THE NEW VENEZUELAN CODE FOR EARTHQUAKE RESISTANT BUILDINGS

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SUMMARY

This paper presents a synthesis of the innovating aspects included in the New Venezuelan Building Code. Its applicability is limited to resistant systems whose behavior can be classifed by type, i.e. the system's resisting elements must also satisfy pre-established codes for design which permits to consider ductility in an explicit form. A zoning map and response spectra based on a probabilistic evaluation of seismic hazard is included. The selection of the method of analysis is conditioned by the irregularity of the structural configuration. Specifications for retaining walls and slopes are also included.

INTRODUCTION

As a consequence of the 1967 Caracas earthquake a provisional code was promulgated in order to update the 1955 code in force. Both codes were established by the Ministry of Public Works (MOP) Structural Code Commission and were extensively used as a nation wide design criteria. In 1980 the Venezuelan Foundation for Seismological Research (FUNVISIS), designated to revise the provisional code, nominated a Technical Committee formed by the authors of this paper in order to prepare a first draft. This was presented at the III Vene - zuelan Conference in Earthquake Engineering (1981), revised by an extended commission and finally approved in 1982 (Ref. 1). The code has a temporary character and will be subjected to revision and changes during one year; during this period, allowance is made to use either the 1967 code or the new version here commented. The latter is in good measure the outcome of research done at the Institute of Materiales and Structural Models (IMME) of the Universidad Central de Venezuela and at FUNVISIS, together with ideas and experiences of local Structural Engineers. The prescriptions and recommendations of the codes and bodies such as the Applied Technology Council (ATC) have been of paramount influence in specific areas of the code.

SEISMIC ZONING AND CODE IMPLEMENTATION

Figure 1 shows the new seismic zoning map of the country, where A_o represents the zero period spectral acceleration; values for each zone have been determined on a probabilistic basis and selected in such a way that exceedence in a 50 year period is less than about 15%. Attention is called to the fact that more than 75% of the population and a large part of the economical activity of the country takes place inside seismic zones 4 and 3. Regions located close to

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dams higher than 80 meters are excluded from this seismic zoning and should be subjected to specific studies. The authority responsible for issuing construction and occupation permits is the Office of Municipal Engineering, a community body generally nominated on political grounds. It places responsability for complying with code provisions in the hands of the Structural Engineer who undersigns the project. Municipal Engineers are supposed to check computations and drawings and the construction supervision is performed by experienced engineers under direct contracts. Since Earthquake Engineering is not yet an obliged subjected among undergraduate pensa of most of the universities, the necessity is felt that either Municipal Engineers acquire specialized training in order to adequately evaluate projects or this evaluation be encharged to highly experienced and trained professionals.

SCOPE AND GENERAL PRINCIPLES

The applicability of the code prescriptions is limited to earthquake resistant systems whose expected post-yield behaviour under earthquake-type loading, can somehow be idealized and typified. This hypothesis is admitedly valid due to the fact that the system's resisting elements and their connections also satisfy standardized design criteria; these contain explicit considerations as far as strains exceed yielding. Prefabricated buildings and special structures such as power plants, dams, bridges, transmission lines, electrical and mechanical equipment, etc., are excluded from the code. The proposed methods of analysis assume the existance of an in-plane rigid floor that distributes the shear forces among the resistance lines of the building. Buildings falling outside the code's structural typification should be designed according to the general principles on which it is based.

DESIGN LEVELS AND DUCTILITY FACTORS

Structural behaviour under reversible strain patterns exceeding yielding is conditioned by the structural materials used, the criteria chosen for the design of structural members and joints, as well as reinforcement details. Three design levels (DL) are accepted in the code: DL-1 in which no-special design prescriptions are required for earthquake type actions; DL-2 requires the application of certain prescriptions leading to a reasonable protection against premature brittle failure; DL-3 implies a full set of standardized verifications minimizing the probability of brittle failure and strength deterioration, equivalent to ACI 318-83 Appendix A recommendations. Expected toughness depends on DL. This fact, clearly stated in the commentaries of the code, has permited the treatment of ductility in an explicit form. The allowable ductility factors for each resistant system to be used in the determination of code design spectra, depend on the design level according to Table 1: I, II, III, IV, are buildings having moment-resisting frames, dual, shear walls, and single element systems, respectively. Use of DL-2 is limited according to Table 2. The importance factor (α) also shown in Table 2, is included to allow for an increase in the seismic action on essential facilities; this should be interpreted as prescribing ground movements with a smaller probability of exceedence.

