Seismic Vulnerability of Buildings in the Municipality of Chacao Metropolitan Area of Caracas, Venezuela.

S. Safina
Sismometric, C.A. Seismic Safety. safinasal@gmail.com

A. López, A. Luis, B. Lirio, L. Castillo, M. Marval
Master in Structural Engineering, Faculty of Engineering, U.C.V.

J. Prieto
Institute for Civil Protection and Environment of the Municipality of Chacao (IPCA).

J. González
Venezuelan Foundation of Seismological Investigations (FUNVISIS)

SUMMARY:
The study shows the seismic vulnerability results of the buildings higher than three stories at Los Palos Grandes, and essential buildings of the Municipality of Chacao, metropolitan area of Caracas, Venezuela. The survey includes the visual inspection in each of 231 buildings to identify construction year, stories, materials, plant and elevation scheme, structural system, structural deficiencies, etc., classifying the buildings according to its structural typology, and seismic vulnerability. Likewise the survey of medical facilities is included, educational centers and government buildings.

Since the result has conformed an extended database which includes each of the parameters identified together with a GIS platform. Every building has a physical support, which includes the survey schedules, photos, application ATC-21, measurements records environmental vibration.

The processing of the compiled information allows to establish that practically the totality of structures are frame buildings of reinforced concrete, grouped in eight typologies discriminated by construction year and height.

Keywords: seismic vulnerability of buildings- Caracas.

1. INTRODUCTION

This study summarizes the analysis results of the seismic vulnerability in existent buildings in the municipality of Chacao in Caracas Metropolitan area, and particularly of residential buildings located in residential area of Los Palos Grandes and the essential buildings of the Municipality. The project has been developed in close cooperation between the *Fundación Venezolana de Investigaciones Sismológicas* (FUNVISIS), and the *Instituto Autónomo Municipal de Protección Civil y Ambiente* (IPCA-Chacao), with financed with funds from the Law of Science, Technology e Innovation, (LOCTI).

2. BACKGROUND

The Caracas earthquake of 1967 demonstrated the importance of site effects in the distribution of damage, with a significant concentration of affected buildings in the Chacao Municipality and specifically in the area of Los Palos Grandes, which is why during the last decade, have driven research related with Caracas seismic microzonation, the characterization of seismic vulnerability in existing buildings and even, seismic scenario studies oriented to estimate losses in case of earthquakes for the development of plans for mitigation of seismic risk.

The Los Palos Grandes area is one of the most vulnerable to seismic risk in the Caracas Metropolitan area, as well evidenced during the July 29th 1967 earthquake, which severely affected the stability of some buildings and caused the collapse of four buildings (Funvisis, 1978). Many of the building constructed in this area some decades ago based their designs on existing codes of its time, which do not including earthquake resistant considerations of modern seismic standards. These buildings show marked deficiencies in structural and non-structural which predispose an inappropriate seismic performance from local to global level of the building, so that their identification and determination of its nature and extent represents an important step in reducing seismic vulnerability of the buildings and seismic risk mitigation.

In Caracas, the main effort in this area is represented without any doubt, by the work developed by the Japan Agency for International Cooperation (JICA, 2005) in the Basic Plan of Disaster Prevention in the Metropolitan District of Caracas, which permitted the confrontation of an inventory of buildings in the Libertador, Chacao and Sucre Municipalities, discriminated in two areas; the urbanized areas, and the slum and rural areas, permitting the identification of 20 typologies o categories of buildings whose vulnerability is characterized by damage functions. Another important contribution of this project was the execution, for the first time, of a full-scale experimental research of four representative models at for the typical buildings in the slums of Caracas.

