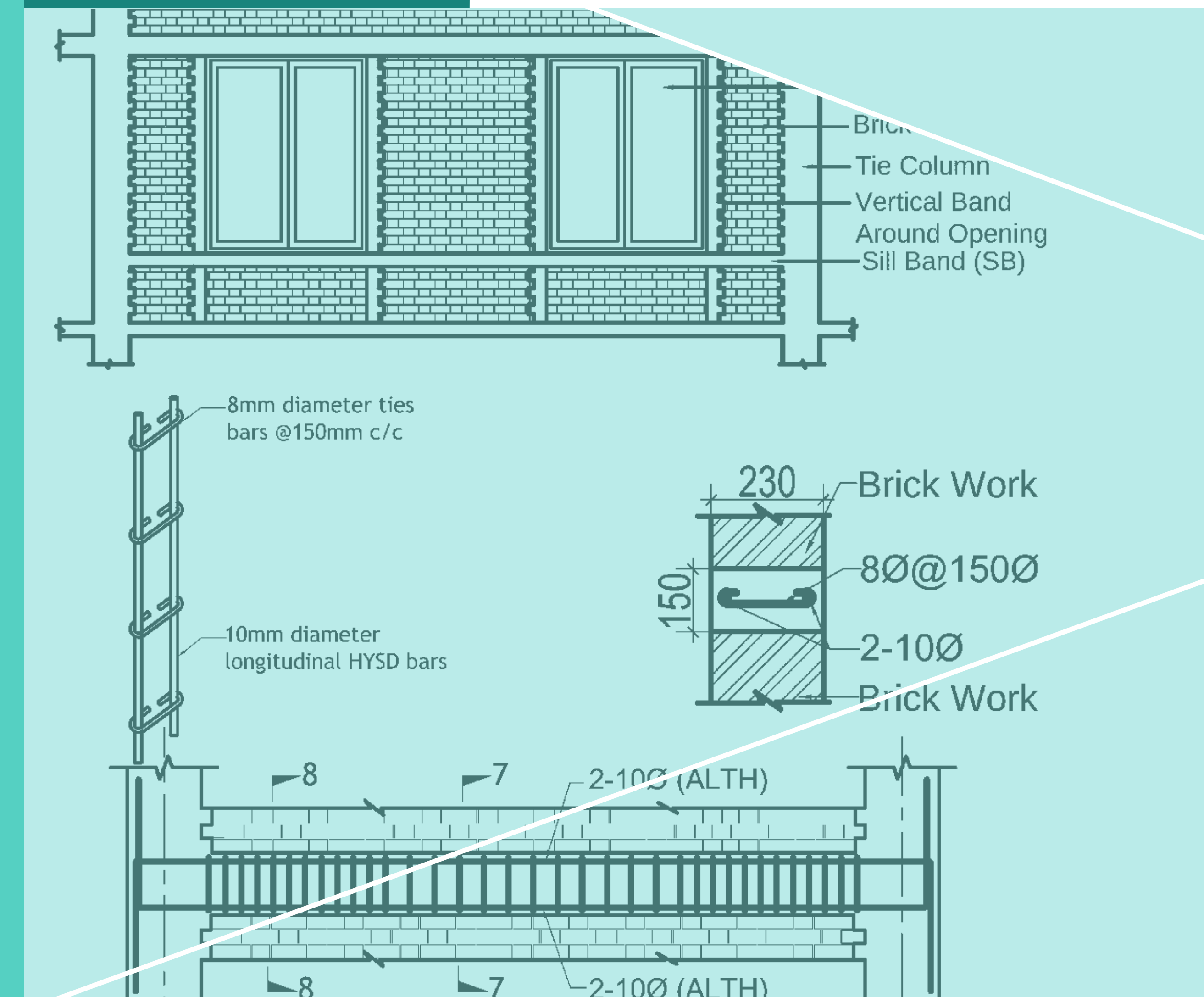
Structural Designs & Detailing for Confined Masonry EWS Houses

- Concepts
- Construction Material & Workmanship Checks
- EWS Housing Plans
- EWS Building Structural Detailing
  (For 2, 3, 4 Stories in Seismic Zone III, IV, & V)



