Multi-disciplinary Indicators for evaluating the Seismic Resilience of Urban Areas

E.Verrucci, T. Rossetto & J.Twigg
University College of London, London

B.J. Adams
Guy Carpenter, London

ABSTRACT
In recent years, resilience has become a fashionable buzzword in many disciplines spanning from civil defence to natural disaster risk reduction. The term itself is seen as an all-encompassing metaphor of a new way to tackle and manage risk. Attaining high levels of resilience against natural threats is a pressing priority in the agenda of national governments and international organizations in the field of Disaster Risk Reduction (DRR). Despite this, there is no widely agreed definition of the term resilience in the literature, and the development of methodologies to evaluate the resilience of communities to natural hazards remains a challenge. Previous efforts (e.g. Bruneau et al., 2003, Cutter et al., 2008) have used indicators to represent some, but not all, of the factors influencing resilience. This paper presents the preliminary application of a comprehensive multidisciplinary set of indicators to evaluate community resilience to earthquake hazards. The paper first introduces a theoretical framework to highlight topical macro-areas (e.g. planning, physical resistance, redundancy of infrastructures, etc.) that are thought to contribute to earthquake resilience. A set of indicators is then assigned to the defined seismic resilience macro-areas. Suggestions are made for the evaluation of a selected subset of indicators, focused on planning and land-use, for the case of the 1994 Northridge earthquake. Census and Tax Assessor data as well as Remote Sensing and GIS techniques have been used in the analysis.

Keywords: Resilience, Earthquakes, Indicators, Remote Sensing, Geographical Information Systems

1. INTRODUCTION

The body of literature in Disaster Risk Reduction shows evidence of a growing consensus towards resilience as a new modus operandi to face well-known as well as emerging security challenges (Buckle et al., 2000). Modern resilience studies build upon the consideration that both modern cities (Vale and Campanella, 2005) but also traditional communities (Gaillard, 2007) exhibit inherent levels of resilience and that some communities show the capacity to adapt, respond and recover better and faster than others after a disruption (Vale and Campanella, 2005).These practical findings have fostered the interest of the world-wide scientific community (Inter-Agency Secretariat of the ISDR., 2007, Kahan et al., 2009, Cutter et al., 2010,) to identify the components of resilience and establish the extent to which these can be transferred to less resilient communities.
So far several frameworks and models of natural disaster resilience have been proposed, and some have captured important characteristics of resilience (see, for instance, Bruneau et al., 2003). However, as those models tend to be discipline-specific, the definition of resilience proposed often fails to comprehensively represent physical, social and economic aspects of communities facing natural disasters. As a result, the practical applicability of this concept to DRR policy and practice remains arguable (Klein et al., 2003).
This study builds upon previous work on seismic risk (Davidson et al., 1997) and seismic resilience (Bruneau et al., 2003) and aims to evaluate community resilience to earthquakes in urban areas. It presents a comprehensive set of multi-disciplinary indicators of seismic resilience and the preliminary findings of their application to the Northridge case study. The methodology for deriving 'Planning and Land-use' indicators is described in detail. Census and Tax Assessor data are complemented by remotely sensed data for spatial retrospective analysis and GIS techniques for data visualisation and query.

2. EVALUATING SEISMIC RESILIENCE: RESEARCH METHODOLOGY

For the purpose of this paper, resilience is defined as "The capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure. This is determined by the degree to which the social system is capable of organising itself to increase this capacity of learning from past disasters for better future protection and to improve risk reduction measures." (International Strategy for Disaster Reduction, 2004).

As can be inferred from the definition, resilience is a term derived from multiple roots and many of these have found application in the DRR field. As such, the concept of resilience allows cross-disciplinary research, but confusion arises when a clear definition of resilience components is needed for its practical application. The lack of a comprehensive framework as well as of a standardised set of indicators to describe resilience is at the centre of recent debates in resilience studies (Kahan et al., 2009, Cutter et al., 2010).

The research methodology aims to fill these gaps and to provide end-users (e.g. local governments) with a new procedure to streamline seismic resilience of urban communities. The methodology does not produce a final single score of resilience. If, on the one hand, a single score gives a rapid overview of the less resilient communities, on the other hand, it limits the understanding of the aspects needing more attention and investment. Instead, this research will produce a comparative and disaggregated assessment of each indicator.

A five step approach has been followed to develop the indicators:

1. Definition of the conceptual framework and identification of topical resilience macro-areas (multi-hazard)
2. Identifications of resilience descriptors for each macro-area (multi-hazard)
3. Identification of resilience indicators, both used previously in the literature or new, for each resilience descriptor (earthquake-specific)
4. Evaluation of best data and technique (Northridge case study)
5. Analysis and Representation of results (Northridge case study)

3. A NEW COMPREHENSIVE FRAMEWORK FOR SEISMIC RESILIENCE UNDERSTANDING

The proposed framework for understanding resilience provides a structured and comprehensive overview of historical and multi-disciplinary dimensions (Figure 1). A detailed literature review of the historical and multi-disciplinary origins of resilience can be found in Verrucci (2009).

