SEISMIC CODE EVALUATION

COLOMBIA

Evaluation conducted by Guillermo Santana

NAME OF DOCUMENT: "Normas Colombianas de Diseño y Construcción Sismo Resistente" (*Colombian Standards for Seismic Resistant Design and Construcion*)

YEAR: 1998

GENERAL REMARKS: Document elaborated by technical committee AIS-100 of the Colombian Association of Earthquake Engineering. Replaces the Colombian Code for Seismic Resistant Constructions published in 1984. It is a large document that covers every aspect of construction including wind loads for the entire Republic of Colombia.

SPECIFIC ITEMS:

NOTE: Bracketed numbers refer to Code specific chapters or articles: [1.2.3]
Parentheses numbers refer to Items of this document: (see 2.2)

1. SCOPE

1.1 Explicit Concepts. [Title 1]

The norm applies to all structures, buildings and non-building structures and parts thereof. The design involves the definition of a unique base shear to be distributed through the height of the structure. The base shear is the stated minimum seismic demand for the facility, which should also comply with a maximum allowed drift based on inelastic response. No explicit restrictions are stated for structural building materials. The norm includes Titles that provide guidelines for structural concrete, masonry, steel, wood, precast prefabricated structures and one and two-story residential buildings.

1.2 Performance Objectives. [Title 1, Art. 1]

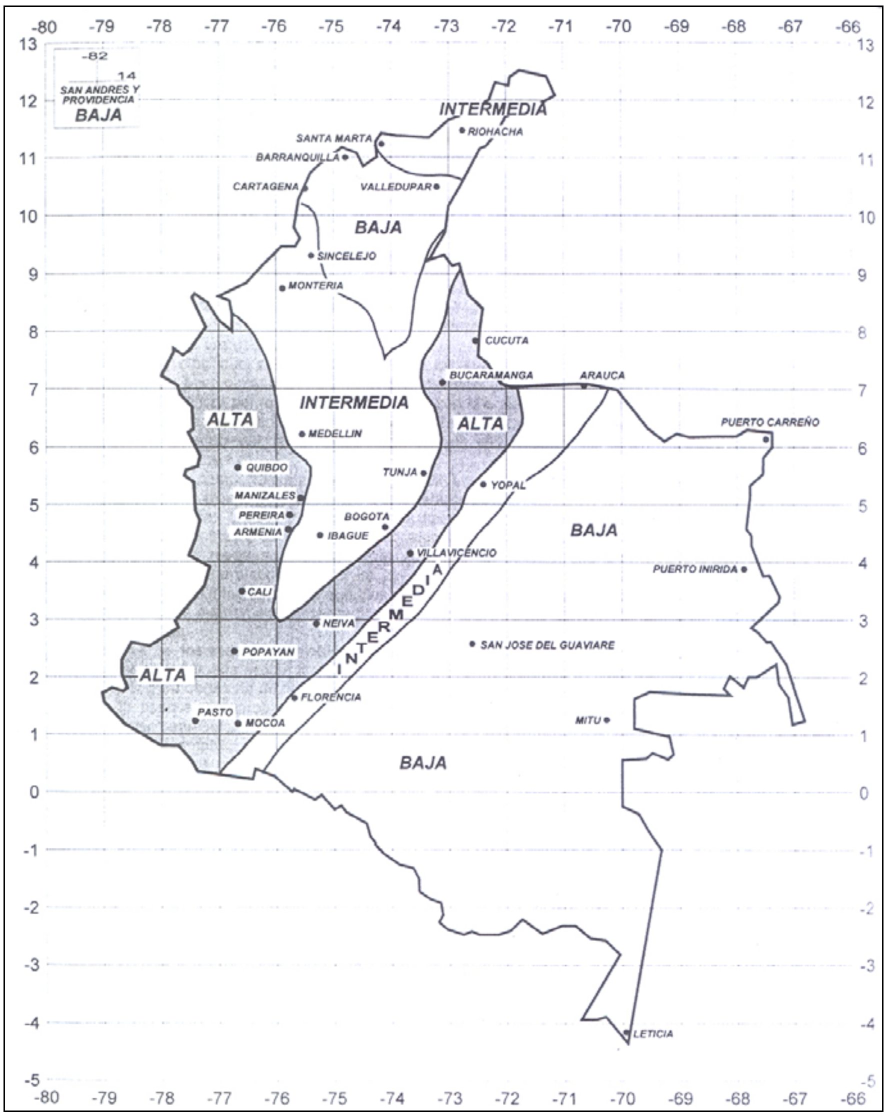
No specific performance objectives are given. The only mention of performance objectives is included in Title 1, Article 1 where it is stated that the "structures designed in conformance with these Norms should, in general, be able to: a) Resist minor level of earthquake ground motion without damage; b) resist a moderate level of earthquake ground motion without structural damage, but possibly experience some nonstructural damage; and

