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Proposal of a pilot resilience plan for a metropolitan region in Mexico City coupling different extreme hazards

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ABSTRACT

Currently, the accelerated development of automation and *e-technologies* are creating a modern and globalized society, in which the traditional urban systems become technologically more complex due to the necessity of provide faster services and products according to the requirements of a globalized market. At the same time, the fragility of the urban systems to natural hazards or human threats increases dramatically. Being **resilience** the ability to handle the negative consequences of a disaster and the capacity to recover from the loss of functionality, it should be convenient to improve the performance of Earthquake Engineering providing a much broader framework for the design of coupled structural systems. The aim of this work is to introduce two objectives: first, to present the outlines of a first approximation for an *Earthquake Resiliency-Based Design* (ERBD) dedicated to an urban region of great size -as it is the case of Mexico City-, potentially affected by a seismic event of major proportions concatenated to some other natural extreme risk. Second, to present the basis for the development of a pilot program for the improvement of resilience (PMR) of a representative metropolitan area placed inside of Mexico City.

1. INTRODUCTION

Nowadays, the large investments made in areas of automation and *e-technologies* are changing very fast the relationships between individuals in the worldwide and creating a technologically modern and globalized society. Consequently, these webs of knowledge based on information are generating complex urban systems adapted to the needs of the global market. In spite of this development, it is remarkable that as soon

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as complexity increases, the fragility of the systems to natural risks or human threats increases as well. Moreover, the drama of a disaster is magnified and spreads very fast among the global population because of the surprising transference of images and data around the world. Due to this, it has been possible to record and distribute in real-time the recent seismic events in Chile, New Zealand and Japan (EERI 2010, EERI 2011, Mahin 2012) - and recently in Mexico City, on March 20th, 2012 and April 18th, 2014 -. The analysis of these events showed that:

- An extensive urban community may have a highly fragility, if different extreme risks occur at the same time.
- The existing reinforced concrete buildings do not develop an efficient ductile response and shows a poor seismic performance, aggravated by the structural irregularities, hidden defects and limited practices of construction (Kawashima 2012) (Fajfar 2007).
- In many cases, local building regulations focus exclusively on residential and office buildings (Tena-Colunga 2009, Tena-Colunga 2010a, Tena-Colunga 2010b), while government regulation for infrastructure is minimal or nonexistent.
- In all cases, each affected community expects a quick response from the authorities.

Briefly, as mentioned by Reinhorn and Cimellaro (2012), each disaster of this type may result in serious political and economic consequences in cases where:

1) *Some critical components of the infrastructure of an affected region are partially or completely collapsed; and*
2) *The social resilience is not ready to be activated as soon as an extreme natural hazard occurs.*

The ability to handle the negative consequences and the ability to recover from the loss of functionality may be summarized to a single term known as **resilience**. This concept can help to quantify the performance of earthquake engineering for complex systems, providing a much broader framework for seismic design, focused exclusively to the structural performance of system components ("*Performance-Based Design*"). In **Resilience Design**, all the structures that provide any kind of service to the most critical building (like a hospital) must be evaluated and reinforced in order to maintain its serviceability to the local region.

To illustrate these ideas, we cite a local recent case occurred in Cancun, one of the most important Caribbean resorts located at the South of Mexico, wherein is placed the main - *and only* - bus station in the region, designed to support high wind loads induced by a hurricane. Indeed, 24 hours after Hurricane "*Karl*" hit the area in 2010, the bus terminal structure was evaluated by engineers who did not detect any damage. Nevertheless, no buses could make any travel during a medium period, because a large number of bridges and roads collapsed in the region, keeping the city of Cancun isolated for more than two weeks.

The aim of this work is to propose a pilot program of resilience for a local urban region –in this case, Mexico City -, to engineers, government and community in order to prepare them to prevent, act and react to natural disasters. In this proposal, the treatment of the complex urban system as a whole implies that each particular component of the system and their coupling must be redesigned, trying to ensure an acceptable level of security and operability, even if the disaster has already happened. This new paradigm also covers the magnification of risk due to the superposition of various solicitations (earthquake, explosion, fire, flood, etc.), being a scenario not considered in the current State-of-Art.

