DEVELOPMENT OF THE COLOMBIAN SEISMIC CODE

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SUMMARY

This paper describes the development of the earthquake resistant regulations of the Colombian Building Code. These regulations were prepared by the Colombian Association for Earthquake Engineering. Maps of "Effective Peak Acceleration - EPA" and "Effective Peak Velocity - EPV" were prepared for all the country. An evaluation was made of the performance in past earthquakes of the structural systems used in Colombia. Special drift evaluation procedures were introduced. The economic impact of the regulations was determinated through a series of trial designs of several complete buildings in the different seismic zones of the Code.

INTRODUCTION

Since it was founded in 1974 one of the main objectives of the Asociación Colombiana de Ingeniería Sísmica - AIS (Colombian Association for Earthquake Engineering) was the development of a meaningfull set of rules of earthquake resistant design of buildings that eventually could be adopted by the Colombian Government as part of the General Building Code, inexistent at that time. The first step was to translate into Spanish the 1974 SEAOC Requirements (Ref.1). This document (Ref.2) was widely distributed through out the country. The main objective of this translation was to point out the relation between the horizontal forces and the special reinforced concrete requirements. The tendency was then to use the horizontal loads but to ignore the detailing requisites.

In 1979 the Association deemed the ATC-3-06 (Ref.3) document so important for the future development of a local seismic code that a translation of the document into Spanish was undertook. This translation appeared in two different documents, one containing the Tentative Provisions (Ref.4) and the other the Commentary (Ref.5). One month after the translation of the Tentative Provisions appeared, on November 23 of 1979, the central part of Colombia was affected by a 6.4 MS magnitude earthquake, and on December 12 of the same year a 7.8 MS magnitude event occurred in the Pacific Coast of Colombia close to the border with Ecuador. The occurrence of these earthquakes brought out a series of deficiencies of the building practice, both design and construction, with respect to adequacy for seismic forces (Ref.6).

The Association at this point decided to develop a set of regulations for earthquake resistant design and construction. The Committee that wrote the document had the invaluable help of Professor Mete A. Sozen of the University of Illinois. The document was approved as a Standard of the Associ-

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ation by balloting of all its members on February 13, 1981. The Standard was denominated "Norma AIS 100-81, Requisitos Sísmicos Para Edificios" (Ref.7).

The Instituto Colombiano de Normas Técnicas - ICONTEC (Colombian Institute for Technical Standars) had been commissioned by the Colombian Government for the development of the Colombian Building Code. ICONTEC decided to use as earthquake resistant requirements the AIS 100-81 document. It was then decided to make a full revision of the original document incorporating requirements for one and two story dwellings, structural masonry and to use revised versions of the seismic risk maps. This revised document was published as Norma AIS 100-83 and is part of the General Building Code. The General Building Code is denominated Norma ICONTEC 2000 (Ref.8) and it is mandatory in all the Republic of Colombia.

RECENT EARTHQUAKES IN COLOMBIA

The catalog of seismic events for Colombia (Ref.9) contains at the moment this paper is being writen 5338 earthquakes, both historic and instrumental. Of these events three recent earthquakes have had great influence in the Colombian Seismic Code:

November 23, 1979 Earthquake

This 6.4 MS magnitude earthquake (Ref.10) had coordinates 4° 30' N - 75° 54' W and was 80 km deep. It affected the central western part of Colombia, specially the coffee growing region. It caused 37 deaths and 439 injured. There was intensive structural damage and even collapse of several buildings specially in the range of 4 to 6 stories. The cities of Manizalez, Pereira and Armenia were affected. Well designed and constructed buildings behaved very well with minor or no damage at all.

December 12, 1979 Tumaco Earthquake

This earthquake (Ref.10) occurred in the Pacific Ocean close to the Colombian city of Tumaco. (2° 30' N - 79° 30' W) The focal depth was 40 km and the magnitude MS 7.8. In the same zone occurred the January 31, 1906 earthquake that Gutenberg deffined as having magnitude 8.9. The Pacific Coast of Colombia is scarcelly inhabited, in spite of this the combination of earthquake and tsunami caused 453 death and 1047 injured. Due to the low development of the region no significant engineered structures were affected, although some damage was reported in Cali, located 280 km from the epicenter.

March 31, 1983 Popayán Earthquake

This earthquake destroyed one of the most beautiful cities of Colombia, which contained some of the best colonial architecture examples in the country. The earthquake had 5.5 MB magnitude and the epicenter was located 10 km from the city. The focal depth was 5 km. It caused 250 death and 1508 injured. It affected all type of construction (Ref.11). The old colonial part of the city was damaged beyond repair. The earthquake produced intensive damage and several collapses to engineered construction. The buildings affected were in the range of 3 to 5 stories. Two buildings designed and constructed using the AIS 100-81 requirements behaved very well with minor non structural damage.