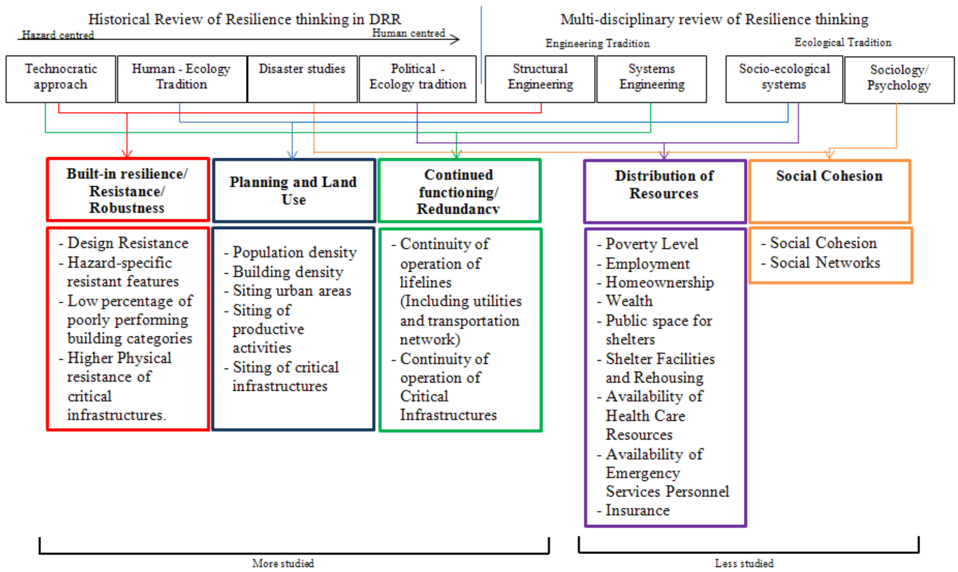

Figure 1. Framework defining topical macro-areas and resilience descriptors.

Five topical macro-areas have been identified:

- Built-in resilience: deriving from the technocratic approach (International Strategy for Disaster Reduction., 2004) and from the application of resilience in structural engineering (Bosher et al., 2007), it relates to aspects of resilience that can be addressed with appropriate design or with strengthening;
- Planning and Land-use: relates to the geographers point of view (Burton et al., 1978) and to the ecological tradition for which resilience is achieved by shaping the spatial location of future development based on hazard awareness (Mileti, 1999, Burby et al., 2000). Development choices are directly linked to the physical exposure of people and built environment to the hazard;
- Continued functioning or Redundancy of Critical service and Infrastructures: stemming from the technocratic approach and from the application of resilience in systems engineering (Bruneau et al., 2003), it is based on the observation that damage to key services and infrastructures is cause of great economic losses and hinders recovery;
- Distribution of resources: derives from the socio-vulnerability perspective (O'Keefe et al., 1976, Blaikie et al., 2003) and from the ecological perspective applied to communities (Folke, 2006), it notes that availability of resources, including monetary resources, is essential for fast and appropriate recovery;
- Social cohesion: developed from disaster studies (Quarantelli and Dynes, 1977) and from the ecological perspective applied to communities, it emphasises the role of citizens as first responders to disasters.

The first three topical macro-areas have received more attention in the past as they relate to systems which performance can be more easily measured in quantitative ways. Social aspects, like the distribution of resources and social cohesion in particular, are less commonly covered by the literature.

4. SEISMIC RESILIENCE INDICATORS

The first hazard-specific step of the methodology concerns the selection of indicators to evaluate seismic resilience. Indicators are defined as "tools…that can be monitored over time…can be disaggregated to the level of the relevant social unit' and can be "quantified in order to rank spatial and social patterns" (King and MacGregor, 2000). The identification of appropriate indicators to populate the candidate set (Table 4.1.) has required the review of previous models available in the literature. The examination has included both qualitative and quantitative models, referring specifically to seismic (Bruneau et al., 2003) or to multi-hazard resilience (or vulnerability) (Cadorna, 2006, Cutter et al., 2010) and to earthquake risk (Davidson et al., 1997; Carreno et al., 2007). This step has highlighted that qualitative models tend to be more comprehensive than quantitative models, which are instead more discipline-orientated. This observation demonstrates the marked disconnect between what is thought to be an ideal understanding of resilience versus what is actually measurable.

Table 4.1. Candidate set of indicators.

