

SEISMIC CODE EVALUATION

EL SALVADOR

Evaluation conducted by Guillermo Santana

NAME OF DOCUMENT: "Norma Técnica para Diseño por Sismo" (*Technical Standard for Seismic Design*)

YEAR: 1994

GENERAL REMARKS: Document elaborated by a technical committee under the supervision of the Ministry of Public Works. Replaces the Seismic Design Emergency Regulations of the Republic of El Salvador promulgated in 1989 and it is part of larger document entitled Regulations for the Structural Safety of Constructions in El Salvador.

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. [1.2.1]

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 although associated documents in the Regulations for the Structural Safety of Constructions in El Salvador provide guidelines for structural concrete and steel.

1.2 Performance Objectives.

No specific performance objectives are given.

2. SEISMIC ZONING AND SITE CHARACTERIZATION

2.1 Seismic Zoning (Quality of Data). [3.2]

The country is divided in two seismic zones along a northwest to southeast line parallel to the Pacific coastline and about 70 km away from it, that goes

from San Antonio Pajonal in the Guatemala border to Goascorán river in the Honduras border. Zone I is assigned a factor of 0.40 and runs between the coast line and the internal division. Zone II is assigned a factor of 0.30.



2.2 Levels of Seismic Intensity. [3.4]

Three levels of seismic intensity are considered. Although not explicitly stated, a normal occupancy is assigned a seismic intensity level, special occupancy is assigned a 20% increase on the intensity and essential and hazardous facilities are assigned a 50% increase on the seismic intensity. One apparently major source document, the SEAOC 1990 Blue Book, states that a 0.40 factor like the one assigned to Zone I 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. Although the document states in its commentary that rather than increasing the intensity to such high levels the details of design and construction often dominate seismic performance, it does not explicitly allow for the use of lower levels when providing additional energy dissipation capacity, redundancy in lateral force resisting systems, special detailing for damage control and construction quality assurance.

2.3 Near Fault considerations.

No near-fault considerations are provided in this document.

2.4 Site Requirements. [3.3]

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. At larger depths than the limits established in each and every category soil profile type $S_1(a)$ 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. [3.3]

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

Type	Description	C_0	T_0
S₁	A soil profile with either: (a) A rock-like material characterized by a shear-wave velocity greater than 500 m/s, or (b) stiff or dense soil condition where the soil depth is less than 30 m.	2.5	0.3
S₂	A soil profile with either: (a) stiff or dense soil conditions, where the soil depth exceeds 30 m or more, or (b) stiff, very stiff or medium dense soil conditions, where the soil depth is less than 30 m.	2.75	0.5
S₃	A soil profile containing 4 to 12 m in thickness of soft- to medium-stiff clays with or without intervening layers of cohesionless soils	3.0	0.6
S₄	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.	3.0	0.9

2.6 Peak Ground Accelerations (Horizontal and Vertical).

As stated in (2.2) [3.2] 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. [5.2] The following table is presented as a comparison of the variation of the Design Coefficient C_sR for all soil types included in this document. It is very similar to the one proposed in the NEHRP 1991 Edition of the Recommended Provisions for the Development of Seismic Regulations for New Buildings which is listed as one of the sources.

Soil type	Zone I	Zone II
S₁	1	.75
S₂	1.1	.825
S₃	1.2	.9
S₄	1.2	.9

3. PARAMETERS FOR STRUCTURAL CLASSIFICATION

3.1 Occupancy and Importance. [3.4]

Three categories are defined. I Essential and Hazardous Facilities ($I = 1.5$); II Special Occupancy Structures ($I = 1.2$); III Standard Occupancy Structure ($I = 1.0$) that include the following:

Occupancy Categories	Occupancy Type or Function of Structure
I Essential and Hazardous Facilities	Hospitals and other medical facilities having surgery, and emergency treatment areas; 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; emergency vehicle and equipment shelters and garages; structures and equipment in emergency preparedness centers; stand-by power generating equipment for essential facilities; structures and equipment in communication centers and other facilities required for emergency response; structures housing, supporting or containing sufficient quantities of toxic or explosive substances to be dangerous to the safety of the general public if released.
II	Special Occupancy Structures	Covered structures whose primary occupancy is public assembly—capacity more than 200 persons or more than 3000 m ² ; 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; medical facilities not included above; buildings of more than 4 stories or more than 1000 m ² per story; museums; monuments; transportation terminals; all structures with occupancy more than 2000 persons; structures housing especially costly equipment; warehouses of more than 10 m in height or 500 m ² per story.
III	Standard Occupancy Structures	All structures having occupancies or functions not listed above.

