Methodological Strategies for Seismic Vulnerability Evaluation

M. B. Romero
Instituto Regional de Planeamiento y Hábitat (IRPHa) - Universidad Nacional de San Juan

A. P. Giuliano
Instituto Nacional de Prevención Sísmica (INPRES).

A. C. Zaragoza
Facultad de Ingeniería – Universidad Nacional de San Juan

15 WCEE
LISBOA 2012

SUMMARY
This paper shows the results of a Project on Reduction of Urban Seismic Risk developed within the frame of a Research Program funded by the National Agency of Science and Technology Promotion (ANPCyT) of the National Ministry of Science, Technology and Productive Innovation (MINCyT), to study the seismic risk in Argentina.
A methodology for urban seismic vulnerability evaluation was developed. It included the construction of models for diagnosis and assessment of hazards, as well as social and physical vulnerabilities. Developed tools were applied to the San Juan city, the capital of San Juan province. Seismic hazard was reevaluated based on spectral ordinates for rock sites corrected for different soil types.
Geographical information systems were used as an analysis tool, and the results obtained were presented in maps, which will be used as input data to design and application to mitigation programs.
Different indexes were developed to identify equal vulnerability zones. The results of the project have been transferred to the government of San Juan province.

Keywords: Seismic urban risk, Vulnerability evaluation methods, Models

1. INTRODUCTION

Since the second half of the twentieth century, there has been a trend toward an increased impact of disasters caused by natural events in the Latin American region and the whole world. Disaster is defined as the fact for which a natural phenomenon causing havocs to human systems. These phenomena as: floods, severe droughts, earthquakes and landslides, among others, are overwhelming ecological disturbances that exceed the capacity for the affected community to readjust itself, requiring external assistance.

Until not long ago, disasters caused by natural phenomena, were known as "natural disasters". This term is not appropriate, because even though a "natural" phenomenon triggers the disaster, the latter is the result of the impact of this phenomenon on the human being and built infrastructure.

Thus, the disaster is not only the result of the occurrence of phenomena, but also of high physical and social vulnerability of settlements, as a result of their irregular growing and the technologies used, the productive depredation activities, etc. Named them "natural" is a way to transfer "guilt" of the facts to the nature rather than human errors. Therefore today we talk about social-natural disasters. The strengths or abilities and the weaknesses of a specific system, generated in their own development process, determine their risk level.

Referring to urban seismic risk, its growth is accelerating worldwide, especially in developing countries. Among the reasons for this, the increasing urbanization, lack of planning and resources of cities to accommodate rapid growth, unequal distribution of wealth, and lack of suitable buildings codes for constructions and control mechanisms, may be mentioned.

Another aspect that influences significantly is the lack of awareness of the community and its leaders. This is manifested in: the low priority given to the subject in all its dimensions, the predominance of the traditional view of acting when disaster has already occurred, the lack of community participation in planning risk management, the presence of a diversity of views, etc.

These mentioned factors hinder or obstruct the implementation of effective risk reduction and consideration in urban development plans. This lack of awareness and information means that often the members of society (which include leaders, professionals, etc.) contribute to increase it by taking wrong decisions.

In our country, INPRES-CIRSOC Regulation 103 (INPRES-CIRSOC, 1991) has divided the country into five zones, from 0 to 4, of increasing seismic hazard. Most of the territory of the provinces of San Juan and Mendoza, in particular the two capital cities, is located within zone 4, very high hazard. The rest of both provinces lie in zone 3, high hazard, as well as part of the provinces of Jujuy, La Rioja, Salta, San Luis, Cordoba and Tierra del Fuego. The remaining Andean provinces and some central, are included in Zones 2 and 1, of moderate hazard and reduced hazard respectively. Figure 1.

