SEISMIC CODE EVALUATION

MEXICO

Evaluation conducted by Jorge Gutiérrez

NAME OF DOCUMENT: "Normas Técnicas Complementarias para Diseño por Sismo" ("Complementary Technical Norms for Earthquake Resistant Design")**.**

This document includes only specific seismic design regulations and it is complemented by the **"**Reglamento de Construcciones para el Distrito Federal" ("Mexico City Building Code")

YEAR: 2003 (see General Remarks).

GENERAL REMARKS: The most widely known seismic regulations in México are those of Mexico City. These provisions are generally adopted for other parts of the country, with due considerations to the differences in seismic hazard and soil conditions.

The Mexico City Building Code is constituted by general provisions included in the main body of the Code, and by Complementary Technical Norms for specific materials such as concrete, steel, masonry or timber and for some specific actions such as wind or earthquake.

Even though the "Complementary Technical Norms for Earthquake Resistant Design" currently in use are from 1995, there is an updated final draft expected to be approved during 2003. The evaluation refers to this updated draft.

SPECIFIC ITEMS:

NOTES:

- Bracketed numbers refer to specific chapters or articles of the 2003 draft of "Complementary Technical Norms for Earthquake Resistant Design": [1.1].
- Some references will be made to the general provisions contained in the main body of the Mexico City Building Code [204 Building Code]. The references to this document have been taken from "Seismic Regulations for Seismic Design, a World List – 1996", IAEE, Japan, 1996.
- Parentheses numbers refer to Items of the present evaluation document: (see 2.2).

1. SCOPE

1.1 Explicit concepts. [1.1]

The Norm defines minimum requirements; the designer, in agreement with the owner, may choose more conservative requirements to reduce economic losses.

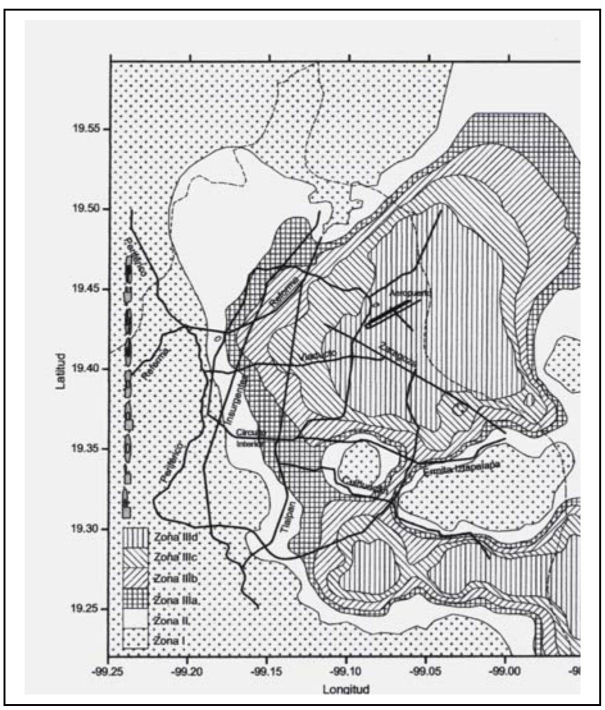
1.2 Performance Objectives. [1.1]

The purpose of the Norm is to obtain an adequate safety to ensure than, for the maximum probable earthquake, there will be no major structural failures nor loss of life, although there could be damages that impair serviceability and demand major repairs.

2. SEISMIC ZONING AND SITE CHARACTERIZATION

2.1 Seismic Zoning (Quality of Data). [1.4]

As mentioned, the Norm is intended for Mexico City. The version of 1995 had three zones (I, II and III). The proposed Norm of 2003 has six Zones because Zone III is further divided into four subzones (I, II, III_a, III_b, III_c and III_d) as shown in next figure:



The Zones are essentially defined by the type of site conditions, which have been extensively studied. Hence, the quality of data is very good.