DESIGN SPECTRA

The code considers three types of generalized soil conditions. For each of them normalized acceleration response spectra are given in the form shown in Figure 2. These are smoothed 5% damping spectral mean values derived from a statistical analysis of a sample of more than 100 actual accelerograms recorded on different soil conditions. Period T* and exponent p were chosen to take into account uncertainties in spectral shapes and in natural period values. The design spectra are obtained dividing the elastic response spectra by the reduction factor R, which is expressed as a function of the ductility factor and the natural period as indicated in Figure 2. The reduction factor decreases with period values less than 0.15 sec.; for larger periods the reduction factor is equal to the ductility factor. The base shear coefficient C is obtained from the static or dynamic analysis of each building. A minimum coefficient of $\alpha A_o/6$ is required for building design; for typical buildings in zone 4 this implies a 5% minimum design value.

METHODS OF ANALYSIS

The prescribed methods of analysis are defined to attain similar risk levels against collapse for regular or irregular buildings; as less regular is the building configuration in plan or vertically, more detailed procedures are prescribed as shown in Table 3. Procedure A allows for static analysis to handle traslational (Equivalent Static Force Method) and torsional effects (Equivalent Static Torque Method). A Modal Superposition Method with One Degree of Freedom per Floor is implied in procedure B, combined with Equivalent Static Method. A complete dynamic analysis (Modal Superposition Method with Three Degrees of Freedom per Floor) is required in procedure C. Torsional analysis, static or dynamic, are included in Method A, B and C, to incorporate calculated and accidental eccentricities of shear and stiffness centers, as well as the effects of the rotational component of ground motion. Even for buildings having a regular plan configuration, i.e., no eccentricity of shear force and rigidity center, a full dynamic analysis (Procedure C) is required if the plan dimensions show a substancial increase with height. For ordinary short buildings with a number of stories not greater than three, the Code allows for simplified analysis procedures to determine the design forces. The procedures indicated in Table 3, are the minimum requirements for analysis. Other methods not included in the Code are allowed if they are shown to be adequated.

Equivalent Static Force Method

The equivalent static method of analysis allows for a simple determination of lateral story forces to be applied for a static analysis of the building. This set of lateral forces yield shear story forces that approximate the true dynamic values (Ref. 2). The lateral force at the Kth floor is given by:

$$F_k = (V_o - F_t) W_k h_k / \sum_{j=1}^{N} W_j h_j$$

$$V_o = \mu A_d W; \quad \mu = \text{the greatest of} \begin{cases} \frac{3}{2} \left(\frac{N+1}{2N+1}\right) \\ 0.80 + \frac{1}{20} \left(\frac{T}{T^*} - 1\right) \end{cases}$$

$$F_t = (0.06(T/T^*) - 0.02)\, V_o; \quad 0.06\, V_o < F_t < 0.10\, V_o$$

where V_o is the base shear, F_t is an additional lateral force at the top story, W_k is the story weight, h_k is the story height measured from the basement, A_d is the dimensionless spectral acceleration corresponding to the fundamental period T, T* is a period value defined by the spectral shape (Fig. 2), W is the total building weight and N is the number of stories. The fundamental period T may be estimated from $0.061\ (h_n)^{3/4}$ for moment-resisting frames or from $0.09\ h_n/\sqrt{L}$ for shear walls or dual systems. The base shear V_o and the additional force F_t are calculated including higher mode effects; those are adequately incorporated by the dimensionless parameter T/T* which describes the location of fundamental period on the response spectrum. As larger is T/T*, more modes contribute to the maximum response and V_o and F_t increase. When higher mode effects are neglegible, the base shear depends on the number of stories as indicated in the above equations. Figure 3 shows a comparison between static and dynamic seismic coefficient determined for a group of buildings in Caracas.