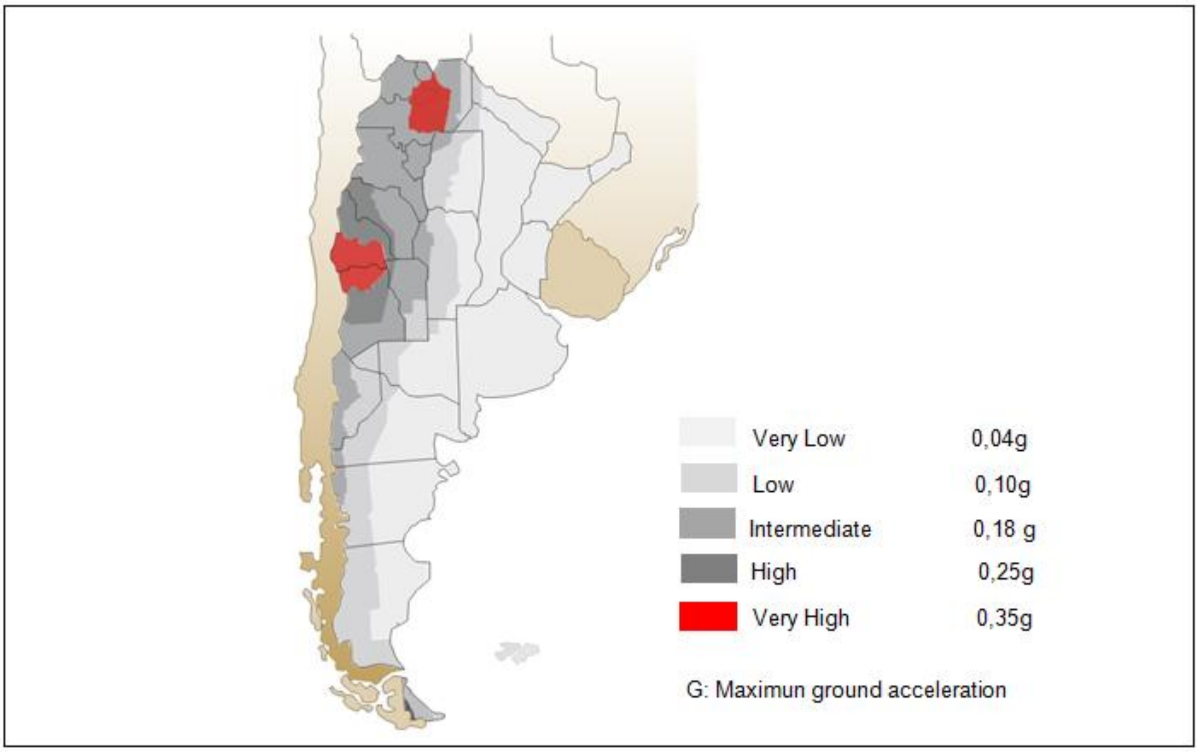

Figure 1. Seismic hazard in Argentina

Despite the importance of this factor of the natural environment plus the amount of highly destructive earthquakes that have struck the country and the vast area subject to this threat, the seismicity has been studied globally; having performed seismic micro zoning only in the provinces of Mendoza and San Juan. Potential sources of seismic activity and its impact on the level of seismic activity has been evaluated.

Relative to the potential vulnerability of existing buildings, there have been some studies over these mentioned provinces and exist a first estimate of the percentage of houses earthquake resistant and not earthquake resistant in the Argentina northwestern (Salta and Jujuy). Beyond that, there is a significant gap in knowledge of the seismic vulnerability of our settlements.
This is worrisome, because although it is now in use a rigorous standard for building construction, applicable throughout the country, there are highly vulnerable urban areas due to different

circumstances. Among them, the existence of buildings constructed with previous standards of earthquake resistance and lower requirements, with little or no maintenance; the fact that there are large segments of the population without access to social housing provided by government agencies. They solve their habitat with the resources they have, without seismic forethought or settling in inappropriate areas which increase their vulnerability.

Also obsolescence or lack of foresight seismic of some infrastructure, difficult access to certain areas, segregation taking place in cities such as effects of economic and social processes, etc., are factors that increase vulnerability.

Therefore a real challenge remains the definition of theoretical guidelines that will address the problem in all its complexity and the generation of new methodological tools to assess vulnerabilities, from a holistic concept of risk. The issue must be resolved multi-disciplinarily, focusing on the physical and environmental aspects, technological and social issues that determine their interrelationships to achieve comprehensive diagnostics.

