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Fundamentals of the seismic design code of bridges in Venezuela

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ABSTRACT: In this paper the fundamental aspects of the proposed Code of Seismic Bridges Design of the Venezuelan Ministry of Transportation and Communications (MTC) are published. After making a survey among specialist engineers in construction and design of bridges, the objective was to update the map of seismic zonification, to make uniform the design actions and to improve the methods of analysis, the structural conception and the structural and non-structural details.

1 APPLICABILITY AND PHILOSOPHY

In Venezuela, the design of new bridges and the retrofit of existing bridges are under the responsibility of the Ministry of Transportation and Communications (MTC). This code considers conventional concrete and steel bridges with spans not exceeding 150 meters.

In order to take into account the inelastic behavior, enough ductility is given by designing regions of energy dissipation located in points of easy acces to it's restoration. Seismic performance categories SP are defined to account for the seismic zonification, the levels of forces and displacements and the procedures and analysis methods. The bridges can support minor earthquakes in the elastic range, moderate earthquakes with remediable damages and intense earthquakes accepting important damages without collapsing.

2 SEISMIC ZONIFICATION, FACTOR OF IMPORTANCE AND SOIL AMPLIFICATION

The actions depend on the spectral accelerations Ao obtained to ensure a probability of exceedence between 5% and 15% with a design life of 65 years. The map of zonification shown in Figure 1 includes 4 zones Z with the following values of (Ao/g): Z4: 0.400; Z3: 0.300; Z2: 0.200 and Z1: 0.100. The vertical accelerations are taken as 2/3 Ao and the maximum velocities are obtained as Vo = 120 (Ao/g) in cm./sec.

The coefficient of importance α = 1.25 is for essential bridges "A" and α = 1 for the other bridges "B". In Table 1 the design life Td, the return period Tr and the probability of exceedence p, are given. The special bridges and the temporary bridges are mentioned in the commentary of the code.

The soil profiles are S1 (rock and stiff soils), S2 (deep profiles of sands and clays) and S3 (soft soils). These typical profiles have amplification factors β of the spectral accelerations Ao which are: S1: β = 2.5; S2: β = 2.2 and S3: β = 2.0.

Table 1. Coefficient of importance and values of Td (years), Tr (years) and p.

Type	α	Td	Tr	p
Special	1.40	100	1,950	0.05
Essential	1.25	65	617	0.10
Others	1.00	50	308	0.15
Temporary	0.75	30	70	0.30

3 TYPES OF STRUCTURES, DUCTILITY AND RESPONSE MODIFICATION

The energy dissipation capacity is taken into account in the following classification of structures: Type I (Multiple column bents); Type II (Two column bents); Type III (Vertical pile only) and Type IV (Wall-type pier or diagonal bents). The ductility factors

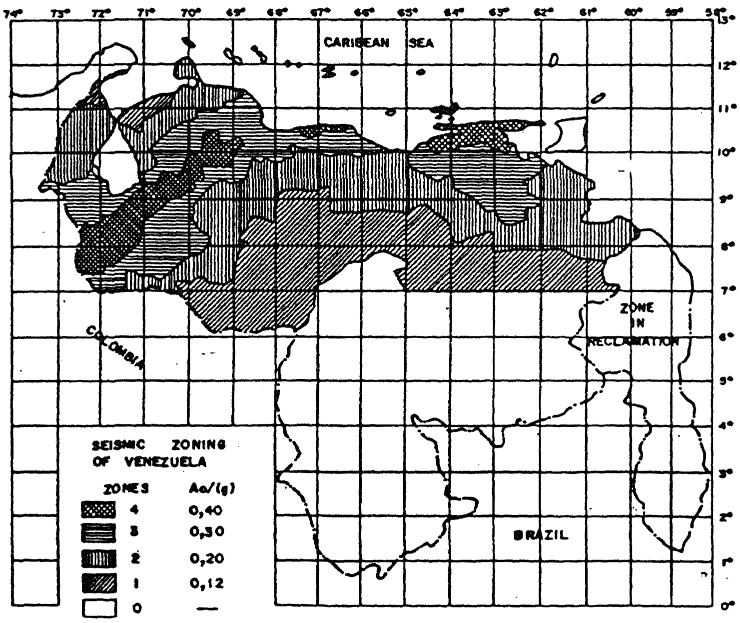

Figure 1. Map of seismic zonification of Venezuela

"D" for each system are given in Table 2.