2.2 Levels of Seismic Intensity. [1.5]

For Group B buildings (see 3.1) only one level of seismic intensity is assigned to each particular seismic zone or subzone (see 2.6). These levels are incremented by 50% for Group A buildings (see 3.1) and are also different for the simplified method of analysis (see 5.2). However, these modifications are not associated to specific seismic intensities.

2.3 Near Fault considerations.

Not considered.

2.4 Site Requirements.

Not mentioned.

2.5 Site Classification. [1.4]

As mentioned (see 2.1), the area is divided into six different zones and subzones according to site characteristics:

Zone I: Hard Ground
Zone II: Transition
Zone III: Soft Soil (divided into four subzones)

2.6 Peak Ground Accelerations (Horizontal and Vertical). [3]

Horizontal peak ground accelerations a_0 (as related to gravity) are defined for each zone or subzone:

Zone	a_0
I	0.04
II	0.08
III_a	0.10
III_b	0.11
III_c	0.10
III_d	0.10

There are no references to peak ground vertical accelerations

3. PARAMETERS FOR STRUCTURAL CLASSIFICATION

3.1 Occupancy and Importance. [174 Building Code]

There are two Groups, with corresponding Importance Factors:

Group A: Are those structures whose failure may cause a high number of deaths, high economic or cultural losses, hazard due to their toxic or explosive contents. Also includes those which must remain serviceable after an urban emergency. Importance Factor I = 1.5

Group B: All structures not included in Group A. Importance Factor I = 1.0

3.2 Structural Type. [5]

No specific chapter or article of the Norm explicitly defines the structural types. However several structural types are mentioned in relation with the definition of the Reduction Factor Q used in the Design Spectra (see 4.2). These are:

- Frame systems (steel, concrete, steel-concrete composites).
- Flat slab systems (concrete, steel,
- Wall systems (masonry, concrete, steel, steel-concrete composites).
- Braced frame systems (steel, concentric and eccentric).
- Prefabricated concrete systems.
- Dual systems, combination of the above systems with minimum strength for the frames.

3.3 Structural Regularity: Plan and Vertical. [6]

A Regular structure must satisfy eleven requirements (for plan and vertical regularity); otherwise it will be Irregular:

- Essentially symmetric plan. Orthogonal resisting components.
- Slenderness ratio less than 2.5.
- With to length ratio less than 2.5
- No plan reentrant corners.
- Stiff and strong diaphragms.
- Diaphragms without openings.
- Uniform floor weights along weight (no more than 10% increase over inferior floor).
- Uniform floor dimensions along height.
- All columns restricted in both horizontal directions at each floor.
- No more than 50% reduction on strength and stiffness among adjacent floors.
- Eccentricity less than 10% of plan dimensions in floor (both directions).

Additionally, an Irregular structure is defined as Severely Irregular if:

- Presents more than 100% reduction on strength and stiffness among adjacent floors.
- Contains eccentricities larger than 20% of plan dimensions in any floor.

For an Irregular structure, the Reduction Factor Q (see 4.2) will be multiplied by 0.9 if one irregularity is present, by 0.8 if there are two irregularities and by 0.7 for Severe Irregularities (keeping $Q \geq 1$).

3.4 Structural Redundancy. [1.2]

If any column, wall or braced frame contributes with more than 35% of the total strength, its strength will be 80% of the corresponding nominal value estimated with the Norms.

3.5 Ductility of elements and components. [5]

The Mexico City Building Code contains specific requirements to achieve either high or moderate ductility on the structural members and components for each structural material. The Reduction Factor Q is larger for structures designed with high ductility elements (see 4.2).

