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Rapid Inventory of Earthquake Damage (RIED)

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The 25 January 1999 Quindío earthquake in Colombia was a major disaster for the coffee-growing region in Colombia. Most of the damage occurred in the city of Armenia and surrounding villages. Damage due to earthquakes is strongly related to topographic and subsurface geotechnical conditions underneath structures and houses. The RIED project used aerial photographs to obtain a rapid inventory of the earthquake damage right after the seismic event. This inventory was subsequently used to identify any existing relation with subsurface- and topographic conditions.

Hazard zonation maps were made on the basis of seismic response analysis of a three-dimensional model of the subsurface that has been created in the GIS. Also indicative zonation maps were created outlining potential areas where topographic amplification may occur. These seismic zonation maps delineate those areas that are most likely affected by subsurface and topographic resonance effects during a future and similar earthquake. The maps have been presented to the city planning authorities of Armenia so that reconstruction of the damaged areas can be carried out in such a way that high risk areas will be avoided or that structures and houses will be built according to the standards for high seismic risk areas.

INTRODUCTION

The coffee region is located in the western part of Colombia, an area that contributes greatly to Colombia's economy. Armenia, which is the capital city of the Quindío Department, has a population of approximately 270,000 inhabitants. Pereira, another important city, located 31 km north of Armenia, is the capital city of the Risaralda Department and has a population of approximately 380,000 (see Figure 1). The 25 January 1999 Quindío earthquake, with a magnitude of 6.1 on the Richter scale, killed more than 1,100 people and about 4,800 persons were injured. Approximately 45,000 houses were either destroyed or damaged (Photo 1). In order to make a rapid assessment of the damage inflicted by this earthquake and to make recommendations for the reconstruction of the damaged areas, the Dutch government offered assistance to the Colombian authorities. The ITC and the Delft University of Technology (TUD) in The Netherlands were subsequently requested to carry out this task.

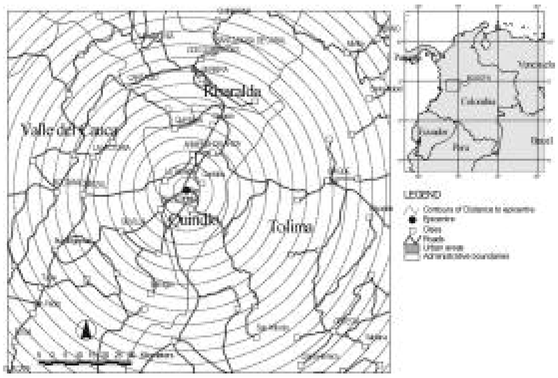

Figure 1. Location map

***Photo 1.** Neighborhood in the city of Armenia that was almost completely destroyed by the earthquake*

AERIAL AND FIELD SURVEY

A few weeks after the earthquake a team of Dutch experts from ITC and the TUD went to visit the two cities in the Quindío area that were affected most. The task was to make a first inventory of the damage and acquire all relevant geographic, topographic, and geologic information. An aerial survey was conducted during which several series of high-resolution aerial photographs were taken. It is important to carry out this kind of survey as soon as possible after an earthquake, because immediate cleaning, removal and rebuilding operations that are carried out may hamper a proper assessment of the inflicted damage.

