SEISMIC CODE EVALUATION

NICARAGUA

Evaluation conducted by Guillermo Santana

NAME OF DOCUMENT: "Reglamento de Construcción que regirá el Territorio Nacional" (*Construction Regulation that will govern in the National Territory*)

YEAR: 1983

GENERAL REMARKS: Document elaborated by a technical committee under the supervision of the Ministry of Housing and Human Settlements of the Government of National Reconstruction of the Republic of Nicaragua.

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. [Art. 1]

The norm applies to the design and construction of new buildings, as well as to the repair and retrofitting of existing facilities. It includes load prescriptions for earthquake, wind and even volcanic ash deposition, with the associated zoning.

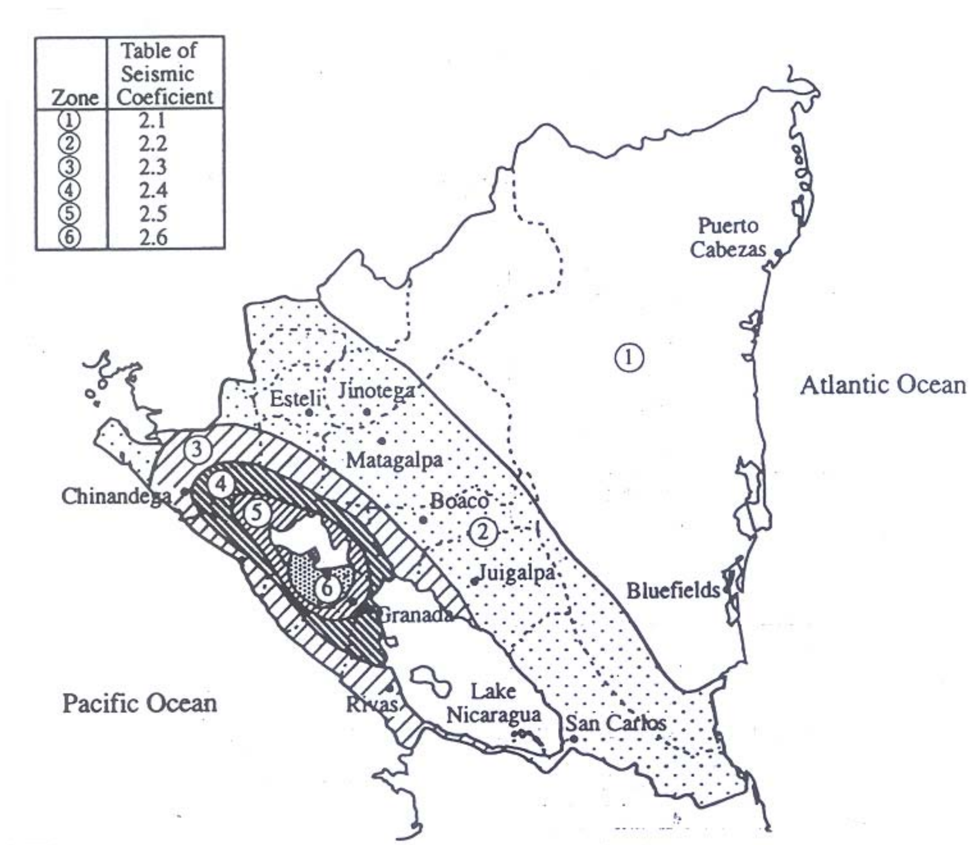
1.2 Performance Objectives. [Art. 1]

The performance objectives are stated as a) to avoid the loss of lives and to reduce the possibility of physical damages to persons; b) to resist smaller earthquakes without damages; c) to resist moderate earthquakes with mild structural damages and moderate non structural damages; d) to avoid the collapse of buildings due to large earthquake, reducing the damages at economically admissible levels and e) to resist wind effects and other accidental actions without damage.

