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NONSTRUCTURAL SEISMIC VULNERABILITY EVALUATION METHOD FOR HEALTH-CARE FACILITIES IN VENEZUELA

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ABSTRACT

This paper presents the preliminary results of the first phase "Nonstructural Seismic Vulnerability Evaluation Method" of the demonstrative project "Qualitative Evaluation of Health Care Facilities in 'La Candelaria' 'San Bernardino' and 'San Jose' Districts in Caracas." The purpose of this study is to develop a qualitative evaluation method for the assessment of the seismic vulnerability of nonstructural aspects of the existing health care facilities in Venezuela. The area constituted by the mentioned districts, was selected as a case study for the implementation, testing and improvement (if necessary) of the method, due to the significant concentration of this building type and the severity of seismic hazard in the zone. In the demonstrative project, the evaluation method for the architectural configuration aspects, the functionality of layouts and the nonstructural components, are developed in parallel with, and as a supplement of, the structural evaluation that is being developed by a team of structural engineers. The information herein contained is: (a) a brief description of the preliminary qualitative evaluation method; (b) the description of the case study and the selection of the sample; (d) results; and (e) a list of the references.

KEYWORDS

Hospitals; Caracas, Venezuela; Health Care Facilities; Seismic Vulnerability; Qualitative Evaluation Method.

INTRODUCTION

The purpose of this study is to develop a qualitative evaluation method for the assessment of the seismic vulnerability of nonstructural aspects of the existing health care facilities (HCF) in Venezuela. This institutions are essential facilities which should function after an earthquake has occurred, in order to provide assistance to injured people. On the one hand, structural and nonstructural damage must be minimized and, critical services such as electricity, emergency generators, communication systems, clean water and sewerage and especial equipment be well protected, in order to avoid the functional disruption of the facility. On the other hand, the urban, social and economic impact that the disruption of health care services due to hospital damage or collapse can produce, should be minimized.

Currently there are many approaches to assess the seismic performance of HCF's, but mostly considering them as any other type of building. However, the specific characteristics of HCF, creates a critical situation when evaluating the seismic vulnerability of this type of facility. In them, the particular medical functions are combined with those of a hotel, office buildings, laboratories and other. Besides, they are heavily occupied all over the year (they house a variety of population such as patients, medical and administrative personnel, visitors and others, for the 24 hours a day). The recurrent collapse and severe structural and nonstructural damage of many important HCF's due to earthquakes, have produced relevant information in this field, mainly aimed to the engineering practice. However, many, structural and architectural designers, fail to apply these principles effectively and, when an earthquake occurs, these factors are, once again, found in damaged HCF's worldwide. Examples of this situation are the earthquakes of San Fernando, California in 1971, Mexico City in 1985, and El Salvador in 1986, where the main hospitals suffered severe damage or collapsed and were rendered unable to respond to the emergency even though information was available before each of these earthquakes, to mitigate the seismic risk. Another important reason for reducing the vulnerability of HCF's, is that it incorporates additional critical social and economic implications in the recovery process.

The main objective of the proposed method is to evaluate from the *nonstructural vulnerability* point of view, the degree of susceptibility intrinsic to HCF's, to suffer damage or loss as the consequence of probable earthquakes. Therefore, the proposed evaluation method is of primary importance in that no such instrument now exists that specifically applies to the health field. Hospitals are very complex entities that cannot be evaluated with a method generally used for a regular housing or office building. There have been many advances in earthquake engineering in the last decades, however, much of the information compiled and implemented by building codes has been strictly applied to the structural systems, but there have been little application to the architectural or nonstructural aspects of the building. The proposed evaluation method is specifically developed for HCF's, and to be used in assessing *nonstructural seismic vulnerability* in said HCF's on a national basis. For the implementation and testing of the evaluation method the area comprised by 'La Candelaria' 'San Bernardino' and 'San José' districts in Caracas, was selected.