Behavior of Buildings during these Earthquakes

The following conclusions were drawn of the behavior observed during these earthquakes:

a) The lack of enforcement od a seismic code added to the prevalent misconception that low rise buildings in the range of 3 to 5 stories, need no seismic design, caused the great majority of the structural damage observed. The later misconception developed from the good behavior observed during previous earthquakes of reinforced concrete frames with very stiff and strong masonry infill walls. Unfortunately construction practice have changed and these walls have been either suppresed or changed to wall of very weak tile with the frame now taking all the seismic effect.

b) The great majority of member failures occurred in columns. Lack of proper transverse reinforcement and in some cases low flexural strength causing weak columns compared with strong beams was the cause of the failure. These type of failures again pointed out lack of understanding of the modern earthquake resistant design principles.

c) Excesive flexibility of the frames causing intensive damage of non structural elements. The reasons behind this type of behavior ranged from lack of use of horizontal loads in the design of the structure producing very flexible frames, to non observance of the drift requirements in some cases.

d) Lack of knowledge by architecs and engineers of the type of details that are known to produce bad behavior such as short columns, walls in one direction only, etc. In the Popayán earthquake the damage to unreinforced masonry was intensive.

STRUCTURAL SYSTEMS IN COLOMBIA

The unbraced concrete frame is the most widely used structural system for buildings through out the country. For one and two story family dwellings it is usual to have bearing walls of masonry as the prevalent system. Because of the type of behavior encountered in the unbraced frames a large debate took place in the Committee that developed the Seismic Code whether enphasis should be given to a different structural system and if the Code should be used as a vehicle of change of the prevalent structural system. The previous experience of Venezuela, where after the 1967 Caracas Earthquake very strict drift requirements were imposed in the Venezuelan Building Code, causing a change in the usage of structural systems from unbraced frames to wall type structures.

The evidence that properly designed and constructed structures had behaved well during the previously described earthquakes added to the fact that structural masonry was being used more every day for the type of buildings that had failed made the Committee compromise on introducing strict drift requirements and the inclusion of a complete chapter on reinforced masonry. Besides this an evaluation was performed of typical Colombian buildings using an inelastic step by step computer program (Ref.12) for the level of acceleration obtained in the seismic risk analysis. From this study (Ref.13) it was possible to estimate the ammount of drift and damage for the level of acceleration expected. The response od the structures studied was found adequate with respect to drift and inelastic demand on the reinforced concrete members.

THE AIS 100-83 STANDARD

The general objectives of the AIS 100-83 Standard are common to most seismic codes and are stated as: a building designed using this code should be able to sustain a small earthquake without damage, a moderate earthquake with some damage to non structural elements but without damage to the structure and a severe earthquake without collapse and loos of life. The most important aspects of the Standard are the following:

Seismic Risk and Design Spectra

In 1972 a Seismic Risk Map compatible with the SEAOC Requirements was developed (Ref.14). This Map was corrected in 1978 (Ref.15). It is shown in Figure 1. In 1979 Interconexión Eléctrica S.A. initiated work on a revised catalog of Colombian Earthquakes (Ref.9) with the processing of most of the seismographs recorded in Colombian seismic stations. Besides this seismic risk evaluations were performed for several cities in the country and routinely for the largest hydroelectric proyects being developed. Using the seismic zoning of the Map in Figure 1, which is based in energy release, and the acceleration and velocity values from specific sites, values of Aa and Av were assigned to each seismic zone. The probability of excedance of the values in these maps is ten percent for a fifty year period. The Map of Aa is shown in Figure 2. At the present moment a complete revision of these maps is being performed by the Association with a grant provided by the National Department of Planning, a government agency. This revision will be ready in early 1984.

The Design Spectra used in the code is the same of ATC-3-06 (Ref.3). Unfortunately there are not enough records to develop a response spectra that could be incorporated in the Code. An Importance Factor was introduced in the Spectra that varies from 1.0 to 1.5 depending on the importance of the building for post earthquake recovery. The country was divided into three Seismic Risk Zones depending on the values of Aa and Av. Low Risk for values of Aa or Av under 0.10, Intermediate for values between 0.15 and 0.20 and High for values of 0.25 and higher. The requirements for each zone are different for each construction material.