c) resist a major level of earthquake ground motion without collapse, but possibly with some structural as well as nonstructural damage.

2. SEISMIC ZONING AND SITE CHARACTERIZATION

2.1 Seismic Zoning (Quality of Data). [Title A, Cap A.2, Art. A.2.3]

The country is divided in three seismic zones along a northeast to southwest region parallel to the Bucaramanga fault zone into Ecuador. The zones are designated as High Seismic Hazard, Intermediate Seismic Hazard and Low Seismic Hazard. The map presented below is taken from the document being evaluated and it shows the geographic distribution of the seismic zonation.



[Figure A.2-1 Seismic Hazard Zonation.]

2.2 Levels of Seismic Intensity. [A.2.5]

Four levels of seismic intensity are considered. Standard Occupancy is assigned a seismic intensity level on 1.0, Special Occupancy is assigned a 10% increase on the intensity, Emergency and Relief Services Facilities Occupancy a 20% increase and Essential Facilities Occupancy are assigned a 30% increase on the seismic intensity. One major source document, the SEAOC 1996 Blue Book, states that a 0.40 factor like the one assigned to High Seismic Hazard Zone is representative of the expected effective peak acceleration (EPA) that has a 10 percent probability of exceedance in 50 years. This represents a 475 year return period for the EPA. In this document, EPA for the High Seismic Hazard Zone is assigned several levels of EPA ranging from 0.25 to 0.45.

2.3 Near Fault considerations.

No near-fault considerations are provided in this document.

2.4 Site Requirements. [A.2.4]

Four soil types are established from properly substantiated geotechnical data. In locations where the soil properties are not known in sufficient detail to determine the soil profile type, soil profile S_3 is to be used. The four soil types help define the maximum value and the frequency content of the effective acceleration response spectrum envelope.

2.5 Site Classification. [A.2.4]

The site definitions and associated coefficients are given in the following table

Table 1. Site coefficients

Type	Description	S
S_1	A soil profile with either: (a) A rock-like material characterized by a shear-wave velocity greater than 750 m/s, or (b) stiff or dense soil condition where the soil depth is less than 60 m of stable sands, gravel or hard clay characterized by a shear-wave velocity greater or equal to 400 m/s.	1.0
S_2	A soil profile with either: (a) stiff or dense soil conditions, where the soil depth exceeds 60 m or more, characterized by a shear-wave velocity greater or equal to 400 m/s, or (b) stiff, very stiff or medium dense soil conditions, where the soil depth is less than 60 m, characterized by a shear-wave velocity greater or equal to 400 m/s.	1.2
S_3	A soil profile containing less than 12 m in thickness of soft clays imbedded in a deposit of soft to medium clay characterized by a shear-wave velocity between 150 and 270 m/s.	1.5
S_4	A soil profile, characterized by a shear wave velocity less than 150 m/s, containing more than 12 m of soft clay or cohesionless soil.	2.0

2.6 Peak Ground Accelerations (Horizontal and Vertical).

As stated in (2.2) [A.2.5] the EPA is used in lieu of peak ground accelerations. The vertical component of ground motion is defined by scaling the corresponding adjusted horizontal accelerations by a factor of two-thirds, [A.2.8]. The following map shows the distribution of EPA according to a regionalization which further breaks down the proposed seismic zonation presented in (2.1). Also, Table 2 shows the relation between seismic hazard zone and the assigned EPA.