Caracas, Venezuela's capital city, is located in the northern-central region of the country. It is surrounded by fault zones that are part of the San Sebastián Fault subsystem which has been considered as the origin of the earthquakes that affect this city. Its seismicity has been cataloged in the moderate range; however, this city has experienced a series of very destructive earthquakes in the past (1641, 1812, 1900). The strongest earthquake that Caracas has experienced in the last 90 years was a moderate 6.3 Richter magnitude, on July 29, 1967. After the earthquake, observers recognized that extensive structural and nonstructural damage was mainly located in two very well defined areas of the city: (1) 'Los Palos Grandes' and 'Altamira' districts; and (2) 'San Bernardino' district and surrounding areas. Several authors suggested, at that time, anomalous ground amplifications in these areas and studies carried out afterwards corroborated the correlation between the concentration of damage and the depths, the dynamic soil characteristics and the behavior of underlying alluvium.

The relevance of developing and implementing the evaluation method in the case study, relies on the fact that this zone gives a chance for testing the method in a wide range of *design*, *context* and *performance* variable combinations. The following examples illustrate these variables: (1) as context variables (c-v), *Soil types*, alluvial soils which range from 0 to 120 meters in depth; (2) as design variables (d-v), a variety of health services rendered, building shapes and heights, ages, structural systems, and others, ranging from very complex structures designed specifically for health care, to residential or commercial spaces converted for said use; and, (3) as performance variables (p-v), *the probability of damage due to pounding* between a 12-story-high slender hospital module and an adjacent 4-story-high flattened module (d-v) located on a 120 meter-deep alluvial soil (c-v).

THE PRELIMINARY EVALUATION METHOD

First of all, the scope of this evaluation method for determining the Nonstructural Seismic Vulnerability of HCF's, is based on: (1) the definition of *Nonstructural Components* adopted by Reitherman (1985); (2) the definition and scope of *Building Configuration* developed by Guevara (1986, 1989) based on Arnold and Reitherman (1982), and the *Evaluation Method* by Guevara (1986) based on Rittel (1964-1990); and (3) the *Architectural Aspects* in the vulnerability of HCF's published by PAHO (1993) and developed by Cardona *et al.*; this approach, besides building configuration aspects, includes functional analysis of HCF's. Though important and useful evaluation techniques, the *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook ATC-21* (ATC, 1988) and the *NEHRP Handbook for the Seismic Evaluation of Existing Buildings* (BSSC, 1992) were developed for a cultural context different to the studied. Some of their features are considered and incorporated within the evaluation method here studied, adapting it to the local characteristics. It is important to mention that this study is in the first phase of developing the evaluation method in parallel with the inventory of the HCF of the case study, therefore, the examples used to demonstrate the methodological application of the method are not definitive but just illustrative.

Secondly, the definition of "*Evaluation*" is included in order to establish the theoretical and methodological reference. *Evaluation is an activity aiming to the establishment of an overall judgment (performance variables, p-v), of an object (design variables, d-v), behaving within a set of particular conditions (context variables, c-v).* There are three types of variables (Rittel, 1964-1990, and 1973): d-v, those under the control of the building designer (architect, engineer, etc.), as for instance, the N° of floors, N° of building blocks, location of vertical services, elevators and stairs, type and materials of structural system, etc.; the values of each of these variables are the different choices; for example, in the *Structural System Materials*, the values are, R/C, steel, unreinforced masonry, reinforced masonry, etc.; c-v, which are those factors affecting the object under study, but not under the control of the designers; examples are, seismic zone, type of soils, etc.; for example, the values for *Seismic Zone* are Z1, Z2, Z3, Z4; p-v: those that express desired characteristics of the object, on terms of how it "has to be like" to perform satisfactorily in determined context, according to pre-established criteria; these express the terms in which the building and its parts will be evaluated: quality, quantity, appropriateness, capability, cost, etc. The Overall p-v for each HCF for this study is the *Capability of the evaluated HCF to withstand earthquakes without major damage*. Thus, the *vulnerability* of HCF is determined by the *design variables*, and the *seismic hazard* by the *context variables*. Performance is a function of d-v's and c-v's, P = f (D, C). Then, the capability of a HCF to withstand earthquakes without major damage, is a function of its vulnerability and of the local seismic hazard. The following Fig. 1 shows the interrelation between the three types of variables.