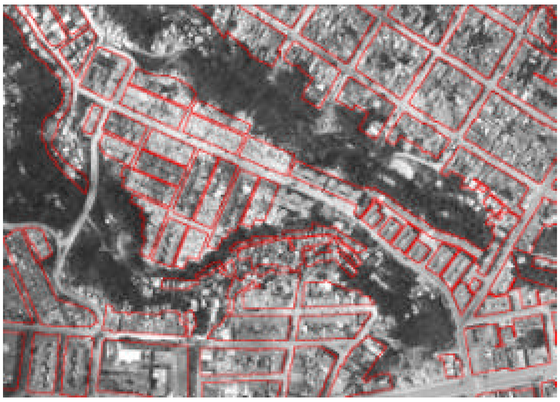

***Figure 2.** Digital orthophoto combined with existing cadastral data in the GIS*

The aerial photographs were ortho-corrected (removal of camera- and topographic distortion) and with existing cadastral and topographic information a comprehensive Geographic Information System (GIS) database was set up in a short amount of time. The aerial photographs were interpreted in order to assess for each individual house or building whether it was damaged and what type of damage was inflicted (see Figure 2). The damaged structures have been classified and marked on aerial photographs and simultaneously imported in a GIS. Maps for various types of damage to structures have been made and analyzed. In this way a large database was constructed with in total more than 33000 observations. An example of an analysis carried out on the basis of this damage inventory is given in Figure 3.

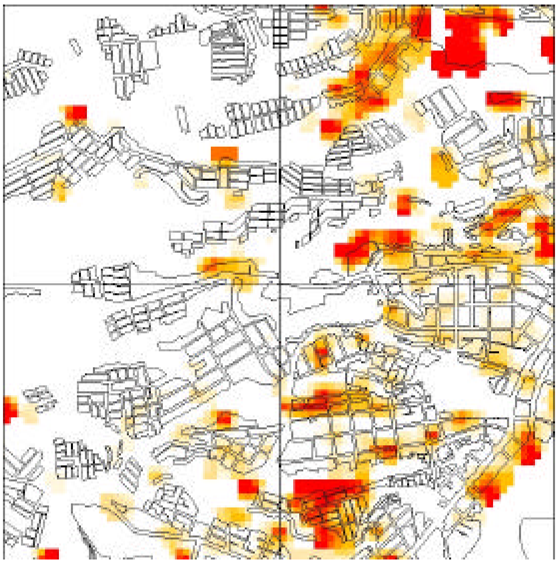

***Figure 3.** Damage intensity (damaged buildings as percentage of the total number of buildings)*

GEOLOGY AND GEOTECHNICAL SUBSURFACE CONDITIONS

The region around Armenia is located in the western piedmont of the Central Cordillera, and consists mainly of metamorphic and sedimentary rocks from Paleozoic to Cretaceous ages. Volcano-clastic deposits (the so-called Quindío Glacis) of Plio-quaternary age cover these rocks. The deposit consists of several lenses and layers of alternating and interfingering pyroclastic- and lahar flows. In the Armenia area two main (active) faults have been identified. A lineament analysis of the area of Armenia has been executed on 1:20,000 aerial photographs of 1981. The identified lineaments are defined by anomalies in the drainage pattern as well as slight topographical events in the surface of the "Glacis del Quindío". Near surface all sub-surface materials have been weathered to residual soils with varying thickness.

Man-made landfills consist of materials (natural or man-made) that are used to fill natural depressions or enlarging level terrain in urban areas. In Armenia the most common places for landfills are the natural drainage channels. The landfills are mixtures of organic soils with ashes and lapilli's, construction material, spoil heaps, organic material, garbage, etc.

The residual soil and landfill material creates particular poor circumstances for foundations during earthquakes as in these materials amplification of the earthquake tremor occurs. The damage inventory survey clearly showed the relation between the thickness of loose materials and actual damage due to the 25 January earthquake.

TOPOGRAPHIC INFLUENCE

The presence of topographic undulations (Figure 4) has a marked influence on the surface accelerations of an earthquake. Near steep slopes an amplification of the effects of an earthquake can be expected. Also resonance effects are possible if the dimensions of ridges in the topography coincide with the frequencies of the major tremor of the earthquake. The locations where this resonance effect may take place has been modeled in the GIS and an example of this analysis is given in Figure 5. Both topographic effects can be correlated to the damage patterns of the city of Armenia.

