

EVALUATION OF SEISMIC VULNERABLE AREAS IN LIMA CITY BY USING SATELLITE INFORMATION

Miguel Estrada¹⁾, Masashi Matsuoka²⁾, and Hiroyuki Miura³⁾

1) Associate Professor, Faculty of Civil Engineering, National University of Engineering, Peru

2) Associate Professor, Department of Built Environment, Tokyo Institute of Technology, Japan

3) Associate Professor, Faculty of Engineering, Hiroshima University, Japan

estrada@uni.edu.pe, matsuoka.m.ab@m.titech.ac.jp, hmiura@hiroshima-u.ac.jp

Abstract: Within the project Enhancement of Earthquake and Tsunami Disaster Mitigation Technology in Peru, one of the objectives is to know the most vulnerable areas in the event of a big earthquake. In Lima, the capital city of the Peru, for many years has become the destination of inhabitants of the interior of the country, which has led to use unsuitable terrain areas as for example the slopes of the hills. This disorderly development has caused that the cadastral maps are not updated and therefore the extension occupied by these populations cannot be quantified. This article presents the use and integration of two sources of satellite information for the determination of vulnerable areas in the city of Lima, high resolution optical satellite images and images from PRISM sensor, which allows getting the digital elevation model. With this integration, it is possible to delineate and evaluate the likely areas of urban concentration in areas of threat. Also it is carried out the integration with social information obtained from national census in order to determine the homes of people with low economic resources that occupy this type of land.

1. INTRODUCTION

It is well known that seismic activity in Peru is very high, due to its location in the circum-Pacific seismic belt, therefore, the evaluation of the building vulnerability is a very important issue to prevent and mitigate the effects of an eventual occurrence of an earthquake. In Peru the development of cities is carried out, in many cases, without development planning projects, people from the countryside that comes to the capital city, looking for better living conditions, settles where they can, and this situation generates two big problems: first, they occupy land that is inadequate for construction of buildings, like soils with incompetent conditions as soils with low load capacity or they occupy the hillside surrounding the city. On the other hand, those people build their houses as they can, using low quality materials and without any technical direction. Therefore, these non-engineered buildings located in non-suitable locations, makes them very vulnerable structures in the case of an earthquake, thus their identification is very important for local authorities to make preparedness and mitigation plans.

Other problem to be faced is the lack of cadastral and topographic information that do not allow to make a building inventory and thus to evaluate the building seismic vulnerability (Estrada et. al., 2012). Therefore, it is necessary to use a technology that allows the identification of populated areas, especially those that are occupied on the

hillside.

Additionally to the physical information, another type of data is the social one. The social information allows to know the economic situation of the building owner and thus to infer the quality and condition of the building.

In this paper it is proposed the use of PRISM sensor imagery to determine the location of those populated places on hillsides and with the census data added to complement the study of the vulnerability.

2. PRESENT SITUATION

2.1 Study area

The study area is located in Lima, the capital city of Peru. Lima city is politically divided in 43 districts; one of them is Comas district. This district has a growing population of more or less half a million people, and the flat area of the district is already densely occupied, this is the reason that the hillsides are being populated rapidly, therefore the evaluation of these areas are necessary. Figure 1 shows the location of the study area. There it can be seen that the flat area is already populated and the growth of the city is towards the hills.

Figure 2, shows the conditions of the buildings built on the hillsides. It can be appreciated the informality of buildings and poor building practices, like building their houses on land fill, to accommodate to the topography of the land. This situation generates a highly risky area in case of

the occurrence of a severe earthquake.

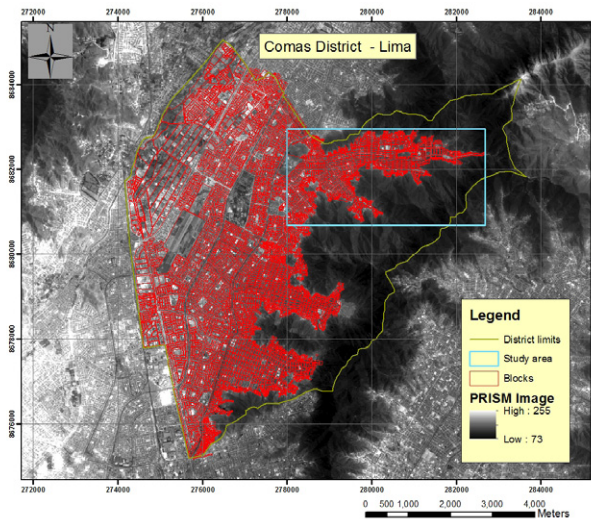


Figure 1 Map of the Comas District and selected study area.



