A MEXICAN CITY CASE STUDY (MORELIA, MICHOACAN) ABOUT BUILDINGS AND INFRASTRUCTURE DAMAGES FROM ACTIVE GEOLOGICAL FAULTS

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ABSTRACT :

This is a case study in a Mexican City (Morelia, Michoacan), about an inventory of present and potential damages in buildings and infrastructure along one of its main geological faults called “La Paloma.” Morelia City is the capital of the State of Michoacan, which is in the central part of Mexico. The City is located in a valley originated by the Mexican Volcanic Belt tectonic activity. It extends over the Cuitzeo Basin, which lies on top of a section of the “Sierra de Mil Cumbres.” This area is intersected by the active system of the Morelia-Acambay fault. The tectonic activity of the region have provoked multiple geological faults and sinking phenomena in the City. Just in October 2007 there were a couple of low intensity earthquakes with epicenter within the City, reminding Us about the faults’ active status. “La Paloma” is among the most critical faults. It extends in an East-West direction, with variable height differences (200 meters at its maximum). Last decades have witnessed considerable construction of buildings along and around this fault: Reasons are multiple and often related with a high real state revenue. However, serious soil displacements have occurred along some sectors of the fault, damaging partial or completely constructions and infrastructure. In this context, the article presents a documented inventory of the relevant buildings and infrastructure damaged, thorough photographs, geo-positioning, owners’ standpoint, and third party opinions. Derived from this information, possible future scenarios for damages are also discussed.

KEYWORDS: Geological fault, vulnerability, damaged building

INTRODUCTION

Morelia is the capital of the State of Michoacan. It is situated in the central part of Mexico at an altitude of about 1941 meters above sea level, and its historic downtown area was considered as a World Heritage by the UNESCO in 1991. The city has experienced a large population increment since the eighties, which has brought a growing demand for infrastructure and housing. This fact, combined with a lack of planning and regulation from authorities, have resulted in widespread settlements in the City, sometimes in areas heavily affected by the multiple geological faults that cross the City in different directions. Some of these areas present four to six centimeters of ground subsidence due to this phenomena and to the aquifers overexploitation [Arreygue-R et al., 2002]. Last decades have witnessed considerable construction of buildings along and around these areas. In particular, there is an urban growing development along the fault called “La Paloma,” in the South of the city, which is considered the longest fault and a vulnerable area of land slope instability and seismic activity. The fault has variable height (up to 200 meters difference) with an approximate length of 300 km, due to a regional normal fault with E-W direction. (see Figure 1).

Constructions along the fault present different level of damage, from simple fissures on the floor to stress and deformation on main elements, provoking vulnerability to collapse in case of an earthquake ocurrs. Though there is a geological map and studies of vulnerability and report of damages, authorities have allowed owners to build over the fault area, which has brought problems in the buildings and in the infrastructure. Up to now, no systematic work has been done documenting damages in buildings and infrastructure. In fact, damaged buildings owners have been dealing in multiple ways to repair or somewhat to solve the problem: From different repair approaches up to demolition or abandon. Among main effects there are wall falling, houses no-apt for living, structural damage in infrastructure (streets, pavements, water piping, sewing system, etc.). Up to now there are guidelines in current legislation [H. Ayuntamiento, 2004] to prevent construction in those areas, but they are recent and many times unobserved, due to a long corruption story. In this context, this paper aims to document and discuss about some representative damaged buildings along the fault “La Paloma.”

GEOLOGICAL BACKGROUND

It is convenient to identify the main faults behavior factors in the city: Tectonic plates movement, volcanic eruptions, drastic changes in stratigraphy and aquifer overexploitation. This last factor implies the continuous deformation along time of previously consolidated sediments due to ground water extraction, provoking a ground pore pressure change and consequently, a variation in its thickness while being compressed [Echeverria, 2004]. This phenomenon has been damaging some building works. Based on a description done by Alcantara and Garduno [Alcantara, 2004] about Morelia’s faults, and following an orientation criterion, faults in the City may be classified as North West-South East, North East-South West and East-West. “La Paloma” is an E-W direction fault and it is located in the so called “Morelia-Acambay Fault System” with the highest seismic potential. For this paper purposes and in accordance with the configuration of the fault, this one was divided into four zones: Zone I (neighborhoods of Ejidos de Santa Maria and Balcones de Santa Maria), Zone II (neighborhoods of Prados del Campestre, Condagua and Ejidal Santa Maria), Zone III (neighborhoods of Fray Antonio San Miguel Iglesias, Villas San Miguel and Ocolusen), and Zone IV (neighborhoods of Villa San Miguel, Esmeralda and El Periodista). The center of each zone was determined by © 2007 Google Earth ™ by the latitude and longitude of its central point. Figure 1 shows general location in the City, while Figure 2 depicts an aerial site view of the study area.

