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DESIGN AND CONSTRUCTION IN SEISMIC-RESISTANT MASONRY STANDARDS IN FORCE IN THE PROVINCE OF MENDOZA, ARGENTINA

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ABSTRACT

This paper contains the fundamentals underlaying Chapter 7 of the Seismic-resistant Building Code of the Province of Mendoza (1987) related to design and construction of masonry building within the zone of the highest seismic danger in the country.

It is established the classification of the various types of masonry: lateral bounded, extra reinforced and reinforced and the different types of bearing wall bricks as well as masonry building quality control.

Geometrics conditions are given for bearing seismic-resistant walls. Structural conditions are established for the placing of reinforced concrete lateral bonded structures their dimensions and reinforcements as well as seismic-resistant design criteria.

Seismic-resistant building details related to wall insulating horizontal layer, quality of bond grout and the use of various types of bricks in plane and in the structure are standarized.

INTRODUCTION

The city of Mendoza (Republic of Argentina) was the first in all Americas to enact a seismic-resistant building code (Ordenance 553 of 1923) which has its origin in the 1861 and 1873 earthquakes and is mainly based on the knowledge of building material resistance. The code was improved by technological advances and the experience gained in different seismic movements. In every instance the community had an active participacion which assured an ample degree of acceptance and appliance hardly found in other types of regulations. Its last version was in bill 4235/87 enacted by the Provincial Executive Power. Local technological possibilities and economy professional knowledge of seismic engineering and lasted design criteria were taken into consideration in the formulation of this code.

The experience attained by the members of the Antisismic Construction Group, of the Facultad Regional Mendoza, Universidad Tecnológica Nacional in their research on masonry building behaviour subjected to seismic loading has been included in the code. The subject under considerations refers to Chapter 7: Design and Building Characteristics, item 7.2. Masonry.

SCOPE
The present code is applied to buildings in general. Their components, members, installations and equipment aimed at housing, clerical, business and industrial facilities situated, or to be situated, in the territory of the province of Mendoza, Republic of Argentina.

AIM

This code establishes basic requirements for design, calculation, execution, repair and reinforcement of buildings and their component parts in order to consider seismic effects on them. Its specific aims are:

a) To avoid losses of human lives.
b) To decrease the incidence of physical injuries to human beings.
c) To avoid collapses due to intense earthquakes, lessening damages to acceptable economic levels.
d) To avoid damages effected by moderate seismic movements which are the most frequent in the region.
e) To avoid damage to people and properties not belonging directly to the buildings.

MASONRY: BASIC DEFINITIONS

I) Lateral Bonded Masonry: walls are formed by bonded panels. Bonds must be reinforced concrete or its equivalent.

II) Extra Reinforced Masonry: besides bond mentioned in (I) walls have horizontal or vertical reinforcements, or both with a geometric minimum value of $\lambda \geq 280/\beta$ (%) where a maximum separation of 0.50 m. Reinforced joints must exclusively be made of concrete mortar. All 0.125 m thick walls, either bearing or not must be reinforced.

III) Reinforced Masonry: reinforcements are distributed in the wall forming a mesh, with eventual concentrations on the edges. Reinforcements are fixed with cement or concrete mortar. Members of reinforced masonry are designed according to reinforced concrete method substituting referent masonry resistance for concrete resistance design. Contribution of concrete components may be considered provided their minimum thickness is 0.05 m.

IV) Wall: vertical resistant system, usually flat mainly bearing action in its vertical and/or horizontal plane.

CLASSIFICATION OF MASONRY UNITS

LMC: Massive ordinary ceramic bricks pressed or semi-pressed.

BCS: Semi-massive blocks whose minimum net section is 50 % of the gross surface with vertical or horizontal cells.

BCV: Blocks with vertical cells. Its minimum net section is 40 % of the gross section. Minimum wall thickness is 0.008 m and maximum cell cross section its 5 times wall width.

BCH: Blocks with horizontal cells. Same characteristics as BCV.

BM : Massive concrete blocks. Silica-lime bricks or made of natural stone with rugged faces to promote mortar adherence.

In each type two categories are established:
"A" with a medium compression resistance of 12 N/mm².
"B" with a medium compression resistance of 7.5 N/mm².