As part of the seismic microzonation of the city of Caracas being conducted by the Venezuelan Foundation for Seismological Research (FUNVISIS) developed an analytical on the seismic response of nine (9) real buildings constructed in the Municipality of Baruta. The selected buildings presents an structural system based on reinforced concrete frames with low heights (3-4 levels), medium (6-8 levels) and high (13-17 levels), designed under the current rules, before the years 1967 (Pre-‘67), between the years 1967 and 1982 (‘67-‘82), and after 1982 (Post-‘82), which corresponding with changes in seismic design codes. The obtained results have generated preliminary fragility curves for each building which shows the relative vulnerability of these buildings (Safina et al., 2008).

3. OBJECTIVES

The overall objective of this study consists is to analyze the seismic vulnerability of residential buildings of more than three stories high in Los Palos Grandes as well as the schools, care centers and seats of existing government in the Chacao Municipality, and as a basis for making recommendations regarding the need for interventions and/or reinforcement of the same, for reducing and/or mitigate existing seismic risk levels in the Municipality. Specific objectives include; Revise, update and expand the data base of buildings higher than three levels in Los Palos Grandes buildings and essential buildings (schools, medical-care centers and seats of government institutions) in the Municipality of Chacao. Implementing simplified methodology to quantify and rank the relative vulnerability of buildings. Indentify the main construction types used in the Municipality of Chacao and preliminarily estimate its vulnerability. Detailed Studies of seismic vulnerability of representative buildings of the main building typologies of the Municipality.

4. METHODOLOGY

4.1. Step 1. Starting from evaluation of available information.

Task force was formed consisting of one (1) representative of the IPCA-Chacao, one (1) representative of (FUNVISIS), and seven (7) civil engineers, among them, one (1) project coordinator. The existing information in the databases of the cadastre of the Municipality of Chacao and part of the GIS platform of the Municipality, served as the starting point for the research. The data of the cadastre of the Municipality of Chacao is based on a census of buildings in 2006 and contains the following items: number of cadastre, property name, type of facility, number of plants, number of basements and urbanization.

From this database residential buildings of more than three stories high were identified in Los Palos Grandes and schools, care- centers and seats of existing government institutions in the Municipality of Chacao. This phase involved all procedures and administrative management was carried out to achieve coordinated planning among those responsible for executing the project. Based on the Los Palos Grandes area lay out, were sorted by blocks, the buildings which would be inspected each week. The initially selected sample correspond to 231 residential buildings over three stories high in Los Palos Grandes, 66 existing school buildings in the Municipality, 35 medical-care buildings among which are clinics, health centers and other care centers and 16 government buildings.

4.2. Step 2. Gathering information in the field

This stage includes, the collection of data about buildings using a detailed lay out created for this purpose, the application of seismic inspection quick format proposed by ATC-21 (FEMA, 2002), performing ambient vibration measurements in high rise buildings and conformation of the records (digital and physical) of each building. In this phase the forms of information recollection were designed. The inspection process of each building was developed, with emphasis on direct observation of the buildings characteristics, being the obtained data registered in the forms for the residential and essential building types.

The data collection instrument for the gathering of information in the field, was a form developed by the team, which included the variables which would be processed in the future. In each work sheet a schematic plan of the area of the building was made free-handedly, as well as two laterals raised in the main directions, emphasizing the presence of appendages such as tanks and engine rooms, etc. In case of building consisting of several structural modules highlights the location of joints and the survey was conducted on each module.

4.2.1. Data recollection sheet

For the preparation of the template used in the residential buildings, the forms used in the Basic Disasters Prevention Plan in the Metropolitan District of Caracas (JICA, 2005) were used; as well as the form implemented by FUNVISIS in the Seismic Microzonification in the Cities of Caracas y Barquisimeto and the form used by IPCA for the Buildings Vulnerability Elements of the Autonomic Institute of Civil Protection and Environment of the Municipality of Chacao.