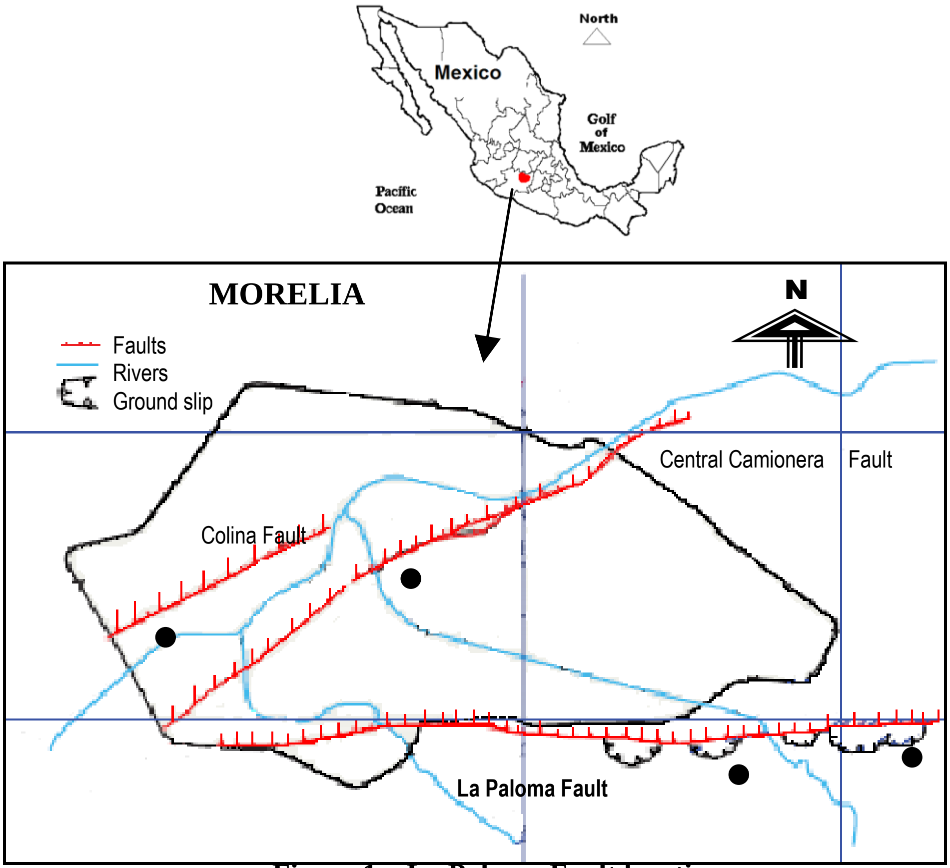


Figure 1 La Paloma Fault location

© 2007 Google Earth ™ Viewer's high 6.34 km

Figure 2 Study area overview: zones I, II, III and IV.

ZONE CASE STUDIES

As previously mentioned, the area of study was divided into four zones, which can be seen on Figure 2. Characteristics for each zone are provided and instanced by some particular, representative buildings.

Zone I

The virtual central point is located at 19°40'49.10" N and 101°10'47.02" W (© 2007 Google Earth ™). Building has been developed all around the scarp, from bottom to top. In the lower part, houses are from one to three stories. Damages are kept under control by considerable maintenance and repair expenses. Fissures are repaired each two months on average. There is a building called IMCED which is representative of two stories houses which are common in this area. The first floor of IMCED is on the ground and the second one was built on the upper part of the ground. This is a typical way of house construction in the area, by "taking advantage" of the slope. Transversal walls to the slope exhibit diagonal fissures due to shear forces (see Figure 3). The floor presents cracks in some areas. Land slope instability is the main problem, damaging the structure by the house sliding, separating the upper structure from the foundation.

