Designing Retrofits

The 15 high-risk schools and the two types of school modules identified in this project (see the High-Risk Schools table on the facing page) were chosen to be "retrofit" so as to prevent injury to their occupants even during Quito's largest earthquakes.

To retrofit a building is to improve its earthquake resistance. A retrofit design is a specification of the structural changes to a building required to achieve a desired level of earthquake resistance. The desired level of earthquake resistance is expressed in terms of design criteria — the levels of damage acceptable for various intensities of ground shaking.

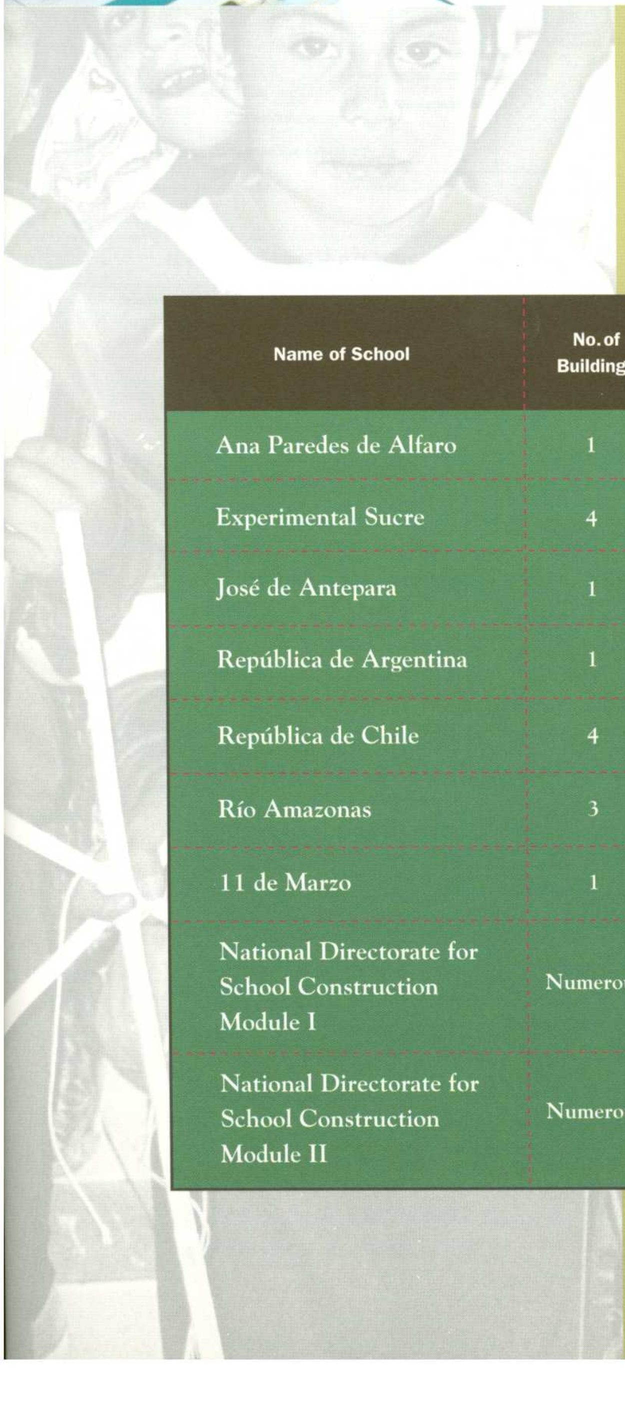
Strength of Ground Shaking	Historical Frequency of Occurrence	School Retrofit Criterion
Heavy furniture moves (6%g)	Every 2 decades	Minimal nonstructural damage, no structural damage
Difficult for some to stand (9%g)	Every century	Moderate nonstructural damage, no structural damage
Difficult for most to stand (26%g)	Every 5 centuries	Structural damage but no collapse

Retrofit Design Criteria

The design criteria used in this project (see Retrofit Design Criteria table) state, for example, that retrofit schools should be able to withstand ground acceleration of 6% gravity (ground shaking strong enough to move heavy furniture) with no structural damage and with only minimal nonstructural damage. Based on historical records, earthquakes producing such ground shaking in Quito are expected every two decades.

Retrofit designs were created for each of the 15 high-risk school buildings and the two types of school modules. These designs are affordable and utilize local materials and local construction techniques. They are summarized in the following pages.