		CANDIDATE SET OF INDICATORS
TOPICAL MACRO-AREA	**RESILIENCE DESCRIPTORS**	**INDICATORS**
PLANNING AND LAND-USE	Low population density in high risk areas	♦ % of population in high risk areas
	Low Building density in high risk areas	♦ % of building in high risk areas
	Appropriate siting of old and new development	♦ % of urbanised risk area
	Appropriate siting of productive activities	♦% of commercial and manufacturing establishments sited in/outside high risk areas
	Appropriate siting of critical infrastructures	♦% of Critical Infrastructures sited in/outside high risk areas

BUILT-IN RESILIENCE	Design resistance	♦BUILDING STOCK - Building age and corresponding building code
	Hazard-specific resistant features	♦BUILDING STOCK - Spatial extent of retrofitting programs ♦BUILDING STOCK - % of retrofitted buildings
	Low percentage of poorly performing building categories	♦BUILDING STOCK - % of buildings with poorly performing construction types
	Higher Physical resistance of Critical infrastructures (including hospitals and emergency facilities)	♦HOSPITALS-building age and correspondent building code ♦SCHOOLS-building age and correspondent building code ♦FIRE STATIONS-building age and correspondent building code ♦POLICE STATIONS-building age and correspondent building code ♦ HOSPITALS-% of retrofitted hospitals ♦SCHOOLS-% of retrofitted schools ♦FIRE STATIONS-% of retrofitted fire stations ♦POLICE STATIONS-% of retrofitted police stations ♦LIFELINES - spatial extent of seismic risk reduction programs (for vulnerable components)
CONTINUED FUNCTIONING/ REDUNDANCY	Continuity of operation of lifelines (including utilities and transportation network)	♦Level of system redundancy (based on analysis of alternative routes and service lines) ♦ Existence of mutual aid programs with neighbouring utilities (QUALITATIVE) ♦Total length of roads
	Continuity of operation of Critical Infrastructures	♦N. and distribution of HOSPITALS per square kilometre ♦N. and distribution of SCHOOLS per square kilometre ♦N. and distribution of FIRE STATIONS per square kilometre ♦N. and distribution of POLICE STATIONS per square kilometre
RESOURCES	Poverty Level	♦% population living below poverty level
	Employment	♦% employed
	Homeownership	♦% homeownership
	Wealth	♦Per capita GDP
	Public space for shelters	♦N. of SCHOOLS per square kilometre
	Shelter Facilities and Rehousing	♦N. of temporary shelters per 1000 population ♦% of vacant rental units ♦N. of HOTELS/MOTELS per square kilometre ♦N. of personnel available for expedite assessment of accessibility of buildings per 1000 population
	Availability of Health Care Resources	♦N. of HOSPITAL BEDS for 1000 population ♦N. of PHYSICIAN per 1000 population
	Availability of Emergency Services Personnel	♦N. of FIRE STATIONS personnel per 1000 population ♦N. of POLICE STATIONS personnel per 1000 population ♦N. of social advocacy organizations per 1000 population
	Insurance	♦% of earthquake insured households ♦% of earthquake insured businesses
SOCIAL COHESION	Social Cohesion	♦Crime Rate
	Social Networks	♦N. of civil organizations per 1000 population

When analysing quantitative models, the frequency of use of a particular variable has given a good

indication as to which indicators are considered more representative and relevant for each resilience descriptor.
The candidate set of indicators has been revised according to data availability and quality. Several sources of data (e.g. Census data, Tax Assessor data) have been examined to measure the suggested indicators. However, as many of the suggested indicators have also a spatial component, open-source remotely sensed data and Geographic Information Systems have also been included.
The review of potential data and techniques has, as expected, shown that of the five macro-areas defined in Table 1 'Social Cohesion' is the most difficult to be evaluated in quantitative terms.

5. APPLICATION TO THE NORTHRIDGE CASE STUDY

This paper presents the preliminary results of applying the 'Planning and Land-use' subset of indicators to the case study of the 1994 Northridge Earthquake. Of the five topical macro-areas, 'Planning and Land-Use' has the strongest spatial component and therefore shows the added value of the application of Remote Sensing and GIS systems. The contribution of these technologies is instead more limited for the other macro-areas, where the use is often narrowed to data representation and interactive data query.

The analysis provides a comparative assessment of the 'Planning and land-use' component of resilience. The subsample consists of 7 zip codes (of 33 analysed) located near Northridge, in Los Angeles County. The sample was chosen consistently with the distribution of damage associated to the highest MMI records at the time of the earthquake (Figure 2 – Left). The assumption is that where damage was greater, momentum towards improvement was also higher. Processed data include zonation maps provided by the California Department of Conservation, Los Angeles County Tax Assessor for the year 2006, zip codes boundary from Census 2000, and population data from Census 2000 and Census 2010. Given the data available, the results provide an understanding of how the 5 indicators vary spatially, in the area delimited by the chosen sample, for the year 2006. The same methodology can also be applied to multi-temporal studies, if multiple sets of data are obtainable. The indicators have been derived as described in Table 5.1.