For residential buildings an information gathering template model was made, for register the building basic data: building name and location, year of construction; before 1995, between 1995 – 1997; between 1968 – 1982; between 1983 – 1997; between 1998 – 2001; after 2001, as well as the lay out in plant and elevation. The use of the first floor was separated in relation with the rest of the building, itself, was considered the original condition as residential, must indicate the number of apartments by floor and the total apartment quantity in the building. With regards to the services: the gas supply system was established, according to: direct, cylinders, and non-existente. In relation to the physical conditions, were considered; number of floors, number of stair (main and emergency stairs), height of the first floor and between plant types, number of span in X and Y directions, plant scheme: the shape of the plants classified according to: rectangular shape, H, L, U, O, S and others, elevation scheme and the relationship between the base and the building height, predominant coating in the front. As to the earthquake resistant elements in the building, the structural system were considered. For reinforced concrete, concrete moment frame in one or two directions; walls and mixed. For steel ones, steel moment frame and steel braced frame. Regarding the slab system the reinforced concrete ones were classified as: flat slab; unidirectional ribbed slab, bi-directional ribbed slab; while the buildings constructed in steel: collaborating steel plate; auxiliary beams and others.

The template continues with the record of structural deficiencies; free ground/intermediate floors, short column, opening ins slabs, strong slab / weak beam, strong beam / weak beam, among others. In relation to its masses, high concentration of elevated tanks, etc. The existence of boundaries between buildings was also identified, as well as the determination of non-structural elements fixed to the fronts as for example gardens, balconies. This data collection instrument also considers the experience of the users as to whether the building had suffered damages caused by seismic events or other events, or whether renovations had taken place and/or considerable repairs at the supervised building have also been made. Finally, the template format ATC-21 which highlights the structural modifier rates and the determining requirement of a more detailed research of each building.

For the essential buildings, specifically medical-care facilities, another form was designed taking based on the form intended for residential buildings and the one used in the project for Seismic Vulnerability of the Hospital Network in Catalunya (Safina, 2003). For school buildings, the data entry form used in the Project UCV-FUNVISIS-FEDE-FONACIT No. 2005000188, entitled “School Project”, which is currently under way. In this case, the information collected information in one (1) page, where besides the basic information, we record year of construction, as well as a lay out without scale of the building plant, dimensions of the elements, seismic zone, plant shape, details of the structures, impairment indicators, among others.

4.2.2. Measurement of environmental vibrations in tall buildings

With the support of technical personnel and the FUNVISIS teams and of a group of interns from geophysical engineering, we proceeded to make a measurement campaign for environmental vibrations in tall buildings. A total of 95 buildings were instrumented with 108 records of three components each one. In some buildings two records were taken in different parts of the plant. Each record has duration of 10 minutes at a sampling frequency of 200 mps. The teams were located on the top level of the building and placed in the proximity of the center of the plant of the building. In building of elongated plant we took an additional record in one of its extremes. The orientation of the equipments is in correspondence with the building main axis. For the the instrumentation the following equipment was used: Guralp Sismometer – model CMG – 40T; Dynamic Range: 145 DB; Sensibility: 400 volt/m/second. Flat response between 0.10 to 50 Hz. A/D Card Nanometric Brand – model Orion 24 bits – capacity 3-6 channels, Sensibility: 2.55 uvolt/account.

4.3. Step 3. Processing of collected information

At this stage the adaptation of an extended database which will feed the GIS platform of the IPCA Chacao were created, likewise generated thematic maps illustrating the distribution and statistics of the different elements recorded during the inspection of the buildings; the main building typologies of the Municipality were identified, with which representative buildings of this typologies were subsequently selected in relation to the year of construction and the number of floors; with the purpose of characterizing the buildings according to the structural typology.

Of the total of 231 residential buildings over three stories high identified in the Cadastre of the neighborhood of Los Palos Grandes, 199 buildings (86.14%) were effectively identified of 199 which represents a significant achievement. As to the essential buildings there were 17 medical-care facilities and 27 schools now on record. Most of the cases not on record obey to the fact that these installations operate in houses and/or buildings between one and two levels which have been remodeled, modified and/or expanded in order to provide the service they nowadays offer.