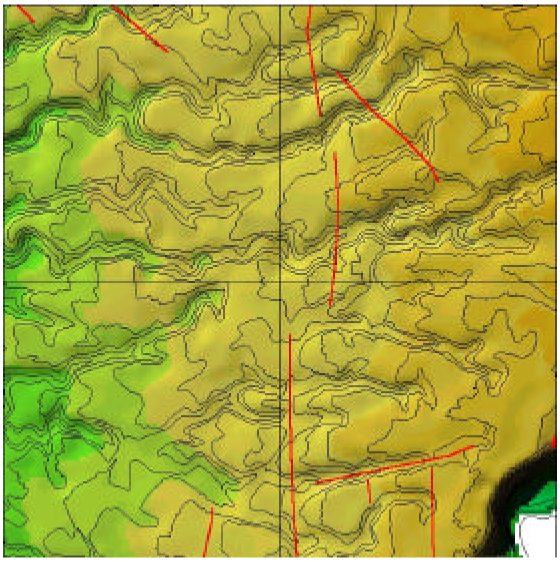

Figure 4. *Topographic relief*

SEISMIC RESPONSE ANALYSIS

Certain geological conditions (the characteristics of the subsurface) can result in serious amplification of the seismic signal, causing increased intensity of earthquakes at these locations. How the subsurface reacts on a certain seismic wave can be modeled. For this purpose a three-dimensional subsurface model was constructed in the GIS which was subsequently used as input for the seismic response model. On the basis of the results of this seismic response analysis different seismic microzonation maps have been made which delineates the difference in seismic responses throughout the area as a function of the subsurface geology. Examples of these microzonation maps are given in Figures 6 and 7.

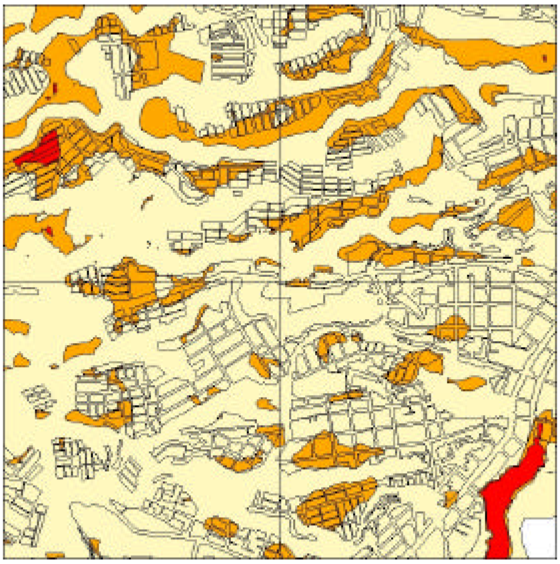

Figure 5. *Potential areas where the topographic resonance effect may take place*

Additional measures should be taken to reinforce the constructions in those areas, or to avoid building structures in such areas. The aerial photographs also show that three-dimensional site effects occur on some of the ridges in the topography. As there is very little known of these effects a research study has been initiated to study in more detail the three-dimensional aspects of topographic effects on seismic response.