The paper presents partial results of the work carried out by researchers at the Regional Institute of Planning and Housing (IRPHa), Faculty of Architecture, Planning and Design (FAUD) of the National University of San Juan, the National Institute of Seismic Prevention (INPRES) and the Faculty of Engineering - UNSJ as part of a Research Project-Oriented Science and Technology (PICTO) funded by the National Agency of Scientific and Technological Promotion (ANPCyT) for urban seismic risk assessment. The draft assessment methodologies on urban seismic risk were developed and applied having performed the application of these instruments to study the city of San Juan, Argentina, located in one of the most seismically active areas of the country.

2. DEVELOPMENT OF THE METHODOLOGY

2.1 Brief descriptions of San Juan province.

The Province of San Juan, located in the midwest region of Argentina, has 80% of its area occupied by mountains, corresponding to the central sector of the Andes and Sierras Pampeanas system. Only 21,000 km^2, composed by valleys and sedimentary basins shaped by dynamic cycles of water and tectonic activity, respectively, provide the space for human occupation.

A very dynamic geological activity generates vulnerabilities in the human activities and their facilities, due to seismic hazard, water related hazards (floods, erosion) and climate hazards (local hot winds (Zonda), frost, hailstone), which have short intervals of occurrence. (Gray de Cerdán, 2006)

The environmental characteristics and conditions of its development have generated urban growth of very few cities, particularly in the area so-called Great San Juan. This crowded quarter was established by an increasing degree of urbanization of the department named Capital which went beyond their original limits incorporating peripheral urban centers with relative autonomy.

Currently, the area is integrated by capital department and urban sectors of Rivadavia, Chimbas, Santa Lucia, Rawson and Pocito departments. It contains a total population of 442,527 inhabitants according to preliminary figures from the 2010 Census.

The characteristic of urban primacy over other human settlements in the Tulum Valley and the rest of the province, is historic and well-marked, accounting for 65% of the total province population, whose figure is 680,427 inhabitants, according to the same census. It sits in a large urban area that contains within it a very low density consolidated, where vacancy coexists with urbanized areas. This promotes urban growth by extension on agricultural soils with the waste of infrastructure.

2.1.1 Seismotectoning setting of San Juan

The province of San Juan is one of the most seismically active areas of the country. It was shaken by five destructive earthquakes in the last 116 years, causing many casualties and serious damage to buildings, infrastructure networks, roads, railways, etc.

The city of San Juan is located about 350 km east of the boundary between the Nazca Plate and South American Plate. The Nazca Plate is being subducted beneath the South American Plate at a rate of 7.5 cm/year. This interaction produces interplate seismicity in the contact of the two plates, intraplate seismicity in the Nazca Plate and Intraplate seismicity in the South American Plate.

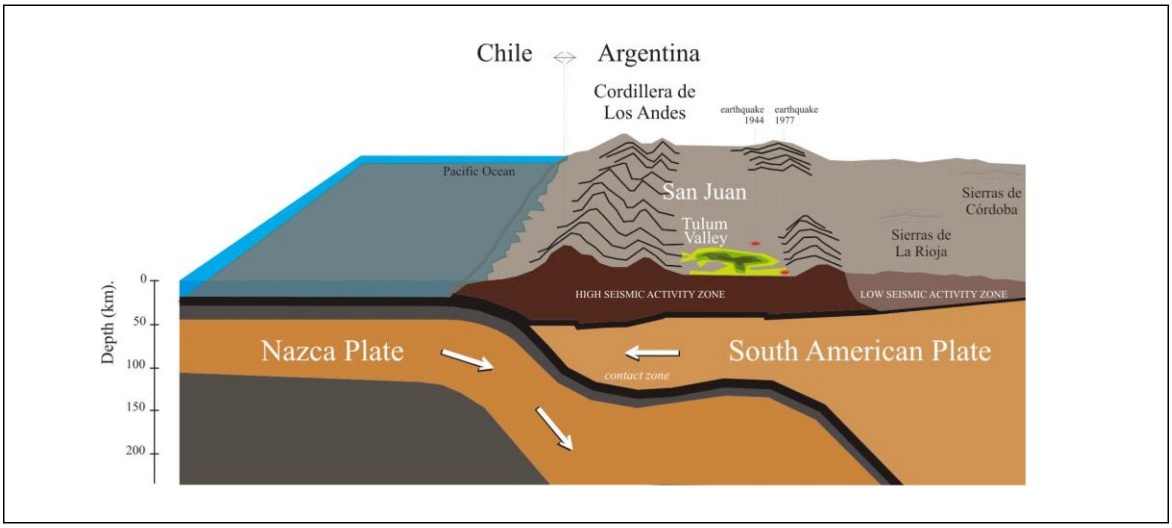

Figure 2. Profile showing the interaction between the Nazca and South American plate.