4. SEISMIC ACTIONS

4.1 Elastic Response Spectra (Horizontal and Vertical). [3]

An elastic response spectrum is defined only for the Mode Superposition methods (see 5.4). The horizontal acceleration response spectra, a, is given by:

$$a = a_o + (c - a)(T/T_a) \qquad \text{for } T < T_a$$
$$a = c \qquad \text{for } T_a \leq T \leq T_b$$
$$a = q\,c \qquad \text{for } T > T_b$$

where $q = (T_b / T)^r$ and the values of c, a_o , T_a , T_b and r for each Zone are given in the following Table:

Zone	c	a_o	T_a	T_b	r
I	0.16	0.04	0.20	1.35	1.0
II	0.32	0.08	0.20	1.35	1.33
III_a	0.40	0.10	0.53	1.8	2
III_b	0.45	0.11	0.85	3.0	2
III_c	0.40	0.10	1.25	4.2	2
III_d	0.30	0.10	0.85	4.2	2

A vertical elastic spectrum is not considered.

4.2 Design Spectra. [4]

A Reduction Factor Q' is used for calculation of lateral seismic forces with Static (see 5.3) and Mode Superposition Methods (see 5.4), where:

$Q' = Q$ for T unknown or $T \geq T_a$
$Q' = 1 + (T / T_a)(Q - 1)$ for $T < T_a$

Where Q can take values of 1, 1.5, 2, 3 and 4 according to Structural Types (see 3.2), structural materials and ductility of elements and components (see 3.5). The following Table summarizes the requirements for different Q values:

Q	Requirements
4	a. Frame or Dual structural types of steel, concrete or steel-concrete composites with frames able to resist 50% of acting seismic force. b. Dual structural types with masonry walls if the structure without them is able to resist 80% of total lateral forces. c. Minimum lateral strength on any story is within 35% of the total average. d. If steel braced frames are present, they must be eccentrically braced. e. Elements and components designed for high ductility.
3	a. Previous (Q=4) conditions b, d and e are satisfied but either conditions a or c are not (in any story) b. Concentric steel braced frames designed for high ductility.
2	a. Frame, wall or dual structural types of steel, concrete, steel-concrete composites or masonry not satisfying any of the requirements for previous (Q= 3 or 4) conditions. b. Prefabricated concrete buildings. c. Some types of timber or steel buildings according to their specific norms.
1.5	a. Wall structural types with hollow masonry walls. b. Timber frame buildings.
1	Buildings with other structural materials and without technical justification for higher values.

4.3 Representation of acceleration time histories. [9.2]

Acceleration time histories, either registered, simulated or a combination of both can be used for non linear dynamic analysis (see 5.5). At least four independent time histories must be used; they should be compatible with all the criteria established in the Norm.

4.4 Design Ground Displacement.

Not considered.

5. DESIGN FORCES, METHODS OF ANALYSIS AND DRIFT LIMITATIONS

5.1 Load Combinations including Orthogonal Seismic Load Effects. [Chapter III, Building Code]

$CU = 1.5\ (CM + CV_{max})$ for Group A Structures
$CU = 1.4\ (CM + CV_{max})$ for Group B Structures
$CU = 1.1\ (CM + CV_{inst}) + CS$
$CU = 0.9\ (CM + CV_{min}) + CS$

where
CU = Combined Load (for LRFD or Strength Design)
CM = Dead Load
CV_{max} = Live Load with maximum intensity
CV_{inst} = Live Load with instantaneous intensity
CV_{min} = Live Load with minimum intensity
CS = Seismic Load

The structure must be designed for the simultaneous action of both horizontal seismic components using the total value in one direction plus 30% of the value in the other direction.

5.2 Simplified Analysis and Design Procedures. [2.1; 7]

A Simplified Analysis Method can be applied to buildings satisfying the following requirements:

- At each plant, at least 75% of vertical loads are supported by nearly symmetrically distributed walls (masonry, concrete, steel plate, concrete-steel composite or braced timber walls) integrated by horizontal diaphragms (slabs) with enough stiffness and strength.
- Plan length to width ratio is less than 2.
- Height is less than 13m and its ratio to minimum horizontal dimension is less than 1.5.