Table 5.1. Planning and Land use set of indicators – methodology.

INDICATORS	METHODOLOGY
A1 - % of population in high hazard areas (% of total)	Count of units in parcels at high hazard/low hazard then multiplied by the averaged population per unit.
A2 - % of building in high hazard areas (% of total)	Count of buildings in parcels at high hazard/low hazard
A3 - % of urban high hazard areas	Computation and sum of urbanised areas (urban areas – urban green) compare against total areas in parcels at high hazard
A4 -% of commercial and manufacturing establishments sited in/outside high hazard areas	Computation and sum of commercial and industrial areas in parcels at high hazard/low hazard
A5 - % of Critical Infrastructures sited in/outside high hazard areas	Computation and sum of area of critical infrastructures in parcels at high hazard/low hazard

As the overarching aim of the analysis is to assess the seismic resilience of communities in urban areas, the first step relates to the definition of the urban areas exposed to high seismic hazard. High hazard areas are defined as areas where the conditions of near-faulting, soft soils and high estimated ground motion concur. As 'Planning and Land-use' indicators provide an understanding of how well safe development is pursued, zonation maps produced by the California Department of Conservation have been used for seismic hazard characterization. The map is based upon a 10% probability of exceedance in 50 years (Figure 2 – Right). After defining the areas susceptible to the highest seismic hazard, the following step is to delineate the spatial concurrence of high seismic hazard and urban development. This has been attained by performing a spatial correlation between the zonation maps and the Tax Assessor data with known geo-referenced parcel data and use code. The outcome of this first level of analysis consists of the spatial delineation of three classes (Urban-High hazard – Red, Not urban-High hazard – Yellow, Low hazard –Green).

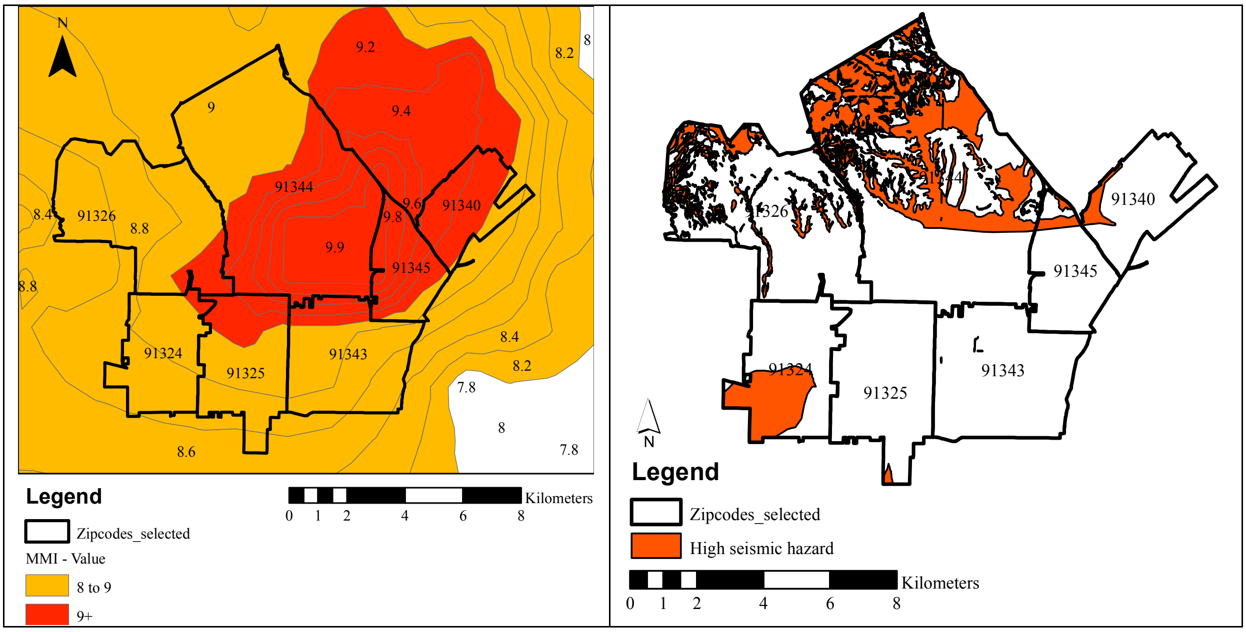

Figure 2. Left - Sampling. Right - Seismic hazard characterization.

In this first level of analysis, all parcels completely contained or intersecting the border of the hazard zones have been classified as exposed to high hazard. The analysis has been further refined by dividing urban areas into residential, commercial & industrial and governmental, which include urban green and critical infrastructures (Figure 3).