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Disclaimer

These Guidelines are intended to provide a reliable basis for the seismic design of confined buildings based on the present state of knowledge, laboratory and analytical research, and the engineering judgments of persons with substantial knowledge in the design and seismic behavior of CM buildings. When properly implemented, these Guidelines should permit design of CM buildings that are capable of seismic performance equivalent or superior to that attainable by design in accordance with present prescriptive Building Code provisions. Earthquake engineering is a rapidly developing field and it is likely that knowledge gained in the future will suggest that some recommendations presented herein should be modified. Individual engineers and building officials implementing these Guidelines must exercise their own independent judgments as to the suitability of these recommendations for that purpose. CSIR-CBRI and the individual contributors to this document offer no warranty, either expressed or implied, as to the suitability of these Guidelines for application to individual building projects.

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FOREWORD

The CSIR-Central Building Research Institute, Roorkee, India has done extensive analytical and experimental studies on 'Confined Masonry'. In its pursuit to promote disaster resilient construction of low to medium rise masonry buildings for EWS housing under National Mission *"Housing for All'*, we are committed to publish this book which not only help professionals, Governments but also to people of India. The CSIR-CBRI is happy to present this book on '*Structural Designs of EWS Confined Masonry Houses'* covering aspects namely concept, method & principles of construction, checks to be performed on material & workmanship in construction of CM buildings, and typified architectural and structural designs for EWS housing.

It is well-known that the provision of earthquake resistance is accomplished through structural means, the architectural design, play a major role in determining the building's performance, which generally be neglected in planning of EWS housing schemes. This book covers the alternative options for EWS housing from architectural perspective. Furthermore, each of the EWS housing plan has been designed and detailed structural drawings are presented for two, three and four stories in different seismic zones of India i.e. III, IV, and V.

Occasional re-reading of the text, by the architects and engineer, may refresh his/her appreciation of the basic important aspects of building construction, which can often be forgotten when judging the merits of often over-emphasized and over-*reactive responses to relatively rare* problems.

I would like to appreciate the efforts made by Dr Ajay Chourasia, in bringing out this book and Dr Ashok Kumar for developing typified EWS housing plans. This work is one of the outcome of CSIR Mission Mode Programme on Mass Housing, which will contribute to National Mission – "Housing for All".

It is hoped that this book will go a long way in Indian subcontinent and elsewhere to fulfil dream of people of India to have a cost-effective, disaster resilient, comfortable, sustainable, durable and buildable house.

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PREFACE

'Why yet another book on "Confined Masonry"?' – a good question which deserves an answer.

Knowing the fact about performance of 'Confined Masonry' (CM) and its edge over other types of masonry buildings, in contrast huge housing demand for low-to-medium rise (Economically Weaker Sections - EWS) buildings in the country, it was felt that simply providing information about CM will not be adequate unless the detailed alternative typified designs are made available. This will not only reduce time in planning & design of EWS schemes but also provides cost-effective robust housing system for people of India. This book has grown out of our extensive experience in often difficult and always cost-competitive conditions. Many of the existing good books are written with a civil engineering bias and devote long sections. We expect architect, engineer and people involved in the execution should know-- concept, method & principles of construction, checks to be performed on material & workmanship in construction of CM buildings, typified detailed designs for EWS housing and where to turn for reference when necessary. However, there is no such document available to the best of knowledge of author, which covers these aspects to cater the EWS housing solution in India.

The book is arranged so that it is possible for individual professionals and common man to use it in different ways, depending upon their experience and the particular aspects of consideration. The book, which is divided into five sections, chapter 1 deals with the introduction to confined masonry, planning principles, construction methods etc., from a practical engineering viewpoint. Chapters 2 and 3 cover design approach and checks on materials & workmanship for construction of CM building. Chapter 4 contains the typified plans for EWS housing schemes along with their detailed structural design using CM technology for different stories namely 2, 3, 4 in seismic zone III, IV and V of India. Chapter 5 illustrates the detailed design for one of the EWS housing scheme for better understanding of the designer. Design and construction should be interactive, but in absence of soil condition, we decided, to broadly cover different types of foundation which can be adopted, with regret to restrict detailed foundation design. As in all engineering design there is no unique 'right' answer to a problem - designers differ on approach, priorities, evaluation of criteria, etc. We discussed, debated each aspect and concluded to arrive at practical approach. Therefore, we do not expect all designers to agree totally with us and long may individual preference be important. All engineering design, while based on the same studies and knowledge, is an exercise in judgement backed by experience and expertise. Some designers can be daring and others over-cautious; some are innovative and others prefer to use stock solutions. But all the design must be safe, cost-effective, durable and buildable, and these have been our main priorities. We hope that all professionals and people of the country find this book useful.