2. SEISMIC ZONING AND SITE CHARACTERIZATION

2.1 Seismic Zoning (Quality of Data). [Art. 22]

The country is divided into six seismic zones. The lowest level is assigned to the northeastern half of the country. This area, shown in the map below, covers 80 percent of the Caribbean coastline and all the lowlands of that region. The other half of the country is divided into the additional five zones, which increase in intensity as it surrounds the Lake of Managua and the capital city of the same name. The map is a derivation of the one proposed in A Study of Seismic Risk for Nicaragua conducted in 1975 by the John Blume Earthquake Center at Stanford University, California, USA. This study was contracted after the devastating December 23, 1972 earthquake centered under Managua that killed over 8,000 people. Considerable attention is paid to that event. It is of particular interest to note that the subduction zone is not deemed as a more severe earthquake source in this proposed zonation. Another important fact is that most of the population was located in zones 5 and 6 at the time of publication of this document. Other important events have taken place after the publication of this document as is the case of the 1992 earthquake and tsunami that affected Rivas, near the Costa Rican border, shown in the map.



2.2 Levels of Seismic Intensity. [Art. 11]

Three levels of seismic intensity are considered. Although not explicitly stated, a normal occupancy is assigned a group (seismic intensity) level II, special occupancy is named group I and assigned a variable increase on the intensity depending on zonation (21% to 45%, where the higher the hazard the lower the increase). Group II includes essential and hazardous facilities. Finally, group III includes isolated structures, warehouses, barns, silos and similar facilities. They are assigned a reduction factor that ranges between

85 and 91% of the value given for group II. These factors are presented implicitly in [Tables 9 to 14].

2.3 Near Fault considerations.

No near-fault considerations are provided in this document.

2.4 Site Requirements. [Art. 23]

Three soil types are established. Soft, medium and hard soil definitions are given in terms of depth of strata and number of blows *N*. In locations where the soil properties are not known in sufficient detail to determine the soil profile type, medium soil profile is to be used. For sites prone to liquefaction, the use of the soil types defined in [Art. 23] in not permitted. The three soil types help define the frequency content of the acceleration response spectrum envelope.

2.5 Site Classification. [Art. 23]

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

Table 1. Site coefficients

Type	Description
Hard	A soil profile with either: (a) Rock of any type, hard and sound or soft or meteorized, or (b) stiff or dense soil condition where the soil depth is less than 60 m, $N > 50$ for cohesionless soil and $N > 30$ for cohesive soil.
Medium	A soil profile where the soil depth exceeds 60 m with either: (a) sand or gravel of medium to high compaction ($21 > N > 50$), or (b) silts and/or clay medium stiff to stiff ($9 > N > 30$).
Soft	A soil profile containing 10 m in thickness of either: (a) soft- to medium-stiff clays with or without intervening layers of cohesionless or cohesive soils ($2 < N < 8$) (b) loose to firm cohesionless soils ($0 < N < 20$)

2.6 Peak Ground Accelerations (Horizontal and Vertical). [Art. 22]

Horizontal peak ground accelerations are defined in terms of the *C* coefficient presented in [Tables 9 through 14], as a function of type of structure, occupancy and quality of construction [Tables 1 & 2]. Peak accelerations range from 0.026*g* in Zone 1 to 0.452*g* in Zone 6 for normal occupancy. The vertical component of ground motion is not considered in these regulations.

3. PARAMETERS FOR STRUCTURAL CLASSIFICATION

3.1 Occupancy and Importance. [Art. 11]

Three categories are defined. I Essential/Hazardous Facilities and Special Occupancy ($1.21 < I < 1.45$); II Standard Occupancy Structures ($I = 1.0$); III Miscellaneous Occupancy Structures ($0.84 < I < 0.91$) that include the following:

Table 3. Occupancy Groups		
Occupancy Groups		**Occupancy Type or Function of Structure**
I	**Essential/Hazardous Facilities and Special Occupancy**	Hospitals and other medical facilities having surgery, and emergency treatment areas or large medical supplies storage facilities; fire and police stations; 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; public markets; waste water treatment plants; power-generating plants, including transmission lines and substations; local and national government buildings; jails; stadiums; structures and equipment in communication centers and other facilities required for emergency response; radio broadcasting stations; structures housing, supporting or containing sufficient quantities of toxic, explosive or radioactive substances; high occupancy buildings intended for public assembly; buildings for schools or day-care centers; museums; air and ground transportation terminals; libraries; structures housing especially costly items.
II	**Standard Occupancy Structures**	High occupancy buildings intended for public assembly (Churches, Movie Cinemas; Auditoriums; Marketplaces); Low frequency high occupancy buildings like: Hotels, Office Buildings; Factories; Banks, Commercial Buildings; Restaurants; Dwellings; Outpatient Health Facilities; Motor Vehicle Service Stations. All other structures whose collapse may endanger structures listed in groups I or II.
III	**Miscellaneous Occupancy Structures**	All isolated structures not classified in any of the previous groups such as warehouses, commercial structures under 100 m^2, repair shops, stables, silos, posts, fences. All other structures whose collapse will not endanger structures listed in groups I or II.