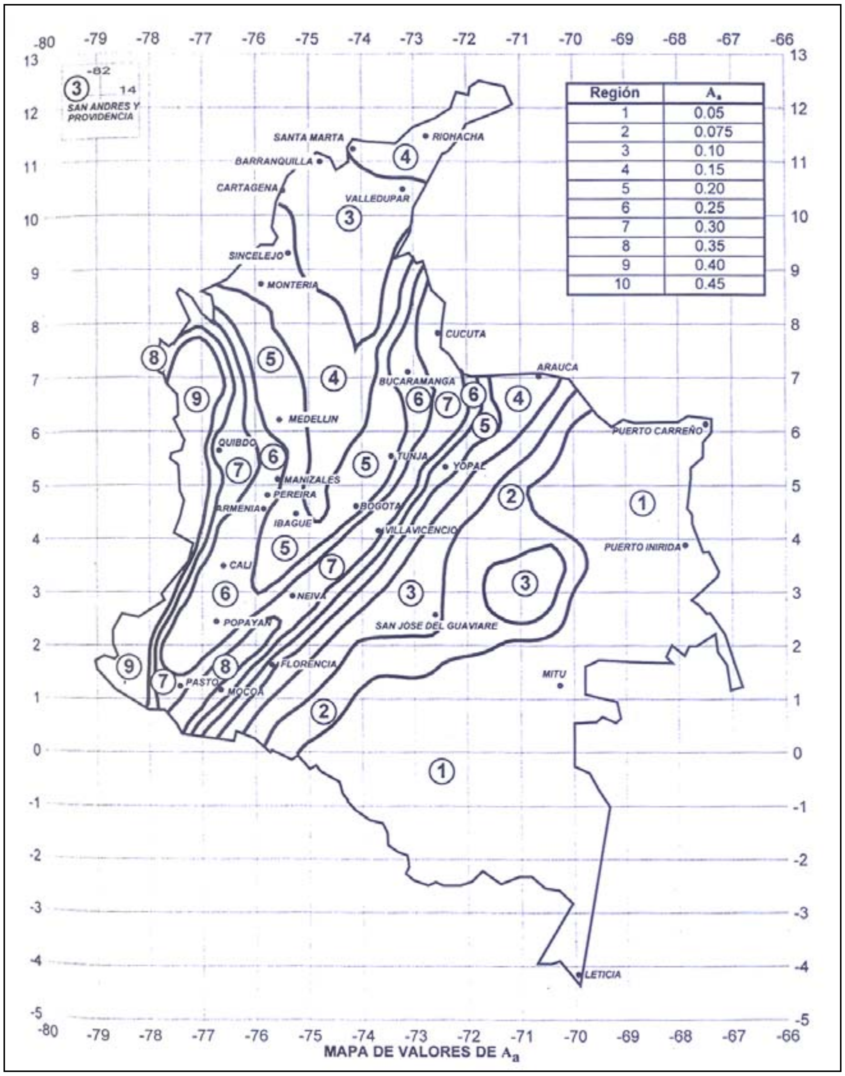


Figure A.2-2 EPA values for Colombia.
Please note that EPA level 10 is not assigned to any region.

Table 2. A_a value and Seismic Hazard Level		
Region	**A_a**	**Seismic Hazard Zone**
10	0.45	High
9	0.40	High
8	0.35	High
7	0.30	High
6	0.25	High
5	0.20	Intermediate
4	0.15	Intermediate
3	0.10	Low
2	0.075	Low
1	0.05	Low

3. PARAMETERS FOR STRUCTURAL CLASSIFICATION

3.1 Occupancy and Importance. [A.2.5]

Four categories are defined. IV Essential Facilities Occupancy (I = 1.3); III Emergency and Relief Services Facilities Occupancy ; II Special Occupancy Structures (I = 1.1); I Standard Occupancy Structure (I = 1.0) that include the following:

Table 3. Occupancy Categories

Occupancy Categories		Occupancy Type or Function of Structure
IV	**Essential Facilities**	Hospitals and other medical facilities having surgery, and emergency treatment areas; structures and equipment in communication centers and other facilities required for emergency response; tanks or other structures containing, housing, or supporting water or other fire-suppression materials or equipment required for the protection of essential or hazardous facilities, or special occupancy structures; structures and equipment in emergency preparedness centers; stand-by power generating equipment for essential facilities.
III	**Special Occupancy Structures**	Emergency vehicle and equipment shelters and garages; fire and police stations; all facilities so designated by the municipali administration.
II		Covered structures whose primary occupancy is public assembly—capacity more than 3000 persons; buildings for schools (through secondary) or day-care centers—capacity more than 200 students; buildings for colleges or adult education schools— capacity more than 200 students; all structures with occupancy more than 2000 persons; stores and shopping centers of more than 500 m^2 per story; all governmental buildings.
I	**Standard Occupancy Structures**	All structures having occupancies or functions not listed above.

3.2 Structural Systems. [A.3.2]

Four structural systems are defined and an R_0 value is assigned to each. This R_0 value is a system quality factor that identifies the acceptable level of inelastic deformation demand. Also, height limitations H are assigned to each system. Drift limitations are not stated as a function of the structural type but only as a function of the construction material. The four structural systems are: a) Moment Resisting Frame; b) Dual; c) Building Frame (Shear Walls or Braced Frames); and Combined. The Dual System is a system where moment resisting frames are used together with shear walls or braced frames. The Combined system is defined as a system in which lateral loads are resisted by shear walls or braced frames and the vertical loads are carried by non special frame**.** Height limitation of 72 m is given for buildings in High Seismic Hazard Zone for shear walls and combined systems. No limits are imposed for Dual systems. Also, rules are given for the combination, both in plan and elevation, of the different structural systems previously defined.

3.3 Structural Regularity: [A.3.3]

Plan and Vertical. Defines regularity not only as a function of the physical continuity but also the nature, dimensions and localization of both structural and non-structural elements that could affect the response of the building to seismic actions. When a structure is deemed as irregular, a reduction of the R coefficient is requested according to

$$R = \phi_a \phi_p R_0$$

where the first coefficient ϕ_a ranges between 0.8 and 0.9 and applies to irregularities in elevation and the second coefficient ϕ_p also ranges between 0.8 and 0.9 and applies to plan irregularities.

3.4 Structural Redundancy.

Not explicitly considered.

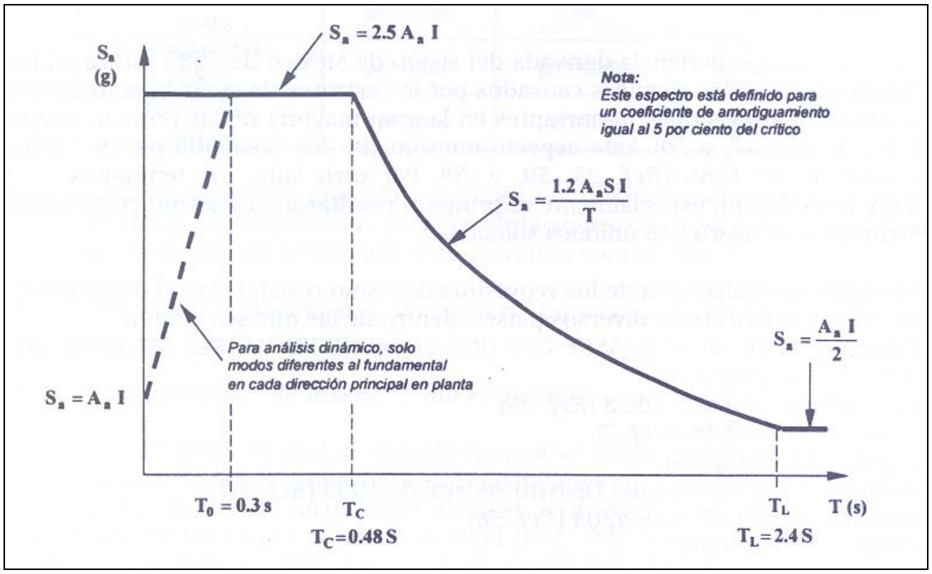
3.5 Ductility of elements and components. [A.3.2]

Special (**SMRF**), Intermediate (**IMRF**) and Ordinary (**ORMF**) Moment Resisting Frames are prescribed. Special and Intermediate have ductility requirements given in the specific chapters for each construction material. Special Moment Resisting Frames are the ones that provide the highest ductility because of the more stringent detailing requirements.