BHV: Concrete blocks with vertical cells. Minimum massive net section is 40% of gross section; minimum wall width is 0.025 m and maximum cross cell dimension is 6 times the wall width.
Medium compression resistance for category "A" is 9.5 N/mm² and for "B" is 5 N/mm².

Units that not comply with the afore mentioned requirements could only be used provided the cells are filled with the same mortar used for joints. Filling must be done every three layers or at every 0.50 m height.

MASONRY MORTAR COMPOSITION

<table>
<thead>
<tr>
<th>CLASS (**)</th>
<th>CEMENT (*)</th>
<th>LIME (*)</th>
<th>SAND (*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.25</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
<td>5 or 6</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>-</td>
<td>3</td>
</tr>
</tbody>
</table>

(*) Volume doses.
(**) Class of mortar depends on the use intended for the building.

WALL RESISTANT CAPACITY

a) Stress of reference are expressed in (N/mm²).

<table>
<thead>
<tr>
<th>CLASS</th>
<th>STRESS</th>
<th>MORTAR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>LCM - A</td>
<td>0.0</td>
<td>3</td>
</tr>
<tr>
<td>BCS - A</td>
<td>0.0</td>
<td>0.3</td>
</tr>
<tr>
<td>LMC - B</td>
<td>0.0</td>
<td>1.5</td>
</tr>
<tr>
<td>BCS - B</td>
<td>0.0</td>
<td>0.15</td>
</tr>
<tr>
<td>BCV - A</td>
<td>0.0</td>
<td>0.2</td>
</tr>
<tr>
<td>BCV - B</td>
<td>0.0</td>
<td>1.2</td>
</tr>
<tr>
<td>BCH - A</td>
<td>0.0</td>
<td>0.12</td>
</tr>
<tr>
<td>BCH - B</td>
<td>0.0</td>
<td>1</td>
</tr>
<tr>
<td>BHV - A</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td>BHV - B</td>
<td>0.0</td>
<td>0.12</td>
</tr>
<tr>
<td>BM - A</td>
<td>0.0</td>
<td>3</td>
</tr>
<tr>
<td>BM - B</td>
<td>0.0</td>
<td>0.3</td>
</tr>
<tr>
<td>Relleno</td>
<td>0.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Relleno</td>
<td>0.0</td>
<td>0.15</td>
</tr>
<tr>
<td>Relleno</td>
<td>0.0</td>
<td>2.5</td>
</tr>
<tr>
<td>Relleno</td>
<td>0.0</td>
<td>0.2</td>
</tr>
</tbody>
</table>
b) Masonry tests and systematic quality controls will accept:
   \[ \sigma_0 = \frac{\sigma_m}{2} \]  
   \[ \tau_0 = \frac{\tau_m}{20} \]
where \( \sigma_m \) is medium compression resistance obtained from tests and \( \tau_m \) is medium shear resistance obtained from tests.

c) Values of class "A" masonry may be used pronounced regular systematic quality controls are performed during the building process.

d) For conditions with no seismic loading, permissible stresses result from dividing reference stresses by minimum security coefficient 2.5.

e) For compression stresses in tall, slender buildings, reference stresses or proportional reductions of the specified DIN 1053 for \( h/d > 10 \) will be applied.

f) Shear capacity
   - For lateral bounded or reinforced masonry walls:
     \[ T_u = 2 \tau_0 e \ 1 + 0.3 \ Nu \leq 2 \tau_0 e 1 \]
   - For reinforced masonry walls
     \[ T_u = F_{es} \beta_0 + 0.3 \ Nu \leq 20 \tau_0 e 1 \]

where:
\( e \) : Wall thickness without grout
\( l \) : Wall length including edge bonds
\( Nu \) : Simultaneous normal strength refered to load condition under consideration.
\( F_{es} \) : Reinforcement per meter of wall.

QUALITY CONTROL ON MASONRY BUILDING

a) It is compulsory in type A or AE buildings over 150 m2 and individual houses over 300 m2.

b) Quality control consists in testing compression according to applicable IRAM Norm in two specimens for 20 m3. or lower fraction of masonry to be executed.

c) So as to justify using stresses higher than those corresponding to class "A" or to obtain due approval of masonry, diagonal compression tests or total wall tests must be performed.

d) It is also compulsory for collective houses with more than 10 living units and for commercial or industrial building intended for more a hundred occupants.

