CONFINED MASONRY

Concepts

Experimental Evaluation & Retrofit

Structural Analysis & Design

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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 is happy to present this book on *Confined Masonry* covering aspects namely *Concepts, Construction guide, Experimental investigation and retrofit, Structural Analysis & Design and Cost assessment* for worldwide distribution and dissemination.

The sustainability of buildings construction claims, more than never, for solutions which simultaneously respond to several requirements, as these functional, structural, societal, economical and environmental. Historically, masonry structural system provides best solution to these issues. However, such buildings caused thousands of lives in past earthquakes due to their brittle behaviour, in contrast most of the reinforced masonry or concrete buildings are constructed with no or poor quality in design and construction. This prompted a need for alternate building technology like confined masonry, with enhanced seismic performance. While some of building codes in developed countries do address the confined masonry construction, but not always be implemented in developing countries like India due to various reasons like construction material & practice. In absence of such provisions, professional felt difficulty in deploying the new technology.

CSIR-CBRI has done extensive analytical and experimental studies in this direction and in its pursuit to promote disaster resilient construction for low to medium rise buildings, is committed to publish this book which not only help academician, professional but also to common people of India to reinforce "Housing for All" national mission.

It is hoped that this book will go a long way in Indian subcontinent and elsewhere to fulfil dream of common man to have a disaster resilient, economical house.

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Roorkee

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PREFACE

Around 85% of prevalent form of residential construction in India is unreinforced or partially reinforced masonry. Regrettably, such constructions have performed poorly in past seismic events. To improve the seismic performance of masonry buildings, exhaustive research program was initiated at CSIR-CBRI, Roorkee, as a result improved method of masonry building system called 'confined masonry' (CM) has emerged to be the best which can be adopted in India. In confined masonry, unreinforced masonry wall panels are embraced and confined by lightly reinforced concrete elements, the horizontal ones are bond beams and vertical are tie columns, which keeps masonry intact during seismic motions.

The literature available on confined masonry is very scanty and the different aspects were dealt differently. Therefore, this book is one step forward in compiling the data on confined masonry based on the experience gained, experimental studies conducted at CSIR-CBRI and practice being adopted world over, so that the professionals may get fairly a good idea about the technology.

The aim of this book is to provide guide to construct safe and affordable confined masonry housing in seismically-active regions. The book explains confined masonry and its key components; past performance; behaviour behave during seismic shaking; materials & specifications; principles of design and construction; comparison of different housing technologies; cost analysis and illustrative design example of CM building. Though slightly more expensive than more conventional unreinforced masonry construction, CM housing exhibits far superior earthquake performance when it is constructed properly. As a cautionary note, the aspects related to confined masonry covered in this book are not meant to be implemented blindly; rather, intend to apply engineering principles to enhance seismic resistance and aid professionals / academicians to local materials, conditions and regulations in confined masonry buildings.

Government of India has launched an ambitious national mission – *Housing for All,* which commits to provide disaster resilient housing to common man. CSIR-CBRI in its pursuit to promote appropriate building technology for low-to-medium rise construction, bring out this book, which not only help the professionals but also to common people of India to embrace disaster resistant features in housing construction which can withstand the vagaries of nature's wrath without inflicting loss of life.

Reference has been made to several literatures (as given in references and appropriate places) are gratefully acknowledged. My sincere thanks are due to Prof. C.V.R. Murty, Prof. Pradeep Bhargava, whose extraordinary pedagogic skills guided me in this research. The encouragement and financial support by CSIR under Mission Mode Project on Mass Housing were instrumental in reaching its current form; without the generosity and vision, this book would never have obtained its current depth and scope.

Finally, I am thankful to Dr N. Gopalakrishnan, Director, CSIR-CBRI for providing encouragement and support in bringing out this book, and reposing his faith & confidence in me and giving freedom, independence and opportunity to work. Last but not the least, I am thankful to entire CSIR-CBRI family for enthusiastic support.

Ajay Chourasia

CONTENTS

CHAPTER 1 | Confined Masonry : Concepts

1.1. Preamble

Even today, masonry construction is the most common typology being adopted for low to medium rise buildings. Masonry buildings have several advantages such as fire resistance, durability, acoustic and thermal insulation, easy availability of materials and economic construction etc. However, masonry elements suffer from a few drawbacks like 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, 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. The reasons for failure of masonry under lateral loads 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, varying construction practices and lack of understanding about design procedure. Majority of the masonry buildings in developing countries are constructed without considering any lateral loading aspects and thus are highly vulnerable to earthquakes. This has stressed a need for advancement in seismic resisting features of masonry buildings, as incorporated in confined masonry technique. This further widens the scope of proper design, construction practices and economy of Confined Masonry (CM) buildings.