3.2 Structural Systems. [Art 12]

Five structural systems are defined and a *K* value is assigned to each. This *K* value is a *system quality factor* that identifies the acceptable level of inelastic deformation demand. Also, height limitations specified as limits on the number of stories are assigned to each system.

Table 4. Structural Types		
Structural Type	**Lateral Force Resisting System —Description**	***K***
1	Only ductile moment resisting frames.	0.67
2	Combined ductile moment resisting frames and shear walls.	0.80
3	Combined non-ductile moment resisting frames and shear walls.	1.00
4	One or two-story structures made of shear walls.	1.17
5	Only shear walls or braced frames.	1.33
6	All structures not classified as types 1 through 5.	1.67
7	Elevated tanks.	2.00

3.3 Structural Regularity: [Art 10, 14, 30 and 39]

Article 10 states that, as a condition for improvement of the seismic performance of buildings, symmetry in mass and stiffness distributions and avoidance of abrupt changes in lateral resistance should be taken into consideration. Later on, in [Art. 14], symmetry requirements are used to assign a grade to each structural system as defined in [Table 1]. Structural regularity is defined at the bottom of [Table 1] as follows: *Symmetric* (*sic*) when the eccentricity is equal or less than 10%, *Regular Symmetry* (*sic*) when the eccentricity is between 10 and 20%. [Art. 30] defines eccentricity limits for the consideration of torsional effects when using the static equivalent method. [Art. 39] establishes a procedure for the consideration of abrupt changes in lateral resistance only as a reduction in the allowable design stresses.

3.4 Structural Redundancy.

Not explicitly considered.

3.5 Ductility of elements and components.

[Art. 10, 12, 35] [Art. 10] states as a conceptual guideline that design should be based on ductility considerations in order to warrant better structural performance. Later on, [Art. 12] states that special ductility requirements apply to reinforced concrete moment resisting frames for **Zone 6**. Also, [Art. 35] provides guidelines for the determination of design forces for elements and joints of structural types 2 and 3 according to ultimate strength design. The document does not give any reference for the ductility requirements for specific construction materials.

4. SEISMIC ACTIONS

4.1 Elastic Response Spectra (Horizontal and Vertical).

The seismic actions are defined in terms of the mass and stiffness of the structure. Three methods are given for the numerical calculations. These are the simplified method [Art. 29], the equivalent static method [Art. 30] and the dynamic method [Art. 31]. Elastic response spectra are defined for both the equivalent static and the dynamic methods of analysis. In the first case, a reduction factor $D = \left(\lambda / T\right)^{0.5}$, where λ is 0.5 for medium and hard soils, for T > 0.5 s. and 0.8 for soft soils, for T > 0.8 s, is prescribed as a modification factor for the set of seismic coefficients C given in [Tables 9 to 14]. For the second case, a further linear reduction in the seismic coefficient C is applied to structures with period T less than 0.1 s. so that the coefficient is ultimately reduced to one half for T = 0. These coefficients represent the upper value for the seismic forces as a function of seismic zone, occupancy, structural type and grade.

4.2 Design Spectra. [Art. 33]

The Design Spectra are defined in terms of the value d_T which is a function of coefficients K and D defined in [Art. 12] and [Art. 23] respectively. This relationship is given as $K = D / d_T$ and it follows the recommendations given in the seismic risk study for Nicaragua mentioned in (2.1).

4.3 Representation of acceleration time histories.

Acceleration time histories not explicitly considered.

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.