Figure 2 Photograph of the condition of the buildings on the hillsides.

2.1 Cadastral Information

In 2007 the National Institute of Statistics and Informatics (INEI) carried out the National Census 2007: XI of population and VI of Housing (INEI, 2007). The information is aggregated in each block from where it is extracted the following information, within the study area, shown in Table 1:

Table 1. Census data of the study area.

Description	Value
Number of blocks	1016
Average number of houses per block	22
Total number of houses	14374
Total number of habitants	77900
Average Number of habitants per house	5.42

As it can be seen in Table 1, the density of habitants in each house is relatively high, this situation makes this area a highly risk one in case of a severe earthquake.

Besides of the population density, another important factor is the social class of the people. The social class is a good indicator of the quality of the building where the people live. It is obvious that well accommodated people lives in houses well constructed, while low income people construct their houses as they can and as they want, making these non-engineered buildings very vulnerable against seismic forces.

Information about social classes is shown in Table 2. As it can be seen mainly the population in this area is represented for low and middle low social class people, being almost 90% of the total number of blocks with information.

Table 2. Type of social class from census data.

Socioeconomic level	Number of blocks
Low	289
Middle low	474
Middle	82
Middle high	4
High	0
No Data	167

Another important parameter to evaluate the vulnerability of buildings is the material used in the construction. Table 3 shows the number of houses built with the different material used in this area:

Table 3. Type of social class from census data.

Material	Number of houses
Masonry	11200
Adobe	101
Wood	1979
Quincha (bamboo with wood frame)	17
Bamboo	446
Other/No Data	631

As it can be seen in this table, the main material used for construction is masonry, but even the masonry is a good material for construction the quality of the construction process is the problem, since the people built their houses by themselves, without any technical direction, these houses do not accomplish the requirements of national code, therefore their vulnerability is very high.

The presented tables show statistical values of the social condition of the people that live in this area. This is a high density populated area that is under developing with problems that make this area very vulnerable in case of an occurrence of an earthquake. Mainly there are two big problems the self-construction of the houses and the bad soil condition, as it can be seen in Figure 2. The topography of the area is very rugged and the uneven soil forces people to build their houses on landfill. Therefore, it is necessary to evaluate the topography of the area to determine the occupied land with important value of slope.

3. UMBRELLA PROJECT

This research is under the project “Enhancement of Earthquake and Tsunami Disaster Mitigation Technology in Peru”. Generally speaking, the purpose of this project is to developed technologies and measures for prediction and mitigation of earthquake/tsunami disasters caused by large-magnitude inter-plate earthquakes occurring off the coast of Peru (Yamazaki et. al., 2012)

This project is divided into five active groups. Group 1, researches on seismology and geotechnical issues, and give the final response of the soils, like probable peak ground acceleration. Group 2, studies the source, effects and countermeasures of tsunamis produced by an earthquake, mainly the output is the travel time and high of the tsunami waves to evaluate the possible damage in the affected area. Group 3, identifies the most typical building problems and will propose retrofitting methods or will give some advises to improve the actual building code. Group 4, will develop methodologies to identify the land use, by using the satellite imagery and integrating all the information in a GIS platform to assess the risk of the building as well as to develop a methodology for fast assessment of the damaged area by an earthquake or tsunami. Finally, Group 5 will take the entire group’s output and will disseminate this knowledge and propose policies for a sustainable development of the population. This project is under the support of Japan International Cooperation Agency (JICA), Japan Science and Technology Agency (JST) and Peruvian International Cooperation Agency (APCI). The institutions directly involved in this project are Chiba University, Tohoku University, Building Research Institute, Yokohama University, Tokyo Institute of Technology, Tsukuba University and Kyoto University, from the Japanese side and the Japan Peru Center for Earthquake Engineering Research and Disaster Mitigation (CISMID), Hydrograph National Direction (DHN), Geophysics Institute of Peruvian (IGP), Ministry of Construction, Housing and Sanitation, National Commission of Aerospace Research and Development (CONIDA), National Institution of Civil Defense and National Center of Assessment, Prevention and Mitigation of risk Disasters (CENEPRED).

