BUILDING CODE REQUIREMENTS FOR DESIGN AND CONSTRUCTION OF MASONRY STRUCTURES IN MEXICO

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Abstract

The Mexico City Building Code is the most comprehensive and advanced set of requirements in the country. This code is used as a model code in most regions of Mexico. As part of the 2004 revision of the Mexico City Building Code, the code requirements for the design and construction of masonry structures were updated. Such provisions are of utmost importance because over 70 percent of buildings in the country are made of masonry walls. This paper discusses the current situation in which masonry design and construction is carried out in Mexico. Comments are made on how masonry design provisions are developed, the implicit design approach, materials and types of masonry included in the code, masonry elements considered, seismic design, current plans to update masonry design provisions, and some of the most important challenges in updating design provisions.

Introduction

In Mexico, building codes should be issued by each municipality. Because there are over 2400 municipalities in the country, the number of potential building codes is, therefore, immense. However, due to economic and technical limitations, few municipalities have issued their own codes. Among them, the Mexico City Building Code (MCBC) is the most comprehensive and advanced set of requirements, and is used as a model code in most regions of the country. As part of the 2004 revision of MCBC, the requirements for the design and construction of masonry structures (NTCM) were also updated. Such provisions are of

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utmost importance because over 70 percent of buildings in the country are made of masonry walls. Walls are typically used as load-bearing elements, intended to resist both the vertical and lateral actions. Masonry walls are also heavily used as infills in reinforced concrete and steel frame structures. Masonry is most widely used for housing, especially in low-cost housing. The intent of this paper is to discuss the current situation in which masonry design and construction is carried out in Mexico.

Masonry Design Provisions

The MCBC comprises a group of technical norms for the different types of loading and for the structural systems and materials (Fig. 1). Consensus design provisions for those norms are developed by different technical committees. The technical committee for the design and construction of masonry structures (NTCM) involves designers, design consultants, academics, industry representatives, and local authorities.

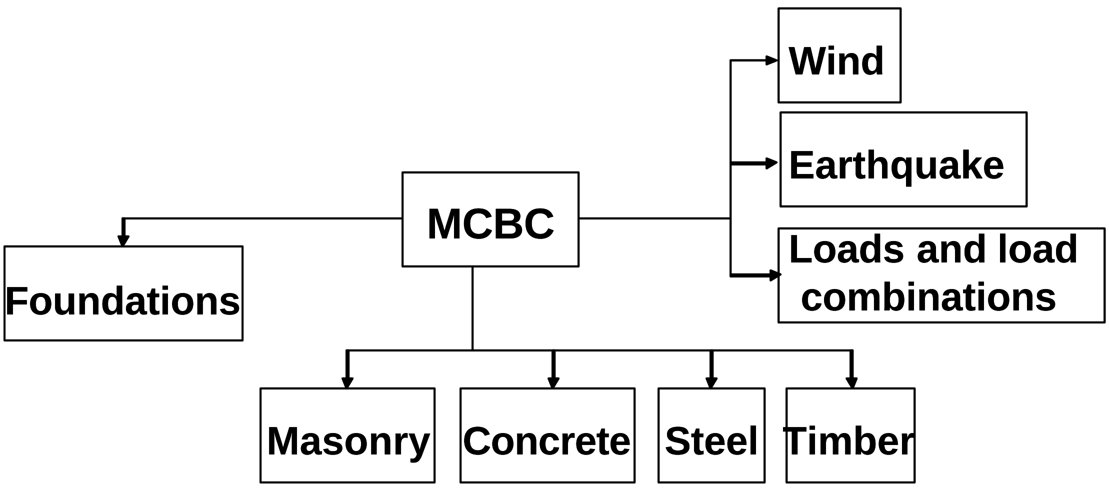

Fig. 1 Technical Norms for the Mexico City Building Code

Consensus specifications for materials and testing methods (NMX) are developed and specified nationwide by special independent non-governmental organizations (ONNCCE). Masonry units are specified in standard NMX–C–404–ONNCCE and NTCM. Joint mortars are specified in NMX–C–061–ONNCCE and NTCM.

Masonry requirements, based on allowable stresses, were included in the first version of the MCBC in 1942. In 1976, the MCBC adopted a limit-state design format and included design material strengths and stiffnesses that were obtained from a comprehensive experimental research program carried out at that time. After the 1985 Mexico City earthquakes, NTCM was revised and updated. Strength reduction factors were slightly increased to reflect the excellent performance of well-designed and well-constructed masonry structures, as well as to counteract the increase in the design seismic shear coefficient adopted in the code.