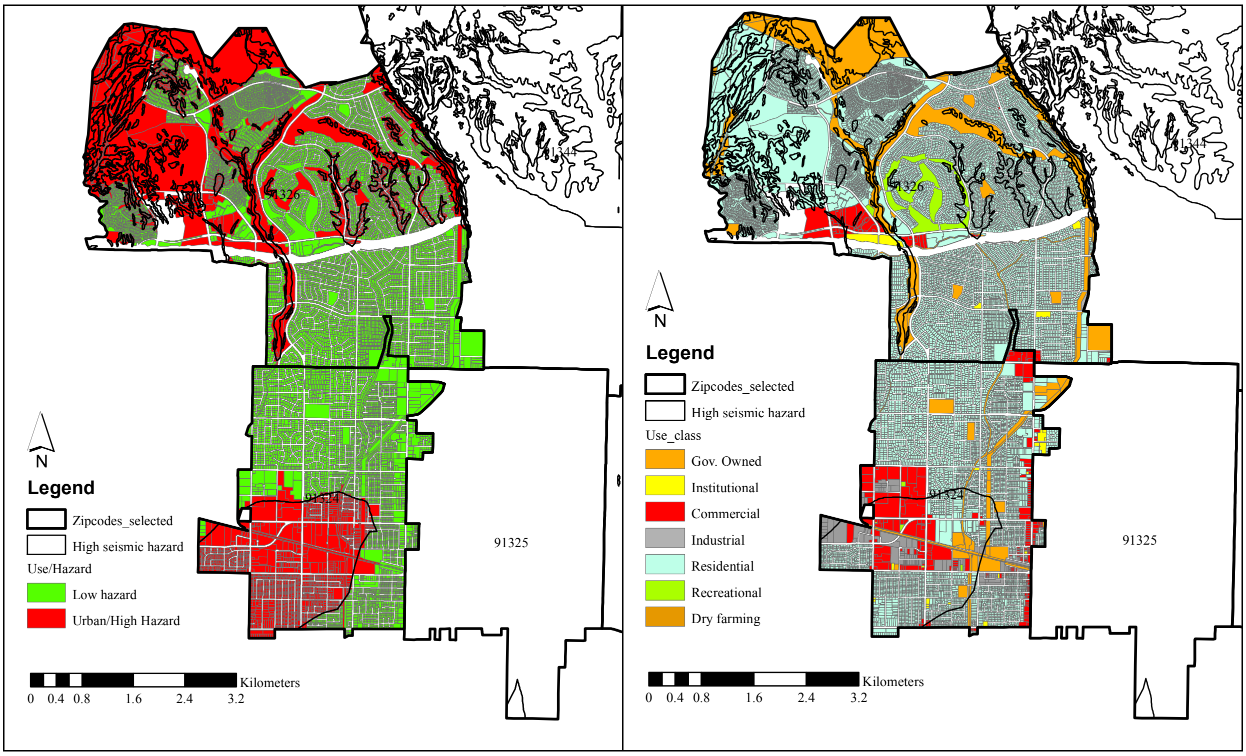

Figure 3. Example of thematic maps for zip codes 91324 and 91326. Left - Use/Hazard correlation. Right - Detailed use code.

The visual interpretation of the 'Use/Hazard' thematic map allows discerning, before any computation, what zip codes are likely to be greatly exposed to the hazard. In the sample, urban areas largely prevail over the rural areas. Hence, large portions of the urban environment can be exposed to high seismic

hazard when spatial correlation occurs, as for the area in zip code 91324 (Figure 3).
This level of analysis has a strong dependency on the 'Use Code' information provided in the Tax Assessors data. A rapid validation of the reliability of the use code data has been performed via visual interpretation using Google Earth. 'Use code' values from the 2006 Tax Assessor data have been compared against the 2006 Google archive satellite image. The level of detail of Google Earth satellite data offers a bird-eye synoptic view of the spatial location of big clusters of buildings associated to the different categories. For instance, commercial and industrial establishment are easily recognisable as they greatly differ in size and building type from residential units. However, the exact use of each parcel cannot be derived via visual interpretation. Buildings with mixed use (e.g. commercial and residential) and critical infrastructures are less distinguishable from the predominant residential pattern (Figure 4 - Right). Hence, Tax Assessor data is an essential dataset in order to perform analysis at this scale.

