The Quito, Ecuador School Earthquake Safety Project

Investing in Quito’s Future

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Schools teach civics, educating citizens of their rights and duties. They foster an appreciation of culture through the study of literature and the arts. In schools, students learn the lessons of history, the discoveries of science, and the rewards of public service. Schools benefit the economy by providing a skilled and literate work force. They are used for social gatherings, continuing education, theater and musical productions, and sports. Schools are a measure of community well-being.

Earthquake-threatened communities need earthquake-resistant schools. When schools are closed because of earthquake damage, education is delayed and community life disrupted. Repair and construction of school buildings are difficult and expensive after an earthquake, when government resources are strained. Where school attendance is compulsory, communities have a moral obligation to provide a safe study and work environment. But most important, earthquake-threatened communities need earthquake-resistant schools to protect their teachers and children.

A recent assessment of earthquake risk to Quito, the capital of Ecuador, concluded that many of its public schools are vulnerable to collapse during major earthquakes. That assessment was made over a period of two years, ending in May of 1994, by a team of Ecuadorian and International scientists and engineers. They found that while Quito has not been struck by a major earthquake recently, it has been in the past and will be in the future. They recommended that Quito's public school buildings be evaluated and, if found vulnerable, strengthened.

In response, GeoHazards International initiated the Quito School Earthquake Safety Project in December of 1994. GeoHazards International, a nonprofit corporation dedicated to improving earthquake safety worldwide, collaborated with Ecuador's National Polytechnic School and the University of British Columbia in defining the project. It had three objectives:

- Evaluate the vulnerability of Quito's public schools to earthquakes;
- Design affordable means of strengthening a sample of those schools that are vulnerable; and
- Strengthen the sample of vulnerable schools.

This report describes progress in meeting these objectives during the project's first year and concludes by offering recommendations for making Quito's schools safe.
Because of the number and diversity of school buildings, it was not practical to evaluate the vulnerability of them all. Instead, this project focused on a sample of schools that are in high use (a large number of students using the building per day per building area), highly vulnerable to earthquakes, and representative of the three prevalent construction materials. Schools that are both in high use and highly vulnerable are referred to as “high-risk” schools.

The process of choosing this sample and evaluating the vulnerability of its schools consisted of selecting Quito’s high-use schools, classifying them by construction material, and determining the most vulnerable within each group. Data provided by the City of Quito were used to select 340 high-use school buildings. Inspectors visited each, recording information including construction material and superficial condition of the structure. The buildings were then grouped according to construction material. Three steps were taken to determine the vulnerability of buildings in each group. First, project engineers selected a total of 60 buildings that appeared the most vulnerable. Next, each of these buildings was given a vulnerability ranking using the Applied Technology Council’s “rapid visual screening” method, adapted by project engineers to local seismicity and local construction materials. Finally, detailed structural analyses were performed for those buildings, a total of 20, with the highest vulnerability rankings within each group. The analyses included an investigation of the structural system (including that of the foundation) to evaluate the location, size, and connection details of all structural elements. Structural deterioration was also documented. Dynamic analyses were completed for each building, considering various levels of earthquake ground shaking. Soils engineers determined, based on a preliminary evaluation, that none of the buildings was situated on unstable soils.

As a result of this process, project engineers identified 15 individual high-risk school buildings. They also concluded that the two types of school modules constructed by the National Directorate for School Construction were at risk. The 15 individual school buildings and the thousands of modular schools located throughout Ecuador are the focus of the next section.