NTCM is organized according to the type of loading for which the wall must be analyzed and designed (i.e. vertical, lateral). Therefore, general analysis and design requirements are spread out in different chapters. NTCM is divided into 11 chapters and one appendix. Chapters 1, 2 and 3 are related to general considerations, materials, and specifications for analysis and design, respectively. Strength reduction factors, and general design and detailing rules are also included in that chapter. Chapters 4 to 8 refer to the different types of masonry systems considered, i.e. infill walls, confined masonry, reinforced masonry, unconfined/unreinforced masonry, and fieldstone masonry. Chapter 9, 10 and 11 relate to construction requirements, inspection and quality assurance, and structural evaluation and rehabilitation of existing structures, respectively. Appendix A refers to experimental evaluation of masonry structures for seismic design.

Masonry Materials in NTCM

Masonry units and mortar

Solid and hollow masonry units, either handmade or industrialized, are allowed. Handmade solid clay bricks, industrialized hollow clay bricks (with two cells and multiperforated) and semi-industrialized hollow concrete units are the most commonly used in several parts of the country. In the last decade, multiperforated industrialized clay bricks have become well accepted in low-cost housing, particularly because of their cost (Alcocer, 1999). The unit is typically used in combination of hollow units with two cells. In tests and in the field, it has been observed that the typical mode of failure of masonry walls built with hollow units and subjected to large cyclic lateral displacements is quite brittle, and is characterized by a sudden crushing and spalling of their exterior walls. To avoid such types of failures, NTCM limits the minimum thickness of the exterior wall of the unit to 15 mm, and the minimum net area to 50 percent. Also, only hollow units with vertical perforations are allowed for structural purposes. The latter requirement intends to avoid the catastrophic failures observed in masonry walls in the 1999 Colombia and Turkey earthquakes (EERI 2003, 2000).

Joint mortar shall be proportioned by volume and shall be a combination of Portland cement, lime and sand (PC:L:S). For structural purposes, three types of mortar are recommended: Type I (1 : 0 to ¼ : S) with a cube strength, f_j*, of 12.5 MPa; Type II (1 : ¼ to ½ : S) with f_j* of 7.5 MPa, and Type III (1 : ½ to 1¼ : S), with f_j* of 4 MPa. In all cases, Portland cement shall be used and the volume of sand, S, shall be between 2.25 and 3 times the sum of the volumes of Portland cement and lime.

Mechanical Properties of Masonry

Differently from other building codes, material design properties adopted in the MCBC correspond to a 2% lower fractile. The reason for this value is the large variation of material properties, as well as the lax quality control procedures in the Mexican construction industry. Three types of design strengths are used in NTCM: the unit compressive strength, f_p*; the masonry axial compression strength, f_m*; and the masonry diagonal compression strength, v_m*. The latter is considered as an indicator of masonry shear strength. To determine the axial compressive and shear design properties, i.e. strengths and stiffnesses, NTCM favors laboratory tests of masonry prisms under axial compression, and of masonry walls under diagonal compression. In this regard, any design material property, Z_m*, shall be calculated from Eq. 1.

$$Z_m^* = \frac{\bar{Z}_m}{1 + 2.5C_z} \qquad \textbf{[1]}$$

In the equation above $\bar{Z}_m$ and C_z are the mean value and the coefficient of variation, respectively, of the material property under consideration. In those cases when laboratory test results are not readily available, such as for single-family dwellings, the recommended strength properties presented in Table 1 may be used.

Table 1 Recommended Strength Properties for Masonry

Type of Unit	f_p* (MPa)	f_m* (MPa)			V_m* ($\leq 0.25\sqrt{f_m^*}$) (MPa)	
		Mortar I	Mortar II	Mortar III	Mortal I	Mortar II & III
Solid clay brick (hand-made)	6	1.5	1.5	1.5	0.35	0.3
Hollow clay brick (industrialized)	10	4	4	3	0.3	0.2
Hollow concrete (semi-industrialized)	6	2	1.5	1.5	0.35	0.25
Solid concrete brick	10	2	1.5	1.5	0.3	0.2

Types of Masonry in NTCM

Confined Masonry

Confined masonry is the most popular masonry construction system in Mexico City and in the country. Developed in Italy at the beginning of the 20th century to improve the seismic performance of masonry structures, it became popular in Mexico City in the 1940´s as a method to control wall cracking due to differential settlements that occurred in the soft soil area of the city. Subsequent earthquakes provided evidence of the excellent performance of well-constructed confined masonry structures (EERI & SMIS 2006). Since then, Mexican design and construction professionals adopted the system. As expected from a system that was actually developed on-site, and not through a rational process of testing and research, most design and detailing requirements are empirical. Confined masonry walls are confined vertically and horizontally with tie-columns and bond beams, respectively. In Mexican buildings, such elements have very small cross-sectional dimensions, typically equal to the wall thickness. Confining elements are intended to tie structural walls and floor/roof systems together, and to improve wall energy dissipation and deformation capacities. When properly designed and detailed, an increase in lateral strength can be quantified. To solve code misinterpretations, illustrations, like that shown in Fig. 2, are included in NTCM.