Horizontal displacements, torsion and overturning moments are not considered. It is only necessary to check that, at each story and for each horizontal direction, the shear strength is at least equal to the seismic demand calculated with the Static Method Procedures (see 5.3) but using the Seismic Coefficients given in the following Table for type B buildings (or 1.5 times those values for Type A buildings):

Zone	Concrete or solid masonry walls			Hollow masonry walls		
	Construction high H (m)			Construction high H (m)		
	H < 4	4<H<7	7<H<13	H < 4	4<H<7	7<H<13
I	0.07	0.08	0.08	0.10	0.11	0.11
II or III	0.13	0.16	0.19	0.15	0.19	0.23

Coefficients for timber buildings are given in their specific norms. For other structural materials their Seismic Coefficients must be based on analytical and experimental evidence of their behavior under horizontal cyclic loads.

5.3 Static Method Procedures. [2.2; 8.1; 8.2]

This method can be applied to regular buildings (see 3.3) no more than 30m high or irregular buildings no more than 20m high in Zones II and III, or for buildings no more than 40m high for regular and no more than 30m high for irregular in Zone I.

Initially, the total base shear force V_o as a ratio of the total structural weight W_o is calculated as:

$V_o / W_o = c / Q' \geq a_o$ (for c and a_o values see Table in 4.1; for Q' see 4.2)

V_o is distributed as forces F_i on each floor of weight W_i and height h_i :

$F_i = V_o [W_i h_i / \Sigma_k W_k h_k]$

The fundamental period T is then calculated by Rayleigh's Method.

If $T \leq T_b$ then $V_o / W_o = (a/Q')$ (see 4.1) and F_i is recalculated with the above equation.

If $T > T_b$ then the forces F_i at each level are:

$F_i = W_i (k_1 h_i + k_2 h_i^2) (a/Q')$ where $a \geq a_o$

and $k_1 = [1 – 0.5 r (1-q)] [W_o / \Sigma_k W_k h_k]$

$k_2 = 0.75 r (1–q) [W_o / \Sigma_k W_k h_k^2]$

$q = (T_b / T)^r$ (see 4.2)

5.4 Mode Superposition Methods. [2.2; 9.1]

This standard method of analysis can be applied to all types of buildings.
The Design Spectrum is (a/Q') (see 4.1 and 4.2).
Two analytical procedures are considered:

- Two Dimensional (1 dof per level)
- Three Dimensional with Rigid Diaphragms (3 dof per level)

In the first case all modes with natural period greater than 0.4s must be included (no less than the number of stories for buildings with 3 or less stories). In the second case the number of modes considered must have an accumulated effective weight of 90% of the total weight.

Modes can be combined according to SRSS for frequencies separated more than 10% from each other, otherwise their coupling effects must be considered.

The inelastic displacements will be estimated as Q (see 4.2) times the elastic displacements obtained from the analysis. These inelastic displacements will be used to check drift limits and P-Δ effects (see 6.4).

5.5 Non-Linear Methods. [9.2]

A short paragraph states that nonlinear time history analysis is allowed. At least four compatible acceleration records (see 4.3) in each horizontal direction should be used and the uncertainties on the structural parameters must be considered.

5.6 Torsional considerations. [8.5; 9.1]

For Static Method Procedures (see 5.3) torsional moments at each floor will be calculated as the floor shear force times the most unfavorable eccentricity of either $1.5\ e_i + 0.1b$ or $e_i - 0.1b$, where e_i is the calculated eccentricity and b is the plan dimension normal to the seismic direction. For buildings with $Q \geq 3$ (see 4.2) the accidental eccentricity can not exceed 0.2b. For these building types there must be a similar distribution of stiffness and strength among lateral force resistant elements and components.

For Mode Superposition Methods (see 5.5) an accidental torsion effect of $\pm 0.1b$ should be included at each floor level for each seismic direction.