Load Combinations are given in [Art. 32] as:

a) Ultimate Strength Design.

$$C_1^u = 1.7\left(CM + CV\right)$$

$$C_2^u = \left(CM + CV\right) + S \text{ o } P$$

$$C_3^u = 0.8CM + S$$

b) Allowable Stress Design.

$$C_1^e = CM + CV$$

$$C_2^e = CM + CV + 0.71S \text{ o } P$$

$$C_3^e = 0.80CM + 0.71S$$

where *CM* = Dead load
CV = *Live load*
S = Horizontal seismic action
P = Wind pressure or force

Orthogonal Seismic Load Effects are considered in [Art. 25] where it is stated that for structural types 1, 2 and 3, vertical elements and its foundations must be designed for 100% of the effect in one direction plus 30% of the vertical load due to seismic action in the orthogonal direction. For structural type 7 and all similar structures must be designed for 100% of the effect in one direction plus 50% of the vertical load due to seismic action in the orthogonal direction.

5.2 Simplified Analysis and Design Procedures.

A simplified analysis procedure is stated in [Art. 29] for buildings of less than 12 m in height. Also, the building must comply with the following: a) for each level, at least 75% of the vertical loads shall be carried by walls joined together by rigid diaphragms, where the walls may be built of reinforced concrete, confined masonry or reinforced masonry, according to the corresponding construction material specifications; b) for each level and each direction of analysis, there should exist at least two parallel or nearly parallel walls (forming an angle of less than 20°), where the joint between each wall and the rigid diaphragm should cover at least 50% of the length of the building in the direction of the walls, also, these walls should be not differ more than 70% lengthwise, be made of the same material and be located in opposing sides; c) the height to smallest base dimension should not exceed 1.5; d) the base length to width ratio should not be more than 2.0, except in cases when for seismic purposes, the structure may be considered as constituted by separate modules that satisfy this condition as well as the requirements of [Art. 29]; e) wood structures of up to 6 m in height, with flexible diaphragms that comply with the Technical Guidelines (Normas Técnicas) issued by the Ministry of Housing and Human Settlements of the Government of Reconstruction of Nicaragua.

5.3 Static Method Procedures.

A Static Equivalent Method is prescribed in [Art. 30]. The total force is distributed over the height of the structure in conformance with the following relations, for the *i*th level

$$F_i = \alpha \frac{W_i h_i}{\sum_{i=1}^{n} W_i h_i} S$$

for the top level

$$F_n = \frac{W_n h_n}{\sum_{i=1}^{n} W_i h_i} \alpha S + (1-\alpha) S$$

$\alpha = 1$ when $T \leq 0.5$ s.
$\alpha = 0.95$ when $0.5 \leq T \leq 1.0$ s.
$\alpha = 0.90$ when $T \geq 1.0$ s.

$$S_i = \sum_{j=i}^{n} F_j$$

where:

- α = Coefficient for shear force distribution along height of the building.
- F_i = Horizontal force applied at the *i*th level.
- h_i = Height of the *i*th level measured from the base.
- W_i = Weight of the *i*th floor calculated according to [Art. 32].

5.4 Mode Superposition Methods. [Art. 31]

It is required whenever the Static Equivalent Method is not allowed. Number of modes should be at least three or all modes whose modal period exceeds 0.4 s. Modal combination is to be performed using the square root of the sum of the squares procedure (SRSS) in order to estimate resultant maximum values.

5.5 Non-Linear Methods.

Non-Linear Methods are not prescribed in this document.

5.6 Torsional considerations. [Art. 30]

It is required as part of the Static Equivalent Method and it may not be less than an accidental torsion rising from uncertainties in location of loads (5 percent of building dimension).

5.7 Drift Limitations. [Art. 34]

Story drift is calculated as $\delta' = d_T\delta$ where δ is the horizontal displacement of the center of mass obtained by elastic analysis without consideration of torsion and using the coefficient d_T assigned for each structural type listed in Art. 34 and reproduced below

Tipo	K	d_t
1	0.67	3.00
2	0.80	2.50
3	1.00	2.00
4	1.17	1.70
5	1.33	1.50
6	1.67	1.20
7	2.00	1.00

Calculated story drift is not to exceed the values given in the following table, under the provision that the windows, façade and other fragile ornaments be placed so as to avoid damage due to distortion.

