SOCIAL SEISMOLOGY : THE EARTHQUAKE RISK MANAGEMENT PROJECT IN QUITO, ECUADOR

J.-L. Chatelain[1,2], B. Guillier[1,2], H. Yepes[2], J. Fernandez[2], J. Valverde[2], B. Tucker[3], M. Souris[1,4], G. Hoefer[3], F. Kaneko[5], T. Yamada[5], G. Bustamante[4], C. Villacis[5].

[1] ORSTOM, Quito, Ecuador.
[2] Escuela Politecnica Nacional, Quito, Ecuador.
[3] GeoHazards International, Stanford, USA.
[4] Ilustre Municipio de Quito, Ecuador.
[5] Oyo Corporation, Saitama, Japan.

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Introduction

The worldwide threat from earthquakes is growing : in 1900, one of every three large earthquakes killed humans, while today nearly two out of three are fatal. Earthquakes are not more frequent nor more powerful, rather, the number and size of vulnerable cities is growing. The world's urban population is dramatically increasing : from about 30% of the world's population in 1950 it is expected to reach roughly 50% by 2000. This growth is absorbed by cities becoming larger and more vulnerable : in 1950, only 25% of the world's 50 largest cities were located within 200 kilometers of an historical magnitude 7 earthquake compared to about 50% in the year 2000.

As countries become more developed, earthquakes cause fewer deaths and greater economic losses : the 1987 Loma Prieta earthquake (USA) caused 62 deaths and $4.7 billion of economic losses in and around San Fransisco, while a similar sized earthquake in Spitak (Armenia) killed over 20000 people and $570 million of economic losses. The economic loss in Spitak represented 95% of Armenia's GNP, while the loss from the Loma Prieta Earthquake represented only 0.2% of the United States GNP.

The Quito earthquake risk management project is a pilot project in social seismology launched in a developing country. Its purpose was to provide direction to government officials, business leaders, and the public in general, to reduce damage and injury in the next major earthquake. The scientific work involved institutions from Ecuador, Canada, France, Japan and the United States, in the fields of seismology, geology, soil mechanics, structural engineering, and city planning.

The project was divided into three phases. In the first, damaging earthquakes and their effects on Quito were analyzed. In the second, the impact on life in Quito during the month following one of these earthquakes was described in vivid, non technical terms. Finally, based on the first two phases of the project, recommendations for managing Quito's earthquake risk were formulated by a group of Ecuadorian and international specialists.

To provide objectivity, a group of international experts in the various fields involved in the project was formed. Its task was to check and endorse the work done. A group of potential users of the data was also formed in order to insure that the results of the project could be used. This group included representants of the local authorities, the main economical elements (e.g., banks, insurance, industry, and commerce) and the agencies responsible for the city services (e.g., water, electricity, sewage, and streets system).

Why an earthquake risk management project in Quito ?

Out of the 23 events felt in Quito with an intensity of VI or bigger since 1541, 8 produced intensities of VII or bigger in 1587, 1627, 1698, 1755, 1797, 1859, 1868, and 1923.

The past damaging earthquakes occurred while Quito was quite different from the modern Quito. The city has changed significantly in the last 40 years. In that period, the population increased from 420 000 to 1.2 million, with a considerable expansion of the city. This has resulted in increased urban densities, which, linked to expanding poverty, have resulted in an increase in poorly-constructed buildings and development in hazardous areas such as steep mountain slopes. In addition, high-rise buildings that did not exist in the 1950's have spread in the northern lower lands as a result of a more dynamic economy. Furthermore, the outcome of this dramatic growth is uncontrolled development and construction practices. Apart from the city's large modern structures, most dwellings in Quito were constructed without engineering guidelines. The Quito of today and tomorrow will respond to repetitions of the large historical earthquakes in very different ways than the Quito of the past.

It is expected that because of Quito's growth and earthquake history, the city's vulnerability will increase in the future unless concerted action is taken. While in 1990 the city began drafting a detailed development plan, in which earthquake hazards were taken into account, the inadequacy of available data hampered efforts to enhance the city's earthquake preparedness through planning guidance.

In order for the residents of Quito - including government officials, business leaders and the general public - to prepare for the next major earthquake, they must first understand the earthquake threat and the effects that a destructive earthquake will have on Quito. Only then can Quito begin a risk reduction program to reduce damage and loss of life in the next major earthquake.

Description of the project

First phase : future earthquakes and their effects on Quito.

The objective of this phase was to determine the effects of several possible damaging earthquakes on the city. Five steps were taken to reach that objective :

1.- Selection of several possible earthquake sources (location, magnitude) that could threaten the city. From an analysis of the historical seismicity and the distribution of seismogenic structures of the country, ten possible earthquakes with destructive potential for the city of Quito were identified. Three representative earthquakes were selected for detailed analysis :

a.- An inland earthquake of magnitude 7.3 and epicentral distance of 80 km from Quito, selected as a representative earthquake in the subandean region, in the zone of the 1987 earthquake.

b.- A coastal earthquake of magnitude 8.4 and epicentral distance of 200 km, selected because studies indicate a 60% probability of occurrence before the year 2000.

c.- A local earthquake of magnitude 6.5 and epicentral distance of 25 km. The 1990 Pomasqui earthquake indicated that the Catequilla fault is active, and the geometry of the fault

indicates that it has the potential for generating a larger magnitude earthquake. This earthquake is also modeling the 1587 earthquake located, possibly, on an active North-South trending fault.
At the same time, twenty-three earthquakes that produced intensities of VI or greater during Ecuador's 460 years of written history, which includes 1104 seismic intensity observations, were used to establish attenuation relations for the country, which were then corrected for application to the city of Quito.