The most destructive earthquakes are shallow earthquakes (depth less than 50 km) that occur within the South American Plate.

The events occurred in 1894, 1941, 1944.1952 and 1977 belong to this category, with magnitudes ranging from 6.8 to 8 and maximum MMI ranging from VII to IX.

The most destructive of these was the January 15, 1944, which destroyed the city of San Juan (buildings and infrastructure collapsed), and caused around 10,000 deaths and many more injured. The most recent event, November 23, 1977 totally destroyed the city of Caucete, located 30Km from the capital.

2.2 Design Spectra

The new seismic code of Argentina includes new elastic design spectra for different seismic zones and different site conditions. These spectra present significant conceptual differences with the old ones. Mainly the consideration of two soil amplification factors, one for short periods (0,2sec) and one for long periods (1sec). Accordingly, two parameters describe the spectra, Ca and Cv, the first corresponds to the soil and seismic zone dependent ground acceleration, and the second to the soil and seismic zone dependent spectral ordinate at 1.0 sec.

The branch of the spectra controlled by the ground velocity decays proportionally to the inverse of the period T, instead of T exp (2/3) of the old code. The ground displacement controlled branch of the spectra is included to be compatible with the future use of direct displacement based design. Fig. 3 shows the general form of the spectra, and Fig. 4 the main parameters. Although six soil types are considered they are included in only three spectral shapes.

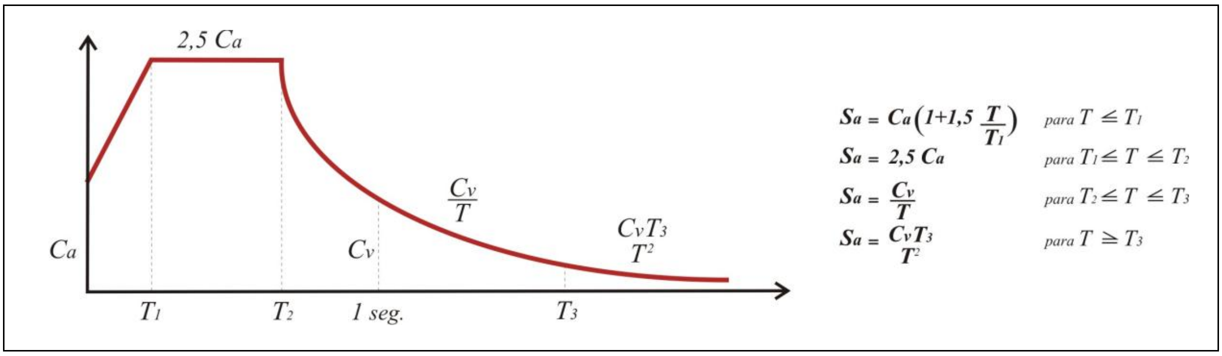

Figure 3. General form of the spectra

Table 1. Main parameters

Spectral Tipe	SISMIC ZONE							
	4		3		2		1	
	a_x : 0.35		a_x : 0.25		a_x : 0.15		a_x : 0.08	
	C_a	C_v	C_a	C_v	C_a	C_v	C_a	C_v
3	0.37 N_a	0.51 N_v	0.29 N_a	0.39 N_v	0.18	0.25	0.09	0.13
2	0.40 N_a	0.59 N_v	0.32 N_a	0.47 N_v	0.22	0.32	0.12	0.18
1	0.36 N_a	0.90 N_v	0.35 N_a	0.74 N_v	0.30	0.50	0.19	0.26

2.3 Assessment of urban seismic vulnerability.

Vulnerability shows how easy and severely, the human settlement exposed can be affected. It is the result of the interaction between the hazard and the characteristics of what is exposed. Cardona (2001).

The methodology for the study of physical and social vulnerabilities and urban seismic risk should be simplified so that it can be applied to large areas and all existing buildings and population. For physical vulnerability the methodology should be adapted to existing data and elements to be studied: buildings, lifelines, etc.