I am grateful for the trust and confidence of Director, CSIR-CBRI, Dr. N. Gopalakrishnan, who readily gave freedom to develop this compendium. I am also thankful to Dr Ashok Kumar, Chief Scientist for providing typified plans for EWS housing developed under 'CSIR Mission Mode Programme on Mass Housing'. I appreciate the help given by many friends in the construction industry, design professionals and academic institutions in the process of development of this book.

Ajay Chourasia

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CHAPTER - 1

CONFINED MASONRY: OVERVIEW

1.1. BACKDROP

Since the dawn of civilization, masonry has been and still is the most commonly used material in building industries, primarily for low rise buildings. The success of brick masonry is mainly due to its durability, excellent fire resistance, acoustic and thermal insulation characteristics and relative simple in realisation and cost. However, masonry elements suffer from a few drawbacks as well. Some of these include distinct directional (orthotropic) properties; poor strength of masonry units and mortar; non-uniform thickness of mortar joints, low interfacial bond strength between brick and mortar, arrangement of bricks, state of bricks before casting, curing, workmanship etc. It is not surprising that masonry is the material of choice for residential construction in many parts of the world, in spite of the associated difficulties.

Like most building materials, masonry has its weaknesses, leading to poor performance during seismic events. Unreinforced masonry (URM) buildings, in particular, have proven to be vulnerable in seismic events, with significant building damage and numbers of fatalities world-wide. Experience reveals that masonry constructions remain susceptible to earthquake forces due to various reasons. A few of them may be listed as lack of integral action between bricks and mortar; inadequate strength against out-of-plane forces, low tensile and shear strength of masonry, relatively heavy mass and varying construction practices. It is essential to enhance the seismic resistance of masonry system by providing suitable features so as to overcome the inherent deficiencies. To upgrade the seismic performance of URM systems, different reinforcing measures were adopted and eventually led to the development of reinforced masonry (RM) and confined masonry (CM) systems.

Low-to-medium rise buildings (up to 4 storeys) are the frequent typology for housing, in developing countries all over the world. The key requirement for sustainable building construction demands fulfilment of functional, structural, societal, economical and environmental criterion. Unreinforced masonry was historically, and is actually, the structural solution that best addresses these requirements. The occurrence of recent earthquakes in India, even in moderate seismicity zones, highlighted the consequences of poorly built masonry structures, comprising around 85% of existing building stock in India. The seismic action needs to be adequately considered combining sustainability, earthquake resistance and cost-effectiveness, and on these counts confined masonry (CM) appears to be the best alternative for low-medium rise buildings.

CSIR-Central Building Research Institute (CBRI), Roorkee has performed extensive experimental and analytical studies on full-scale single-room masonry buildings of different typology, i.e., unreinforced (URM), reinforced (RM) and Confined Masonry (CM). These buildings were tested under cyclic loading in quasi-static manner to study the seismic performance. Consequent upon the failures of these buildings at ultimate loads, these buildings were strengthened using different techniques and retested. The observations made and the test data collected were for different damage grades and displacement capacity were utilised for development of design procedure for CM Buildings. This book is an attempt to implement the developed design procedure of confined masonry in construction of houses for Economically Weaker Sections (EWS) in different seismic zones of the country under National Mission “Housing for All' of Government of India. The recommendations are based on design/construction experience and research studies conducted at CSIR-CBRI and from countries where confined masonry construction has been practiced. References to relevant provisions of various international standards and codes have been made.

This book is spitted into five chapters. Chapter 1 outlines about confined masonry construction and principals of construction. Chapter 2 presents materials and specifications for confined masonry. Chapter 3 provides a guideline for design of confined masonry buildings subjected to earthquake forces as per Indian Seismic Codes. Chapter 4 covers the detailed structural design and details of typified EWS houses of different stories in various seismic zones of India, whereas Chapter 5 illustrates the typical calculation procedures for analysis and design of confined masonry building. For further detailed understanding on confined masonry, a book a “Confined Masonry” brought by CSIR-CBRI (2018) may be referred.