CHARACTERISTICS OF BEARING WALLS

Bearing walls must resist horizontal or vertical seismic loading or both and will possess the following geometric limitations:
1) Minimum thickness 0.17 m for the three types of masonry.
2) Length and height for the three types of masonry:
   - for 2-horizontal supported edges walls
   - for walls with 2-horizontal supported edges and
     one vertical supported edge
   \[ \leq 2 \]
   \[ \leq 2.5 \]
3) Length for the three types of masonry
   \[ \geq 1.5 \text{ m} \]
4) Permissible Openings:
   - For lateral bonded and reinforced masonry 10 % of maximum
     panel surface and 1/3 of maximum panel dimensions.
   - For reinforced masonry, cross reinforcement surrounding
     the openings must be calculated.
5) Maximum height of buildings with bearing walls:

<table>
<thead>
<tr>
<th>Type of building</th>
<th>Type of masonry</th>
<th>Reinforced</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lateral bounded</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>--</td>
<td>3 m, 1 level</td>
</tr>
<tr>
<td>B or C</td>
<td>10 m, 3 levels</td>
<td>13 m, 4 levels</td>
</tr>
<tr>
<td></td>
<td>Extra reinforced</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>--</td>
<td>13 m, 4 levels</td>
</tr>
<tr>
<td>B or C</td>
<td>10 m, 3 levels</td>
<td>15 m, 5 levels</td>
</tr>
</tbody>
</table>

6) Bearing walls with thickness less than 0.17 m and up to
   0.125 m are admitted exclusively in one or two floor building
   destined to housing for extra reinforced and reinforced
   masonry with a relation height \( \leq 1 \), minimum total length \( \geq 2.5 \text{ m} \) and in between walls bonds not admitted and at least
   two edges are supported.

7) Using of various masonry units
   When using different types of masonry units in the building,
   elasticity module of each must be taken into consideration.
   Use of different types of units is not admitted for the same
   bearing wall or co-plane bearing walls and horizontal
   continuos.

8) Masonry walls of several vertical layers.
   - Each layer must be of only one type of units.
   - It is admitted that some of the layers could be bearing.
   - Lateral bonds must be placed in the bearing layers.
   - Bonds in non-bearing layers may be omitted provided non-
     bearing are bonded to bearing layers.

BOND SYSTEM

Placements and bonding system.

![Diagram](attachment:image.png)

PLANT
PLACEMENTS AND BONDING SYSTEM

Horizontal connection
slab, roof or intermediate
level

\[ S \leq 20 \text{ m}^2 \]
\[ \leq 5 \text{ m} \]

Horizontal connection
over the foundation

\[ \geq 1.5 \text{ m} \]

Vertical connection
joint to the foundation
(bearing wall)

Vertical connection
joint to the connection
of foundation
(non-bearing wall)

SECTION

IN CASE OF ELIMINATION OF CONNECTIONS

Edges of openings

\[ 55 \text{ m}^2 \]
\[ \leq 1.5 \text{ m} \]
\[ a \]

Edges of wall
(horizontal or vertical)

\[ \leq 1.5 \text{ m} \]

\[ a \]

\[ a \]

a: casting anchor 0.60 m (min)
reinforcement parapet and top

SECTION
Dimensions of reinforced concrete bonds.

These bonds must have rectangular section with a minimum concrete area:

\[ B = e_1 \times e_2 \]

For bonds in walls corners \( e_1 \) and \( e_2 \) are the thickness, in the other cases \( e_1 \) is wall thickness and \( e_2 = 0.15 \) m. Bond minimum dimension will be 0.08 m or half the wall thickness of the thickest wall to which it is bonded.

Reinforced concrete bond reinforcement.

a) Minimum geometric measures

\[ \mu_b = 980 \gamma_d / \beta_s \quad (\%) \quad \gamma_d = \text{type of building coefficient} \]

b) Minimum reinforcement

- \( \beta_s = 240 \) MN/m² 4 \( \varnothing \) 10 mm and close or winding stirrups \( \varnothing 6 \) mm at each 0.20 m
- \( \beta_s = 420 \) MN/m² 4 \( \varnothing \) 8 mm and close or winding stirrups \( \varnothing 4 \) mm at each 0.20 m

c) Stirrups and bar splices at tension always with hooks.

d) Reinforcements of bearing walls bonds will be racionally determinated.

e) In unframed parapet with openings half of the bond reinforcement in joint with concrete mortar will be used and it will be placed immediately below the parapet. This reinforcement must be prolongated 0.60 m at each side of the opening.