To evaluate and understand the behaviour of CM buildings under seismic actions, simulation of masonry materials and assemblage is essential. The book illustrates extensive experimental work carried out for the determination of properties for different types of masonry units and masonry assemblage, concepts and construction method of confined masonry, full-scale tests on CM building subjected to lateral load and its retrofit strategies, design guidelines and detailing of reinforcement in CM buildings and design example of a typical CM building.

Confined masonry has been widely adopted in certain developing countries as an alternative to unreinforced masonry on the grounds of better seismic resistance. However available codes state limited provisions on their construction techniques/methodology and structural analysis. The seismic performance of confined masonry is primarily governed by the geometry of building, quality of building materials, construction methodology and sequence, slenderness of masonry walls, position of openings, wall density, provision of confining elements etc. These factors shall be taken into the account while designing a CM building. The book presents a simplified structural analysis and design procedure for confined masonry, which can be adopted for low-to-medium rise CM buildings.

1.2. What is Confined Masonry

1.2.1. General

Confined masonry is a building system comprising of masonry walls confined with lightly reinforced structural elements at the periphery of walls. In CM, masonry is held from dilating in all its in-plane directions; here masonry units and mortar are prevented from separation from each other when subjected

CHAPTER 2

Material Properties of Masonry Units

2.1. General

Building materials used in confined masonry construction are same as in masonry and reinforced concrete buildings. Performance of confined masonry significantly depends on the quality of masonry units used in its construction. Masonry unit refers to individual brick, block or stone used in the construction of buildings. Solid burnt clay bricks, concrete blocks, hollow clay tiles or hollow concrete blocks shall be used for confined masonry construction. However, masonry units with horizontal perforations and stone masonry shall not be used for confined masonry construction. Parameters such as young's modulus, compressive strength and shear strength of masonry depend on the strength and quality of masonry units and mortar used. The compressive strength of masonry units shall be characterized in accordance with IS 3495: 2003, whereas criteria for selection of mortar for building construction shall comply with IS 2250: 1981.

2.2. Masonry Units

Solid burnt clay bricks are the most prevalent masonry units, which are adopted worldwide. However, it is found that these units have varying material properties which mainly depend upon the soil type and manufacturing method. Moreover, solid burnt clay units cause environmental pollution due to their rudimentary manufacturing process, where the units are burnt. In order to overcome such hazards over the environment, alternate materials and eco-friendly manufacturing process shall be adopted. Autoclaved