The fundamental basis to begin the study of physics vulnerability on an urban scale is to have data to establish constructive and structural features of buildings that are to be evaluated, and the characteristics of the soils on which they settle. The study of the characteristics of the buildings and their interaction with the hazard, allows determining the damage state that they may suffer in case of an earthquake. It is based on knowledge of available information that may raise the assessment methodology.

For the study of socioeconomic vulnerability it is a need to have census data, disaggregated at fraction and radio. Both, the radius and the fraction, are territorial units formed by the number of people. A set of radios is a fraction.

In the work presented, we proceeded to build a digital model using GIS technology. The model included as elements: departments, fractions, census radios, blocks, parcel and buildings; and it can be applied to the evaluation of various areas of the country~~,~~ subject to seismic hazard. The block is the territorial unit limited by four streets, typical grid layout, which is found in almost all provincial capital cities in Argentina, a legacy of Spanish colonization.

2.3.1 Determination of Physical Vulnerability of Greater San Juan.

A methodology was developed to determine the direct physical damage to buildings, knowing building type, seismic design criteria used and the height of the building. The hazard is taking into account through the pseudo-acceleration spectra. We also discuss the existence of collateral hazards, such as the possibility of soil liquefaction.

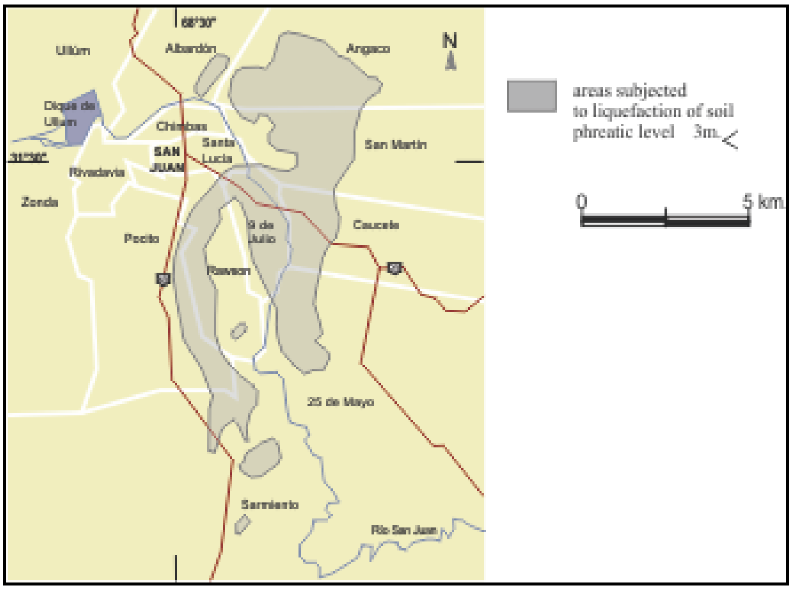

Figure 4. Areas subjected to liquefaction of soil

This methodology was applied to the physical vulnerability assessment in the Greater San Juan. Buildings were divided into groups with similar characteristics feasible to suffer damage or loss in a seismic event.

We studied the empirical vulnerability functions proposed by Petrovsky et al (1984), Milutinovic and Petrovski (1985), Coburn and Spence (1992), Spence (1993) and the theoretical vulnerability suggested by Cardona (1986), Petrovski et al (1990), Spence (1990) and Ordaz et al (1994); also the matrix resulting from the development of damage. (Whitman, 1973; Whitman et al, 1993).

Arrays of data, which combined–construction types, height and design criteria, were jointed with seismic scenarios, particularly with the scenario of an earthquake in the IX IMM area, equivalent to an epicenter nears the town center, hypothesis perfectly possible because the seismic history of San Juan. Romero and Zaragoza (2006).

For the analysis, damage matrices were used, depending on the Modified Mercalli Intensity (MMI), proposed in the ATC13 (1985). These matrices were properly calibrated and modified for application to the regional context, adopting the values that can be seen in Table 2. Romero et al (2004).

Table 2. Damage state of the building.