1.2. PURPOSE

The problem of earthquake resistant construction of masonry buildings has attracted the attention in recent years. As a solution, confined masonry has emerged as a promising cost-effective construction technique for low-to-medium rise construction in seismic regions. As an alternative to the prevalent prescriptive procedures for seismic design of CM buildings, these Guidelines may be used as a basis for the seismic design of individual CM buildings; or a basis for development and adoption of future Building Code provisions governing the design of CM buildings.

Properly designed and executed, the Guidelines are intended to result in CM buildings that are capable of achieving the seismic performance objectives for Occupancy Category II buildings (life safety and collapse prevention in the event of severe earthquake) as intended by ASCE 7, having capabilities as under:

- withstand Maximum Considered Earthquake shaking, as defined in ASCE 7/IS-1893, with low probability (on the order of 10%) of either total or partial collapse;
- withstand Design Earthquake shaking, having an intensity two thirds that of Maximum Considered Earthquake shaking without generation of significant hazards to individual lives through design measures intended to assure that non-structural components and systems remain anchored and secured to the structure and that building drifts are maintained at levels that will not create undue hazards; and
- withstand relatively frequent, more moderate-intensity earthquake shaking with limited damage.

Alternatively, individual users may adapt and modify these procedure to serve as the basis for designs intended to achieve higher seismic performance objectives. This book will be a useful resource for design engineers and architects, academics and non-governmental organizations in India for analysis & design of CM buildings due to lack of seismic design code for confined masonry construction. Though, this document do not addresses the analysis and design procedures of foundations as it depends on soil type and its bearing capacity but outlines the typical foundations which can be adopted of such construction.

CHAPTER - 2

MATERIAL AND CONSTRUCTION ASPECTS FOR EWS HOUSES

2.1. MATERIALS

Structural performance of confined masonry is largely influenced with the quality and strength of materials used. Bricks, sand, aggregates, cement and rebars are the basic materials deployed in the construction of confined masonry buildings. Material selection and its usage on the construction site shall be such that the desired material properties are achieved to ensure satisfactory performance of the confined masonry building. General specifications for the proper use of materials are given below.

2.1.1. BRICKS

Clay brick is obtained by moulding good clay into a block, which is dried and then burnt. This is the oldest building block to replace stone. Manufacture of clay brick started with hand moulding, sun drying and burning in clamps. A considerable amount of technological development has taken place with better knowledge about the properties of raw materials, better machineries and improved techniques of moulding drying and burning.

- Use burnt solid clay bricks, solid concrete blocks, hollow clay tiles or hollow concrete blocks.
- Bricks should be watered for about 4 hours before laying.
- Bricks should have a minimum of 35 kg/cm^2 compressive strength, uniform shape, size and a maximum of 20% water absorption.
- Bricks should have a maximum of 20% water absorption capacity.
- Bricks should have uniform shape, size and sharp edges.

Masonry Wall Construction

Masonry wall construction comprised of array of bricks (masonry units) bonded together with the mortar. The strength of wall depends upon quality and strength of masonry unit, mortar and method of bonding adopted in construction. The strength of wall is one of the important aspects to resist gravity and earthquake loads, which needs proper attention. Masonry wall construction consists of following steps:

- Select good quality bricks with uniform shape, size and having sharp edges.
- Dig out a trench for wall foundation and pour concrete layer to make the base solid and levelled.
- Lay first row of bricks in the foundation.
- Burnt solid clay bricks should be soaked in water and dried before using.
- Spacing should be appropriate for filling the mortar in the joints.
- Wipe off the extra mortar as the bricks are laid.
- Keep laying bricks until the row is finished.
- Start second roe with half brick at both the ends.
- Repeat the steps as carried out for the previous row and continue laying the rows.
- Not more than 1.5 m brickwork height should be laid in a single day.
- Cure the masonry for a minimum of 7 to 10 days.
- 12 mm thick plaster should be provided on both the surfaces of the wall.

2.1.2. SAND

Sand and gravels are obtained for housing construction from nearby river / query. One has to be very cautious while selecting quality of sand and gravel as it contributes to better strength of mortar and concrete.