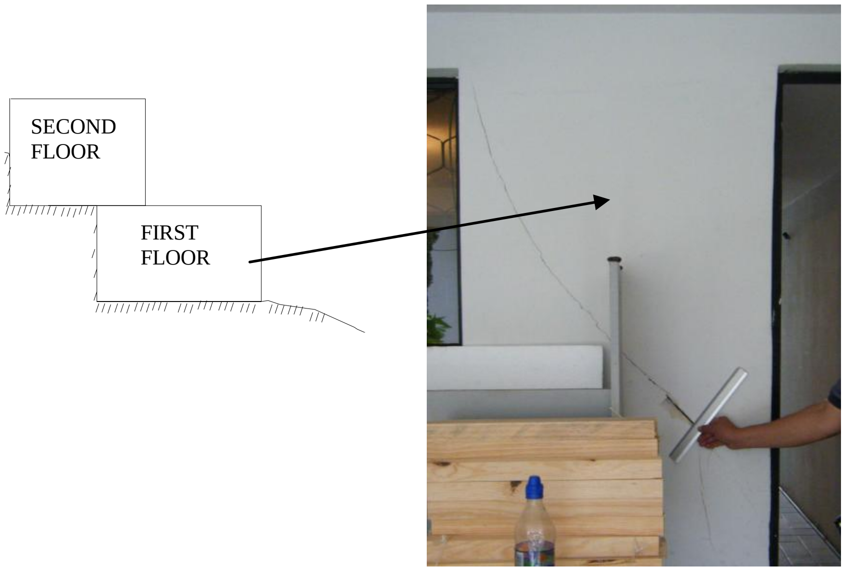


Figure 3 Representative two stories house wall damaged (IMCED).

In the upper part of the scarp, buildings are from one up to six stories, where ground subsidence used to be the main problem (see Figure 4). In the middle of the scarp, two houses (Franz Liszt St.) experienced such a subsidence event on September, 2006: Authorities said the problem was caused by faulty construction, assuming none responsibility on damages, although they had granted the corresponding building permits. Nowadays one of those houses is non-habitable. Following the road up the scarp, some houses exhibit structure displacements from its foundation (4 cm on average). Roads are repaired each two month according to inhabitants comment. Potential danger comes up from a normal fault and historic seismic activity evidence, land slide and falling blocks [Arreygue-R et al, 2002]. This area offers a beautiful view of the city, and it is an expensive neighborhood, so that owners may afford to pay for repairs like cracks on floors, cracks on walls, cracks on foundation and even to make major repairs like building and rebuilding contention walls and so. Some owners have decided to sell their houses, but on the other hand, three new buildings appeared on last year. One of those buildings is made out of steel, meanwhile the others are made by reinforced concrete frames.

Figure 4 Construction on progress along the scarp (zone II)

Zone II

The virtual central point is located at 19°40’51.68” N and 101°10’01.99” W (© 2007 Google Earth ™). SEDUE building (government department now days called SUMA) is located at the bottom of the scarp, and it is an important building in the zone. Mud runoff is the main problem that occurs each year (rain season). This urban area does not present evident structure damages, even though it is being determined that the area is sliding with a translational movement of a large block (600 m long, 400 m width and 40 m thick) [Arreygue-R et al, 2002]. Up the hill there are not buildings.

Problem in houses along the scarp bottom is being solved by building barrier walls, which send mud and water flow to the streets and main avenue. At the top of the scarp there are ground fractures parallel to the fault. However, there are not buildings over there.

Zone III

The virtual central point is located at 19°41’01.24” N and 101°09’12.60” W (© 2007 Google Earth ™). The zone exhibits a number of different troubles with buildings, so that different areas will be addressed: Villas San Miguel, Fray Antonio San Miguel, and Ocolusen.