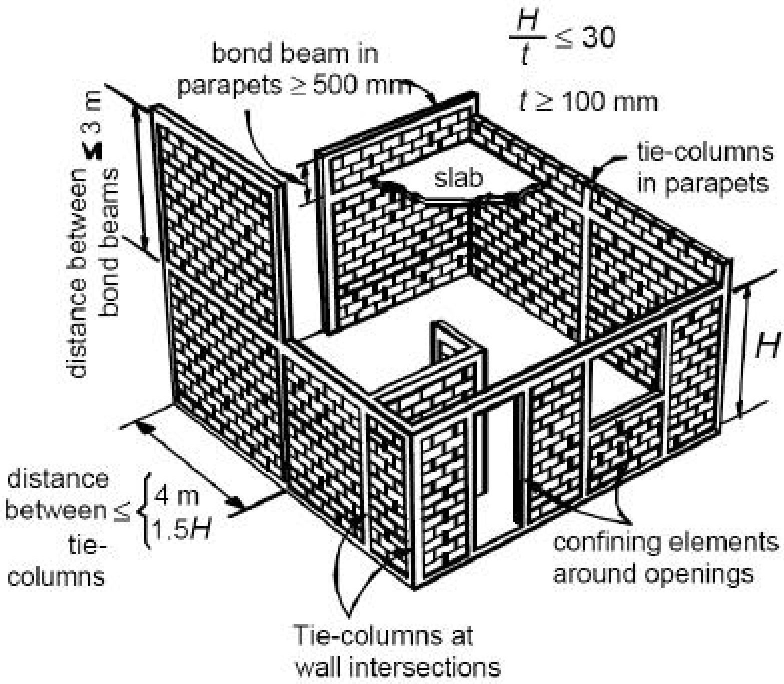

Fig. 2 Requirements for Confined Masonry

NTCM requires the ends of tie-columns adjacent to wall openings be reinforced with closely-spaced transverse reinforcement when the design diagonal compression strength of the masonry, v_m*, exceeds 0.6 MPa. Laboratory tests and field observations have shown that the diagonal cracking of walls made with strong masonry, typically penetrate and shear off the tie-column, in a sudden manner, compromising the stability of the structure under vertical loads. Detailing requirements for bond beams and tie columns are shown in Fig. 3.

Reinforced Masonry

Mexican internally reinforced masonry has departed from reinforced masonry systems developed in other countries, such as in the United States, New Zealand and Japan. In these countries, all cells in a hollow masonry unit are typically filled with grout. In contrast, in Mexico, only those with vertical reinforcement are grouted through the wall height; therefore, a large number of cells are left void. Because of the relatively low demand for this system, special units for placement of horizontal and vertical reinforcement are not longer available in the domestic market. Horizontal reinforcement comprises cold-drawn wires which are embedded in the joint mortar. Specified yield stresses of joint reinforcement typically vary from 500 to 600 MPa. Similarly to confined masonry, figures to clarify and highlight the requirements are included in NTCM (Fig. 4).