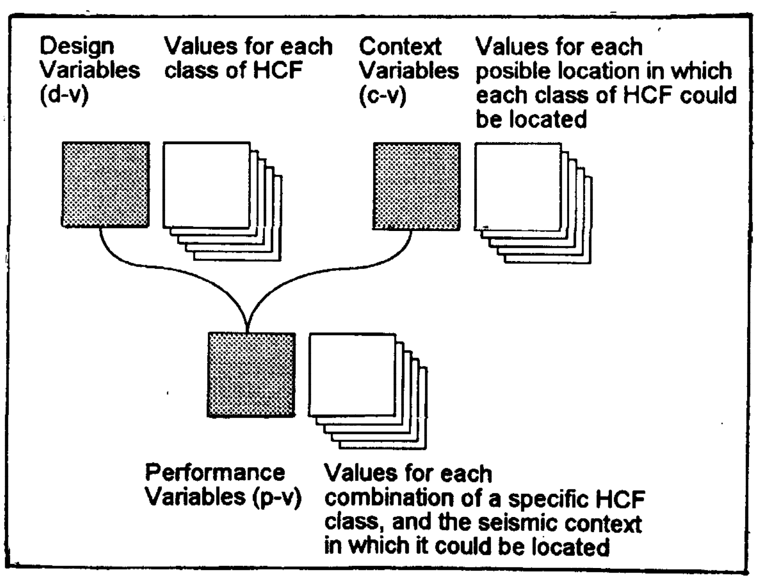

Fig. 1 The Three Types of Variables Showing: a) the Interrelation Between Them; b) Their Values.

Each p-v or p-aspect, which should be logically independent from the others, will be branched into the various performance subaspects depending on it. In turn, each subaspect can be disaggregated onto other detailing levels, depending on the degree of specification the specialists want to reach. The set of these aspects and subaspects can be graphically represented in an evaluation tree of *performance variables*. Each branch has a sum total of 100% weight, with each aspect receiving a portion of this. The weight distribution in each branch is assigned by experts, and is based on the relative importance of each subaspect. This permits grouping the variables and avoiding mixing those that are of different nature and evaluating an aspect twice. Because situations change, some times there will be changes of weights. The change of weights can go as far as to give a "zero percentage," which means that this aspect is not going to be taken into account. One of the most difficult tasks in the evaluation process is assigning the different weights (α i), because they are the "grade of relevance" relative to the overall objective which is in direct relation to the "Overall Performance-OP" (Xo). For example, if the OP is the *Capability of the evaluated HCF to withstand earthquakes without major damage*, then we might have as relevant aspects: (1) proficiency of the structural analysis; (2) adequacy of building configuration; (3) functionality of the distribution layout of spaces for emergency attention. The highest weight will indeed be assigned to 1, because if the structure collapses it does not matter how good the building configuration or the space distribution was, but, how much?. Another difficulty is the assigning of "proficiency" grade (value judgments (Xi)), which is the score for the different aspects of the object. This proficiency should be recorded in a scale which expresses the grades for measuring the level of accomplishment. The sum of the best values accomplished for each aspect becomes the best possible solution and becomes the desired model of the object, in order to perform 100 %, in a specific context, according to pre-established criteria. The evaluation pattern is shown in Fig. 2.

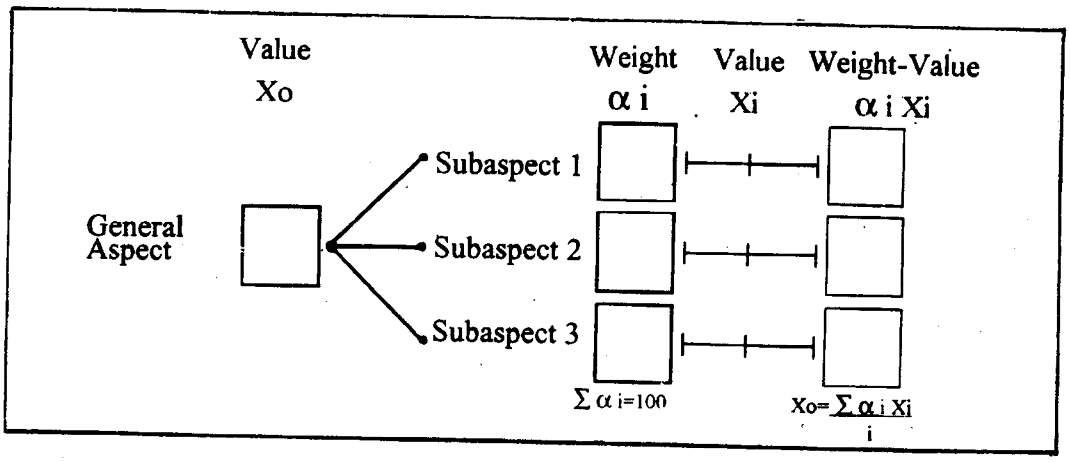

Fig. 2 The Basic Evaluation Pattern Component.