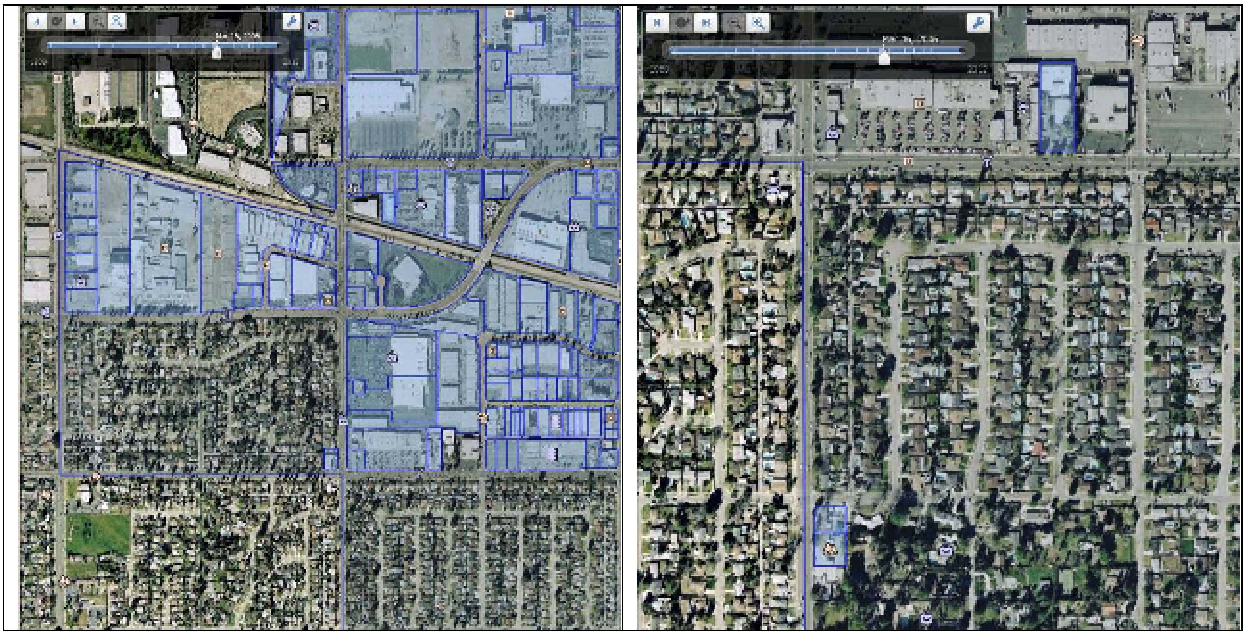

Figure 4. Left - Boundary of commercial areas extracted by Tax Assessors 2006 overlaid in transparency on the Google Earth 2006 (time slider) acquisition. Right - Location of some critical facilities.

Using a GIS platform, indicators of the 'Planning and Land-Use' have been computed (Table 6.1):

- the '% Population/ High Hazard' (A1) provides an understanding of what percentage of the total population is located in hazardous areas. The allocation of high hazard areas to rural, urban green or low density residential reflect in higher levels of resilience and lower levels of population exposure. This indicator has been quantified by multiplying the number of units by the average population per residential unit. A linear trend in population growth from Census 2000 and Census 2010 is assumed. Uncertainties in the estimate are due to the difficulty in assessing the location (high hazard/low hazard) of vacant units and to the impossibility of knowing the exact number of units in "five and more" class in the use code;
- the '% Buildings/ High Hazard (A2) helps understand how many buildings of the total residential building stock have been located in areas with high hazard. This indicator offers information about how consistent urban development is with the principle of sustainable development, embedded in the concept of resilience. A2 has been determined by assessing the use of the specific parcels. The number of parcels with residential use is usually a good proxy to assess building density;
- the '% of Urban high hazard areas' (A3) gives an indication of how much of the total areas exposed to high seismic hazard has been urbanised. The urban areas have been calculated excluding the areas allocated to urban green. Assigning high seismic hazard

areas to urban green destination is a further way to limit the exposure of building stock to seismic hazard;

- the '% of Productive Activities/ High hazard' (A4) is an assessment of how much of the local productive capacity of a zip code is located in areas at risk. Ideally local industries and commercial centres should be located outside hazardous areas to avoid delaying the recovery of the local economy;
- the '% of Critical Infrastructures/ High hazard' (A5) identifies how much of the total area reserved for critical infrastructures is exposed to high levels of seismic hazard. Schools, hospitals, fire stations and police stations have been assigned to this category. These facilities are essential for the exercise of normal routine operations and also crucial for emergency activities. Limiting the exposure of these services to the hazards gives higher levels of resilience.

Table 6.1. Summary table of indicators computation and representation.