3.2 Structural Systems. [3.6]

Five structural systems are defined and an R value is assigned to each. This R value is a system quality factor that identifies the acceptable level of inelastic deformation demand. Also, height limitations H and drift factors C_d are assigned to each system. The difference in the R and C_d values reflects the presence of over strength in the different systems.

Basic Structural System	Lateral Force Resisting System —Description	C_d	R	H
A (Moment Resisting Frame)	Steel Special Moment Resisting Frames (SMRF)	8	12	N.L.
	Concrete Intermediate Moment Resisting Frames (IMRF)	5	5	15
	Steel Ordinary Moment Resisting Frames (OMRF)	6	7	30
B (Building Frame)	Shear Walls			
	a. Concrete	7	8	50
	b. Masonry	6	7	35
	Braced Frames (steel)			
	a. Eccentrically braced (EBF)	6	10	50
b. Concentrically braced (CBF)	7	8	50	
C (Dual) Moment resisting frames shall be designed to independently resist at least 25 percent of the base shear	Shear Walls (concrete)			
	a. With SMRF (steel or concrete)	9	12	N.L.
	b. With IMRF (concrete) or with OMRF (steel)	7	8	N.L.
	Shear Walls (masonry)			
	a. With SMRF (steel or concrete)	6	7	50
	b. With IMRF (concrete) or with OMRF (steel)	5	6	30
	Braced Frames			
a. EBF with SMRF (steel or concrete)	6	12	N.L.	
b. CBF with SMRF (steel or concrete)	7	10	N.L.	
D (Bearing Wall)	Shear Walls			
	a. Concrete	6	7	35
	b. Masonry	5	6	25
	Steel Braced Frames	5	6	50
E (Undefined)	Inverted Pendulum	3	3	
	Distributed Mass	4	4	

3.3 Structural Regularity: [3.5]

Plan and Vertical. Defines regular structures as those having no significant physical discontinuities in plan or vertical configuration or in their lateral force resisting systems. The criteria for determining Vertical or Plan irregularities is summarized in the following two tables:

Table 5. Vertical Structural Irregularities	
Irregularity Type and Definition	
A	Stiffness Irregularity — Soft Story
	A soft story is one in which the lateral stiffness is less than 70 percent of that in the story immediately above or less than 80 percent of the average stiffness of the three stories above.
B	Weight (mass) Irregularity
	Mass irregularity shall be considered to exist where the effective mass of any story is more than 150 percent of the effective mass of an adjacent story. A roof which is lighter than the floor below need not be considered a mass irregularity.
C	Vertical Geometric Irregularity
	Vertical geometric irregularity shall be considered to exist where the horizontal dimension of the lateral force resisting system in any story is more than 130 percent of that in an adjacent story. One-story penthouses need not be considered.
D	In-Plane Discontinuity in Vertical Lateral Force Resisting Element
	An in-plane offset of the lateral load resisting elements greater than the length of those elements.
E	Discontinuity in Capacity — Weak Story
	A weak story is one in which the story strength is less than 80 percent of that in the story above. The story strength is the total strength of all seismic resisting elements sharing the story shear for the direction under consideration.

Table 6. Plan Structural Irregularities	
Irregularity Type and Definition	
A	Torsional Irregularity, to be considered when diaphragms are not flexible.
	Torsional irregularity shall be considered to exist when the maximum story drift, computed including accidental torsion, at one end of the structure transverse to an axis is more than 1.2 times the average of the story drifts of the two ends of the structure.
B	Reentrant Corners
	Plan configurations of a structure and its lateral force resisting system contain reentrant corners, where both projections of the structure beyond a reentrant corner are greater than 15 percent of the plan dimension of the structure in the given direction.
C	Diaphragm Discontinuity
	Diaphragms with abrupt discontinuities or variations in stiffness, including those having cutout or open areas greater than 50 percent of the gross enclosed area of the diaphragm.
D	Out-of-Plane Offsets
	Discontinuities in a lateral force path, such as out-of-plane offsets of the vertical elements.
E	Nonparallel Systems
	The vertical lateral load resisting elements are nor parallel to nor symmetric about the major orthogonal axes of the lateral force resisting system.