5.7 Drift Limitations. [1.8]

Lateral interstory drift angles should be limited to 0.006 if elements cannot withstand larger drifts, otherwise to 0.012. Inelastic drifts are the elastic values multiplied by the Reduction Factor Q (see 4.2).

Drift in flat slab systems will be always limited to 0.006.

5.8 Soil-Structure Interaction Considerations. [Appendix A]

Due to soft soil conditions present in important parts of Mexico City, Soil-Structure Interaction effects are a particularly sensitive issue. Specific and detailed regulations to account for these effects are included in Appendix

A, to be used for the earthquake resistant design of structures in Zones II and III.

6. SAFETY VERIFICATIONS

6.1 Building Separation. [1.10]

The Code specifies minimum separations from site boundaries of 50mm or the corresponding inelastic horizontal displacements increased by 0,001, 0.003 or 0.006 times the height for Zones I, II or III. For the Simplified Method of Analysis (see 5.2) the increments are 0.007, 0.009 and 0.012. When significant, base rotations (see 5.8) must be considered.

From adjacent buildings or independent bodies of one building, their total separation will be the added values of both bodies or half of it if they have similar structural systems and the same height in all levels.

6.2 Requirements for Horizontal Diaphragms.

Apart from the fact than the diaphragms of Regular Structures must satisfy certain requirements (see 3.3), there are no specific design requirements for them other than the statement that they should have enough strength and stiffness to resist and transmit the seismic forces to the EQ resistant systems.

6.3 Requirements for Foundations.

Apart from a minor reference that both the structure and its foundation must satisfy all ultimate and serviceability limits [1.2], foundation requirements are not included in the "Complementary Technical Norms for Earthquake Resistant Design" but in the "Mexico City Building Code".

Stiffness and damping properties of foundations are specified for evaluation of soil-structure interaction effects (see 5.8).

6.4 P-Δ Considerations. [8.6]

Second order *P-Δ* effects must be included in the analysis (either Static Method or Mode Superposition) if at any story i:

$$\theta_i = (\Delta / \Delta h)_i > 0.08 \, [V_i / (\Sigma_{k=i} W_k)]$$

where Δ = Inelastic drift (see 5.7).
Δh = Story height
V_i = Lateral story shear at level i
$\Sigma_{k=i} W_k$ = Total building weight above i

6.5 Non-Structural Components. [1.3.2; 8.4]

Non structural elements and components at level h_i must resist a lateral force equal $(1+c'/a_o)$ times the corresponding force if the components were placed at the structure base level; $c' = (F_i / W_i)$.

Glass panels and non EQ resistant walls should not participate in the corresponding inelastic building displacements in their own direction but should resist the seismic out of plane forces.

6.6 Provisions for Base Isolation. [1.12]

A single paragraph states that when base isolation or passive dissipation devices are adopted, alternative earthquake design criteria different from but congruent with the Norm can be used as long as their efficacy and all design parameters are properly justified.

7. SMALL RESIDENTIAL BUILDINGS. [7]

No specific recommendations are given for small residential buildings but the provisions for Simplified Analysis (see 5.2) are applicable to many of these buildings.

8. PROVISIONS FOR EXISTING BUILDINGS. [11]

A specific chapter deals with this subject. It considers and penalizes the case of tilted structures present in many existing buildings due to the city soft soil conditions.

RECOMMENDATIONS FOR CODE IMPROVEMENT

The main drawback on the Seismic Code Regulations for Mexico is the absence of a national Code. The evaluated Norms may be considered state of the art but they are specifically meant for Mexico City, with very specific seismicity and site conditions. National authorities should be encouraged to issue a National Code with due consideration to the country's seismicity and site conditions.

Additionally, it is recommended that the Static Method Procedures be limited to Regular structures only, as their inherent approximations can lead to gross errors in the analysis of Irregular structures of any height.