To obtain the design accelerations, the response modification factors R are applied, according to the following equations:

$$T = 0 \quad ; \quad R = 1 \qquad (1)$$

$$0 < T < T^{*}/4 \quad ; \quad R = 1+(4T/T^{*})(D-1) \qquad (2)$$

$$T > T^{*}/4 \quad ; \quad R = D \qquad (3)$$

where T is the period of the structure and T^{*} the characteristic spectral period, p is the exponent of the spectral descending branch from Table 3. In connections, R = 0.8 in abutments and expansion joints and R = 1 in columns, piers or pile bents.

Table 2. Factors of Ductility D

Categories	Type of Structural System			
	I	II	III	IV
SP3	6	5	5	4
SP2	3	2.5	2.5	2
SP1	1	1	1	1

4. SPECTRAL DESIGN

The spectral design accelerations shown in Figure 2 are defined in following expressions:

Table 3. Characteristic Periods T^{*} and the exponents p.

Soil	S1	S2	S3
T^{*}	0.40	0.65	1.20
p	0.80	0.70	0.60

$$T<T^{*}/4 : Ad = (\alpha Ao/R)\,[1+(4T/T^{*})\,(\beta-1)] \qquad (4)$$

$$T^{*}/4 \le T < T^{*} : Ad = (\alpha\,\beta\,Ao)/R \qquad (5)$$

$$T \ge T^{*} : Ad = (\alpha\,\beta\,Ao/R)\,(T^{*}/T)^{p} \qquad (6)$$

Figure 3 compares the elastic design spectra in stiff soils of this code with the ARS Spectra of Caltrans 77, the New Zealand Code 80, the Japanese Code 80 and the ATC-6-81.

5 CATEGORIES OF SEISMIC PERFORMANCES AND REGULARITY

Following the definition of SP mentioned above and according to the seismic zonification and the importance of bridges, the categories of seismic performances are given in Table 4. For a particular bridge, different SP categories can not be considered.

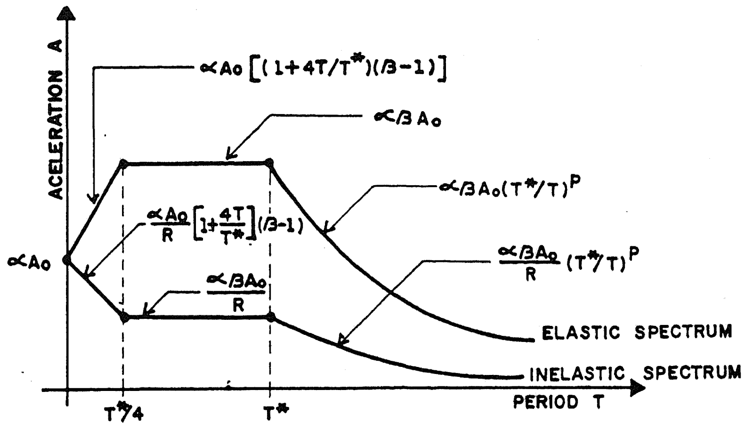

Figure 2. Spectral shapes

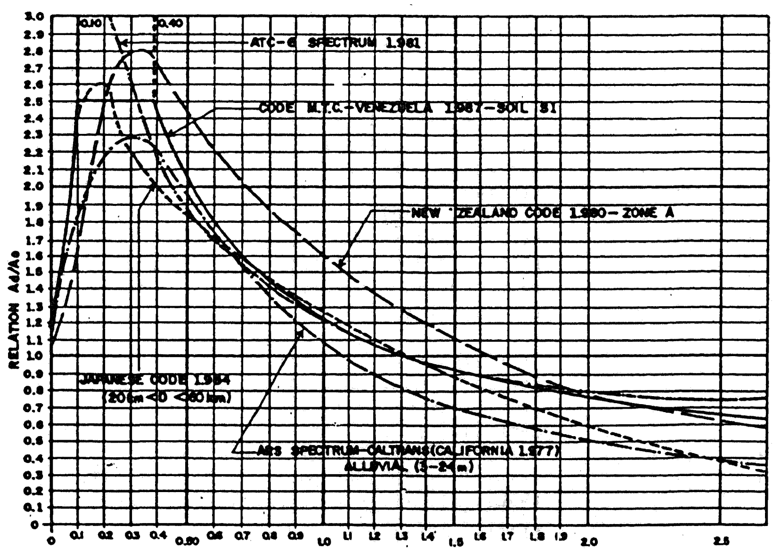

Figure 3. Comparison of spectra design for different codes

Table 4. Categories of Seismic Performance SP

	Seismic Zones			
Importance	1	2	3	4
A	SP1,SP2	SP2,SP3	SP3	SP3
B	SP1,SP2,SP3	SP2,SP3	SP2,SP3	SP3

Bridges are regular when they do not have abrupt changes of geometry, mass and stiffness or the curved bridges when the deflection angle does not exceed 60°. A bridge that does not satisfy the above definition is considered irregular.