4.3.1. Adaptation of GIS Platform

After integration with the GIS platform for the study results, a set of thematic maps was generated permitting to illustrate the distribution of the buildings for each element during recorded the inspection, as well as related statistics. For example, Figure1: “Distribution of buildings by year” is one of tematics maps.

Figure 1: Distribution of buildings by year of construction

With respect to the Essentials buildings: it can be determined that there are 66 schools, 35 medical-care buildings, clinics, health centers and other care centers, and 16 government buildings.

4.3.2. Vulnerability Index

For determining vulnerability index, which permits to estimate the relative vulnerability between the buildings and help their hierarchy, an adaptation of the Inspection and Scoring Method was implemented which takes into account, for some of the main explored variables, a ponderation according to its relative importance and its weight in the vulnerability of the building. For such purposes eight (8) parameters were included in the data recording form for buildings. Each parameter is classified according to its kind of vulnerability, from the least vulnerable (class A) to the most vulnerable (class D). And assigned the correspondent factor according to the class of vulnerability Ki and the respective weighting factor or weight Wi according to the relative importance of the scoring parameter in the vulnerability of the building.

Table No. 1 Factors and weight for each structural parameter shows the adopted parameters in this evaluation, with its respective factors in accordance to vulnerability class and its weights. For each building, in Vulnerability Index (Iv) it is determined as shown in the Equation 4.3.2.1:

$$Iv = \frac{\left(\sum_{i=1}^{8} Ki\ Wi\right)}{100} \tag{4.3.2.1}$$

Table No.1 - Factors and weight for each structural parameter shows the factors according to vulnerability class and the weights have been adjusted in a way the Vulnerability Index Iv varies between 0 and 1, being 0 a building with no vulnerability and 1 a highly vulnerable building. According to the plan proposed in this study, the more influential parameters in the assessment of the vulnerability of a building are the number of stories of the building (height), year of construction (Design Code), and the structural system with a weight Wi=1.00, followed by the scheme of the plant and its elevation, and the existence of irregularities with a weight Wi=0.50, and finally, the boundary relation and history of damage with a weight Wi=0.25

Table No. 1 - Factors and weight for each structural parameter

	Parameter	**Factor according to Vulnerability Class**				**Weight**
		A	**B**	**C**	**D**	**Wi**
1	N° Stories	4 - 7	8 - 12	13 -16	>17	
		0	**10**	**15**	**20**	**1**
2	Design Code (year of construction)	>1998 (5 - 6)	1998 - 1983 (4)	1982 - 1968 (3)	< 1967 (1 - 2)	
		0	**5**	**15**	**20**	**1**
3	Plant Scheme	Rectangular (1)	Circular (5)	H - L - U (2 - 3 - 4)	S - Otro (6 -7)	
		0	**5**	**15**	**20**	**0.5**
4	Elevation Scheme	Rectangular (3)	Square (1)	Rect/Piram (2 - 6)	L, T, Otro (4-5-7)	
		0	**5**	**10**	**20**	**0.5**
5	Estructural System	Main frame in two directions (2)	Mixed (4)	Walls (3)	Main frames in one dirección (1)	
		0	**5**	**10**	**20**	**1**
6	Irregularities / Defficiencies	None	Flat beams – slab opening	Short column –slab Strong/Beam weak	Free PB - Free plant- Strong Beam/Weak Column – Beam only 1 Direction	
	(Obsv: Take the most critical class)	**0**	**5**	**15**	**20**	**0.5**
7	Boundaries	Isolated (1)	Attached without defase, equals height (2)	Attached with/without defase, (4 - 5)	Attached with plant defase, equal heights (3)	
		0	**5**	**15**	**20**	**0.25**
8	Background damages	No previous damage	Important Expansion/Remodelation	Previously repaired damage	Non repaired previous damage	
		0	**5**	**10**	**20**	**0.25**

In applying the vulnerability factor to studied buildings, it can be determined that 25.1% have a low relative vulnerability (less than 0.25), 39.2% a medium relative vulnerability (between 0.26 and 0.50). 31.2% a high relative vulnerability (between 0.51 and 0.75%), and 4.5% a very high relative vulnerability (greater than 0.75).