4. SEISMIC ACTIONS

4.1 Elastic Response Spectra (Horizontal and Vertical). [A.2.6]

The seismic actions are defined in terms of the mass and stiffness of the structure, according to the plot shown below. Three methods are given for the numerical calculations. In the first method an elastic response spectra is defined and a prescription is given for an Equivalent Horizontal Force procedure. In the second method, a procedure for an elastic dynamic analysis is given. The third method is a procedure for an inelastic dynamic analysis. The response spectra defined in the first procedure is intended to represent a minimum requirement for structures that satisfy the following conditions:



1) All buildings, regular and irregular, located in Low Seismic Hazard Zones.
2) All buildings, regular and irregular, belonging to occupancy group I and located in Intermediate Seismic Hazard Zones.
3) Regular structures under 20 stories or 60 m in height with lateral force resistance provided by systems listed in the table of section [A.3.2] except for structures located in soil site S_4 which have a period greater than 0.7 seconds.
4) Irregular structures not more than 6 stories or 18 m in height.
5) Flexible structures supported by more rigid structures that comply with requirements specified in [A.3.2.4.3].

The Equivalent Horizontal Force method consists of the definition of a Design Base Shear that is later distributed along the height of the structure. The Design Base Shear is defined as $V_s = S_a Mg$, where *M* is the mass of the total seismic dead load plus the instantaneous live load, and S_a is the seismic coefficient to be determined by the following equation

$$S_a = \frac{1.2 A_a SI}{T}$$

where $T_C < T < T_L$, A_a is defined in section (2.6) and *S* is defined in (Table 1) and *I* is the importance factor associated with the occupancy categories. For $T_C \leq 0.48S$, it is established that $S_a = 2.5 A_a I$, and for $T_L \geq 2.4S$, it is established that $S_a = 0.5 A_a I$. The Design Base Shear is the minimum base shear that all buildings must satisfy regardless of the method of analysis chosen.

The vertical elastic response spectra are defined by scaling the corresponding adjusted horizontal response spectra by a factor of two-thirds.

4.2 Design Spectra. [A.2.6]

The Design Spectra are defined in terms of the Elastic Response Spectra and the corresponding R_0 coefficients assigned for each structural system as given in [Table A.3-1].

4.3 Representation of acceleration time histories. [A.5.5]

Ground motion time histories developed for the specific site are accepted as a ground motion representation for the dynamic analysis (second method, section (4.1) above) if its response spectra lies within 80% of the elastic response spectra discussed above in section (4.1). No provisions are stated for the probability of exceedance in 50 years for the chosen ground motions or for the geologic, tectonic, seismologic, and soil characteristics associated with the site.

4.4 Design Ground Displacement.

The design ground displacement is not explicitly considered.

5. DESIGN FORCES, METHODS OF ANALYSIS AND DRIFT LIMITATIONS

5.1 Load Combinations including Orthogonal Seismic Load Effects.

The provisions only address the determination of the seismic actions by means of the determination of lateral forces in the simplified design and horizontal and vertical forces for the dynamic analysis. The orthogonal effects are addressed in section [A.3.6.3]. In that section, provisions are made for the consideration of the effects of earthquake motions acting in directions other than parallel to the direction of resistance under consideration when a) the structure has plan irregularity Type 5P as given in [Table A.3.6], b) the structure has plan irregularity Type 1P as given in [Table A.3.6] for both major axes or c) a column of a structure forms part of two or more intersecting lateral force resisting systems. The requirement that orthogonal effects be considered are satisfied if the structural elements are designed for 100 percent of the prescribed seismic forces in one direction plus 30 percent of the prescribed forces in the perpendicular direction. The combination requiring the greater component strength is then be used for design. Alternatively, the two orthogonal directions may be combined on the SRSS basis.