Equivalent Static Torque Method

When methods A or B are used, the torsional effect on buildings are taken into account by means of static analysis. In order to get the design forces on frames and walls that make up the lateral force system, the story shear effects should be added to the effects arising from the more unfavorable conditions given by the application of the following torsional moments at each story:

$$T = V(\tau e + 0.1B)$$

$$T = V(\ e - 0.1B)$$

where T=story torsional moment related to stiffness center, V=story shear force, e=eccentricity between shear center and stiffness center, B=plan dimension perpendicular to the shear force direction, τ=dynamic amplification factor, dependent on the stiffness distribution in plan. It becomes 1.5, 3 or 5, by sake of simplicity. For buildings with a significan lateral torsional coupling, the use of $\tau=5$ avoids the need for a full three degrees of freedom per floor dynamic analysis. Accidental eccentricity 0.1B was chosen by means of averaging the eccentricities that take into account: i) a possible error of 0.03B in the e value, and ii) the effects of a torsional ground motion due to shear waves having a horizontal apparent velocity equal to 3 kilometers per second. The procedures for selecting the 0.1B value was to determine the β_1 and β_2 values defined by the equations shown below, so that the torsional moments T1 and T2 yield the maximum and minimum dynamic moments, respectively: $T_1=V(\tau e+\beta_1 B)$ and $T_2=V(\ e+\beta_2 B)$. Some numerical results are shown in Fig. 5.

Modal Superposition Method with One Degree of Freedom Per Floor

The maximum response values are determined from the root-sum-square of the maximum modal responses for buildings with well separated modal frequencies. The number of modes (N1) to be combined is specified in explicit form as a function of the parameter T/T* defined previously, which controls the higher modes demand for the spectral shapes defined in the Code.

$N_1 = 0.5((T/T^*)-1.5)) + 3 \geqslant 3$, for $N < 20$ stories

$N_1 = 0.67((T/T^*)-1.5)) + 4 \geqslant 4$, for $N \geqslant 20$ stories

As indicated in Ref. 3, the use of these equations yield relative errors in response values not greater than 5%. The relative errors in the top shear force obtained from the above criteria for a 20 story building with a fundamental period of 1.5 sec. and different T* values, are shown in Figure 4 as a function of T/T* for two typical spectral shapes. The errors are compared with the ones determined from application of the criteria recommended by the ATC-3-05, which allows three modes to be used in the dynamic analysis. While the ATC criteria yield relative errors which increase steadily for increasing T/T* values, the code criteria give relative errors which are below the 5% value and are approximately independent of the spectrum (T*) considered.

Modal Superposition Method With Three Degrees of Freedom Per Floor

A dynamic analysis by modal superposition considering two horizontal translations and one rotation about a vertical axis is required in this method. The two horizontal ground motion components, each one defined by the design spectrum, are incorporated separately, one at a time. The modal responses are combined considering the coupling effects of modes having close natural frequencies. The minimum number of modes to be combined is 3 N_1, where N_1 is the number of modes required in the simpler method of one degree of freedom per floor. The torsional effects due to variations in the geometry of the system and due to the rotational component of ground motion, are added statically by means of torsional moments in each story given by the product of the story shear multiplied by 0.10 the plan dimension.

ALLOWABLE DISPLACEMENTS

The verification of the allowable displacements of the structure is performed through a drift calculations and the so-called P-Δ effects. The code limits computed drift to 0.018 in ordinary structures and 0.015 in those of special importance. These limits are 0.024 and 0.020 when non-structural elements are tied to the structure in such a way as not to be damaged by structural deformations. Drifts limits are intended to be associated only with frame distortion and not with overall flexure. For better understanding of the previous limits, it should be recalled that design spectra values have a small probability of being exceeded, the drift limits being therefore concerned with prevention of reaching collapse limit states. Control of serviceability limit states, with shorter return periods design values, is not explicitly stated in the Code.