Design Procedure

The Code has two different design procedures, one is intended for buildings and the other for one and two story dwellings. For buildings the procedure has the following steps: Obtain the values of Aa and Av from the appropriate Map. Define a Seismic Risk Level, either Low, Intermediate or High. For each Seismic Risk Level different analysis and design requirements are given. Depending on the irregularity of the building an analysis procedure is choosen, either the Equivalent Lateral Force Procedure or the Modal Analysis Procedure. The Base Shear is established dividing the spectral value obtained for the period of the building by a Response Modification Factor, R, that varies for each structural system, material and seismic risk level, and multipliying by the weight of the building. With the horizontal forces thus obtained a linear elastic analysis of the structure is performed. The drift is obtained from the elastic deflections amplified by a Deflection Amplification Factor, Cd. This factor also depends of the structural system, material and seismic risk level. If the drift is within the allowable limits the designer should proceed to design the different elements using the appropiate requirements for each seismic risk level. If the drift requirements are not met the structure should be stiffened and reanalized.

The typical Colombian one and two story dwelling is constructed with masonry walls, usually unreinforced. The bad behavior of these structures during the Popayán Earthquake (Ref.11) motivated the Committee to introduce in the AIS 100-83 Edition a full chapter that covers this type of construction. The design procedure for one and two story dwellings is very simple and straith forward with additional requirements for programs that include more than 25 units.

Analysis and Design Requirements

The Code has a complete set of requirements for each Seismic Risk Zone. This set of requirements include restrictions on the type of structural systems permited, the method of analysis that should be used depending on how irregular the structure is. Values for the Response Modification Factor,R, and the Deflection Amplification Factor, Cd, are given with corresponding requirements for Reinforced Concrete, Structural Steel and Structural Masonry.

The requirements for Reinforced Concrete follow the Apendix A of the ACI 318-83 Code (Ref.16). For Low Seismic Risk Zones anly the Code without Apendix A is required, for Intermediate Zones the requirements of Section A.9 of Apendix A are required and for High Seismic Risk Zones the complete Apendix A should be used. The code gives forces at the level of resistance, therefore the load factor for the seismic forces is 1.0. The Masonry Requirements are based in chapter 12.A of ATC-3-06 with suitable modifications for local materials. For types of Masonry different from Hollow Unit the requirements were derived from experience obtained from those that behaved well in the earthquakes mentioned previously.

Cost Impact Evaluation

A Cost Impact Evaluation was performed (Ref.17) for the Code. Two buildings that were considered representative, one a four story apartment building, the other a nine story office building, were designed for four different levels of seismic risk. The buildings were real buildings at the time under construction in Bogotá. The following results were obtained:

	Zone A	Zone B	Zone C	Zone D
Value of Aa	0.00	0.05	0.20	0.30
Value of Av	0.00	0.10	0.20	0.30
Four Story Apartment Building				
kg of steel / m^2 of area	27.50	29.40	31.80	34.40
m^3 of concrete / m^2 of area	0.274	0.276	0.283	0.300
cost of the structure	100 %	103 %	105 %	114 %
total cost of the building	100 %	101 %	101 %	103 %
Nine Story Office Building				
kg of steel / m^2 of area	25.50	27.80	34.30	36.60
m^3 of concrete / m^2 of area	0.228	0.241	0.246	0.267
cost of the structure	100 %	105 %	114 %	122 %
total cost of the building	100 %	102 %	105 %	107 %