Allowable Story Drift	
Type of Building	**Drift Limitation**
Masonry structure	0.003*h*
Concrete structure	0.006*h*
Steel structure	0.009*h*
h is the inter-story height	

5.8 Soil-Structure Interaction Considerations.

No consideration is made of soil-structure interaction.

6. SAFETY VERIFICATIONS

6.1 Building Separation. [Art. 38]

All structures are to be separated from adjoining structures by a distance equal to 5 cm at each level i, but not less than $4\delta'$ calculated with respect to the base and where δ' is taken in accordance with [Art. 34].

6.2 Requirements for Horizontal Diaphragms. [Art. 6 & 12]

Floor and roof diaphragms are required to comply with the following condition:

$$F = \frac{\Delta_w \times 10^6}{2.2qL} \leq 1.0$$

where F is the stiffness factor of the core of the diaphragm, Δ_w is the deflection due to shear applied on the core of the diaphragm in cm, q is the average shear on the diaphragm in kg/m over a length *L*. For reinforced concrete slabs it is possible to apply the following formula:

$$F = \frac{7.5 \times 10^6}{t\sqrt{W^3 f_c'}} \leq 1.0$$

where *t* is the thickness of the slab in cm, *W* is the weight of the concrete in kg/m³ but larger than 1450 kg/m³, f_c' is the concrete compression strength at 28 days in kg/cm², and *F* is the stiffness factor in micro-cm/m of clear length and for unit shear in kg/m. As stated in (3.2), [Art. 12] defines the different structural types allowed. In here the specific recommendations are made for the use of flexible versus rigid diaphragms. Flexible diaphragms are allowed for structural type 1 only for buildings of up to 3 stories with the proviso that the ductile frames be designed for lateral forces calculated using tributary width per frame. For structural type 2, flexible diaphragms for buildings or up to 3 stories is also permitted with the proviso that there be at least one wall connected to the frames in each axis of each floor of the building and also designing for lateral forces calculated considering the tributary width. Type 3 requires rigid diaphragms, although it is not clear from the definition whether for buildings of up to 3 it is permitted to use flexible diaphragms with the above mentioned proviso. Type 4 clearly allows the use of flexible diaphragms and finally, type 5 clearly states that the this type of structure shall have rigid diaphragms.

6.3 Requirements for Foundations. [Art. 37]

This article gives a recommendation for the design of foundations that is not substantiated by any sort of numerical analysis. It simply states that the design should prevent differential settlements specially in soils of low bearing capacity. Reference is made to a companion document entitled Normas Técnicas para Fundaciones that this reviewer has not had access to for this evaluation.

6.4 P-Δ Considerations.

P-Δ effects are explicitly considered in this norm.

6.5 Non-Structural Components. [Art. 36]

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, $F_P = C_P W_P$ where C_p is defined in [Art. 36] and a table of minimum values is also provided in the same article.

6.6 Provisions for Base Isolation.

No provisions are made for Base Isolation.

7. SMALL RESIDENTIAL BUILDINGS

Small residential buildings are considered in this document as those consisting of Structural Type 4 lateral resisting systems [Art. 12]. According to [Art. 28] this type of buildings can be analyzed using the *simplified method* [Art. 29]. No consideration is given to torsion, overturning moment nor drift for this method of analysis.

8. PROVISIONS FOR EXISTING BUILDINGS

Provisions are given for existing buildings only in as much as it requires that any retrofitting made should comply with the same level of forces prescribed for new buildings which is obviously too high for most existing facilities. Also, provisions are made for the assignment of limited ductility for existing buildings that are being retrofitted.

RECOMMENDATIONS FOR CODE IMPROVEMENT

High praise should be given to the code writing committee in Nicaragua for producing this document under very difficult conditions back in 1983. However the present evaluation has revealed that the current Nicaraguan provisions need to be updated quickly. No commentary sections is included and attempt to provide background information is given in the form of Observations at the end of Chapter IV where an example of calculation of lateral forces is presented. This clearly belongs in a Commentary section that is unfortunately lacking. On the positive side, one must take notice of the fact that this Norm includes provisions for small residential facilities and also considers loads due to ash depositions coming from volcanic activity. This feature is lacking in all Central American documents consulted.