Zip code	Indicators				
	A1	**A2**	**A3**	**A4**	**A5**
91324	0.31	0.29	1.00	0.55	0.32
91325	0.01	0.01	1.00	0.00	0.00
91326	0.19	0.19	1.00	0.08	0.00
91340	0.10	0.09	1.00	0.06	0.05
91343	0.01	0.01	1.00	0.00	0.00
91344	0.29	0.30	0.91	0.36	0.31
91345	0.01	0.011	1.00	0.20	0.24

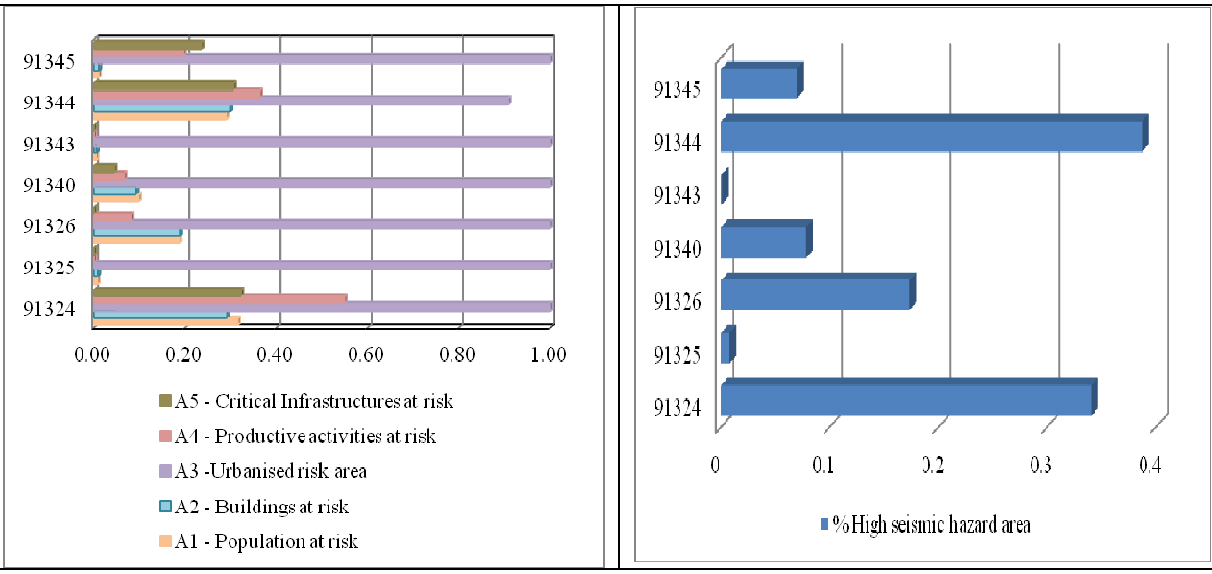

Figure 5. Left – Indicators values, expressed as percentages. Right – Spatial extent of high seismic hazard areas compared against total area of each zip code, expressed as percentages.

6. DISCUSSION AND CONCLUSIONS

Coherently with the hypothesis based on the visual interpretation of the thematic maps, the computation of the indicators confirms higher level of exposure for zip codes (e.g. 91344, 91324) with greater spatial correlation with high seismic hazard zones (Figure 5). This is due to the high level of urbanization in hazardous areas (A3 – in Figure 5 Left). This condition is very common in locations similar to Northridge, where activities linked to urban infrastructures are more common than rural-based activities. However, the overall level of exposure of population (A1) and building stock (A2) is rather limited (30% of the total). Exposure of residential areas is greatly influenced by the density of the population and of the built environment. For the analysed sample, residential areas are mostly low density and the majority of the structures are single residential units.

The chosen sample of zip codes offers a good array of different cases. The 'optimal' cases are represented by the zip codes 91325 and 91343. In those, the spatial extent of hazardous areas is very limited. Equally limited is the overall exposure of the population and of the built environment. At the other end of the spectrum, zip code 91344 has the greatest extent of hazardous areas. Nonetheless, it shows lower values of population exposure (A1) and building exposure (A2) than zip code 91324, as parts of the hazardous areas are intended for rural use (see A3 – 91344 value). Another way to limit the exposure of population and built environment is for the Government to retain the property of some of the hazardous areas, limiting urbanization. This is the case of the zip code 91326 where a portion of the hazardous areas are government owned (colour-coded in orange in Figure 3 - Right).

The sample also highlights the great variation in the exposure of productive activities and critical infrastructures. Of the two categories, the exposure of the critical infrastructure is easier to reduce. Critical infrastructures are similar in size to big multi-units residential buildings. Hence, they do not require big vacant areas to be built. Non-hazardous sites of smaller dimensions are easier to be found. Yet again, it is zip code 91324 that has the largest number of critical infrastructures in hazardous areas.

Commercial and Industrial areas need bigger available sites to be developed. They are not scattered over the territory but they are usually developed around specific areas (e.g. new residential expansions) or facilities. Being grouped in clusters, exposure can be very high if the site is on hazardous areas. This is again the case of the zip code 91324, where more than 50% of the total productive areas are exposed to high seismic risk.

In summary, considerations of resilience based only on the 'Planning and Land use' indicators would point at the zip code 91324 as a 'not so resilient' example. On the contrary, the zip code 91326 seems to be a 'resilient' example of the use of territory. In general terms, building stock and population exposure is limited in all the zip codes of the chosen study area and this is a good characteristic in terms of overall resilience.