FOUNDATIONS

The chapter dealing with foundations and related systems prescribes general analysis and design requirements. Load combinations are carried out with nominal gravitational loads and the codes seismic load, but the abscence of live loads must be considered. The admissible pressure under seismic loads for surface foundations may be doubled, but must not exceed one half of the soil's bearing capacity. For pile foundations, the resistance to tension must be of special consideration. The dynamic thrust from the soil must be added in the design of retaining walls. The stability of slopes near buildings must be evaluated if minimum safety separations are not met. Lastly, the code requires that the liquefaction potential of soils be studied if these contain layers of not very dense sands under the phreatic level.

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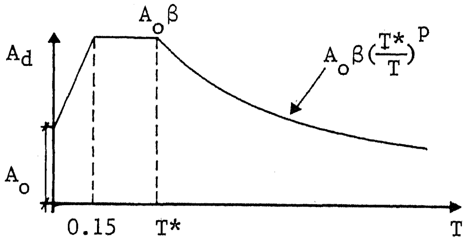
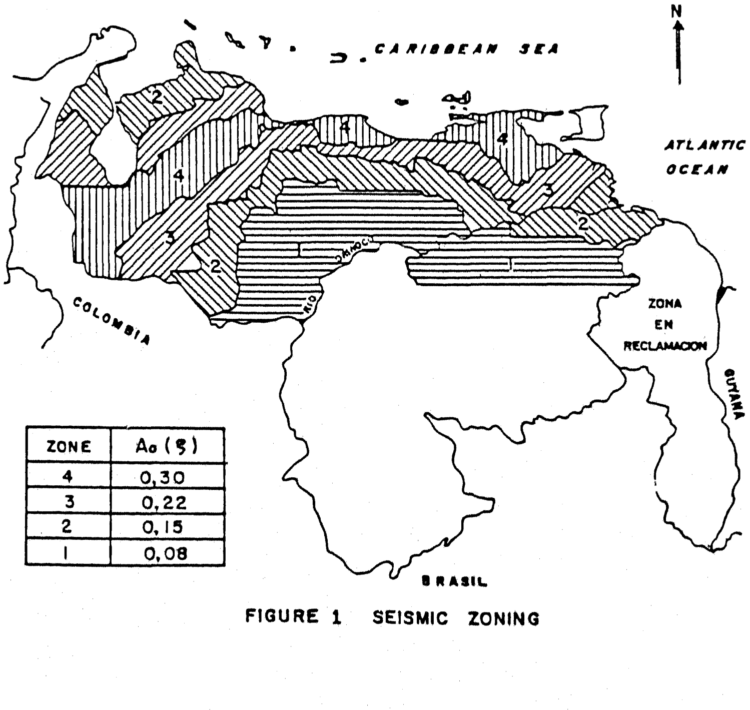
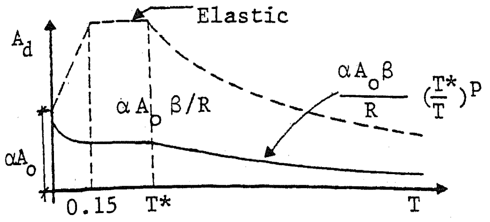




ZONE	A_o (g)
4	0,30
3	0,22
2	0,15
1	0,08

FIGURE 1 SEISMIC ZONING



Generalized soil conditions		β	T* sec.	p
Type	Description (abridged)			
S1	Rock; stiff soils	2.2	0.4	0.8
S2	Deep soil deposits and gravel of intermediate density	2.2	0.6	0.7
S3	Soft soils, lightly dense granular soils	2.0	1.0	0.6