STATE OF DAMAGES	DAMAGE RATE DR (%)
1 - No damage or minor located damage to nonstructural components.	To 5 %
2- Moderate. Damage to nonstructural components. Small damage to structural components	6% to 20 %
3 - Large. Substantial damage to structural components.	21% to 45 %
4 - Extensive. Significant damage to structural components.	46 % to 80 %
5 - Complete. Great damage to structural components. Collapse	81% to 100 %

Damage Index (D. R.) was defined as the ratio between the repair cost and the replacement cost. For its determination, damage curves proposed by several authors were consulted according to the IMM. The methodology allowed us to determine, based on different seismic scenarios, the expected damage for every ~~–~~buildings. It was also possible to construct a continuous map, which allowed the identification of urban areas with similar damage range.

We evaluated a total of 187,794 buildings. Table 3 shows the distribution in every department that make up the Greater San Juan.

Table 3. Existing buildings in the Greater San Juan

DEPARTMENT	FRAGMENT	RADIO	PARCEL	BUILDING
Capital	7	113	33.521	80.473
Chimbas	3	61	18.897	31.150
Pocito	1	10	11.859	11.538
Rawson	7	87	26.457	51.276
Rivadavia	5	68	22.209	35.827
Sta. Lucía	4	43	13.478	23.350

2.3.2 Determination of Socioeconomic Vulnerability.
To study the socioeconomic aspect, not only indices to quantify the risk were developed, but also the spatial distribution of them.

The analysis aimed to define and characterize the social space of the city of San Juan on a statistical basis, at a detailed level of spatial disaggregation. The aim was to achieve a reliable picture of the social housing level of urban areas and its main trends.

The core of the study is the analysis of the social territorial structure of the Greater San Juan and how it influences the seismic vulnerability. The concept of social territorial structure refers to the identification of the urban residential areas and socioeconomic backgrounds, characterized from the analysis of census variables. We define its limits, study their interrelationships and identify the social - territorial basest, formulating hypotheses to explain them.

From these analyzers and working with the GIS, a comprehensive set of thematic maps that cover aspects of population, housing and households needed to define the social housing was developed. The comparative analysis of spatial distribution patterns of these variables helped to identify and describe statistically different urban areas of social housing.

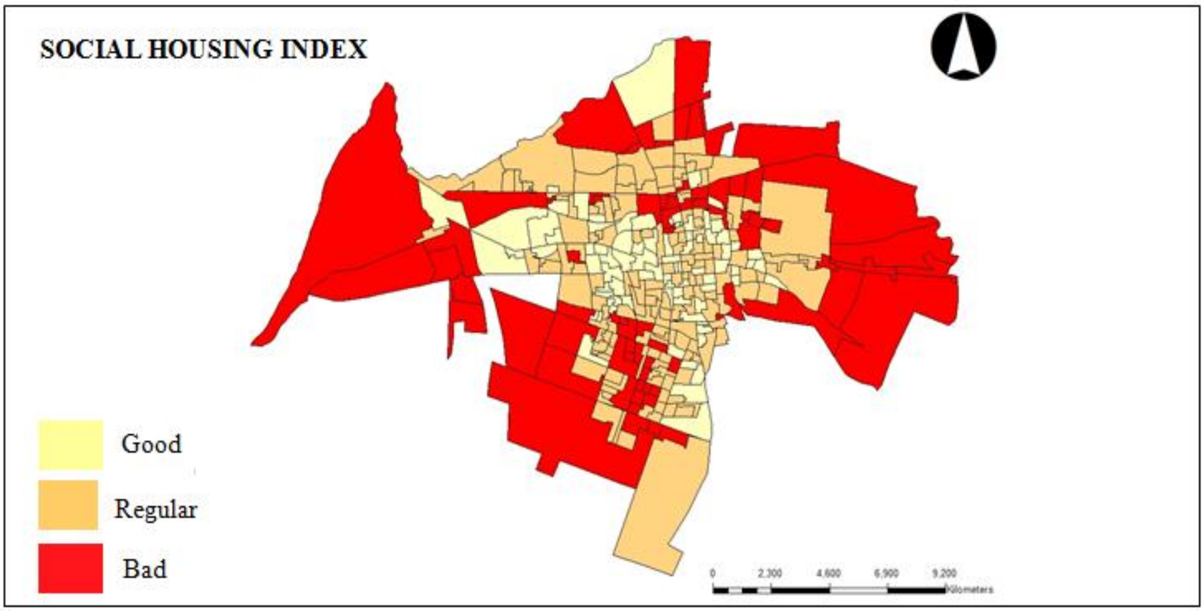

Figure 5. Social housing level of the Greater San Juan

We could then characterize the Great San Juan, in three different areas based on the values obtained: Residential areas with good, medium or bad social housing level. The first are located in the Northwest sector Capital department, in an important sector of Rivadavia, in a small sector of the Rawson department and in some recent developments of St. Lucia department. Areas of middle social housing level relate to the domains of the Capital department not included within the first category and areas of other departments closer to the center. Areas of bad social housing level show their highest concentration in the peripheral areas of the Great San Juan, belong with the departments of Rivadavia, Pocito, St. Lucia and Chimbas.