2. DESCRIPTION OF THE RESILIENCE-BASED DESIGN

According to Reinhorn and Cimellaro (2012), the **Resilience-Based Design** (**RBD**) should be seen, in a sense, as an evolution of the *Performance-Based Design* (PBD), in which the objective is to ensure the stability of the structure in order to protect human life: this methodology seeks to balance the relationship between loads and resistances inherent in the system. In RBD, this design criterion must be applied not only for an isolated building, but also for all the multi-structure system: each building or facility should have a specific level of structural safety related to its importance, focusing in reducing the recovery time of the community affected by one or more extreme events.
In this philosophy of design, the primary objective is to make that communities increase their level of resilience developing technologies, plans and actions, making that the three agents (engineers-government-community) be trained to act together before, during and after a catastrophic event occurs, in the framework of an evolutive disaster management plan, better known as **Resilience Improvement Program** (**RIP**).

The scope of this program involves not only the assurance of the good performance of a set of interrelated structures - unlike **PBD**, which focuses only to one structure -, but also identifies and prioritizes the level of importance that each set of structures can have, and it implements various criteria of design in order of importance. To clarify this, let us cite a recent case. In 2009, *L'Aquila's* earthquake destroyed the small town of *Castelnuovo*, Italy, keeping intact only one electric unit that, despite its good structural performance, it was not helpful for the reactivation of the city after the earthquake, because it was completely isolated from other infrastructure components (pumping machines). Making an exercise of imagination, if the **RBD** were applied to this case, as a first step of the **RBD** program, a group of main structures of the community (a hospital, for example) must be identified and insured, and as a second step, all the infrastructure that provides serviceability to them. As a third step, government and engineers must evaluate the safety conditions of the primary set of structures, in order to guarantee their functionality (electrical units, potable water, sewerage) and in parallel to ensure the integrity of lifelines (land crossings, bridges) that link the community to these buildings. Secondly, the application of the program also implies a discrimination/selection of the structural design requirements for each building. As an example, in the case of five hospitals in a given region, at least one must be selected to comply with higher standards of security, in case of a simultaneous collapse. The complete methodology for the analysis and structural design of infrastructure according to the **RBD,** is understood as an extension of the current *Performance-Based Design*, and includes the following items:

i. Identification, review and monitoring of critical components of the urban system;
ii. Incorporation of non-linear geometric and material models for civil engineering structures behavior;
iii. Concatenation dynamic analysis methodologies, stochastic and nonlinearity (see (Pérez-Mota 2011); (Jehel 2010));
iv. Adoption of multi-scale computational strategies (MACRO-MICRO-MEGA) (see (Kassiotis 2011a) (Kassiotis 2011b));
v. Reliable Interpretation of the mechanisms of damage to the Micro-Macro scales (see (Ibrahimbegovic 2014));
vi. Analysis of multi-extreme event risk (hurricane) in combination with other simultaneous or subsequent extreme events (floods, explosions, fires, etc.) (see (Colliat 2006); (Dominguez 2012); (Ibrahimbegovic 2012)).

3. A PROPOSAL OF A RESILIENCE IMPROVEMENT PROGRAM FOR A LOCAL URBAN REGION

Taking into account the considerations presented previously and based on an interdisciplinary scientific work, **five immediate actions** can be taken in order to build and develop a pilot **RIP** for some Metropolitan urban region placed inside of Mexico City:

1) First, start developing a program to improve the resilience or **RIP** ("**Resilience Improvement Program**") for urban areas potentially affected by a weather event magnum, as well as other combinations of ultimate load state from other events high-risk derivatives or related thereto.
2) As a second action is necessary to deepen both the fundamental knowledge of weather phenomena (understood as a combination of wind, waves and rain), and in the understanding of the actual non-linear behavior of the components of a building and infrastructure systems, and hence thermodynamic models to develop a very fine scale.
3) Advanced research in complex numerical methods should be promoted to improve the ability to predict reliably the actual last state structures.
4) Propose and provide new methodologies that replace refined simplified engineering methodologies traditionally used by designers, builders, inspectors, etc., which can integrate probabilistic aspects quantifying the behavior of a complex system and the applied loads.
5) Finally, two critical points are, firstly, how to integrate the perspective of the community in the development of PMR, and secondly, develop a strategy to

create awareness among the people inviting them to participate in its PMR town, under the supervision of government authorities.