5.2 Simplified Analysis and Design Procedures.

Simplified analysis and design procedures are provided for one or two-story residential buildings.

5.3 Static Method Procedures.

An Equivalent Horizontal Force procedure is provided in (4.1) [Chapter A.4] above. The total force is distributed over the height of the structure in conformance with the following relations

$$F_x = C_{vx} V_s$$

$$C_{vx} = \frac{m_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k}$$

where k is related to the value of T so that for $T \le 0.5\text{s}, k = 1.0$, for $0.5 < T < 2.5\text{s}, k = 0.75 + 0.5T$ and for $T > 2.5\text{s}, k = 2.0$. The value of *T* use here may approximated by $T = C_t \left(h_n\right)^{3/4}$, where C_t is defined for different building materials and h_n is the height above the base to level *n*.

5.4 Mode Superposition Methods. [Chap A.5]

Required whenever the Equivalent Horizontal Force procedure is not allowed. Number of modes should include at least 90 percent of the participating mass of the structure. Modal combination is to be performed using established procedures in order to estimate resultant maximum values. No specific combination rule is mentioned. For 3D analysis, modal interaction effects are to be considered when combining modal maxima. Again, no specific rules are mentioned.

5.5 Non-Linear Methods. [A.5.5]

Elastic and inelastic time history dynamic analysis are permitted. When the base shear resulting from applying this method is less than the one obtained from section (4.1) above it is to be increased to 100 percent of this value for irregular structures and to 80 percent for regular structures.

5.6 Torsional considerations. [A.3.6.7]

Requires the consideration of accidental torsion rising from uncertainties in location of loads (5 percent of building dimension). Recommends the consideration of increased shears resulting from horizontal torsion where diaphragms are not flexible. Where torsional irregularity exists (plan irregularity types 1P and 3P as defined in [Table A.3.6] the effects are accounted for by increasing the accidental torsion at each level by an amplification factor, A_x, that depends on the maximum displacement at level *x* relative to the average of the displacements at extreme positions of the building at that level but is not taken larger than a factor of three.

5.7 Drift Limitations. [Chap A.6]

Story drift is calculated as the summation of three components: horizontal displacement of the center of mass, the additional displacements due to torsional effects and P-Delta effects. Calculated story drift is not to exceed 1.0% of the story height for all buildings except for those constructed with masonry, in which case, the limit is 0.5%.

5.8 Soil-Structure Interaction Considerations. [Chap A.7]

Brief guidelines are given for the consideration of soil-structure interaction.

6. SAFETY VERIFICATIONS

6.1 Building Separation.

All structures are to be separated from adjoining structures by a distance sufficient to avoid contact under deflection from seismic motion. Separation shall allow for the displacement due to design seismic forces as specified in [A.6.2.1].

6.2 Requirements for Horizontal Diaphragms. [A.3.6.8]

Floor and roof diaphragms are required to be designed to resist the forces determined by

$$F_{px} = \frac{\sum_{i=x}^{n} F_i}{\sum_{i=x}^{n} m_i} m_{px}$$

where the force F_{px} need not exceed 0.75 $AIgm_{px}$ nor be less than 0.35 $AIgm_{px}$. When the diaphragm is required to transfer lateral forces from the vertical resisting elements above the diaphragm to other vertical resisting elements below the diaphragm due to offset in the placement of the elements or to changes in stiffness in the vertical elements, these forces shall be added to those determined for F_{px} above.

6.3 Requirements for Foundations.

It is required in [A.3.6.9] that the strength and stiffness of the framing between the base and the foundation is not less than that of the superstructure. The special detailing requirements of the Titles that govern materials specifications apply to columns supporting the lateral force resisting elements and to frame system elements below the base. The foundation is to be capable of transmitting the design base shear and the overturning forces defined as Equivalent Horizontal Forces in section (4.1) from the structure into the supporting soil, but the short term dynamic nature of the loads may be taken into account in establishing the soil properties.