The singularity of HCFs. evaluations is that each HCF (a specific design proposal) is located in one particular piece of land (a specific contextual location). Therefore, a particularization of the general structure of the evaluation instrument (the tree of aspects and subaspects) should be carried out in order to do a competent assessment. The following Fig. 3 shows this particularization situation.

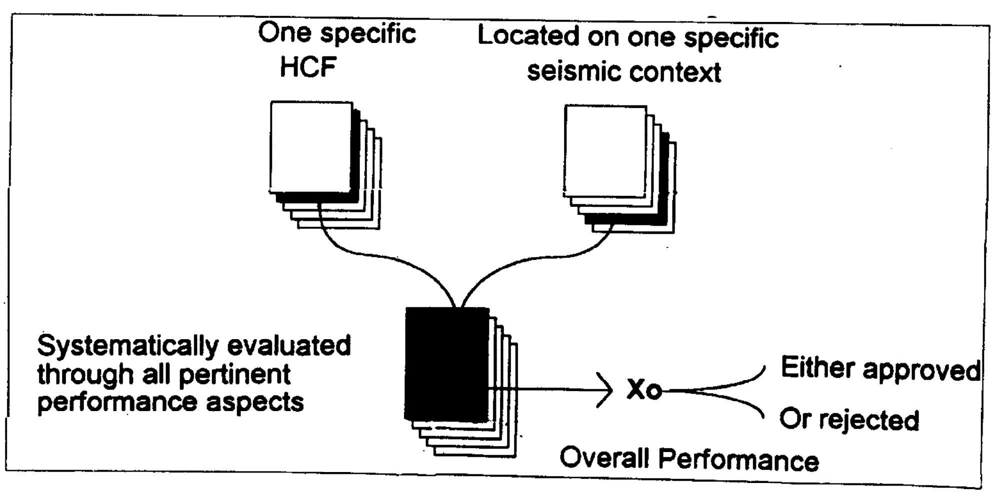

Fig. 3 The Particularization of Each HCF Evaluation Process.

The Evaluation Process

The application of evaluation techniques requires a well formulated *evaluation process*. An Evaluation Committee should be created, to take control and responsibility of the different phases. The following evaluation process principles should be discussed by the specialists and the Committee in charge:

1. The *list of relevant aspects* is formulated for an overall view of the object. They identify the properties of the p-v, which are considered essential for each class of HCF (d-v) to properly perform in a specific situation (c-v). The following list of p-v's is an example of those independent aspects which could be taken into account. The aspect *Building Configuration* could be subdivided into the four subaspects: building geometry, nonstructural components configuration, adjacency, and structural components configuration.

2. Each aspect *is disaggregated into branches of sub-aspects*, and these into sub-subaspects.

3. *An evaluation tree-like is constructed*, where all evaluation disaggregation levels are organized including the relevant aspects and their respective branches of subaspects. For example:

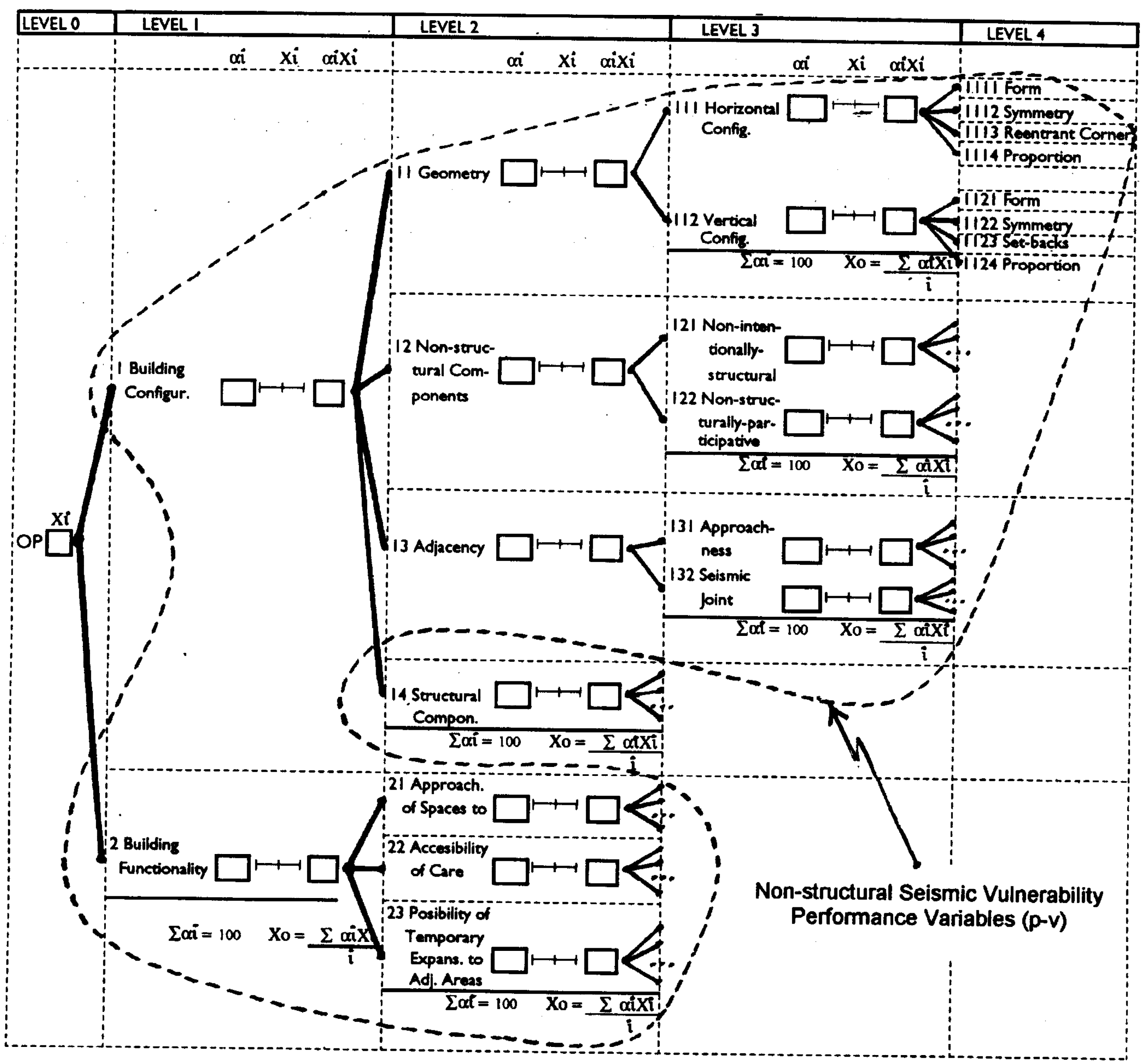

Fig. 4 Example of a Tree of Nonstructural Seismic Vulnerability Performance Aspects

4. At the end of every branch, the specialists should *develop a criteria*, from which a *transformation function* is built, with the purpose of translating qualitative and/or quantitative value judgment into a score. Most performance subaspects cannot be measure in numerals, then, in order to make evaluator's judgment sufficiently explicit and communicable, this instrument should help to clearly express what are the basis for the assignments of each scoring scale. The specialists, in order to delegate their judgment on the evaluator, should be very explicit in the description of each value or score of the ranking scale.

5. The *evaluation instrument* is designed, including survey forms and instructions for using them.

6. Once the characteristics of the HCF that is being evaluated, are translated into the same units used in the standard values of each final subaspect of the evaluation tree, the evaluators compare those values particular to each HCF and the standard values and assign a score according to the appropriate T-F. These partial score are aggregated, then, according to pre-established A-F for a particular context. The final result will be the aggregation of groups of partial scores related to the performance of HCF's in a particular context.

7. This instrument has *to be tested and approved*, and afterwords has to be *given to evaluators for their training*. Once the evaluators are trained, the proper evaluation process is carried out: the *values for the different variables or parameters are assigned* through the transformation functions previously formulated by the experienced specialists, who set the scores for comparing the characteristics of the existing facilities with the pre-established standards, for ranking them.