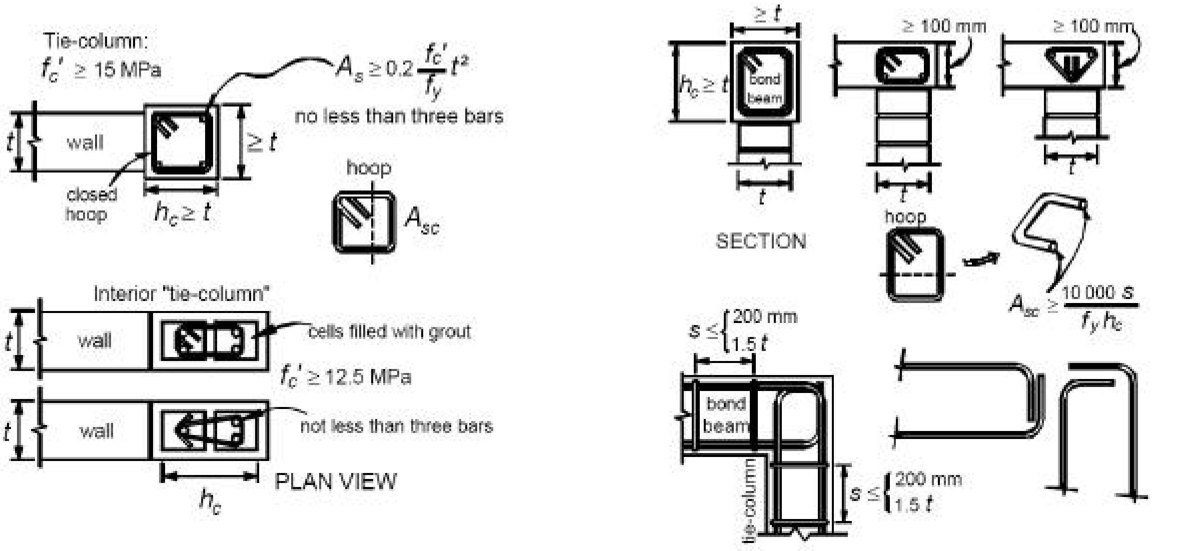

Fig. 3 Detailing Requirements for Bond Beams and Tie Columns

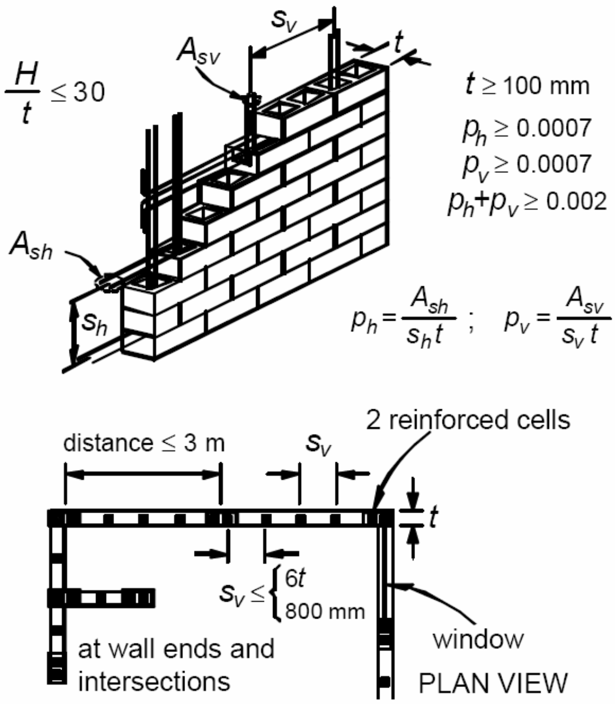

Fig. 4 Detailing for Reinforced Masonry

Infill Walls, Unconfined/Unreinforced Masonry and Fieldstone Masonry

Infill walls are defined in NTCM as walls surrounded by columns and beams of a frame. Infill walls may be made of confined masonry, reinforced masonry or unconfined/unreinforced masonry. The shear strength of infill walls can be calculated, if the case, considering both the contribution of the masonry and the steel reinforcement. Columns around infill walls have to be designed considering the wall-frame interaction. Aimed at precluding a shear failure at the ends of the columns, and following a capacity-design approach, each column is required to be designed and detailed to resist a shear force equal to half of the lateral load resisted by the infill (Esteva 1966).

Unreinforced masonry is defined in NTCM as masonry that does not comply with all the requirements to be classified either as confined masonry or as internally reinforced masonry. Recent earthquakes have provided evidence of the large seismic vulnerability of unreinforced masonry construction in Mexico (Alcocer 2001; López 2001; EERI & SMIS 2006). To discourage the use of unreinforced masonry, reinforcement for structural integrity is now required. This is to be placed vertically at wall intersections and at every 4 m, and horizontally along the top of the walls. The percentage of integrity reinforcement is, roughly, two-thirds that required for confined masonry structures.

Fieldstone masonry construction is rarely used in Mexico, except for residential construction and mostly for esthetic reasons. This is mainly to the use of artificial masonry units as clay bricks and concrete units. The requirements specified in NTCM for that type of masonry are mainly for the design of retaining walls and foundations.