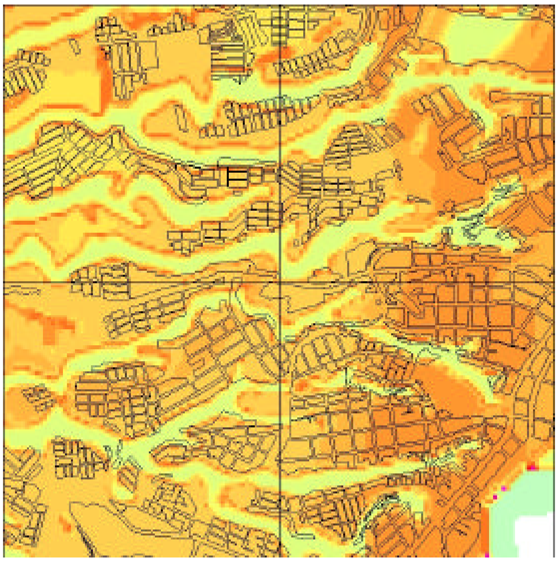

Figure 6. *Seismic acceleration response distribution for 1-2 story buildings*

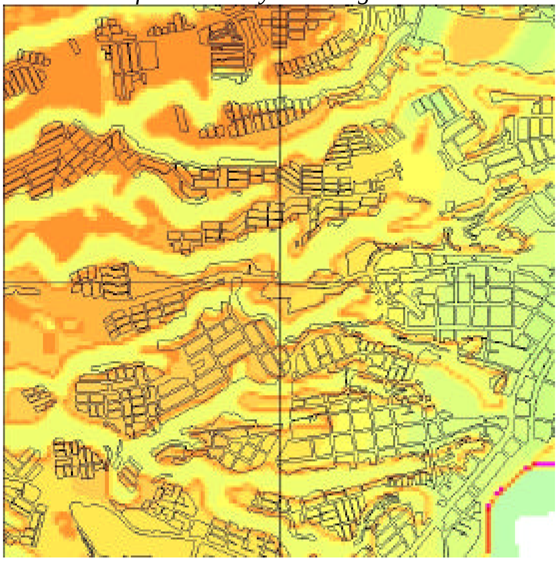

Figure 7. *Seismic acceleration response distribution for 2-4 story buildings*

RESULTS

The damage inventory made by aerial photographs clearly shows that the damage is concentrated in a more or less wedge-shaped area bounded by the Armenia fault on the East side and by alignments in the topography on the West side. The coincidence of this alignment with the boundary of the most damaged areas may indicate that the alignment in the topography is in fact a fault trace. The damage inventory shows further that topographical effects are of important influence on the damage inflicted on the surface structures. The a-priory assumed influence of the landfills on the damage of structures is less obvious from the inventory by aerial photographs. The damage inventory from aerial photographs has been correlated with a ground survey of the damage done by various organizations in Armenia. Both methods have their own merits and in future rapid damage inventories such as this study, it would be recommendable to combine both methodologies to achieve a more comprehensive approach. Generally, the results of the damage inventory by aerial photographs shows that for reconstruction purposes the damage inventory using aerial survey gives a reasonable impression of the damage. Major geological, geotechnical, and morphological features that have influenced the damage inflicted on surface structures are generally easily recognizable. The results of an inventory of damage by aerial photographs can be available very soon after an earthquake compared to a ground survey. This should be of large benefit to the reconstruction planning.

Biography

Adriana Lucia Duque Velasca, Head of the Section City planning of the Corporacion Regional del Quindio (CRQ), Ministerio del Medio Ambiente, in Armenia, Colombia. BSc Civil Engineering.

Robert Hack (project coordinator), Head Section Engineering Geology. B.Sc. Geology, M.Sc Engineering Geology (Delft) and Exploration Geophysics (Utrecht), PhD Technical University Delft, The Netherlands. Worked in Middle East, Indonesia, and Africa in civil engineering as geotechnical consultant. Is a chartered engineer and president of the Dutch Association for Engineering Geology.

Lorena Montoya. Lorena Montoya is currently a lecturer for the Division of Urban Planning and Management (UPM) at ITC. She obtained her Licentiate's degree in Architectural Engineering at the Autonomous University of Central America (UACA) in Costa Rica followed by an MSc. degree in Geo-Information for Urban Planning at ITC. She is also presently conducting Ph.D. research on the topic of Risk Assessment for Urban Planning at ITC.

Siefko Slob, Lecturer in the Section Engineering Geology. B.Sc. and M.Sc. in Engineering Geology (Delft). Worked for many years in civil and geotechnical engineering, and regional hazard and risk studies.

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Rob Soeters, Senior Lecturer in the Section Engineering Geology. B.Sc. and M.Sc. in Mining Engineering. Worked on many projects throughout the world on aerial photograph studies for civil engineering, applications of geographical information systems, and hazard and risk assessment for natural hazards.

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