4.3.3. Processing environmental processing records

For the processing of the environmental vibration a computer program in MatLab environment was implemented allowing the estimation of the main vibration frequency of the buildings from the power density spectrum determined through the Welch's periodogram. A butter bandpass filter within 1-50 Hz was applied for all in all cases, and the periodogram from windows of 8192 points with 50% overlap.

4.4. Step 4. Detailed studies in vulnerability

This stage involves the identification of the main building typologies in the area of study and selection of the representative buildings of these types depending on year of construction and the number of stories. Generation of detailed models, for 5 of the previously buildings selected above. Processing and results.

4.4.1. Main constructive types

To determine the main constructive types used in the area of study, we implemented a methodology based in the combination of three of the main parameters related with the vulnerability of the buildings as, the number of stories (building height), year of construction (related with the designed code used) and the structural system. The combination of options associated with these three parameters it is obtained a total of 59 classes of buildings whose frequency analysis is possible to determine the most representative five building types of the area of study, which group practically 40% of the buildings and the listing of the respective buildings which correspond to each class.

Table No. 2 Main constructive types shows the results of this evaluation have permitted to determine that the main building types are:

Table No. 2 Main constructive types

Type	N° Stories	Year Construction	Estructural System	%
222	8 – 12 floors	1955 - 1967	Main frame in 2 directions	10.60
221	8 – 12 floors	1955 - 1967	Main frame in 1 direction	9.05
321	13 – 16 floors	1955 - 1967	Main frame in 1 direction	7.54
411	Over 16 floors	Before 1955	Main frame in 1 direction	6.03
421	Over 16 floors	1955 - 1967	Main frame in 1 direction	6.03
				39.25

4.4.2. Selection of buildings for the detailed analysis of vulnerability

Based on the list of buildings belonging to the major classes of buildings mentioned above, we proceeded to do a review of the files in the Engineering Direction of the Municipality of Chacao, in order to verify the existence and availability of all the information needed for implementing the detailed study of vulnerability, with the purpose of gathering the architectural drawings (plant), structure drawings (floor joist, beams and columns) and Descriptive Memory and Structural Memory Calculations; study of soils (generally not available).

All the buildings selected are reinforced concrete framed structures. Particularly complex was the identification of complete files of the built buildings previous to 1967, especially in high rise buildings. In most of the gathered files, it does not exist either a project for foundations or a study of soils.

4.4.3. Detailed building analysis

For each building it was implemented a tridimensional analysis model using program SAP2000 V.10. (Sap2000, 2005), from FUNVISIS, reproducing the main characteristics identified in the architectural and structural drawings, especially concerning to distance between axis, mezzanine height, dimensions and reinforcement of structural elements (beams and columns), materials quality, etc., and incorporating the details of reinforcement of the main structural elements oriented towards a non-linear response analysis which allows the estimation of a structural response through simplified non-lineal static analysis in order evaluate the seismic performance of each building. The evaluation centralizes its attention on the application of non-lineal inelastic analysis in order to study the seismic response of the selected buildings. In particular we implemented the methods of non-lineal static analysis as an alternative for evaluating the seismic performance of the buildings.