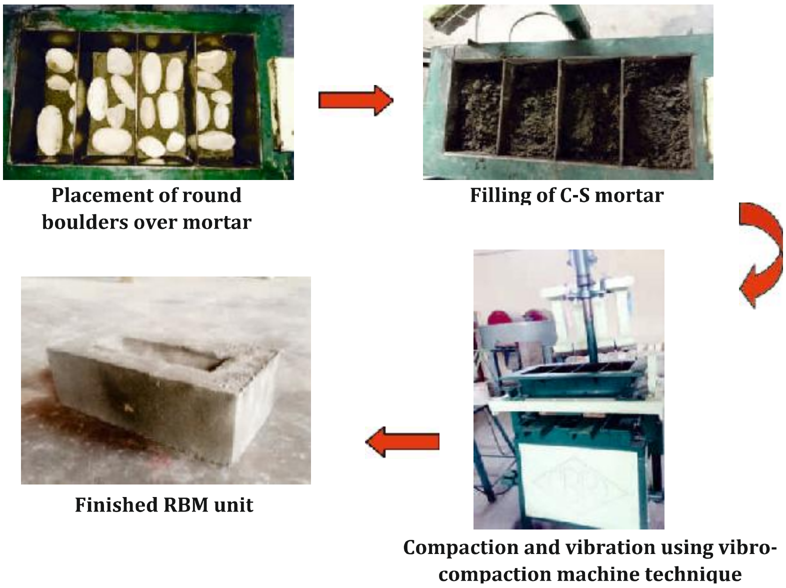


Figure 2.1: Manufacturing Process for RBM Units

CHAPTER 3 | Seismic Evaluation and Retrofit of Confined Masonry

3.1. Preamble

Confined masonry (CM) consists of masonry walls strengthened with lightly reinforced confining RC elements i.e. bond beam and tie-column. With the realization of significant advantages of confined masonry construction, an experimental program was conducted with the aim to assess the better understanding of seismic behavior of confined masonry in comparison to unreinforced masonry (URM) and reinforced masonry (RM). Single storey full-scale URM, RM and CM buildings were subjected to the displacement controlled quasi-static reversed cyclic lateral loading. Possibilities of different materials viz Chicken Mesh, Welded Wire Mesh, Geo-grid Mesh, Polypropylene Mesh, Nylon Mesh and Plastic Cement Bag Mesh. The damaged CM building was then retrofitted with the mesh of plastic cement bag (CM_RET), whose performance under quasi-static lateral loading was compared with its original counterpart. The seismic response of tested masonry buildings was evaluated from the standpoint of damage pattern, failure mechanism and various seismic parameters, i.e. lateral load carrying capacity, lateral deformation, stiffness, drift, ductility, structural behavior factor and energy dissipation.

3.2. Building Model

The test buildings (URM, RM and CM) were constructed using locally available construction materials and prevailing construction practices. The footing of the test buildings was replicated as 230 x 150 mm RC beam casted on strong floor of the laboratory, which was fastened using nuts and bolts to ensure safety against sliding and overturning of masonry walls. All the buildings had similar geometry. URM building did not have any seismic resistant features, while RM building consisted 1-10 mm dia corner vertical rebar and 75 mm thick RC lintel band having 2- 8 mm dia bars (Fe415) and 6 mm dia hooks at 150 mm c/c. The test buildings were 3.01 x 3.01 m in plan and 3.0 m height, with 100 mm thick RC slab and 220 mm thick masonry walls built using burnt solid clay units with 10 mm thick cement-sand (1:6) mortar in the joints. Additionally, the CM building was provided with 220 x 220 mm RC tie-columns, having 4-10ø longitudinal bars and 6 mm diameter lateral ties at 100 mm c/c at end-span and 200 c/c at mid-span. RC tie-beam (220 x 200 mm) was provided at the lintel level, having 4-10ø longitudinal bars and 6 mm

Table 3.1: Description of Confined Masonry Building Model

Building Designation	Building Typology	Material Specification	Structural Features
URM	Unreinforced Masonry	Burnt solid clay brick units, cement : sand (1:6) mortar, M20 grade of concrete used for 100mm thick RCC slab.	220mm thick brick masonry walls with openings for door and window. 100mm thick RCC slab. No seismic resistant features.

CHAPTER 4

Structural Analysis and Design of Confined Masonry

4.1. Preamble

Confined masonry (CM) constructions are classified as load-bearing systems, wherein masonry walls are responsible to carry both vertical loads (including gravity-induced loads) and horizontal loads (including earthquake-induced loads). Under vertical loads, all structural components of the house, namely bond-beams, masonry walls and tie-columns are subjected to compression while under lateral loads, parts of the structure (namely tie-columns and masonry walls) on the front side of load are subjected to tensile and far end side to compressive actions. Normally tie-column and bond-beam act in unison with the masonry wall. Design guidelines for confined masonry building were formulated on the basis of seismic behaviour evaluated during the experimental investigation and specifications given in relevant international and Indian standards. Structural design of CM system is similar to that of URM buildings. Bending and shearing stresses of RC elements in CM system are much less severe than those in RC frame system. As a result, bond-beams and tie-columns in CM system are much smaller in size, and are lightly reinforced in contrast to RC frame system. Various parameters such as building plan, material properties, wall density, stiffness, eccentricity etc. that influence the seismic performance of confined masonry which shall be considered in the design. Even though early codes/guidelines are available for CM buildings from Algeria, Chile, Mexico, Iran and Euro Code, development of design standards for CM buildings in India have been embodied in this chapter based on material properties, experimental investigations conducted (as discussed in previous chapter) in Indian context. The present design philosophy of confined masonry addresses the basic requirements i.e. life safety and collapse prevention. Design procedure and various aspects influencing the structural response of confined masonry buildings are discussed in subsequent sections.