Within this project is Group 4 who is in charge of developing methodologies to assess the vulnerability in Lima by using geo-informatics technologies.

4. SATELLITE IMAGERY INFORMATION

The original images come from the Panchromatic Remote Sensing Instrument for Stereo Mapping (PRISM) sensor that is one of the three sensors that are on board of the Advanced Land Observing Satellite (ALOS). The capability of this sensor to generate three dimensional models, comes from the simultaneous acquisition from three optical systems, as shown in Figure 3 (Pasco Corp. 2013). The general characteristics of this sensor are shown in

Table 4.

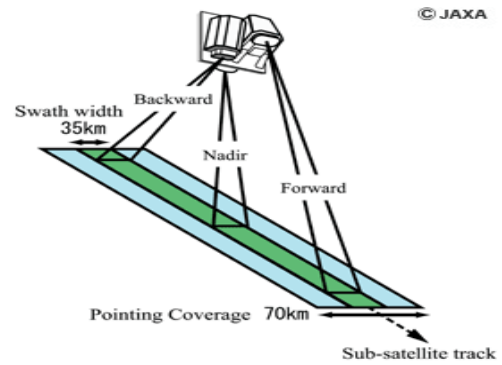


Figure 3 Schematic view of PRISM sensor, with three optical systems: nadir, forward and backward. Source: <http://en.alos-pasco.com/common/images/prism2.gif>

Table 4. Main characteristics of PRISM sensor.

Description	Value
Number of bans	1
Wavelength	0.52 – 0.77 μm
Number of optics	3: nadir, forward, backward
Ground resolution	2.5 m (nadir view)
Swath	70 km

Source: <http://en.alos-pasco.com/alos/prism/index.html>

The raw PRISM satellite images are processed to obtain two kinds of images: First the digital Surface Model (DSM) and the panchromatic image, as shown in Figure 4.

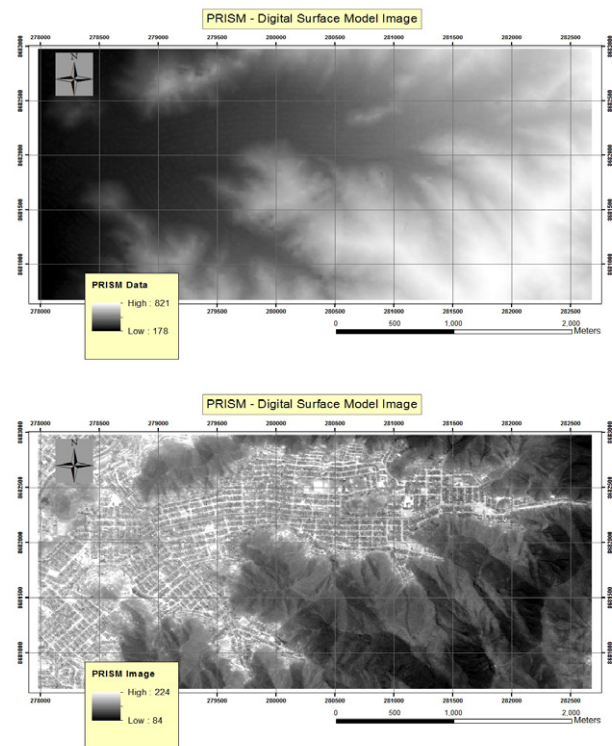


Figure 4 PRISM digital Surface Model and panchromatic image.

Since the cadastral information is not updated and since

the idea is to generate actual risk map it is used another type of optical satellite image, the WorldView-2. The characteristics of this image are shown in Table 5.

Table 5. Main characteristics of WorldView-2 sensor.

Description	Value
Number of bands (MS – P)	8 - 1
Wavelength	0.427 – 0.908µm MS, 0.632 µm P
Spatial resolution	2.0 m MS/0.5 m PAN
Swath	70 km
Acquisition date	10 April 2010

Source: <https://www.digitalglobe.com/>

The raw WorldView-2 image is pansharpened by using Gram-Schmidt Spectral Sharpening (ENVI program) to take advantage of the spectral information of the bands. Then this image is georeferenced to geographically match the block layer. The WorldView-2 image is shown in Figure 5.