Overall, it is proposed that the improvement program designed to Resilience urban region located in Mexico City is comprised of four essential components (see Figure 1):

I. **Development of an urban plan for disaster prevention**: Similar to what is known as a risk map geographical, this plan must spatially identify sets of structural systems hierarchy by setting its review and must be administered under a scheme of risk management.
II. **Developing a Design Methodology Based on Resilience**: Based on the possible combinations of region-specific risks, should be detailed methodology Infrastructure Design following the recommendations mentioned previously.
III. **Enrichment Government Disaster Plan DN-III-E**: Given the specificities of each Improvement Program Resilience, these should be incorporated as a support for the DN-III-E plan, serving as a guide and contact the affected community, organized around that program.
IV. **Implementation of a public awareness campaign at the regional level**: following the philosophy posed integration, this campaign should have a more informative organizational vision, redefining the role of the community in building and managing their own program of resilience.

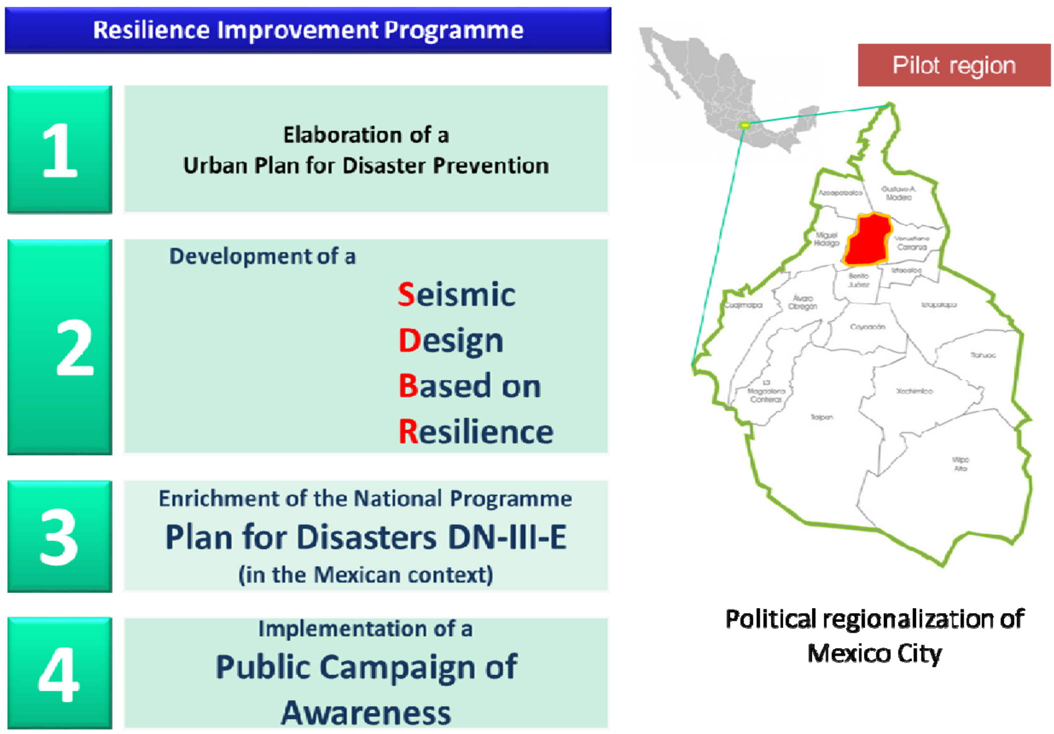

Fig. 1 Description of a Pilot Resilience Improvement Program (RIP) for Mexico City

4. CONCLUSIONS

In this work, the concept of resilience understood as the technical, economic and social resilience that can develop when a community is subject to a set of extreme events that can lead to collapse, by integrating three officers addressed: engineering-government community. Similarly, the high relevance of the development of a new method of Structural Design Based on Resilience (DBR), which would evaluate the nonlinear response of structures interlinked with each other, using the most advanced numerical analysis techniques are analyzed: the dot most important of this advanced methodology is that the structures can be simultaneously subject to large-scale weather events. Based on this philosophy, can be established in the medium-term program to improve resilience for a specific location (proposed for example, start with a delegation from the City of Mexico); in this program will be vital members of the community can participate in collaboration with authorities and specialists to ensure speedy economic, social and political recovery of the affected region.

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