6 ACTIONS AND DESIGN DISPLACEMENTS

Bridges of category SP1 and small bridges do not require seismic analysis. For the categories SP2 and SP3 the seismic actions $S_{1,2}$ are obtained by combination of the principal action "1"

with 30 % of the ortogonal action "2"; and is equal to $S_{2,1}$. When the Limit Design Method (LDM) is applied this combination is not necessary.
The case of ultimate load U shall be used in lieu of the loading for Group VII of the AASHTO Code (American Association of State Highway Transportation Officials) in the load factor de-

sign or Resistant Design Method (RDM) as follows:

$$U = f1 (D + B + SF) + f2 (DE + S_{1,2}) \quad (7)$$

where D is dead load, B is buoyancy, SF is stream flow pressure, and DE is dynamic earth pressure. The values of f1 and f2 are specified below.

SP2 and SP3 : f1 = 1.2; f2 = 1 in structural members and connections.
SP2 : f2 = 2 Foundations.
SP3 : f2 = R Foundations.

$$\text{In SP3 : } U = D + R\, S_{1,2} \text{ (Axial Forces)} \quad (8)$$

The minimum bearing support lengths N must correspond with the structural displacements and for this reason, at the face of abutments, piers or expansion joints, the expression (9) and the values indicated in Table 7 must be satisfied.

$$N = a + b\,L + c\,H \quad \text{(mm)} \quad (9)$$

where L is the span of bridge or the length between joints and H the average height of piers, both in meters.

Table 7. Coefficients a, b, c in Equation (9).

Category	a	b	c
SP1	250	10/6	20/3
SP2	300	20/9	80/9
SP3	400	10/4	10

7 METHODS OF ANALYSIS

For the structural analysis of bridges, two methods can be applied: the Equivalent Static Method (ESM) or the Multimodal Dynamic Analysis (MDA) as shown in Table 8. Simple considerations are applied for category SP1. In ESM the static equivalent load is obtained by means of an assumed function of structural deformation according with the support conditions and the joints. To apply MDA, the mathematical model of the bridge should be three-dimensional with members, supports and nodes having six degrees of freedom. This method uses spectral analysis but in special cases time history analysis must be used.

Table 8. Selection of the method of analysis

Category	Regular	Irregular
SP1	---	---
SP2	ESM	ESM
SP3	ESM	MDA

8 DESIGN OF PIERS AND COLUMNS

In order to design reinforced concrete piers, columns and connections in categories SP1 and SP2, the RDM method should be used and in category SP3 as alternative the Limit Design Method (LDM). Moreover, regions of plastic hinges are proposed to avoid premature failures due to shear, compression and bond.

In prestressed concrete, special consideration is given to avoid premature failures of anchorages, the ductility of beams is increased, the tendons are bonded and the ducts are grouted. In categories SP2 and SP3 the design spectral accelerations are increased in 15% to agree with a low damping of 3%. To improve the ductility of beams it is recommended to use partial prestressing, to have compression steel and the minimum mechanical percentage of prestressed steel is limited to 20%.

The spectral accelerations in steel bridges are the same as in prestressed concrete and for categories SP2 and SP3 ductile bents of "special moment" are designed with overstrength plastic moments. To improve the energy dissipation capacity eccentrical diagonals are specified.

9 LATERAL EARTH PRESSURES IN ABUTMENTS

In this chapter the proposed code considers prescriptions for lateral pressure of eart, design forces of abutments, displacements design, stability of slopes in soil or rock, tie walls, reinforced earth walls, settlements of fields and approach slabs.