3.4 Structural Redundancy.

Not explicitly considered.

3.5 Ductility of elements and components. [3.6]

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 details during construction.

4. SEISMIC ACTIONS

4.1 Elastic Response Spectra (Horizontal and Vertical). [4.2]

The seismic actions are defined in terms of the mass and stiffness of the structure. Two methods are given for the numerical calculations. In the first method an elastic response spectra is defined and a prescription is given for a Static Lateral Force procedure. In the second method, a procedure for a dynamic analysis is given. The response spectra defined in the first procedure is intended to represent a minimum requirement for structures that satisfy the following conditions:

- 1) Regular structures under 70 m in height with lateral force resistance provided by systems listed in the table of section (3.2) except for structures located in soil site S_4 which have a period greater than 0.7 seconds.
- 2) Irregular structures not more than 5 stories nor 20 m in height.
- 3) Structures having a stiffness, weight or geometric vertical irregularity of Type A, B, or C as defined in Table 5, section (3.3) or structures having irregular features not described in either Table 5 or 6 that comply with section [3.8.1].

The Static Lateral Force 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 $V = C_s W$, where W is the total seismic dead load plus the instantaneous live load, and C_s is the seismic coefficient to be determined by the following equation

$$C_s = \frac{AIC_0}{R} \left(\frac{T_0}{T} \right)^{2/3}$$

Where $T_0 < T < 6T_0$, C_0 is defined in section (2.5) and A corresponds to 0.4 for Zone I and 0.3 for Zone II and I is the importance factor associated with the occupancy categories. The R factor was referred to above, see section (3.2), and it identifies the acceptable level of inelastic deformation demand. For the elastic response spectra, $R = 1$ and the maximum value then is equal to C_0 as given in the table presented in section (2.5) above. Observe then that the maximum seismic coefficient allowed is dependent on the site characteristics. The minimum seismic coefficient allowed is 0.303 of the maximum.

The vertical elastic response spectra is defined by scaling the corresponding adjusted horizontal response spectra by a factor of two-thirds. Alternative factors may be used if substantiated by site-specific data.

4.2 Design Spectra. [4.2]

The Design Spectra are defined in terms of the R coefficients assigned for each structural system as given in Table 4, section (3.2).

4.3 Representation of acceleration time histories. [5.2]

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 it has a 10 percent probability of exceedance in 50 years and is based on 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.

Neither the 1994 nor the 1989 provisions give explicitly the load combinations to use for the seismic resistant design of structures for El Salvador. 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 load combinations are left to the particular provisions for the different construction materials to be used. No modifications to any of the referred provisions (ACI 318, etc.) are stated. The orthogonal effects are addressed in section [6.1.4]. 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 E as given in Table 6, b) the structure has plan irregularity Type A as given in Table 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 SRSS or CQC basis.

5.2 Simplified Analysis and Design Procedures.

Simplified analysis and design procedures are not stated explicitly. Somewhat simplified design procedures are given for non-building structures and for elements of structures and non-structural components supported by structures.

5.3 Static Method Procedures.

A Static Lateral Force procedure is explained in section (4.1) [4.2] above. The total force is distributed over the height of the structure in conformance with the following relations

$$V = F_t + \sum_{i=1}^n F_i$$
$$F_t = 0.07TV$$
$$F_x = \frac{(V - F_t)w_x h_x}{\sum_{i=1}^n w_i h_i}$$

where F_t is a concentrated force at the top, which is in addition to F_n . The value of T use here may approximated by $T = C_t (h_n)^{3/4}$, 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. [5.4]

Required whenever the Static Lateral 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. [5.4.2]

Step by step inelastic time history dynamic analysis is permitted. When the base shear resulting from applying this method is less than the one obtained from section [4.2] (see section (4.1) above) it is to be increased to 100 percent of this value for irregular structures and to 90 percent for regular structures.