Villas San Miguel

Over this area the most damaged building is a middle education school. It is a building complex one and two stories height, covering an approximate area of 12,000 m^2. It is located in the South-East part of the City in the "Ejidal Ocolusen" neighborhood, limiting with the "Ahuizotl" Street to the North, with the not-urbanized low section of the scarp to the South, with the "Baltazar Echavis" St. to the East and with the "Jose Manuel Sartorio" St. to the West. Most of the construction is made by steel frames and masonry. Just some one-floor structures are made by reinforced concrete and masonry. Height difference between the upper and lower sections of the fault is about 120 m. In this area, the ground contains pyroclastic rock and presents rototranslational slide and fall effects.

The fault does not affect all the buildings, but just a couple of them and most pavement areas. Subsidence in damaged buildings caused three to five cm. cracks in their foundation and problems with floor coverings. Their footing beams have fissures due to the stress provoked by the subsidence and displacement of the building. This issue has been attended by cross-bracing selected steel frames in the buildings.

The cross-bracing solution has worked up to now. Anyway, owners have accepted to be doomed to repair pavement and stairs in the playground area each four or six months, pouring asphalt and concrete in the cracks, and remaking sidewalks and steps (see Figure 5).

Figure 5 Middle School play ground damages

Because of the horizontal architecture and the buildings' steel frames the problem seems to be under control. However, as the school is just down the scarp of the fault, some large rocks in the upper part might roll down into the buildings. This possibility is critical in the rain season and in case of seismic events. The danger is not only for the middle school, but for the entire housing neighborhood, since nobody knows which path the rolling rocks would follow if falling down. Surely, no one would like to live there, but the area remains crowded. Arreygue et al. [Arreygue-R et al, 2002] performed a free fall rock simulation in the area, considering vegetation, slope, materials, friction angle, etc., resulting in an estimate of about 15 m/sec velocity for the rolling blocks in the housing zone.

School neighbors comment that many houses are damaged by the fault, although this is not always apparent in the façade. They have to repair their houses an average of twice per year. Again, typical repair involves some aggregate plaster and steel mesh for reinforcing. It is interesting to note that many neighbors are not very poor but rather middle class. Inhabitants comment that firemen have dynamited some of the above rocks in previous years, Sometimes successfully but not always, leaving some rocks on risk to roll down.

Fray Antonio San Miguel

Ahuizotl St. is parallel to the fault, which crosses a group of houses impacted by the problem. Damage depends on construction materials, structural type, and wetting conditions derived from water runoff. In this scenario the owner's income plays an important role in building repairs. Houses are from one to three store height and made out of masonry with reinforced concrete frames. Repairs are carried out almost on a semester basis. In all these cases "repair" means the application of some agglutinant plaster, sometimes with wire-mesh reinforcement. It is common practice to offer damaged houses for sale without any warning. Damage in pavement and sidewalk is also evident, and solution has been pouring more asphalt or concrete into the cracks and repairing sewage. Authorities have not responded promptly to all these troubles.