- River sand should be used for construction. Beach sand is not preferred as it contains salts that result in corrosion and strength deterioration of steel.
- Sand with mica or excessive clay should not be used in any construction.
- Sand should be sieved to remove dust, vegetative objects, fine and course particles.
- Sand with excessive dirt, clay should be washed properly before mixing. Sand can be tested by lifting up a handful and letting it fall back to the ground. If a significant portion of it blows away instead of falling straight down, it has too much dust and needs to be sieved.
- Do not allow debris to be mixed with sand / gravel.
- Crushed gravels (less than 20mm size) are best to use in concrete. Not the rounded ones.

2.1.3. AGGREGATE

- Use hard, clean and crushed aggregates that should be free from any kind of material that could result in deterioration of concrete.
- Use 20 mm down aggregate in footing, plinth beam, bond beam, tie column and slab.
- Crushed gravels are preferred over the rounded river stones as coarse aggregate.

2.14. CEMENT

- Do not use the cement which is more than 3 months old.

CHAPTER - 3

STRUCTURAL ANALYSIS AND DESIGN OF CONFINED MASONRY

3.1. OVERVIEW

The basic requirements for seismic design of buildings i.e. simplicity, symmetry, material properties etc., given in various codes including the Indian standards (IS: 4326- 2013; IS: 1893-2002; IS: 13920-2016; IS: 1905-1987; IS: 456- 2000) are applicable for confined masonry buildings as well. However a proper design philosophy is not stated in the Indian standards. In this section, a simplified procedure for analysis and design of confined masonry building is described.

The design philosophy of confined masonry addresses the basic requirements i.e. life safety and collapse prevention. Broadly, the design procedure for confined masonry building encompasses:

- Planning of building i.e. symmetry in plan and elevation, placement of bond beams and tie-columns at appropriate locations and its size, confirming the general guidelines for confined masonry.
- Selection of appropriate physical properties of brick units, mortar, concrete, reinforcement etc.
- Calculation of loads i.e. dead load, live load and seismic loads as per relevant standards. Further detailed calculation includes computation of building weight, base shear; distribution of design lateral force; computation of equivalent wall stiffness, centre of mass and stiffness of the building, eccentricity, computation of torsional stiffness; and seismic forces are distributed in individual walls as forces due to uniform lateral translation and torsion.
- Checks for various parameters such as wall density, overturning, in-plane stability (compressive stress, tensile stress and shear stress), out-of-plane stability for each wall of the building.
- Design of bond-beam and tie-column.
- Providing proper ductile detailing so as to avoid brittle failure of bond beams and tie columns.

The basic assumptions made for analysis and design of confined masonry are:

- The building walls are analysed as panels. The panel length shall be limited to 4.2 m.
- In-plane and out-of-plane behaviour of wall is considered independently.
- The foundation system shall be governed by local site conditions.

3.2. GENERAL PRINCIPLES

3.2.1. Dimensions

Wall panels should satisfy the limits of slenderness ratio, (given in Table 3.1) to prevent buckling due to gravity or lateral loads. Slenderness ratio is the ratio of height (h_w) or length (l_w) to thickness (t_w) of the masonry element.

$$S.R. = \frac{h_w}{t_w} \text{ or } \frac{l_w}{t_w} \quad \text{(Whichever is less)}$$

Table 3.1. Maximum Slenderness Ratio for a Load Bearing Wall

Number of Storeys	Maximum Slenderness Ratio	
	Cement Mortar	Lime Mortar
$\leqslant 2$	27	20
>2	27	13

3.2.2. Wall Density

Wall density (W_d) can be defined as the total cross-sectional area of all walls, A_w (product of wall thickness and wall length) in each direction divided by the total floor area, A_p. Wall density is a key indicator for the safety of confined masonry buildings subjected to seismic and gravity loads. It is observed that masonry buildings with sufficient wall density performed well even during the event of major earthquakes as compared to masonry buildings with relatively low wall density. Properly planned, designed and quality construction of confined masonry buildings with adequate wall density are expected to perform well during earthquakes. In order to avoid brittle failure due to insufficient lateral strength, a minimum wall density should be provided in each principle direction of the building (Fig. 3.1) is calculated as:

$$W_d(\%) = \frac{A_w}{A_p} \times 100$$

It should be noted that this wall density (W_d) must be 33% higher if hollow concrete blocks are used in confined masonry construction. The minimum wall density required for confined masonry buildings located in seismic zone II and III is 2%, while for seismic zones IV and V, the minimum requirements are 4% and 5% respectively.