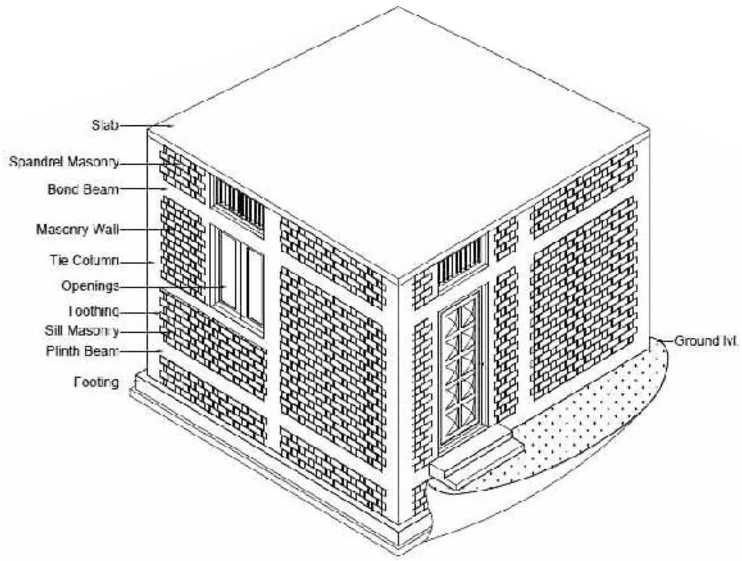
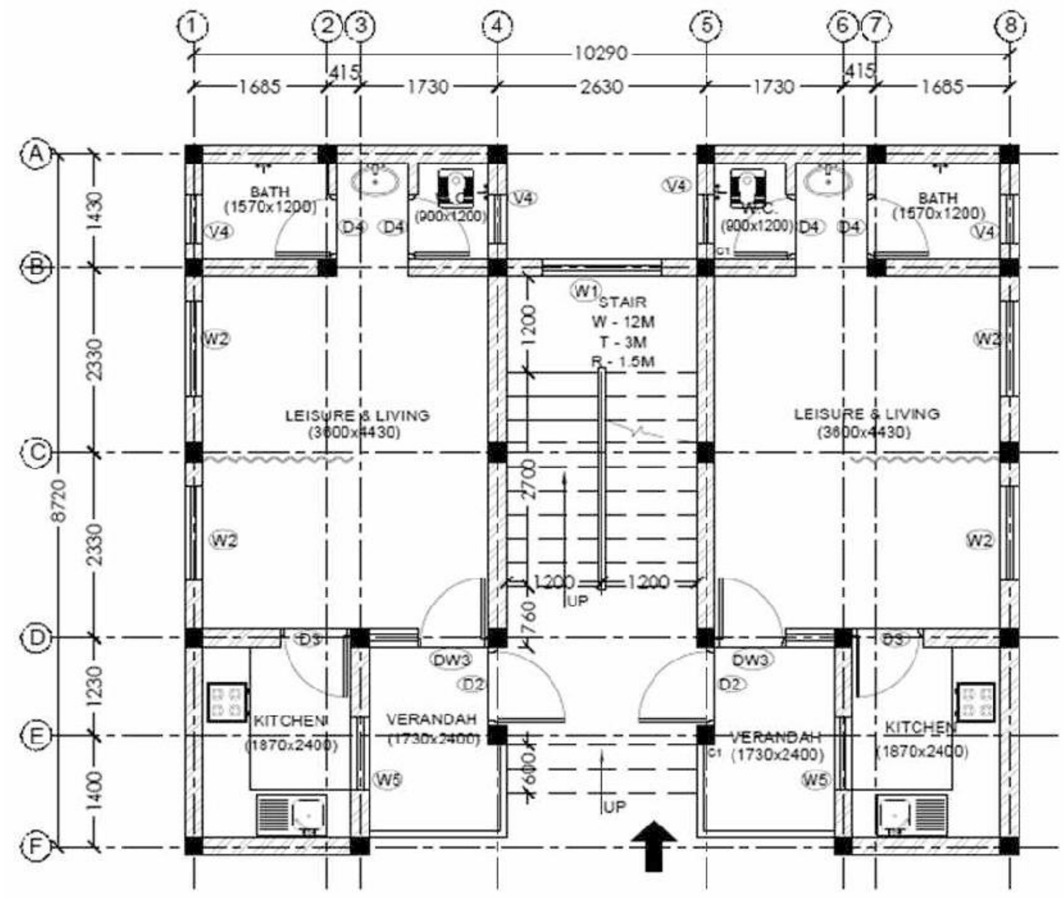


Figure 4.1: Confined Masonry Building Components

CHAPTER 5 | Analysis and Design Example

5.1. Analysis and Design of Confined Masonry

Figure 5.1 shows architectural plan of a building located in seismic zone IV. The building has been analyzed and designed as confined masonry using RBM units for the maximum number of stories for the given geometrical and material properties as per the guidelines provided in Chapter 4.



(All Dimensions in mm)

Figure 5.1: Architectural Plan of the Building