Ocolusen

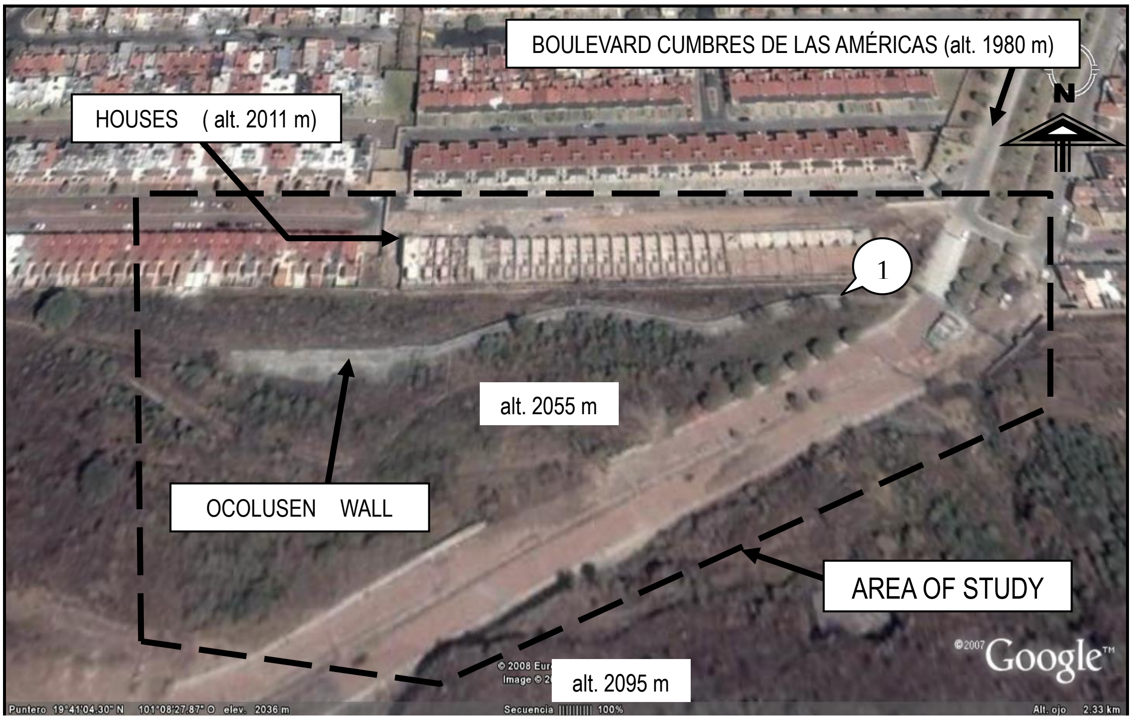
The Ocolusen neighborhood is situated at the bottom of the Paloma scarp in zone III. It presents similar damages than those in Ahuizotl St. There is a small area of four blocks that are flood each three years (over 50 cm of water) as a result of ground configuration and inefficient sewage. In past time this area was a small lake, but it was drained to develop an urban area. Two houses in the area are on sale, other owners have moved up the floor level more than 50 cm. Another approach has been to construct steps and a low wall in front of the residence to avoid water entrance into it. Most affected streets are Jose L Rodriguez, Marcos Ramirez, and Bernal Diaz y Jose Suarez.

Zone IV

The zone encompasses the neighborhoods of Villa San Miguel, Esmeralda and El Periodista. The virtual central point is located at 19°41'06.09" N and 101°08'35.63" W (© 2007 Google Earth ™). Last years the region has experienced different gravitational processes which started with the construction of a way up to the hill to connect neighborhoods from the lower part of the scarp with a new developed urban area in the highest part of the scarp: Modifying and accelerating instability, slide and falling rocks. New fractures and land slides are being present. Four years ago a residence complex was built at the bottom area, and a retaining wall was constructed to protect it from potential slides. Paradoxically, the wall also fractured. Even though, more houses were built in the area after the event.

As previously said, the retaining wall was built to protect a house complex (Lomas de Ocolusen neighborhood) from complex landslide. The wall is made up by mortar-bound stone, with an approximate length of 200 m, and it is oriented in a NE-SW direction. At this point the scarp presents a height difference between the upper and lower blocks of the fault of about 130 m. In this area, the ground contains pyroclastic rock and presents rototranslational slide and toppling effects [Arreygue-R et al, 2002]. Figure 6 offers a Google Earth commented image about the area.

Point 1 in Figure 6 was also located by the GPS. The position was 14 Q 0275631; UTM 2178008. The cross section of the wall is showed in Figure 7, in which it is also possible to view another retaining wall (reinforced concrete) a couple of meters below the stone one. The image shows the distance between the wall and the house complex. There is an open concrete channel between the walls to conduct rain water downstream. This is the water that flows from the higher zone of the stepped scarp. There are 3" pipes in the stone wall to allow water passing through.



© 2007 Google Earth ™ Point 1: 19°41'4.98" N; 101°8'24.79" O; Altitude 2028 m; Viewer's high 2.33 km

