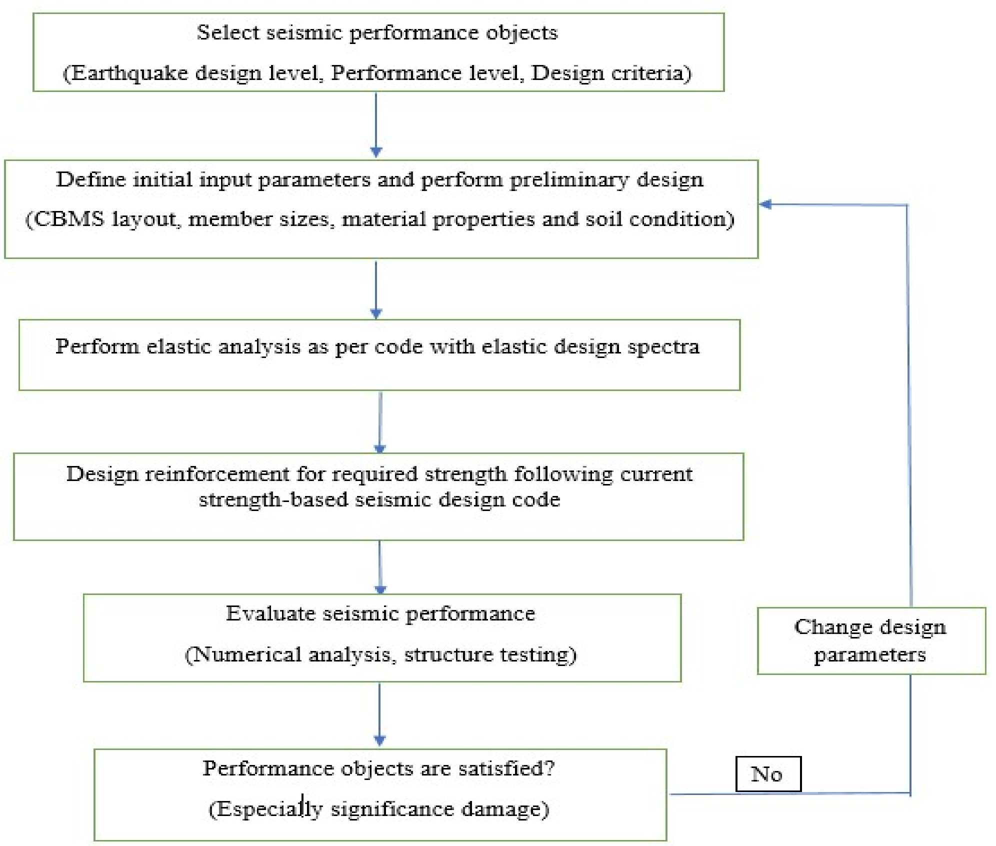


Figure 5.1: Flowchart of the Performance-Based Seismic Design Procedure

The flow chart of the performance-based seismic design is shown in **Figure 5.1** as can be seen in the steps of the design. The performance-based seismic design can be proceeded by above. The flow chart shown in **Figure 5.1** above regarding performance-based seismic design procedure is helpful in economical design as well as providing enough strength of the structure to resist the vertical loads and lateral loads of the earthquake of strong ground motion. For this first select the objects of seismic performance like design level for earthquake or design criteria. 2nd step defines the initial parameters like confined brick masonry structure layout, size of the structure members, properties of the materials, and soil condition for which the analysis is performed. In 3rd step perform the analysis and design as per the code specified. In the 4rth step design the reinforcement for the required strength or demand as per seismic design codes. In the 5th step evaluate the seismic performance which can be performed by numerical analysis and structural testing. In the 6th step check whether the performance objects are satisfied or not if yes then use the design otherwise revise the analysis and design from step 2 as per the flow chart given in **Figure 5.1**.

## 5.4 Summary

In this chapter, the comparison is made between previous studies and this study and the importance of the study required regarding confined brick masonry structures. The practical design guidelines are explained and the importance of the proper design of the confined brick masonry structure is discussed in detail to achieve the required properties of the structures for earthquake-prone regions in Pakistan. The damages level of the confined brick masonry structure is also defined where it was clear that the brick masonry structure with provided vertical and horizontal reinforced concrete stiffeners for seismic zone 4 and soil profile type SD are efficient to resist the lateral forces of the earthquakes of strong ground motions of near-fault and far-fault earthquakes. As the confined brick masonry structure was analyzed with a time-history analysis of far-fault and near-fault strong ground motions of the earthquakes to investigate the seismic demand of the structures.

# Chapter 6

# Conclusion

## 6.1 Conclusions

The confined brick masonry structures are used now mostly for construction due to the easy way of construction and economical. As we know that the confined brick masonry structures include foundation, plinth beam, masonry walls, vertical and horizontal reinforced concrete stiffeners, and floor as well as roof slabs. The confining element provided at a different location in the structure enhances the strength and ductility of the confined brick masonry structures. The proper bonding of the confining element is necessary to get the required properties to avoid the failure of the structure during the strong ground motions of the earthquakes. From this research work on the confined brick masonry structure following conclusions are made;

- The confined brick masonry structures perform well as compared to unconfined brick masonry structures during strong ground motions of the earthquakes.
- The confined brick masonry structures can resist the lateral loads of the strong ground motions of the earthquakes as compared to unreinforced brick masonry structures.
- The confining elements in confined brick masonry structures are the reinforced concrete vertical and horizontal stiffeners.

- The vertical reinforced concrete stiffeners should be provided at the corners of the masonry walls as well as around the openings of doors and windows.
- The horizontal reinforced concrete stiffeners should be provided above the openings of doors and windows as well as at floors levels.
- These reinforced concrete stiffeners do not act as load-bearing members in the structure of the confined brick masonry structures.
- In confined brick masonry structures the brick masonry walls transferred the load of the structure to the foundation (vertical & horizontal).
- The confining element increases the lateral strength of the masonry structure as well as enhances the ductility of the structure.
- The confined brick masonry structures performed well when analyzed under near-fault and far-fault strong ground motions of the earthquakes.
- From the result, it concluded that the seismic demand of the confined brick masonry structure is lower and under limited damages performance levels based on target displacement.
- The formation of plastic hinges increases by reducing the reinforcement of the RC stiffeners, from SD to SC and SB hence the reinforced concrete stiffeners of soil profile types of SB can be used to achieve an economical design.

As we can see from the conclusion that the unreinforced brick masonry structures failed during the past earthquakes due to not being able to resist the lateral loads of the strong ground motions of the earthquakes. The confining elements proposed for masonry structure to resist the lateral loads of the earthquakes can avoid losses of human lives and reduce economic losses due to the failures of the structure hit by strong ground motions of the earthquakes. As the target displacement is calculated for the structures and different damages performance levels of the structures are explained based on which the confined brick masonry structures performed in the limited damages performance level. Using the proper guidelines explained in this paper, we can achieve the required quality of the constructions, which ensures safety.

## 6.2 Future Work

Following recommendations are drawn for future work.

- The nonlinear dynamic behavior of CBMS for other seismic zones and soil profile types may be explored with SAP2000 and other softwares.
- Comparison of the behavior of CBMS and RCC frame structure of the same house along with the cost analysis.

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