3. RESULTS

The determination of social housing index not only allows having a snapshot of the socio-territorial structure of the city, but also to understand the processes that have been structured urban space and its participation in the generation of risk.

Also, the methodology developed for assessing the physical vulnerability allowed to determine, on the basis of seismic scenarios, the expected damage for each of the buildings and the construction of a continuous map, identifying the urban with the rank of similar damage. Generating likely scenario, it was possible to visualize the geographical distribution of physical damage to the building, analyzing their interrelationships, estimate the economic costs and determine the direct and indirect losses caused by the event, among them, the damage suffered by the population, in terms of injuries and deaths.

In applying the two instruments mentioned above to the evaluation of the Great San Juan, we identified the most physically and socially vulnerable urban areas. Figures 5 and 6. A depth study was done for these areas, and main constructive and socioeconomic weaknesses were identified. Also there were determinate their social representations in relation to earthquakes.

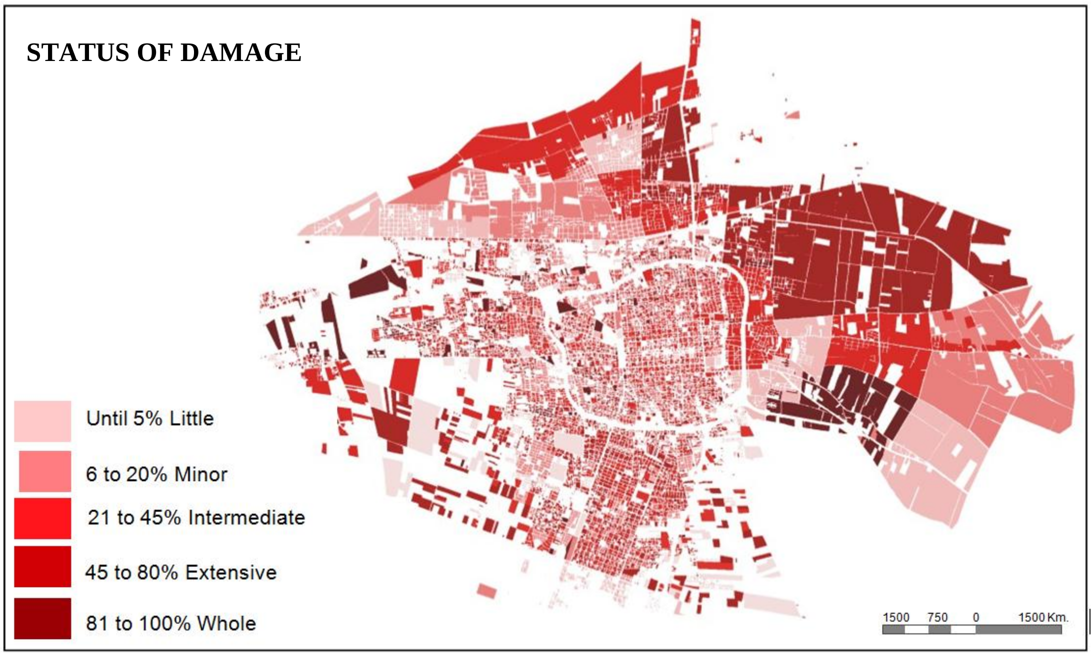

Figure 6: Status of damage to the building in the greater San Juan in an earthquake IMM IX.

This work, conducted in coordination with the Department of Geodesy and Cadaster and the Department of Planning and Urban Development Government of the Province of San Juan, will design tactics (territorial restructuring, human resettlement, recovery and environmental control, etc.) to mitigate the identified risk.