However, an appropriate representation of the seismic resilience of an urban area cannot rely exclusively on the assessment of the planning and land-use. Other indicators need to be evaluated in order to provide a complete understanding of where investments are more needed and how current level of resilience can be enhanced.

AKCNOWLEDGEMENT

This research project has been supported by EPSRC (grant n. EP/F012179/1). I also acknowledge the contribution of ImageCat, Inc., which has provided important information and relevant data for the Northridge event.

REFERENCES

Blaikie, P., Cannon, T., Davis, I., Wisner, B. (2003). At Risk: Natural Hazards, People's Vulnerability and Disasters, Routledge, London.

Bosher, L., Dainty, A., Carrillo, P., Glass, J. (2007). Built-in resilience to disasters: a pre-emptive approach. *Engineering, Construction and Architectural Management* **14:5**, 434–446.

Bruneau, M., Chang, S.E., Eguchi, R.T., Lee, G.C., O'Rourke, T.D., Reinhorn, A.M., Shinozuka, M., Tierney, K., Wallace, W.A., von Winterfeldt, D. (2003). A framework to quantitatively assess and enhance the seismic resilience of communities. *Earthquake Spectra* **19:4**, 733-752.

Buckle, P., Mars, G., Smale, S. (2000). New approaches to assessing vulnerability and resilience. *Australian journal of emergency management* **15:2**, 8-14

Burby, R., Deyle, R.E., Godschalk, D.R., Olshansky, R.B., 2000. Creating hazard resilient communities through land-use planning. *Natural hazards review* **1:2,** 99–106.

Burton, I., Kates, R.W., White, G.F. (1978). The environment as hazard, Oxford University Press, New York.

Cadorna, O.D. (2006). A system of indicators for disaster risk management in the Americas. In Birkmann, J. (2006) Measuring Vulnerability to Natural Hazards: Towards Disaster Resilient Societies (189-209). United Nations University, New York.

Carreno, M.-L., Cadorna, O.D., Barbat, A.H. (2007). Urban Seismic Risk Evaluation: A Holistic Approach. *Natural Hazards* **40:1**, 137–172.

Cutter, S. L., Barnes L., Berry M., Burton C., Evans E., Tate E., Webb J. (2008) Community And Regional Resilience: Perspectives From Hazards, Disasters, And Emergency Management - CARRI research report 1, Community and Regional Resilience Initiative, Oak Ridge, Tennessee.

Cutter, S.L., Burton, C.G., Emrich, C.T. (2010). Disaster Resilience Indicators for Benchmarking Baseline Conditions. *Journal of Homeland Security and Emergency Management* **7:1**, 1–22.

Davidson, R.A., Shah, H.C. (1997). An urban earthquake disaster risk index, The John A. Blume Earthquake Engineering Center, Stanford, California.

Folke, C. (2006). Resilience: The emergence of a perspective for social-ecological systems analyses. *Global environmental change* **16:3**, 253–267.

Gaillard, J.C. (2007). Resilience of traditional societies in facing natural hazards. *Disaster prevention and management* **16:4**, 522–544.

Inter-Agency Secretariat of the ISDR. (2007). Hyogo Framework for Action 2005-2015: building the resilience of nations and communities to disasters, UN ISDR, Geneva.

International Strategy for Disaster Reduction. (2004). Living with risk a global review of disaster reduction initiatives, United Nations, Geneva.

Kahan, J.H., Allen, A.C., George, J.K. (2009). An Operational Framework for Resilience. *Journal of Homeland Security and Emergency Management* **6:1**, 1–48.

King, D., MacGregor, C. (2000). Using social indicators to measure community vulnerability to natural hazards. *Australian Journal of Emergency Management* **15:3**, 52–57.

Klein, R.J., Nicholls, R.J., Thomalla, F. (2003). Resilience to natural hazards: How useful is this concept? *Global Environmental Change Part B: Environmental Hazards* **5:1–2**, 35–45.

Mileti, D. (1999). Disaster by design : a reassessment of natural hazards in the United States , Joseph Henry Press Washington*, D.C.*

O'Keefe, P., Westgate, K., Wisner, B. (1976). Taking the naturalness out of natural disasters. *Nature* **260:5552**, 566–567.

Quarantelli, E.L., Dynes, R.R. (1977). Response to Social Crisis and Disaster. *Annual Review of Sociology* **3:1**, 23–49.

Vale, L.J., Campanella, T.J. (2005). The resilient city: how modern cities recover from disaster, Oxford University Press, New York.

Verrucci, E. (2009). Multi-disciplinary Indicators to measure and monitor Earthquake Resilience by using Remote sensing and GIS. MPhil Report. University College London, London.