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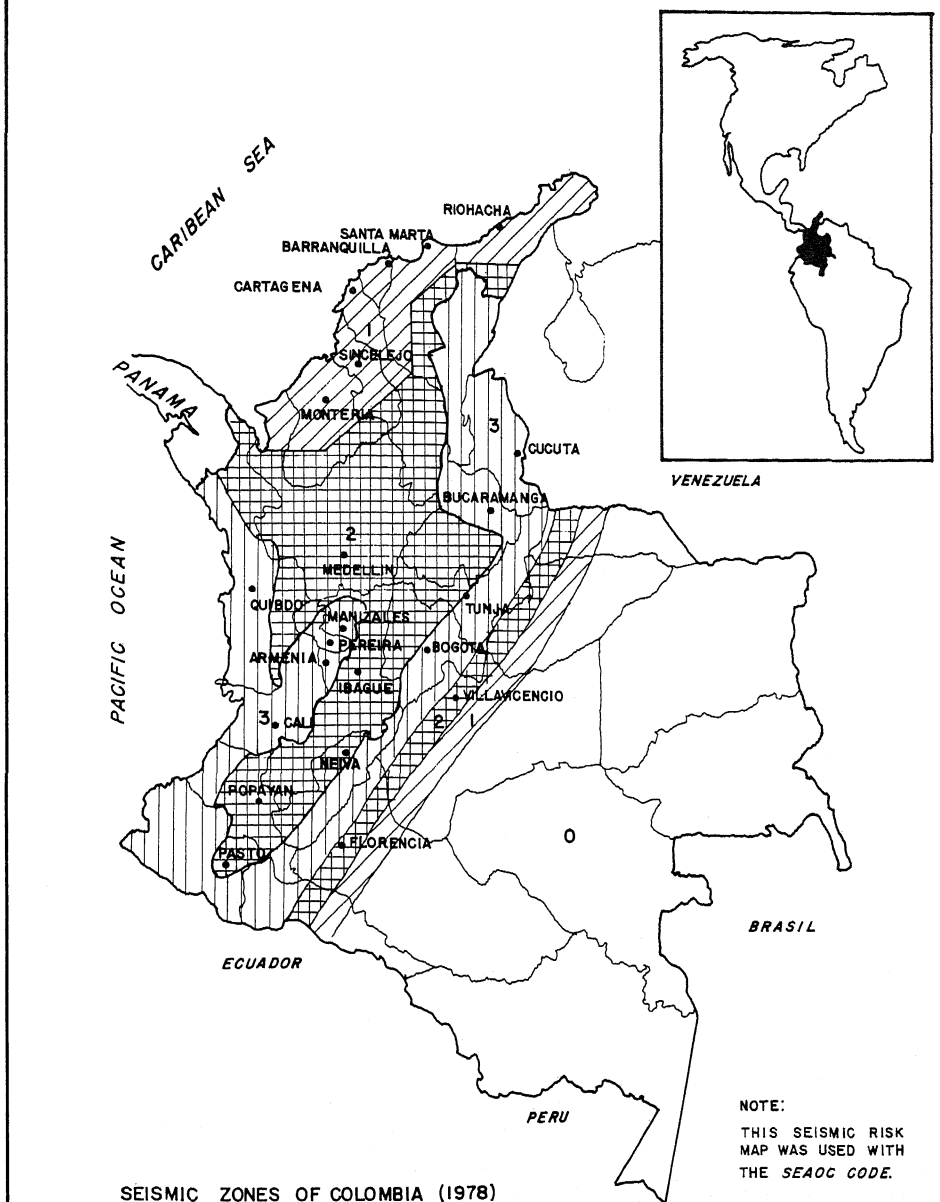
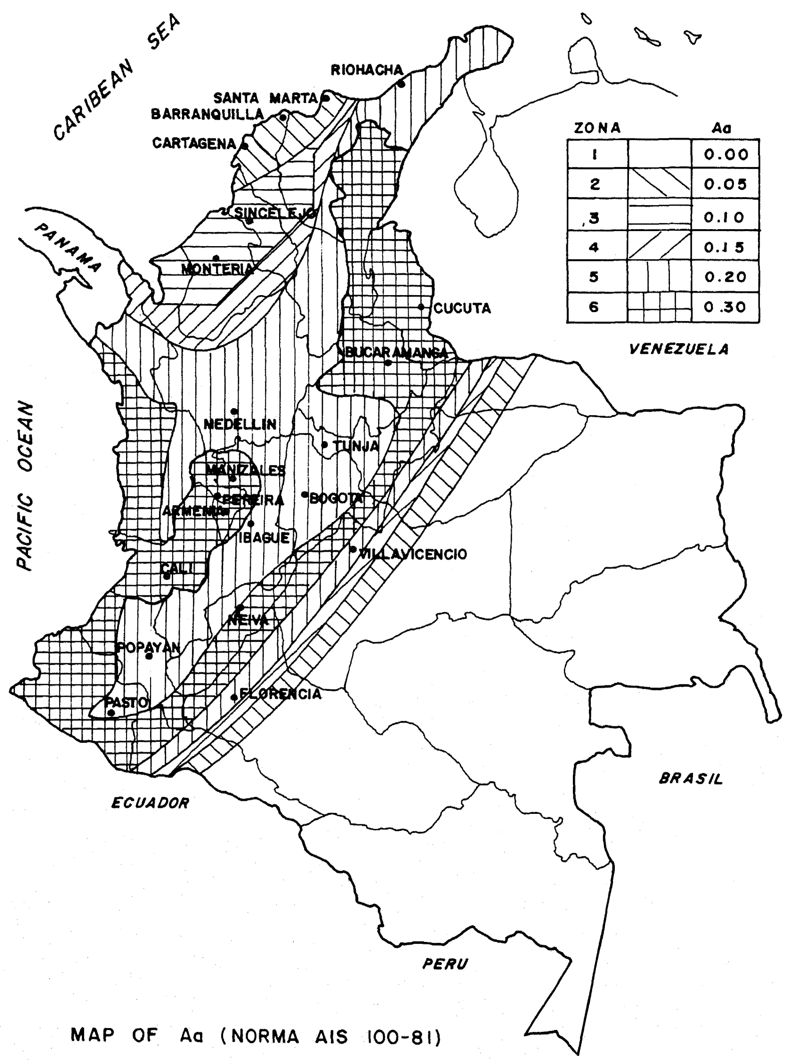


SEISMIC ZONES OF COLOMBIA (1978)

– FIGURE 1 –



MAP OF Aa (NORMA AIS 100-81)

- FIGURE 2 -