"SHORT" COLUMNS

Two common structural deficiencies are “soft” stories (such as stories without infill walls) and "short" columns (columns effectively shortened by partial infill walls). Shown are examples of each in Quito schools, and an earthquake-damaged building that had a “soft” first story.
<table>
<thead>
<tr>
<th>Name of School</th>
<th>No. of Buildings</th>
<th>Construction Material</th>
<th>Year of Construction</th>
<th>Grade Level</th>
<th>Estimated Retrofit Cost (Sucres/US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ana Paredes de Alfaro</td>
<td>1</td>
<td>Reinforced concrete</td>
<td>1956</td>
<td>Kindergarten &amp; elementary</td>
<td>S/ 34,333,000 $14,000</td>
</tr>
<tr>
<td>Experimental Sucre</td>
<td>4</td>
<td>Reinforced concrete</td>
<td>1952–59</td>
<td>Elementary</td>
<td>S/ 144,098,000 $57,000</td>
</tr>
<tr>
<td>José de Antepara</td>
<td>1</td>
<td>Adobe</td>
<td>Pre-1940</td>
<td>Kindergarten &amp; elementary</td>
<td>S/ 27,452,000 $11,000</td>
</tr>
<tr>
<td>República de Argentina</td>
<td>1</td>
<td>Unreinforced masonry</td>
<td>1953</td>
<td>Elementary</td>
<td>Not available</td>
</tr>
<tr>
<td>República de Chile</td>
<td>4</td>
<td>Reinforced concrete</td>
<td>1945/1994</td>
<td>Elementary &amp; high school</td>
<td>S/ 618,698,000 $244,000</td>
</tr>
<tr>
<td>Río Amazonas</td>
<td>3</td>
<td>Reinforced concrete</td>
<td>1978</td>
<td>High school</td>
<td>S/ 98,000,000 $39,000</td>
</tr>
<tr>
<td>11 de Marzo</td>
<td>1</td>
<td>Steel</td>
<td>Unknown</td>
<td>High school</td>
<td>S/ 16,718,000 $7,000</td>
</tr>
<tr>
<td>National Directorate for School Construction Module I</td>
<td>Numerous</td>
<td>Reinforced concrete</td>
<td>Various</td>
<td>Various</td>
<td>S/ 160,000/m² $6/ft²</td>
</tr>
<tr>
<td>National Directorate for School Construction Module II</td>
<td>Numerous</td>
<td>Steel</td>
<td>Various</td>
<td>Various</td>
<td>S/ 33,000/m² $1.20/ft²</td>
</tr>
</tbody>
</table>

**High-Risk Schools**

Project engineers from Ecuador's National Polytechnic School discuss school retrofit designs with a member of the Technical Advisory Committee.
LOCATION: Sucre Street, Barrio La Loma
Year of Construction: 1952-1959
Prevalent Materials: Reinforced concrete
Total Retrofit Area: 3,080 m² (33,140 ft²)
No. of Buildings Studied: 4
Estimated Cost: S/ 144,098,000 (US $57,000)

BUILDING DESCRIPTION
The Experimental Sucre elementary school consists of three- and four-story buildings of reinforced concrete frames with unreinforced masonry infill walls. Four buildings were studied in this project: a four-story structure serving as a longitudinal spine and its 3 three-story transverse blocks.

The 130-m-long spine consists of transverse portal frames with 7.5-m spans and 2.5-m overhangs, spaced every 3 m. Seismic separation spaces detach the 50-m-long central spine section from the rest of the structure. The floors are 35-cm-thick rigid slabs; the columns are connected to each other by dropped beams in the longitudinal direction only.

The three 18-m-long transverse blocks are 25 m apart and perpendicular to the spine, separated from the spine by seismic separation spaces. Each consists of seven portal frames spaced 3 m apart, with 6-m spans and 2.5-m cantilevers. A 35-cm-thick concrete beam embedded in the slab connects the two columns of each frame.

STRUCTURAL DEFICIENCIES
Experimental Sucre's beams and columns are not sufficiently strong to provide earthquake resistance to their structures. Door and window openings have created short columns. The first story of each transverse block lacks infill walls, creating a soft-story condition. The transverse buildings will likely pound against the main building during an earthquake.

RETROFIT SOLUTIONS
Shear walls will be added to the buildings in both the longitudinal and transverse directions. Two options have been proposed for constructing the shear walls. The first consists of adding reinforced masonry walls to the first floor (transverse building only) and replacing the walls of upper floors with properly connected reinforced masonry ones. The second design consists of adding unreinforced masonry walls to the first floor (transverse buildings only), and surface strengthening them and upper-floor walls with steel mesh and concrete. Shear walls will increase the stiffness of the portal frames and thereby mitigate soft-story and pounding hazards. Separation joints will be added between walls and columns to mitigate short-column hazards.