Project engineers from Ecuador's National Polytechnic School discuss school retrofit designs with a member of the Technical Advisory Committee.



Name of School	No. of Buildings	Construction Material	Year of Construction	Grade Level	Estimated Retrofit Cost (Sucres/US$)
Ana Paredes de Alfaro	1	Reinforced concrete	1956	Kindergarten & elementary	S/ 34,333,000 $14,000
Experimental Sucre	4	Reinforced concrete	1952–59	Elementary	S/ 144,098,000 $57,000
José de Antepara	1	Adobe	Pre-1940	Kindergarten & elementary	S/ 27,452,000 $11,000
República de Argentina	1	Unreinforced masonry	1953	Elementary	Not available
República de Chile	4	Reinforced concrete	1945/1994	Elementary & high school	S/ 618,698,000 $244,000
Río Amazonas	3	Reinforced concrete	1978	High school	S/ 98,000,000 $39,000
11 de Marzo	1	Steel	Unknown	High school	S/ 16,718,000 $7,000
National Directorate for School Construction Module I	Numerous	Reinforced concrete	Various	Various	S/ 160,000/m² $6/ft²
National Directorate for School Construction Module II	Numerous	Steel	Various	Various	S/ 33,000/m² $1.20/ft²

High-Risk Schools

Location: Rocafuerte and Rodríguez de Quiroga streets

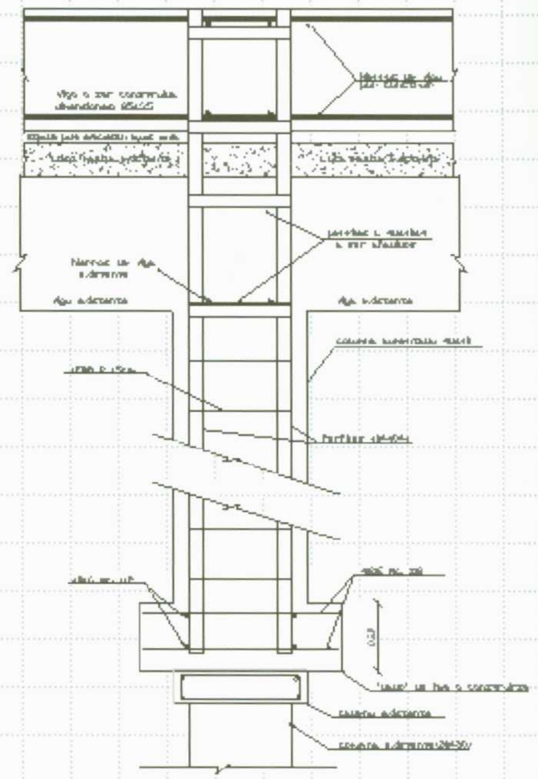
Year of Construction: 1956

Prevalent Materials: Reinforced concrete

Total Retrofit Area: 540 m² (5,810 ft²)

No. of Buildings Studied: 1

Estimated Cost: S/ 34,333,000 (US $14,000)



Detail of Column and Roof Slab

BUILDING DESCRIPTION

The Ana Paredes de Alfaro kindergarten and elementary school consists of a one-story reinforced concrete main building and two steel school modules. The main building was considered in this project.

The main building is C-shaped; its spine and two wings are separated by construction joints. The structure's 15-cm-thick tile-covered concrete roof slab is supported by reinforced concrete columns and 20-cm-thick masonry walls. The foundation consists primarily of stone and reinforced concrete piers. Masonry walls provide support to some parts of the building where there is sloping terrain. The foundation has a 10-cm-thick concrete perimeter tie beam.

STRUCTURAL DEFICIENCIES

Weak concrete beams and columns put the structure's frame at risk of collapse during a major earthquake. Several columns are lacking sufficient reinforcing steel, and most beam-column joints are inadequate. The concrete roof slab is deflecting excessively in several places; cracks in the slab allow rainwater to leak into the building.

RETROFIT SOLUTION

The building will be strengthened by adding reinforced concrete beams above the roof slab and steel columns, and by strengthening the existing reinforced concrete columns and beam-column joints. This would create lateral-load-resisting frames for the building, increasing its ductility during earthquakes, diminishing stress on its structural elements, and halting the deflection of the roof slab. The roof will be sealed with a watertight coating.

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: Jardin de Infantes "Ana Paredes de Alfaro."* (Quito: Escuela Politécnica Nacional, 1995.)