Figure 6 Ocolusen retaining wall area overview

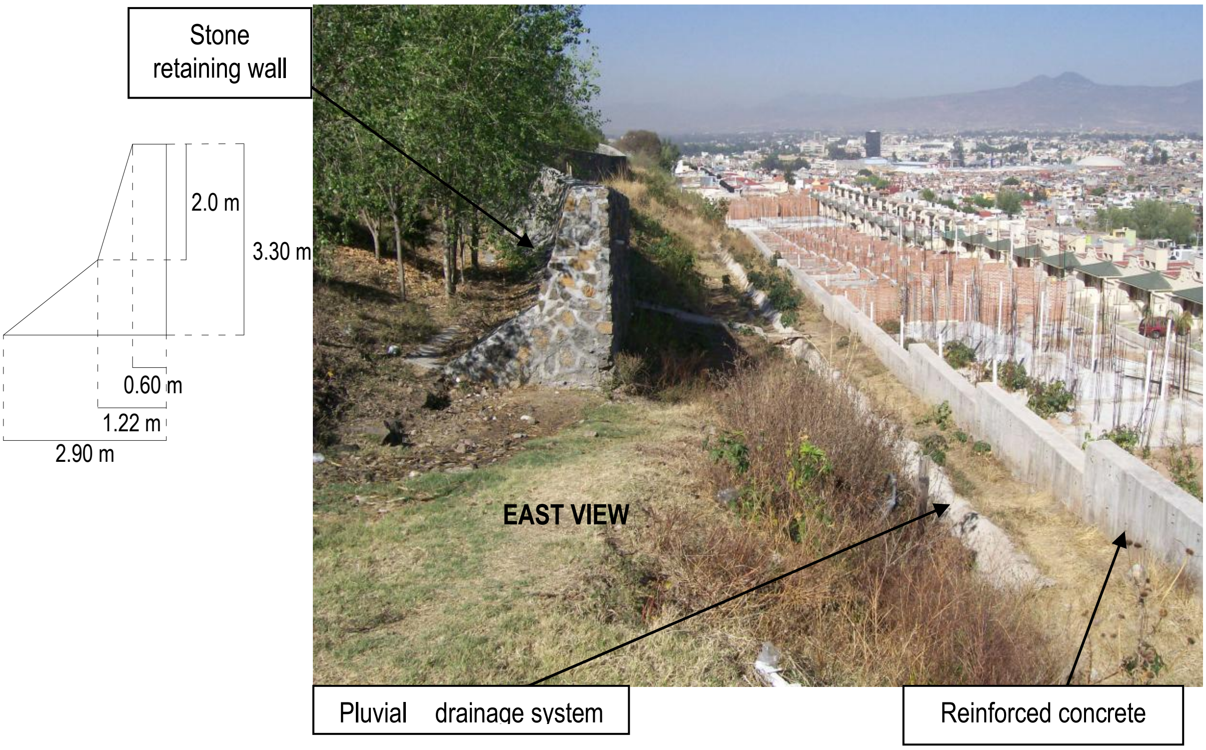


Figure 7 Ocolusen retaining wall geometry

There are slide and toppling in the area, which have caused spectacular falling of the sidewalk and curb along the way up the hill. Owners try to keep repairing the road, but the effort seems to be useless, since the ground keeps yielding. They have experienced different routes for channeling pluvial water downstream, but they have not found a satisfactory alternative yet. However the house complex downstream continues being constructed. On the other hand, the retaining wall is being cracked by the ground slide. Hopefully it will bear the complex landslide should it happened, but unfortunately and just from a rough sight estimation, it will not.

Owners repair approach has consisted in putting more mortar plaster to fill the wall cracks, and improve the way water pass through the wall, besides to keep experiencing with different paths to channel the pluvial water downstream. In the meantime, the house complex keeps going on, cutting the scarp to gain land for the construction of more two story houses.

CONCLUSIONS

In general, the genesis of the problem is closely related with the lack of enforcement to preserve reserved zones from urban development and real state stakeholders. Once people are living along the area, for whatever reasons, it seems that just 'coping' with the problem is the only way to go. Hopefully, authorities would realize this fact and would really prevent further development. In particular, Zone I includes a highly dense constructed area, with potential slides and a never-ending repairing job for house owners, offering also a marvellous view of the downtown area. Zone II is less crowded than zone I, with relatively minor problems. As long as not more buildings are erected, the scenario is not that bad, provided sewage is properly designed and maintained. Zone III is also widely populated and it is paramount that no more building work be made up the scarp. It is also paramount that loose rocks in the hill are removed immediately. Sadly, owners are doomed to keep repairing their property for ever. Zone IV share similar troubles, aggravated by a complex landslide and by the fact that more houses are being built in the dangerous area. In this context of poorly managed urban development, a desirable and minimum remedy is to develop repairing techniques suitable for this environment, assisting owners into their implementation.

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