8. Presentation of scores and final reports, explaining the results and scoring is finally done.. Then decision makers, decide. There should be clear explanations on who and how the final decisions will be taken. For example: if solutions considered from 'fair' and above it, are the ones to obtain the Idoneity Certificate; then, for those HCF whose scores are below, there should be clear definitions about what improvement could be recommended, and/or when some improvement could be recommended and by whom, or when there should be a definitive requirement of going into further evaluation.

9. The gathered data should be systematically stored into computerized information system and processed, during the different phases of the process.

THE CASE STUDY

A sector of Caracas was selected for the implementation, testing and improvement (if necessary) of the method. This area, which holds the greatest concentration of public and private health care facilities, not only in Caracas but in the entire country, presents also a variety of geomorphologic characteristics (alluvial soils with depth to bedrock from 0 to 120 meters; creeks, steep slopes, etc.) which characterizes it as a highly hazardous zone. The seismic hazard analysis, taking into account site effects, is in process by specialists in that field of work. A team of 6 architects and engineers, supervised by one faculty and one specialist in the design of hospitals, conducted on-site HCF inspections. Since it was very difficult to obtain detailed information from the official urban census, a preliminary basic data collection form was designed in order to identify or corroborate, for each entity: the use, the owner's name, the property or administration type (public or private), the address, the catastral identification, the number of modules or building units that constitutes each entity, the structural system, etc. The exact location of each entity was identified on an official urban information map. A variety of building types, structural systems, configurations and types of health services rendered, were found, ranging from very complex structures designed specifically for health care, to residential or commercial spaces converted for said use. The the services rendered by the different institutions, also vary from simple emergency care or ambulatory treatment to sophisticated treatment in nuclear medicine, intensive care units, etc. In all, the area covers the following type of spaces, both public and private: (1) Large hospitals, specially designed for a specific purpose; (2) Medical Centers for doctors' offices, laboratories and support services, specifically designed; (3) Remodeled spaces designed for other uses, either whole buildings or part(s) of one; the latter, often also houses dwellings, offices or commercial spaces; (4) Geriatric residences, located mostly in large houses. A total of 110 HCF were inventoried in the zone: La Candelaria, 9 (7 private, 2 public), San Bernardino, 90 (87 private, 3 public), San Jose, 11 (2 private, 11 public). Of this universe, 16 HCF were selected for the application of the evaluation method. The criteria for the selection of the sample was: (1) exclusive use type: HCF's, general and special care; (2) size; and, (3) services offered. It is important to mention that in San Bernardino, most of the inventoried entities are private doctor's offices; that is the reason for selecting only 5 institutions from an universe of 90.