Considerations for the non-lineal analysis.- The behavior alter the yield point has been incorporated in a discrete form on the extremes of the elements through the plastic articulations, referred hereinafter as "hinges", so that any plastic deformation of a structural element is assumed that it occurs concentrated at this point. While this hypothesis constitutes a notable simplification of the problem, properly considered, permitted reproducing the principal features of the non-lineal response in the structures. Basically two types of hinges were used in the model. "Hinges" type M3 or flexible for the extremes of the beams, and "hinges" type PMM or flexi-compressed for the extreme of the columns. While each project presents specific characteristics in terms of quality detailing of reinforcement in the beams, it is assume that they reproduce to some extent the guidelines prescribed by the regulations in force at the time of development of structural design of the building. In this sense, it is valid to suppose that a reasonable correlation exists between the values that define the form of the normalized curve moment-rotation (moment-rotation), and the age of construction. Table No. 3 reproduces the adopted values in the present evaluation for each model according to the year of construction.

Table No3. Characteristic values curve Moment-Rotation adapted according to year of construction

	B		C		D		E	
	M/My	θ/θy	M/My	θ/θy	M/My	θ/θy	M/My	θ/θy
After 1982	1.00	1	1.25	6	0.20	6	0.20	8
Between 1967 and 1982	1.00	1	1.15	4	0.20	4	0.20	6
Before	1.00	1	1.10	2	0.20	2	0.20	4

Also, Table No. 4 reproduces the adopted referential values in this study, related to the limits of rotation for the different performance levels defined in the ATC-40 (1996).

Table No. 4. Adopted referential values related to the limits of rotation for the different levels of performance

θ/θy	IO	LS	CP
After 1982	2	4	6
Between 1967 and 1982	1.5	3	4
Before	1.1	1.5	2

This values are based on the innitial recomendation assigned by default in the analysis program used for buildings with adequate level of seismic design and which has been related to built buildings after year 1982 in line with standard COVENIN 1756-82 (Covenin, 1982) and COVENIN 1756:2001 (Covenin, 2001) for earth quake-resistant buildings. For other buildings, in absence of explicit recommendations, said values have been simply escalated.

Analysis of methodology.- The capacity curve was obtained for each one of the models in each direction through a lateral loads incremental process until reaching a control displacement in the last level, known as a “push over” analysis. As a result it is obtained a capacity curve which represents the lateral displacement of a point of the top of the building as a function of the lateral force applied to the structure and reduced to the basal shear. During this study it was adopted a lateral loading plan adjusted to the corresponding mode form to first mode of translational vibration of the considered direction.

In order to establish the levels of demand associated to each one of the displacement ranges defined in terms of levels of damage, we use the so-called method of spectrum called capacity-demand proposed by the ATC-40 (1996) which is based on a lineal equivalent of the non-lineal system. In this way it is possible to estimate, for a determined spectral shape, the peak acceleration level of the terrain (PGA) needed to reach mentioned level of deformation.

This methodology permits to represent in a format ADRS (Acceleration-Displacement Response Spectrum) the so-called capacity spectrum (derived from the capacity curve), and demand spectrum (derived from the elastic spectrum) to determine the point of performance which equate structural demand and capacity.

Despite the fact that recent studies show the lack of precision of the method (FEMA 440, 2005), especially the tendency to sub-estimate or overestimate the displacements respect the inelastics according to the nature of the type of histeretic behavior assumed and the characteristics of the demand spectrum , the advantage of this methodology is that besides facilitating a practical graphic interpretation of the problem, recognizes in an explicit manner the existing dependence between the seismic demand and the structural response , when reducing in an iterative process the spectrum of demand in proportion to a factor of equivalent damping (βeff) determined in correspondence with the dissipated energy Turing the incursion experimented by the structure, permitting additionally estimating the modification which the vibration period suffers of the structure in the mode consider (Teff) as a consequence of the degradation suffered by the structure during its inelastic incursion, as an additional indicator of the level of structural damage.

5. CONCLUSIONS

Of the total of 231 residential buildings higher than three levels identified in the cadastre of the neighborhood of Los Palos Grandes, it was achieved the effective recording of the 199 buildings (86.14%), 17 medical-care installations and 27 schools.

Likewise it has been created a digital file for each building with physical back-up, which additionally includes the forms of registering the data, an extended photographical registry, and for the buildings of greater height, the records of the measurements of environment vibration.