4. CONCLUSIONS

Most of the major urban disasters are due to earthquakes, since many of the most densely populated cities are located in seismic regions. The main reason causing casualties and damage after an earthquake is the collapse of buildings and infrastructure. Nevertheless, experiments carried out in cities located in areas of high seismic hazard, show that there are solutions to mitigate urban vulnerability.

The most important condition is that there is political commitment and national-local-to account for urban disaster risk. This is only achieved if today a change in public attitude based on knowledge of risk and believing that cities can be arranged to deal with disasters, acting to carry out this conviction. Only after this knowledge, is feasible to project tactics to reduce urban earthquake risk and plans for the emergency.

They may include:
- Development and modernization of the rules governing land use, banning numerous settlements and construction in hazardous areas, causing them compatible uses or green space.

- Inclusion of risk assessment in development plans. The course of development of a city determines whether disaster risk increases or decreases. When using criteria of risk assessment in developing urban development projects, investments that will be more sustainable development. Even with more limited financial resources, planners could significantly reduce disaster risk in cities.

- Generation of special programs for those high-risk urban areas. This may include, among others, restructuring and consolidation of existing buildings, the possibility that the population has access to credit for the improvement and construction of houses or self-organizing systems, sanitation titles, employment generation, etc.)

- Generation of programs for high risk groups: children, elderly, disabled, homeless. They should include education campaigns, specialized health care, etc.

REFERENCES

Cardona, O. D. (1986). Estudios de vulnerabilidad y evaluación del riesgo sísmico: Planificación Física y Urbana en áreas Propensas. *Asociación Colombiana de Ingeniería Sísmica*, Boletín Técnico AIS **33**. Bogotá, Colombia.

Cardona, O. D. (2001). Estimación Holística del Riesgo Sísmico Utilizando Sistemas Dinámico Complejos. *Tesis Doctoral*. Universidad Politécnica de Cataluña. Barcelona.

Coburn A. & Spence R. (2002). Earthquake Protection. John Wiley & Sons, New York.

Gray de Cerdán, N. (2006). Plan estratégico de Ordenamiento Territorial urbano y rural, Provincia de San Juan. Documento base del trabajo de consultoría realizado para el Ministerio de Economía y Producción de la Nación - Secretaría de política económica - Unidad de Pre inversión (UNPRE)- San Juan

Ordaz, M. et al. (1994). Bases de Datos para la Estimación del Riesgo Sísmico en la ciudad de México. *Cuadernos de Investigación*, **1**. CENAPRED, México, D. F.

Petrovski J. et al. (1984). Development of Empirical and Theoretical Vulnerability and Seismic Risk Models. *Proceedings of the 8th WCEE*, San Francisco.

Petrovski J., Milutinovic, Z. (1990). Modelo para la evaluación de la Vulnerabilidad y el Riesgo Sísmico. *Seminario sobre Desastres Sísmicos en grandes ciudades*. Bogotá.

Romero M. & Zaragoza A. (2006). Generación de escenarios para la evaluación del riesgo sísmico urbano. *Planificación Física - Cuba. Revista de Ordenamiento Territorial y Urbano*. **10**/2006. ISSN 0138 -6239. Cuba.

Romero M. & Zaragoza A. (2007). Evaluation of the Seismic Risk and their consideration among the Strategies of the Urban Development. *Proceedings of the 5th International Conference on Seismology and Earthquake Engineering*. Iran.

Spence, R. (1993). Assessing Vulnerability of Low-income Communities: A Progress Report. *Natural Disasters: Protecting vulnerable communities*. Ed. Merriman & Browitt. ISBN: 9780727719362. London.

Whitman R. V. (1973). Damage Probability Matrices for Prototype Buildings. *Structures Publication*. **380**, Department of Civil Engineering, M.I.T. Boston, Massachusetts.

Whitman R. V., Reed J. W. & Hong S. T. (1973) Earthquake Damage Probability Matrices. *Proceedings of the Fifth World Conference on Earthquake Engineering*, Roma.

CODES (NORMATIVAS)

Applied Technology Council (1985). Earthquake Damage Evaluation Data for California, ATC 13, (FEMA). Redwood city, California.

INPRES-CIRSOC (1991): Normas Argentinas para Construcciones Sismorresistentes, INPRES CIRSOC 103, Vol1. (INTI), Bs. As.