Masonry Elements and Construction in NTCM

The NTCM is intended to be applicable to the structural design of masonry elements composed of units and mortar. Typical elements made of masonry are: walls loaded in plane, walls loaded out of plane, lintels defined by openings, piers and columns. NTCM does not distinguish between residential and commercial construction. NTCM aims at improving the construction quality through tougher requirements, and through inspection and quality assurance programs. A comprehensive list of items to be specified in structural drawings, and to be checked in the field is included in NTCM. Such requirements cover topics ranging from material specifications and mechanical properties, to reinforcement detailing (Fig. 3), building tolerances and approved construction methods. Self-construction is not included in NTCM, but no matter how a building is constructed, it is required to have a construction permit authorized by local authorities, that in turn invokes the use of NTCM requirements.

Seismic Design in NTCM

NTCM favors the use of three methods of analysis for the seismic design of masonry structures: a simplified method, a static method and a modal analysis method. The simplified method is typically allowed for structures up to five stories and when the torsional eccentricity at a given interstory (i.e. distance between the story shear force and the interstory center of rotation) does not exceed 0.1 times the width of the building perpendicular to the direction of analysis. In recent years, most housing buildings do not fully comply with the set of rules required for the application of the simplified method of analysis. Typically, buildings are not symmetric in plan, do not show a uniform distribution of mass or stiffness along the height, and more often, the height surpasses the limit of 13 m. Therefore, specific guidelines for such cases are incorporated in NTCM.

In the static and modal analyses, both the shear and flexural stiffnesses of the walls shall be taken into account. In load bearing walls, cracked section properties under shear shall always be considered. Under axial force and bending moments, cracked properties shall only be included when net vertical tension strains may be expected in the wall. Masonry walls are typically perforated by window and door openings, thus forming lintels and parapets around them. Such elements often possess enough stiffness to modify the free-standing wall deformations. Therefore, the restriction on deformations from lintels, slabs and parapets shall be accounted for. In this regard, as an example, NTCM provides guidance on the effective width of slabs to be considered in analysis. To facilitate modeling of masonry walls, the wide-column frame analogy is allowed (Schwaighofer 1969; Bazán 1998). In this method, prismatic walls are modeled as columns located at wall mid-length. In this analogy, wall mechanical properties are assigned to those fictitious columns, and the beam segments within the wall length are considered rigid for flexure. For a more accurate estimate of building lateral stiffness, the numerical model should incorporate the contribution of transverse walls to the lateral stiffness. NTCM also provides guidance on the width of the effective compression flange. For walls with a complex array of openings, more sophisticated methods of analysis, such as finite elements, or methods based on stress fields and rules of the theory of plasticity, such as strut-and-tie models, may be used.

Plans and Challenges in NTCM

The new version of NTCM was published in the year 2004. Efforts are being carried out to develop a code commentary to explain the most significant modifications included in this new version. Those modifications are largely based on analytical and experimental programs, and field observations conducted in Mexico, particularly those on confined masonry and internally reinforced masonry. In this new version of NTCM, emphasis was given on simplification and clarification of requirements, as well as to incorporate the current state of knowledge.

Currently, other efforts are underway. Firstly, a Residential Model Building Code is under development jointly by the National Commission of Housing (CONAVI) and the Institute of Engineering of UNAM. CONAVI is the Federal Government agency in charge of developing housing policy for the country. A first version of the Code is expected to be available by the en of 2006. Emphasis is given to code adoption and code enforcement procedures.

Sponsored jointly by CONAVI and the Mexican Council for Science and Technology (CONACYT), the Mexican Society of Structural Engineering (SMIE) is developing: 1) Guidelines for analysis of masonry structures; 2) Guidelines (leaflet) for design and construction of new housing in rural areas; and 3) Guidelines (leaflet) for rehabilitation of existing houses in rural areas. The first series of guidelines are intended to provide support information to design professionals on how to carry out structural analyses of masonry structures according to NTCM. The second and third guidelines will be 16-page long leaflets with minimal, yet comprehensive and graphic, information on how to build new housing, as well as on how to rehabilitate existing structures. Such leaflets are intended to replace the manuals that have been previously developed by academic and government institutions. Such documents had been typically 100-pages long, and therefore, their cost of printing has been too high for implementing a wide distribution among the actual builders in the field. In general, these long manuals have been used in central offices in large cities to develop scattered pilot projects for improving housing construction in rural areas.

With regards to future versions of NTCM, it is expected that it will allow other masonry units, such as autoclaved aerated concrete units. Also, an explicit design formulation for analysis and design using strut and tie methodologies is expected to be included.

Summary and Conclusions

This paper presents the current situation in which masonry design and construction is carried out in Mexico. Comments were made on how masonry design provisions are developed, the implicit design approach, materials and types of masonry included, masonry elements included, seismic design, current plans to update masonry design provisions, and most important challenges in updating design provisions.

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