A complete description of these structures, their analysis, and their retrofit designs can be found in: S. Díaz and F. Ponce, Seguridad Sísmica de los Establecimientos Escolares en la Ciudad de Quito: Escuela Sucre. (Quito: Escuela Politécnica Nacional, 1995.)
Location: Between Daule, Pita, and Pique streets, Ciudadela Mexico
Year of Construction: 1953
Prevalent Materials: Unreinforced masonry
Total Retrofit Area: 700 m² (7,530 ft²)
No. of Buildings Studied: 1
Estimated Cost: Not available

BUILDING DESCRIPTION
The República de Argentina elementary school consists of two buildings: a recently constructed reinforced concrete structure and the original two-story brick main building. The main building was considered in this project.

The main building is C-shaped. Because of sloping topography, the first floor contains four levels, and the second floor contains two. The unreinforced brick walls are 40 cm thick. The wood floor of the second story is supported by reinforced concrete beams that, in turn, are supported by the first-floor walls. The roof is supported by wood beams. On the second floor there are several reinforced concrete additions with lightweight metal roofs.

STRUCTURAL DEFICIENCIES
The interior and exterior unreinforced masonry bearing walls have openings that create, in effect, a hazardous short-column condition. The beam-wall connections are deficient. Since the wood beams and roof structure are supported by the walls, failure of the beam-wall connections during an earthquake would result in building collapse.

RETROFIT SOLUTION
The wall openings will be modified to reduce the short-column effect. Better connections will be provided between intersecting walls. The in-plane rigidity of the floor and roof systems, as well as the connections with the supporting walls, will be improved.

A complete description of this structure, its analysis, and its retrofit design can be found in: G. Barahona and F. Vaca, "Seguridad Sísmica de los Establecimientos Escolares en la Ciudad de Quito: Escuela Fiscales Mixta "República de Argentina." (Quito: Escuela Politécnica Nacional, 1995.)
**Building Description**

The Río Amazonas high school consists of 12 two- and three-story reinforced concrete buildings and one steel-frame building, all constructed between 1978 and 1985. This project considered three reinforced concrete buildings constructed in 1978: the two-story, C-shaped main building, and 2 three-story peripheral buildings.

The symmetric wings of the main building consist of a series of portal frames, each 3 m apart, and with construction joints every 9 m. Beams embedded in the floor slab connect the frames in the longitudinal direction. The central part of this block contains a two-story passageway consisting of solid slabs supported every 3 m by columns. The staircase module is located in the middle of the main building.

The two peripheral buildings are of designs similar to the main building except that they have three stories and portal frames spaced every 4 m. Each building has a detached staircase module in the center, connected by 1.5-cm construction joints.

**Structural Deficiencies**

The original building designs did not consider lateral forces. Inadequately connected portal frames in the longitudinal direction do not provide sufficient stiffness or strength to transfer properly lateral loads during an earthquake. Construction joint separations are too small and could permit pounding during an earthquake. Window and door openings and mid-height partition walls create short-column conditions. The staircase modules show excessive deflection.

**Retrofit Solutions**

Additional structural elements will be added to the buildings in order to increase their longitudinal stiffness. Two options are recommended: strengthening the unreinforced masonry infill walls by replacing them with reinforced masonry walls with proper connections to the concrete frames, or surface strengthening the existing walls with steel mesh and reinforced concrete. Separation joints will be added between walls and columns to mitigate short-column hazards. Supporting elements will be added to control deflection of the staircase modules.