2.- Division of the city into seismic zones : soil characteristics were obtained from over 2,000 drillings from various sources (e.g., private consultants, municipality files, and EPN studies). Based on topography, soil characteristics, and surface geology the city has been divided into 20 zones. For each of these zones a representative soil column was established down to a depth of 20 meters, usually not reaching the base rock, whose depth is unknown.

3.- Evaluation of the intensity distribution in the city based on these zone to prepare seismic intensity distribution (SID) maps for each of the three chosen earthquakes. Intensities in the 20 zones were computed using soil models and seismic responses, peak accelerations and soil amplifications, for the 3 hypothetical earthquakes, leading to the following results intensity ranges : subduction earthquake : 5.6 - 6.1 ; inland earthquake : 6.1 - 6.9 ; local earthquake : 6.3 - 8.0
These results were checked by comparing the computed intensity with observed intensities for the 1987 event.

4.- Evaluation of the location and distribution of different structural types (buildings, houses) throughout the city. Fifteen main types of structures were identified in Quito. Among those, each of the 9 most common types of buildings were subdivided in three categories, according to building heights. Then, each city block has been classified according to its predominant structural system, i.e. the structural type that covered the greatest area of the block.
In order to estimate the structural vulnerability of the structures, some buildings that we considered as representative of each type of structures were evaluated individually. Special structures such as hospitals, schools, industrial facilities, as well as the sewage system, water reservoir tanks, transmission towers, gas and oil stations near the city, and the airport were inspected individually with more scrutiny.

5.- Evaluation of the consequences of the intensity distribution on the buildings and city services. Physical damage caused by ground shaking was estimated using a relationship between the damage factor versus Modified Mercalli Intensity scale. In the method used, the damage factor is defined as the ratio of the estimated cost due to earthquake damages divided by the facility replacement value. We considered 7 states of damages : none, slight, light, moderate, heavy, major, destroyed. Finally, the time of recovery for lifelines was estimated. The method has been tested by comparing computed damages to observed damages for the 1987 earthquake.

Second Phase : a month in Quito following a future earthquake.

The scientific analysis of this project, while providing detailed estimates of damage from potential earthquakes, does not communicate the impact of such disasters. The purpose of the second phase of the project was to describe life in Quito during the month following the local earthquake, in order to help government officials, emergency service planners, business leaders and the general public to visualize the consequences of a future major earthquake, and provide the motivation and understanding required to act. The scenario is based on the scientific analysis of the local earthquake and a vulnerability study of Quito's city services, public buildings, and infrastructure.
The vulnerability study was performed by interviewing officials from 17 different city organizations, including sewer, water, power and transportation departments, Civil Defense, and fire and police departments. In a multi-stage process, the interviews were written up and returned to the interviewees

for review. The revisions then underwent further scrutiny at a meeting grouping all participants to the interviews. From this process, a detailed understanding of public services and the functioning of the city was gained and then used to estimate the earthquake's consequences.

The seismic hazard and damage assessments as well as the interviews were combined into a vivid description of possible consequences of the local earthquake. The scenario described the consequences of the earthquake in 6 parts : when the earthquake strikes, one hour later, the first 24 hours, and then at 2 days, 1 week, and one month.

Third phase : Proposition of recommendations to minimize the consequences of the next major earthquake on the city.

After the scientific analyses were reviewed by the international advisory committee, international and Ecuadorian specialists from the fields of business and industry, city government, city planning, emergency services and lifelines met for a two-day workshop in Quito. After estimating the effects on such factors as production capacity, employment, sales and services, the participants developed lists of specific recommendations within their field of expertise for reducing earthquake risks in Quito. For each recommendation, the participants described the steps necessary and the sources of funding, the responsible agencies, and expected start and completion dates. The primary recommendation was the establishment of a Seismic Safety Advisory Board, whose responsibility would be to review, revise and then administer a Seismic Hazard Reduction Program. Other high priority recommendations include projects concerning existing facilities, new facilities, earthquake planning, earthquake recovery and further research needed to improve the findings of this projects.

Conclusion

Because of this project, different scientific groups worked together towards a common goal, which would not have happened otherwise. It was an opportunity to gather and evaluate all earthquake related data for the country. It integrated existing research data and results that were previously scattered in different institutions, and presented them to international experts in each field, seeking their critique. Also, through this project we were able for the first time to convince the Mayor and the other civic leaders that the city was threatened by earthquakes.

This project is only a beginning at defining Quito's seismic hazard. The results represent the state of knowledge presently available in Ecuador for evaluating the seismic risk in the Capital city. In addition, it is a diagnosis of the research needed for making more reliable seismic damage assessments, as well as for improving the awareness of seismic hazard in the city, among the local government, utility managers, emergency services, private sector and the people living in the city.

These results are noteworthy because they reflect decades of work in the fields of seismology, soil engineering and structural engineering. They also represent five years of effort made by the Planing Service of the municipality to map the city on a computer with ORSTOM's GIS Savane©. Without all this previous information, it would have been impossible to accomplish our job in only one and a half years.

Finally, one of the main goals of the experiment was to raise awareness about the seismic threat in Quito. The project has been widely published by Ecuadorian newspapers and presented on TVs and radios as well as in professional journals and presented in various meetings. An overview of the project has been published and distributed to the politic and economic leaders. As consequences of this project, a seismic safety commission has been set up by the Municipality, a seismic code is under way and a project to retrofit several of Quito schools has been launched.