Construction of reinforced concrete bonds.

Masonry panels must be built before placing lateral and top bonds. Connection with concrete joined elements is not admitted before raising masonry by means of bar included in joints between units. Surfaces destined to be in contact with concrete will be rough enough so as to ensure shear stress transfer between bonds and masonry.

Equivalent bonds.

Instead of reinforced concrete bonds it is possible to use others which have equivalent tension, compression and flexural strength and rigidity and which have similar action when connected to masonry.

MASONRY CONSTRUCTION DETAILS
1) Wall building.
   a) Horizontal joints must run through the masonry wall whole thickness.
   b) Masonry units must be placed with its larger face perpendicular to permanent reinforcement direction.
   c) All joints (horizontal and vertical) must be filled with mortar.

2) Insulating layers.
   They must be built with materials and methods which are able to keep masonry structural integrity unchanged. Asphalts that might permeate the wall are not allowed.

3) Bondage
   Bonds must have masonry joint action must be either joined to the main structure or to one another.

SIMPLIFIED STRUCTURAL ANALYSIS

In ordinary buildings having walls resistent to horizontal loads it is sufficient to verify just shear stresses in the walls due to seismic loading defined in the code, provided to following requisites are complied with:
   a) The relation height-maximum rectangular dimension circumscribing the building is \( \leq 1 \).
   b) The dimension relation of the rectangular circumscribing the building is \( \leq 2 \).
   c) In certain direction there exist exterior horizontal load resistant walls parallel or almost parallel slab connected at a minimum of 0.5 the length in the direction of the wall.
   d) In the studied direction there exists, at least, a horizontal load resistant wall slab connected at 0.8 the length of the circumscribing rectangle in that direction or two walls of 0.5 of the dimension.
   e) The walls cited in c) and d) are continuos in the total building height.
   f) The building has up to 2 levels or 7 m as maximum height.
   g) The distance between resistant wall horizontal section gravity center and the gravity center of each level is less or equal to half of the distance between the walls mentioned in c)

Structural Security Verification

Resistant element sections are verified as for seismic loads and non-seismic loads. Seismic loads must be verified in ultimate state without surpassing stress.

SEISMIC-RESISTANT DESIGN CONSIDERATIONS

Parts of construction

It is applied to every element bonded to or forming part of the building under study and whose weight modifies no more than 10% of the actions on the main construction building.

Evaluation of seismic action on parts of the building
Any component or part of the building must resist a load in the direction under study, applied in its center of gravity. Its intensity is defined by:

\[ F_p = c_p \times Q_p \]

where:
\( Q_p \): weight of part or component
\( c_p \): seismic coefficient for part or component
\( F_p \): equivalent dead load on part or component

In masonry walls this action is perpendicular to the wall main plane.

Interaction of components considered non-structural

Some procedures are proposed for the analysis for masonry influence on bar or mesh structures.

a) Equivalent panel
Whenever the set of reinforced concrete beams, columns, girders, etc are wholly filled, masonry behaviour can be analyzed as an equivalent panel whose characteristics are determined for the section resulting from materials homogenization with elasticity modules relation.

b) Equivalent diagonal
In frame structures with isolated masonry panels, these can be represented by a bar according to the compressed diagonal joined at its ends and whose section is:

\[ A = 0.4 \times e \times E_m / E \times (1 + h^2) / (h^2) \]

where:
\( A \): area of equivalent diagonal
\( e \): thickness of masonry panel
\( E_m \): elasticity module of masonry
\( E \): elasticity module of structural material
\( l \): length of masonry panel
\( h \): height of masonry panel

Loads are determined in the system resulting from the addition of diagonals.
Bonding of walls

Wall bonding can be estimated through the application of the criterion mentioned above as equivalent triangulization. Its model is:

\[ \begin{align*}
F_p & \quad \Downarrow \quad h \\
\hline
l & \quad \equiv \\
\hline
F_p & \quad \Downarrow \quad h
\end{align*} \]

Masonry edges in contact with reinforced concrete

Natural roughness of masonry units or hand caved stone is enough for appropriate contact. In case other types of units are used it is recommended to saw cut the surface at 0.04 m for each layer.

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5. Normas IRAM (Instituto Argentino de Racionalización de Materiales).

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