6.4 P-Δ Considerations. [A.6.2.4]

P-Δ effects on story shears and moments, the resulting member forces and moments, and the story drifts induced by these effects are not required to be considered when the stability coefficient (Q_i) as determined by the following equation is equal to or less than 0.10:

$$Q_i = \frac{P_i \Delta_{cm}}{V_i h_{pi}}$$

where P_i is the total vertical design load at and above level *i*, Δ_{cm} is the design story drift occurring simultaneously with V_i, V_i is the seismic shear force acting at level *i* and all levels above it, h_{pi} is the story height between level *i* and the level immediately below. An upper limit for the stability criteria is given by $Q_{i,\max} \le 0.30$ above which the structure is potentially unstable and shall be redesigned.

6.5 Non-Structural Components. [Chap A.7]

Requirements are given in the form of a simplified design seismic force for parts and portions of structures and their attachments, permanent non-structural components and their attachments, and the attachments for permanent equipment supported by a structure. The total lateral design seismic force, $F_p = AIC_pW_p$ where C_p is defined in Table 8, *A* and *I* are defined according to section (4.1).

Table 8 Horizontal Force Factor C_p

Elements of Structures and Non-Structural Components		C_p	Note
I	Part or Portion of Structure		
	1. Walls, including the following:		
	a. Unbraced (cantilevered) parapets	2.00	
	b. Other exterior walls above the ground floor	0.75	
	2. Penthouses (except where framed by an extension of the building frame)	0.75	
II	Non-Structural Components	0.75	
	1. *Tapiales*		
	2. Exterior and interior ornamentations and appendages	2.00	
	3. Chimneys, stacks, trussed towers, and tanks on legs:		
	a. Supported on or projecting as an unbraced cantilever above the roof more than one-half its total height	2.00	
	b. All others, including those supported below the roof with unbraced projection above the roof less than one-half its height, or braced or guyed to the structural frame at or above their centers of mass	0.75	
	3. Signs and billboards	2.00	
	4. Storage racks (include contents)	0.75	
	5. Anchorage for permanent floor-supported cabinets and book stacks more than 1.5 m in height (include contents)	0.75	
	6. Anchorage for suspended ceilings and light fixtures	0.75	*
	7. Access floor systems	0.75	
III	Equipment		
	1. Tanks and vessels (include contents), including support systems and anchorage	0.75	
	2. Electrical, mechanical, and plumbing equipment, and associated conduit, duct work and piping, and machinery	0.75	

*For the determination of the seismic force the weight should be taken as not less than 20 kg/m^2.

6.6 Provisions for Base Isolation.

No provisions are made for Base Isolation.

7. SMALL RESIDENTIAL BUILDINGS [Title E]

Provisions are given for one and two-story residential buildings. The provisions are prescriptive and cover foundations, structural walls made from concrete masonry blocks, confining elements (columns), flooring systems, roofing, partitions and parapets.

8. PROVISIONS FOR EXISTING BUILDINGS [Chap A.10]

Provisions are given for buildings constructed before the present Norm was approved. It gives the basic guidelines that must be followed when evaluating the vulnerability of existing structures. It also gives the guidelines to follow for the case in which the existing building is going to be renovated.

RECOMMENDATIONS FOR CODE IMPROVEMENT

The present evaluation has shown to the author that the present norm is very thorough and complete. The fact that it was based in the state of the art up to 1997 does not diminish it validity. Quite the contrary, the code writers have done such an extensive review of the literature available that the document could probably be used directly as a model code for some of the midsize countries in South and Central America. Therefore, the code is deemed appropriate. Also, it should be noted that provisions have been made by the code writing authorities to set up a protocol for the periodical renewal of the norm. It is further pointed out that some of the members of the code writing body in Colombia are also active members of the international organizations used as reference, such as the ACI International and the *fib*. The wind code provisions are included in this norm as merely a chapter within Title B for Loadings. These provisions do need refurbishing since they are based on little supporting data and studies performed more than 20 years ago by the power industry in Colombia. Therefore it is recommended that the current chapter dealing with this type of loading be improved.