Learning from Earthquakes

The Bahía de Caráquez, Ecuador, Earthquake of August 4, 1998

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Introduction

On August 4, 1998, a magnitude Ms=7.1 earthquake near the coastal city of Bahía de Caráquez, Ecuador, caused significant damage. Most of the reinforced concrete buildings of four stories or more in the area were severely damaged and one totally collapsed. Three people were killed and close to 50 were injured.

The city of Bahía de Caráquez, located in a sandy peninsula on the western coast of Ecuador (see Figure 1), has had important development during the last 20 years, since it has become a resort area due to its beauty and relative closeness to the big cities of Quito and Guayaquil. The population is estimated at 30,000 people in the urban area and its surroundings. This population substantially increases during the summer, and August is usually a very busy time for the area. However, this year the number of visitors dropped since the severe effects of El Niño had crippled the water and wastewater systems and closed roads.

The most recent construction in Bahía has been apartment buildings of six to 12 stories with modern architectural designs, not always appropriate to earthquake-prone zones. They are characterized by long spans, big windows and balconies, free stories to allow the location of swimming pools, and irregularities in the distribution of mass and stiffness with height. There are several four to five-story buildings, most of reinforced concrete. Finally, a number of mixed construction (wood and masonry) buildings are located on the outskirts of the city.

Some little fishing towns (less than 2000 inhabitants) located close to the epicentral region suffered intensive damage to old wooden houses (see Figure 6). Close to Boca de Briceño evidence of soil liquefaction was observed.

Seismological Aspects

The magnitude Ms=7.1 (mb=6.2) earthquake occurred 10 km to the NW of Bahía de Caráquez. The earthquake struck at 13:59 local time and strong ground shaking lasted more than 30 seconds, according to witnesses. A magnitude mb=5.4 (Ms=5.1) foreshock at 12:35, a few kilometers east of the main shock, had frightened people, so most of them were outside the buildings during the strong shaking. Both shocks were subduction events that occurred at a depth of 35 km in the shear zone between the Nazca and South American plates.

Figure 1 – Location of Bahía on Ecuador Coast and Isoseismal Map
Up to the first week of September, around 510 aftershocks were detected by the seismological network of the Geophysics Institute at EPN in Quito. The biggest aftershock occurred at 01:51 local time on August 7, with a magnitude of mb=4.6.

Preliminary location of the aftershocks defines an 80-km rupture semi-parallel to the trench, moving along the subduction plane, away from the main and premonitory shocks (see Figure 2).

**Structural Aspects**

There is no strong-motion record of the earthquake in Bahia. As can be seen in the isoseismal map of the event shown in Figure 1, MM intensities between VII and VIII were estimated for Bahia. These levels of intensity were obtained from damage observation of reinforced concrete and wooden structures which, in general, showed lack of maintenance.

The EPN Structural Department has carried out a detailed evaluation of the performance of six different types of reinforced concrete structures based on the architectural and structural information provided by insurance companies. Analytical evaluation of their response was performed using SAP-90 and ETABS. Comparing this response with the observed damage, the acceleration could be estimated to be 15% to 18% g. No information on the frequency content is available due to the lack of accelerograms in the near field.

Local effects should also be considered since most of the new reinforced concrete structures were built on marine sands deposited on the north side of the city by sea currents during the last 50 years. It is clear that structures built on top of the new marine deposits suffered more damage than others.

**Figure 2 – Ecuadorian Coastal Zone 1998 Seismicity**

Most of the observed damage to reinforced concrete structures can be summarized as follows:

1) It appears that there is extreme flexibility in most of the buildings. The calculated inter-story drift ratio for the sample of six buildings is usually greater than 0.004, and in some cases reaches values of 0.008. The infill walls are able to accept values of 0.001 to 0.002 only.

a) The seismic-resisting system for most of these buildings is formed by space frames, with beams and columns.

b) Few of them have shear walls, but, they are not long enough to carry most of the lateral loads.

c) The slab is usually the so-called "flat slab," so the beam in the frame has the same height as the slab—35 to 40 cm—with the base of the beams ranging between 60 and 80 cm.

d) The infill walls are made of fragile hollow bricks, made out of pumice, with no anchorage to the frames.

2) There are very long spans between columns or resisting walls to provide wide open spaces for windows or swimming pools; in some cases 8 to 11 m.

3) Large balconies resulted in inadequate cantilever systems.

4) Soft first stories performed badly.
the walls are used to hide electrical and sanitary installations, so the consequences to this type of installation were observed to be very severe.

Infrastructure Damage

The first aftershock was strong enough to prompt the evacuation of the Bahía de Caráquez Regional Hospital, which is a structure formed by four blocks separated by construction joints. Two of these blocks have L and T in-plan shapes. The buildings also have a soft first story, and some exterior columns are short due to the presence of incomplete infilled walls (see Figure 4). Since at least six additional hospitals in the country were built using the same architectural and structural designs, it is necessary to start a retrofittting program for them.

Near the epicentral area, the brittle failure of walls and roofs in school buildings was seen (see Figure 5). Fortunately, there were no children in class at the time of the earthquake. The vulnerability of some

5) Short columns were vulnerable.
6) Torsional effects especially affected corner buildings which had two facades with open spaces for windows and two with complete infill walls.
7) Excessive mass unnecessarily added to the structures through partition walls and thick plasters to produce architectural details like rounded walls. In most of the six evaluated buildings, the loads due to walls and plasters range between 250 to 400 Kg/m².

From a sample of around 30 buildings, three suffered severe structural damage and one totally collapsed (see Figure 3). Most of them will need to be repaired and strengthened in order to withstand the strong ground motion that will affect the region in the future.

Nonstructural Damage

The above-mentioned structural deficiencies resulted in severe damage to the exterior and partition walls. In some cases, there was damage to all the walls of the entire building. In most cases, wall destruction was conspicuous in the first three to four stories. Usually,
typical schools across the country was pointed out in a previous report by the EPN and GeoHazards International: *Investing in Quito’s Future: The Schools Seismic Safety Project*. The most common type is a one-story steel structure prototype, very light, with brick or pumice blocks infill walls not attached to the confining steel frames.

Electrical and telephone services were disrupted mainly due to pole collapses and short-circuits; in the case of telephones, there was extensive damage to the building systems. Water supply was already disrupted due to El Niño, but there was no clear evidence of damage to the water tanks and pipes. Minor landslides partially blocked the road between Bahía de Caráquez and Canoa.

**Concluding Remarks**

Excess flexibility was the main cause of the damage observed, especially related to the partition and external walls. Many buildings in Bahía de Caráquez will need to be retrofitted, and the cost will be very high. It is more cost-effective to implement a seismic quality control program during design and construction.

One tool that will help most to reduce the high vulnerability of structures in the country is a revised and updated building code, especially if it is enforced. The current Ecuadorian construction code was published in 1977. It was copied from SEAOC, UBC and ACI standards of that time, but it has never been revised, and local conditions were never taken into account.

One of the most powerful tools for mitigation could be earthquake insurance, but only a few buildings in Bahía were insured, maybe due to the high premiums. It would be desirable to involve the insurance industry in the mitigation process.