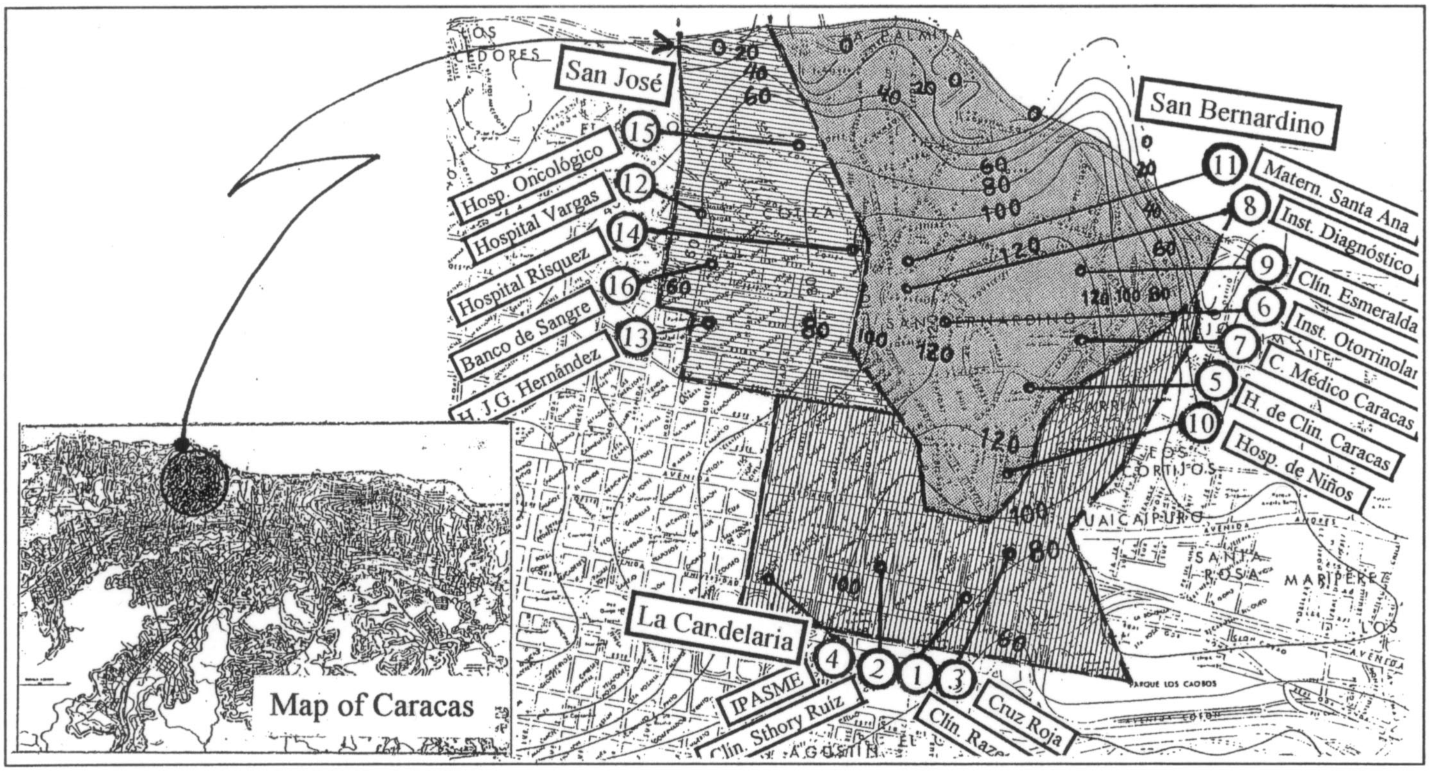

Fig. 5. Section from the Map of "Depth to Bedrock, Caracas Valley," published by the Dirección de Cartografía Nacional (1970) including the location of the selected health care facilities in the studied districts.

RESULTS

The guidelines obtained as a result of this project are aimed to give additional descriptions and methodological explanations of methods that provide the owners, administrators and professional related to HCF's, an instrument for evaluating the nonstructural and functional seismic vulnerability of these facilities and, thus for developing programs for rehabilitating and strengthening or retrofitting them as a first step of a seismic risk mitigation policy.

This method permits to clarify the relation between the aspects that intervene in the vulnerability of HCF's (design variables) and to separate them from those aspects related with the seismic hazard (context variables). The first ones can be modified in order to reduce the vulnerability of HCF, however, the latter are fixed and cannot be modified but they must be clearly identified for the accurate estimation of the performance of the different HCF aspects (performance variables), in order to mitigate the risk.
The evaluation method is to be equally useful for both, the *post-occupancy* (in use) *evaluation* of existing HCF's, and the *design plan evaluation* during and at the end of the design process of new HCF.

The two different regulatory legislation documents that govern the classification of HCF in Venezuela, private and public, do not use the same criteria for classifying them, therefore, neither allows to include all the different classes of HCF´s into one unique comprehensive list. The classification developed for this study permits the unification of approaches and parameters. It was not included due to paper lenght limitation.

The information gathered will assist official agencies in formulating norms and recommendations applicable in the new HCF designs.

The computerized framework of the evaluation method is a system for the *seismic vulnerability control* using the specialized software Microsoft Access under the Windows environment. This system includes; (1) a data base module which comprehend information regarding to each studied HCF, and also to its relationship with the urban environment; and (2) the seismic vulnerability evaluation module, based on the evaluation method presented in this paper. The software AutoCAD is used as a supplement of the data base, for storing, and retrieving architectural and structural drawings. By using MS Access interrelated with AutoCAD, that are worldwide standard software, the expansion to, or integration with, other available systems is very easy. It is also possible to correlate and exchange data with many available Geographic Information Systems (GIS).

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