$$R = D \qquad T \geqslant 0.15 \text{ sec.}$$

$$R = 1 + \frac{T}{0.15}(D-1) \qquad T < 0.15 \text{ sec.}$$

FIGURE 2 DESIGN SPECTRA

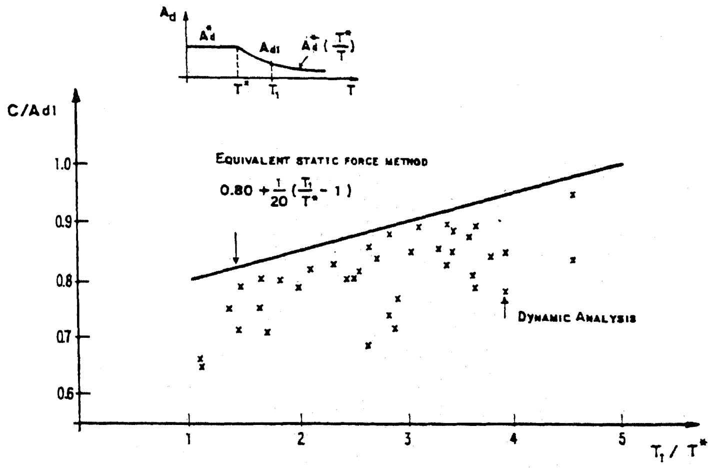


FIGURE 3 SEISMIC COEFFICIENT FROM STATIC AND DYNAMIC ANALYSIS FOR ACTUAL BUILDINGS IN CARACAS

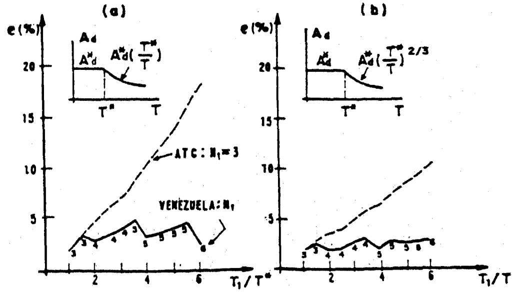


FIGURE 4 RELATIVE ERRORS IN TOP SHEAR FORCE USING THE MINIMUM NUMBER (N_1) OF MODES FOR A 20 STORY BUILDING WITH T_1 = 1.5 sec.

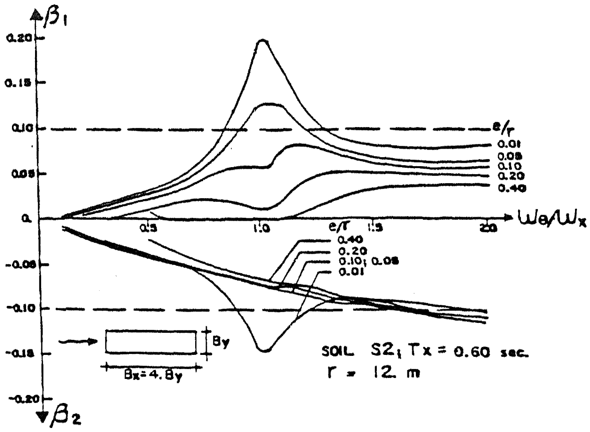


FIGURE 5 ACCIDENTAL ECCENTRICITY FOR ONE-STORY BUILDINGS

TABLE 1 -VALUES OF DUCTILITY FACTOR D

Design Level	Resistant System Type:			
	I	II	III	IV
DL-3	6	5	4	1.5
DL-2	4.5	3.75	3	1.25
DL-1	2.5	2	1.5	1.0

TABLE 2 -ALLOWABLE DESIGN LEVEL

	Importance Factor α	Seismic Zones			
		1	2	3	4
Essential Facilities	1.25	DL-2 DL-3	DL-2 DL-3	DL-3	DL-3
Ordinary Buildings	1.00	DL-1 DL-2 DL-3	DL-2 DL-3	DL-2 DL-3	DL-3

TABLE 3- MINIMUM REQUIREMENTS FOR ANALYSIS

	REGULAR BUILDINGS	IRREGULAR BUILDINGS			
		Irregularity due to :			
		vertical distribution of masses, stiffnesses and strenghts	eccentricity between shear force and stiffness center		significant increase in plan dimensions with height
			> .08 B	> .12 B	
Height ≤ 60 mt and N ≤ 20 stories	A	B	B	C	C
Height > 60 mt or N > 20 stories	B				

3.2 Code Comparison and Analysis