This code takes the lateral pressure as a supperposition of static and dynamic conditions in state of repose, partially active, active and passive with static pressures factors of Ko, Ki, Ka and Kp as shown below.

$$\text{In repose : } E_{ot} = \tfrac{1}{2}\,\tau\,H^2\,(K_o + 2.0\,A_o) \quad (9)$$

$$\text{In partially active : } E_{it} = \tfrac{1}{2}\,\tau\,H^2\,(K_i + 1.2\,A_o) \quad (10)$$

In active : $E_{at} = \frac{1}{2} \tau H^2 (K_a + 3/8 A_o)$ (11)

In passive: $E_{pt} = \frac{1}{2} \tau H^2 (K_p + 0.7 A_o)$ (12)

Where τ is the unit weight of soil and H is the height of the wall. To simplify the expressions $A_o = 0.40$ and the angle of internal friction $\phi = 30°$ were taken. The equation (11) determines the least lateral pressure and suggests the displacement design with known expressions.

In reference with Ki, this code take into acount the Schlosser expression (1978) :

$H \leq H_o$; $K_i = K_o(1- H/H_o) + K_a(H/H_o)$

$H > H_o$; $H_o = 600$ mm; $K_i = K_a$ (13)

The lateral total force Er in reinforced earth can be obtained as :

$$E_r = \frac{1}{2} \tau H^2 K_o (1 + 1.5 A_d) \quad (14)$$

where the design acceleration Ad is the result of the modal superposition :

$$A_d = f \Sigma \Gamma_m A_{dm} \quad (15)$$

where :

- f = reduction factor for damping (12 % to 20 %)
- Γ_m = modal participation factor of the mode m. When we do not use dynamic analysis to take two modes with $\Gamma_1 = 1.5$ and $\Gamma_2 = 0.5$
- A_{dm} = design spectral acceleration given in equations (4), (5) and (6) corresponding to modal period T_m obtained by the shear beam formulation.

When we do not like permanent deformations it works with Ko and R = 1. If we need permissible displacements to take Ki and R = 2.

To design the stability of slopes this code takes in rock a seismic horizontal coefficient Csh = Ao and a vertical coefficient Csv = 2Ao/3. In soil slopes Csh = 0.5 Ao and Csv = Ao/3.

10 DESIGN OF FOUNDATIONS

To design foundations a major importance to the Soil Investigation Report is given with the main requirements being in category SP3. When the stiffness parameters are obtained by static testing methods a reduction in values of 30% in the dynamic condition are accepted. For shallow foundations the bearing area in tension stress under earthquake condition may be 50%. The methods of analysis for pile foundations are classified in the following types : A) Elastic Tri-dimensional (W. E. Saul, 1968; H.G. Poulos, 1971;..), B) Simplified (A. Vesic, 1977; NavFac, 1974; M. Davisson, 1970;...) and C) Soil-Structure Interaction (L. Reese et al, 1970; L. Zeevaert, 1972; J. Penzien, 1970; JSCE, 1988;...). In Table 9 the method of analysis of piles can be selected according to the categories SP and the soil classification.

Table 9. Selection of Methods of Analysis of Piles

	Seismic Performance Category		
Type of Soil	SP1	SP2	SP3
S1	-	B	A,B,C
S2	B	A,B	A,C
S3	B	A,C	C

11. FINAL COMMENTARIES

This Code was justified by a survey made in year 1986 among specialists engineers in bridges and published in 1988. This Code gives special treatment to supports devices, making emphasis on elastomeric supports, design of joints and structural and non-structural details. Since Venezuela has almost 10,000 bridges in essential and secondary highways, and a program of evaluation and retrofitting is being started by MTC, these standards include a chapter with the methods of primary evaluation, following the ATC-6-2 adapted criteria.

The organization of this code includes twelve chapters and four appendices.

Chapters:

1. Applicability.
2. Design philosophy.
3. Nomenclature and definitions.
4. General requirements.
5. Design spectra.
6. Design requirements.
7. Methods of analysis.
8. Design of piles and columns.
9. Retaining structures.
10. Foundations design.
11. Structural and non-structural details.
12. Evaluation and retrofitting of bridges.

Appendices :

A. Loads and overloads.
B. Small bridges.
C. Special bridges.
D. Applications examples.

12 CONCLUSIONS

Having met with the objective of proposing this standards, it can be concluded that:

a. A free discussion among the specialists will allow us to find a consensus in order to have a final code.

b. The design of new bridges has been improved and the program of revision and reinforcement of existing bridges has been pushed forward.

c. The teaching and investigation of earthquake resistant engineering in the area of bridges in Venezuelan Universities has been improved.

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