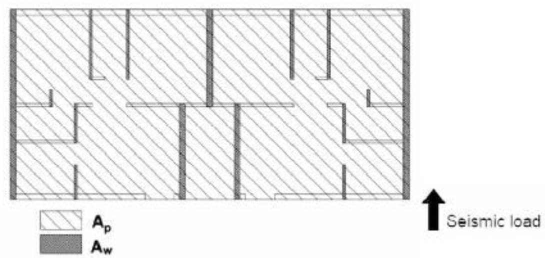


Fig. 3.1. Wall Density in Principal Direction

CHAPTER – 4

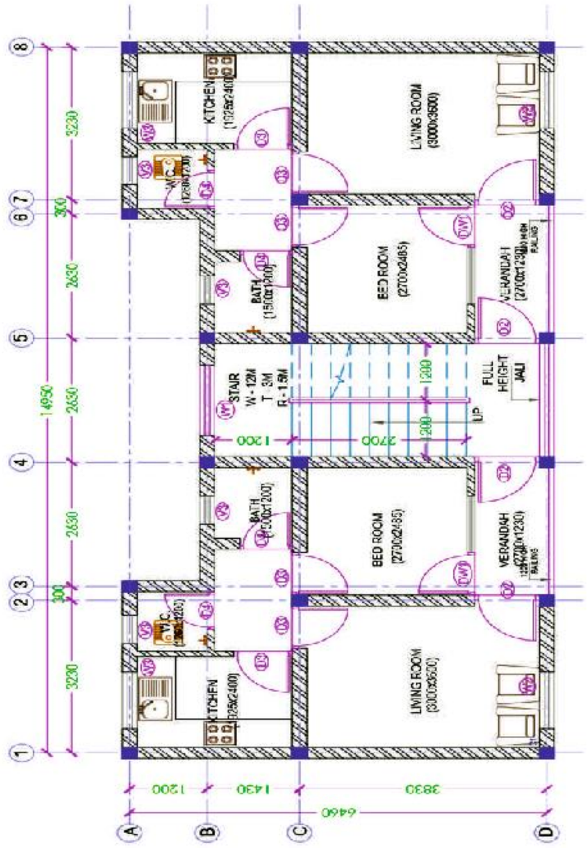
Architectural and Structural Drawings for Confined Masonry EWS Houses

CHAPTER - 5

ANALYSIS AND DESIGN EXAMPLE

5.1 Problem Statement

Design a confined masonry building for the plan shown in Figure 5.1, located in seismic zone IV. Evaluate maximum number of storey which can be built for the given geometry and material specifications.



(All Dimensions in mm)

Figure 5.1. Building Plan

Table 5.1. Building Geometry of CM Building

Component	Dimensions	Unit
Plan Dimension in X Direction	14950	mm
Plan Dimension in Y Direction	6460	mm
Storey Height	3000	mm
Building Height	3125	mm
Bond Beam	230 x 200	mm
Tie Column	230 x 230	mm
Slab	125 thick	mm
DW3	1500 x 2100	mm
D2	1000 x 2100	mm
D3	900 x 2100	mm
D4	800 x 2100	mm
W1	1500 x 2100	mm
W2	1200 x 1200	mm
W5	900 x 900	mm

Table 5.2. Material Properties for Design of CM Building

Component	Parameter	Value	Unit
Brick	Compressive Strength	10.5	N/mm^2
Mortar	Compressive Strength	3	N/mm^2
Masonry	Density	19	kN/m^3
	Tensile Strength	0.25	N/mm^2
Concrete	Density	25	kN/m^3
	Grade	20	N/mm^2
Steel	Grade	415	N/mm^2

Table 5.3. Seismic Parameters for Design CM Building

Parameter	Value
Zone Factor	0.24 (Zone IV)
Importance Factor	1.0 (Residential Building)
Response Reduction Factor	3
Soil Type	Medium