The processing in the GIS platform allows a series of thematic maps which illustrate the distribution of buildings by their height, year of construction, structural system, plant and elevation scheme, etc.

The statistical processing of gathered information has permitted to establish that over the inspected sample, practically the totality of the buildings are framed structures of reinforced concrete, of which

52.2% were built before year 1967, 21.9% built between 1967 and 1982, 21.3% built between 1982 and 1998 and barely 4.5% built since 1998 .

With respect to buildings height, 26.1% are buildings between 4 and 7 stories high, 52.3% are buildings between 8 and 12 stories, 16.1% are buildings between 13 and 16 stories, and 5.5% are buildings higher than 16 stories. In regards to the shape of the building plant, rectangular shapes prevail (53.3%), H shape (23.1%), L shape (4.9%), U shape (8.5%). Practically 25% of the buildings have a free space ground floor. In regards to beams, we found that 3.8% of the buildings have beams in only one direction, while 12.6% of the buildings count with flat beams.
The application of format ATC-21, shows that of the total of inspected buildings, 17.3% present a factor greater or equal to 2.0 and so they do not require a detailed evaluation of vulnerability, while 82.6% left have a factor lesser than 2.0 and so require a detailed evaluation off vulnerability.

An adaptation of the method of Inspection and Scoring was implemented in order to determine a Vulnerability Index for each building which allows estimating the relative vulnerability among the buildings and facilitate its hierarchy process.

From these results we gather that 25.1% have a low relative vulnerability (less than 0.25), 39.2% with a medium relative vulnerability (between 0.26 and 0.50), 31.2% with a high relative vulnerability (between 0.51 and 0.75) and 4,5% with a very high relative vulnerability (greater than 0.75). From the combination between the main structural parameters it was determined the frequencies for each construction type. This allows the selection of representative buildings of the main constructive typologies over which a detailed study on vulnerability is developed.

REFERENCES

- ATC-40 (1996). Seismic evaluation and retrofit of concrete building. Volume 1. Applied Technology Council. Redwood City. California. USA. November 1996.
- COVENIN (1982). Norma venezolana para edificaciones antisísmicas. Covenin 1756-82. Ministerio del Desarrollo Urbano. Fondonorma. Caracas. Venezuela.
- COVENIN (2001). Norma venezolana para edificaciones sismorresistentes. Requisitos y Comentarios. Covenin 1756-1:2001. Ministerio de infraestructuras. Fondonorma. Caracas. Venezuela.
- FEMA (2002). Rapid Visual Screening of Buildings for Potential Seismic Hazard: A Handbook. FEMA 154, Edition 2, March 2002.
- FEMA 440 (2005). Improvement of nonlinear static seismic analysis procedures. Prepared by Applied Technology Council (ATC-55). Redwood City. California. USA.
- FUNVISIS (1978). Segunda fase del estudio del sismo ocurrido en Caracas el 29 de Julio de 1967. Comisión Presidencial para el estudio del sismo. Ministerio de Obras Públicas MOP. Caracas. Funvisis.
- JICA (2005). Metropolitan District of Caracas Bolivarian Republic of Venezuela. Study on Disaster Prevention Basic Plan in the Metropolitan District of Caracas in the Bolivarian Republic of Venezuela. Final Report. Japan International Cooperation Agency.
- SAFINA, S. (2003). Vulnerabilidad sísmica de edificaciones esenciales. Análisis de su contribución al riesgo sísmico. Tesis Doctoral. Universidad Politécnica de Cataluña UPC. Barcelona. España.
- SAFINA, S. et al. (2008). Seismic Response of Reinforced Concrete Buildings in Caracas, Venezuela. 14th World Conference on Earthquake Engineering. October 12-17, 2008, 14WCEE, Beijing, China.
- SAP2000 (2005). SAP2000 – CSI Analysis reference manual. Computer and Structures, Inc. Berkeley. California. USA. October 2005.