A complete description of these structures, their analysis, and their retrofit designs can be found in: S. Díaz and F. Ponce, Seguridad Sísmica de los Establecimientos Escolares en la Ciudad de Quito: Escuela Río Amazonas. (Quito: Escuela Politécnica Nacional, 1995.)
Location: Various locations throughout Ecuador
Year of Construction: Various
Prevalent Materials: Reinforced concrete
Total Retrofit Area: Various
No. of Buildings Studied: Numerous
Estimated Cost: S/ 160,000 per m² (US $6 per ft²)

**Module Description**

These reinforced concrete school modules are connected in various configurations to form one school building. Rectangular columns are used to form longitudinal and transverse frames. Infill walls are made up of clay bricks or cement blocks with vertical reinforcing columns. Depending on soil characteristics, the foundations are made of reinforced concrete: individual or continuous spread footings. Stair shafts are usually located at the corners of adjacent modules.

**Structural Deficiencies**

Because of the modular method of construction, these buildings lack stiffness in the longitudinal direction. Window and door openings in the longitudinal direction create short columns. Design details are inadequate. For example, improper construction joint details between blocks often result in rainwater leakage. In regions of the country with high humidity or frequent rain, the first floor is typically built with large openings in the walls, creating a potentially dangerous soft-story condition. Modules are frequently altered after construction, sometimes creating additional hazards.

**Retrofit Solutions**

Retrofit solutions for the most common deficiencies were developed. In general, the retrofit designs call for increasing the stiffness of the longitudinal walls and reducing the number of short columns by filling in some of the window openings, providing separation between columns and infill walls, and improving construction details.

A complete description of this type of module, its analysis, and its retrofit designs can be found in: J. Fernández and P. Gachet, Seguridad Sísmica de los Establecimientos Escolares en la Ciudad de Quito: Tipo DINACE. (Quito: Escuela Politécnica Nacional, 1995.)
Significant progress has been made in strengthening Quito's high-risk schools during even the first year of this project.

As of this writing, funding has been committed to retrofit 10 of this project's school buildings. The City of Quito has allocated funds to retrofit four buildings at its Experimental Sucre school. Ecuador's Project for Development, Efficiency, and Quality in Basic Education has agreed to retrofit six buildings at three schools: Ana Paredes de Alfaro, José de Antepara, and República de Chile. Retrofit construction for these three schools will commence shortly. Local philanthropic organizations and businesses have expressed interest in sponsoring additional school retrofits.

The City of Quito has agreed to fund the evaluation and retrofit of its Eugenio Espejo school, one identified by this project as vulnerable.

Most important for Ecuador's rapidly growing population, USAID-Ecuador has agreed to sponsor the design of new, earthquake-resistant school modules for the National Directorate for School Construction. These designs will be used for school construction throughout Ecuador.

Significant progress has also been made in learning how to identify and strengthen the remainder of Quito's vulnerable schools. Potentially vulnerable schools can readily be identified by experienced engineers with the methods used in this project. Based on the experience of this project, retrofitting schools to protect the lives of their occupants is affordable and inexpensive relative to a school's replacement cost. The identification of high-risk schools and the design of their retrofits can generate local funding needed to strengthen the schools.
This project primarily involved Quito engineers, government officials, and education advocates. The engineers identified high-risk schools and designed retrofits. The government officials and education advocates provided guidance and raised funds for the retrofit construction. All have shown their commitment to school earthquake safety. They should be supported to continue this work until all of Quito’s vulnerable schools are retrofit.

Parents and teachers were not directly involved in this project, yet they have the greatest personal interest in safe schools and can play an important role in making schools earthquake-resistant. Parents and teachers can:

- Raise awareness of the vulnerability of Quito’s schools and the methods to make them safe.
- Request school inspections by structural engineers from, for example, Quito’s universities and the Ecuadorian Structural Engineering Association.
- Identify and mitigate nonstructural hazards, such as unsecured bookshelves and heavy ceiling tiles, and develop earthquake preparedness and response plans for their schools. These activities are simple, inexpensive, and effective.

Earthquakes will be a part of Quito’s future, as surely as they have been a part of its past. While it is not known when the next major earthquake will occur, it is certain that increasing earthquake safety in Quito’s schools now will reduce future injuries and damage. This project is only the first step toward improving the safety of Quito’s schools. The next step can be taken by Quito’s parents, teachers, and community leaders.