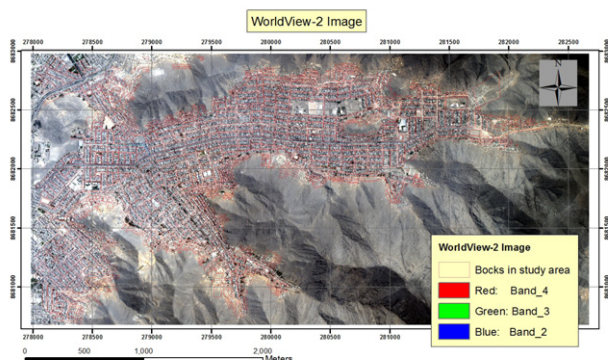


Figure 5 WorldView-2 pansharpened image integrated with blocks layer.

5. EVALUATION OF VULNERABLE AREAS

Once the images have been georeferenced with the block layer the next step is the integration of three sources of information: digital surface model, the high resolution image and the census data. Figure 6 shows the integration of these three sources:



Figure 6 Integration of cadastral information, high resolution satellite image and digital surface model.

Next step is to calculate the percent of slope or gradient of the terrain in the study area. This is carried out by comparing the rate change of pixel values of the DSM image in the horizontal and vertical directions (ArcGIS Slope tool).

The result of the slope analysis is shown in Figure 7.

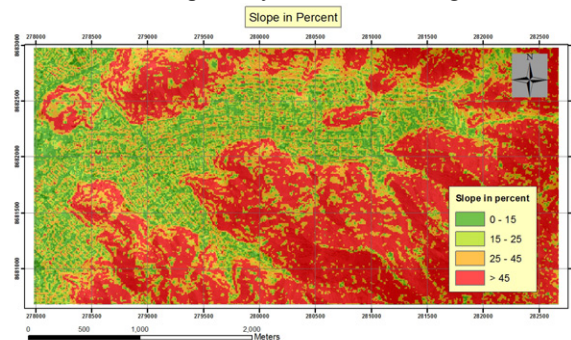


Figure 7 Slope map obtained from the DSM raster image.

Finally, this raster image that represents the slope is converted into point data, where the point value is the slope in percent. Then this point layer is aggregated into the block layer, given to each block an average of the slope. The map showing the slope in the block is shown in Figure 8.

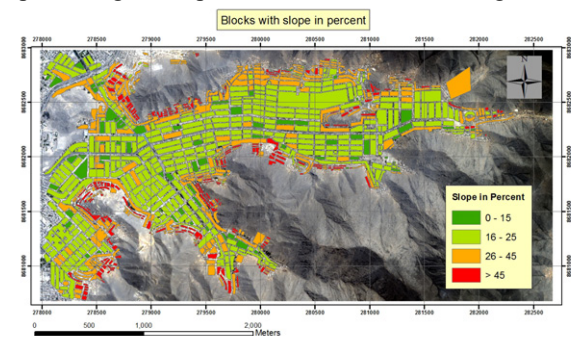


Figure 8 Percent slope integrated in the block layer.

As it can be seen those blocks that are on the hillside have been identify in red and orange color. Those blocks are settled in a land with an important slope that may produce slides in case of an earthquake and therefore people may be affected by this disaster.

6. CONCLUSIONS

The social vulnerability is very related with the social condition of the people.

It has been identified the location of low income people in the hillside that may produce a big loss in case of occurrence of an earthquake.

This proposed methodology may be used to make prevention plans to mitigate the effects of an earthquake.

Acknowledgements:

The authors would like to express their sincere gratitude to the Japan Science and Technology Agency (JST) Japan International Cooperation Agency (JICA) under the SATREPS project "Enhancement of Earthquake and Tsunami Disaster Mitigation Technology in Peru".

References:

- Instituto Nacional de Estadística e Informática (2007), "Censos Nacionales 2007" INEI, Lima, Peru
- Estrada, M., Miura, H., Yamazaki, F. and Midorikawa, S. (2012) "Evaluation of Social Seismic Vulnerability through High Resolution Satellite Imagery" *Proceedings of the 15th World Conference on Earthquake Engineering*
- Yamazaki, F., et. al (2012) "Progress of JST-JICA Project on Earthquake and Tsunami Disaster Mitigation in Peru" *Proceedings of the 15th World Conference on Earthquake Engineering*.