5.6 Torsional considerations. [4.4.4] & [5.4.1]

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 type A as defined in Table 6 above) 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. [4.6]

Story drift is calculated as $\delta_x = C_d \delta_{xe}$ by using the C_d coefficient assigned for each structural system in Table 4 and where δ_{xe} is the horizontal displacement of the center of mass obtained by elastic analysis. Calculated story drift is not to exceed the values given in Table 7. Drift is incremented by the $P-\Delta$ effect when necessary.

Table 7. Allowable Story Drift Δ_a^*			
Type of Building	Occupancy Categories		
	I	II	III
Structural steel building without any equipment attached to it nor fragile finishing	$0.015h_{sx}$	$0.020h_{sx}$	N.L.**
Buildings four stories or less and without fragile finishing	$0.010h_{sx}$	$0.015h_{sx}$	$0.020h_{sx}$
All other buildings	$0.010h_{sx}$	$0.015h_{sx}$	$0.015h_{sx}$

* h_{sx} story height below level x

**N.L. = no limit

5.8 Soil-Structure Interaction Considerations.

No consideration is made 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 C_d times the displacement due to design seismic forces as specified in [6.2.6].

6.2 Requirements for Horizontal Diaphragms.

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

$$F_{px} = \left(\frac{F_t + \sum_{i=x}^n F_i}{\sum_{i=x}^n w_i} \right) w_{px}$$

where the force F_{px} need not exceed $0.75 A/w_{px}$ nor be less than $0.35 A/w_{px}$. 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. [6.2.4].

6.3 Requirements for Foundations.

It is recommended in [6.2.5] 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 companion document Normas Técnicas de Diseño y Construcción (that governs materials specifications for structural concrete and steel) apply to columns supporting discontinuous 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 Minimum Static Lateral 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.

P-Δ effects [4.7] on story shears and moments, the resulting member and moments, and the story drifts induced by these effects are not required to be considered when the stability coefficient (θ) as determined by the following equation is equal to or less than 0.10:

$$\theta = \frac{P_x \Delta}{V_x h_{sx} C_d}$$

where P_x is the total vertical design load at and above level x , Δ is the design story drift occurring simultaneously with V_x , V_x is the seismic shear force acting between level x and $x-1$, h_{sx} is the story height below level x , and C_d is the deflection amplification factor defined in Table 4. An upper limit for the stability criteria is given by $\theta_{\max} = 0.5/\beta C_d \leq 0.25$ above which the structure is potentially unstable and shall be redesigned.

6.5 Non-Structural Components.

Requirements [Chapter 7] 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, $F_p = AIC_p W_p$ where C_p is defined in Table 8, A and I are defined according to section (4.1).

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. <i>Tapiales</i>		
	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/m².

6.6 Provisions for Base Isolation.

No provisions are made for Base Isolation.

7. SMALL RESIDENTIAL BUILDINGS

Even though the 1989 Reglamento de Emergencia de Diseño Sísmico de la República de El Salvador (*Emergency Provisions for Seismic Design*) had a chapter for simplified prescriptive design of small residential buildings, they were dropped in the 1994 Provisions being evaluated.

8. PROVISIONS FOR EXISTING BUILDINGS

No provisions are given for existing buildings.

RECOMMENDATIONS FOR CODE IMPROVEMENT

The present evaluation has revealed the incredible amount of effort by the Salvadorian Code writing committee in updating their standards to the state of the art in 1994. Important sources from México and the United States were consulted and adjusted to the Central American environment. Although more sources could have been included in the final version, it is understandable that the natural area of influence of both México and the United States played a role on the final writing of the standard. Some of the shortcomings in the 1990 SEAOC Blue Book are reproduced in the present document. No load combination equations are stated in the document, which is a possible cause of major problems in the application of the standard.

It is recommended that the standard be updated to the current state of the art. Also, it is recommended that two major additions be made to the present document: a) simplified design rules for one or two family dwellings and b) provisions for existing buildings. Finally, although outside the scope of the present analysis, it is recommended that an enforcing agency be found or created so that loss of life and infrastructure is not repeated as it was in January and February 13, 2001.